KEA - KAKA

POPULATION VIABILITY ASSESSMENT

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1/6/94

POPULATION VIABILITY ANALYSIS
KEA (Nestor notabilis) AND KAKA (Nestor meridionalis)

Orana Park Wildlife Trust
Christchurch, New Zealand

2-5 December 1991

Report Compiled by:

Ulysses Seal (CBSG)
Paul Garland (Orana Park)
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Andrew Grant (Department of Conservation)
Colin O'Donnell (Department of Conservation)

This report includes the results of the Workshop for Kea and Kaka in Christchurch New Zealand 2 - 5 December 1991.

First draft edited by D. Butler 24 September 1992
Second draft edited by A Grant, C. O'Donnell and P Garland 30 June 1993

A collaborative effort of the New Zealand Department of Conservation and the IUCN/SSC Captive Breeding Specialist Group.

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THE ISAAC WILDLIFE TRUST
CAPTIVE BREEDING SPECIALIST GROUP (SSC/IUCN)
DEPARTMENT OF CONSERVATION

Other major contributors included; Airport Gateway Lodge - Christchurch, DSIR Land Resources - Nelson, Dunedin City Council, Auckland Zoo, Massey University - Palmerston North; Victoria University - Wellington; Wellington Zoo, DSIR Land Resources - Christchurch.

Captive Breeding Specialist Group
Species Survival Commission
IUCN -- The World Conservation Union
U. S. Seal, CBSG Chairman

CONSERVATION
TE PAPA ATAWHAI
Threatened Species Unit

THE ISAAC WILDLIFE TRUST

Orana
Park

INTRODUCTION

This is the first Population Viability Analysis to be undertaken in New Zealand. Two closely-related endemic parrot species, the kea and kaka, were chosen for the following reasons:

1. There are ongoing management issues relating to both wild and captive population of both species that require resolution in the longer term. However neither species is considered in immediate threat of extinction and thus neither is yet a top priority for the initiation of recovery plans by the Department of Conservation, the government department with statutory responsibility for conservation of the country's fauna and flora. The PVA provided an opportunity to advance the planning process as a co-operative effort between several organisations.

2. Global planning for parrots is well advanced. Completion of PVA assessments for kea and kaka allows their full incorporation in the Parrot Conservation Management Plan currently in preparation by CBSG.

3. There is sufficient known about both species in the wild and in captivity to obtain meaningful assessments of population viability. It was recognised that one of the main outputs in these cases would be recommendations of which population parameters were priorities for more accurate definition by further work in the field.

There are endangered bird taxa in New Zealand whose population parameters are more precisely known, but these have already been the subject of detailed recovery plans, e.g in the parrots, the Kakapo (Strigops habroptilus) (Powlesland, 1989). It was considered preferable to evaluate the PVA process in New Zealand on species of slightly lower priority, before determining how it could be integrated into the recovery planning process applied to most higher priority bird taxa.

The report of this PVA, like all those produced under the auspices of CBSG, is intended to be a stand-alone document, thus key reference material is included as an appendix.

David Butler
THREATENED SPECIES UNIT
DEPARTMENT OF CONSERVATION

WORKSHOP PURPOSE, GOALS AND OBJECTIVES

PURPOSE OF POPULATION VIABILITY ANALYSIS

The overall purpose of the PVA workshop was to facilitate the development of conservation strategies that will assure with high probability the continued survival and adaptive evolution of kea and kaka. Analysis was carried out using the computer simulation, Vortex (Lacy and Kreeger, 1992), to evaluate the vulnerability of populations of these species to extinction, based on known or estimated life history parameters. Vortex is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental and genetic stochastic events on wildlife populations.

GOALS

1. To conduct population viability analyses on kea and kaka taxa and prepare population models for time periods up to 100 years.

2. To formulate quantitative strategies with risk assessments to prevent extinction and achieve the establishment or maintenance of viable, self-sustaining populations within the historic range of kea and kaka.

3. To develop conservation strategies with specific plans and priorities for the ongoing management of kea and kaka populations.

OBJECTIVES

1. To assemble available information on the current distribution, status and population trends of each taxon.

2. To assemble, with estimates of variance where possible, available life history information on each taxon. This includes age of first reproduction, nesting frequency, clutch size, sex ratio of offspring, and age-related mortality.

3. To assemble available information on estimates of carrying capacity and possible trends in this.

4. To assemble available information on competitors (eg wasps, possums) and predators (eg stoats) of each taxon, evaluate their current impacts and likely future trends in impact.

5. To assemble available information on the interactions between kea and kaka and the human population, and estimate future impacts.

6. To estimate the numbers and sub-population sizes required to achieve a 95% of probability of survival for 25, 50 and 100 years for both taxa, retaining 95% or more of genetic diversity.

7. To evaluate the need for establishing new populations in other locations either in the wild or captivity to contribute to the survival and retention of genetic diversity of the two taxa. To develop recommendations for management of current captive populations.

8. To identify and make recommendations on issues that require management or further research for each taxa.

SUMMARY OF WORKSHOP AGENDA

2 December

Morning:

Introduction to small population biology and PVAs - Ulysses Seal

Objective of PVA is to develop risk assessment tools to investigate management scenarios. It must be considered a management tool not a theoretical answer. Viable population size depends on:

1. Objectives of programme - eg time-frame
2. Biological characteristics of population
3. Levels of stochasticity operating.

Past work on population viability has used deterministic models, eg Leslie Matrix, but the major events leading to final extinction are often stochastic - hence Vortex.

Open debate and dissent is encouraged - all should have had an opportunity to present views by the end of the workshop and see them expressed in a draft document before its completion. It usually however requires a further 3 weeks to run all Vortex simulations to build a complete picture.

Afternoon:

- Introduction to kea in wild - Andrew Grant, Steve Phillipson
- Kea in captivity - Tony Pullar
- Introduction to Vortex - Ulysses Seal

3 December

Morning:

- Introduction to kaka in wild - Colin O'Donnell, Jacqueline Beggs, Ron Moorhouse
- Kaka in captivity - Mick Sibley

Afternoon/Evening:

- File management for Vortex - Ulysses Seal
- Preliminary simulations for kea and kaka.

4 December

All Day:

Vortex simulations and population modelling.

- Kea and Kaka
- Group Discussions and Feedback.

At the end of the day each group reported their preliminary results and sought wider comment and input.

5 December

All Day:

Further Vortex simulations and population modelling. Afternoon spent on development of draft report.

Workshop Report

For some sessions during the last two days, individuals worked in groups on separate tasks as follows, with regular reporting back and discussion with the whole workshop:

Simulating Kea Populations:	Andrew Grant, Steve Phillipson, Paul Garland, David Butler
Simulating Kaka Populations:	Colin O'Donnell, Jacqueline Beggs, Ron Moorhouse
Developing Goals for Captive Populations	Tony Pullar, Mick Sibley, Anne Richardson
Assessments of Disease Issues:	Peter Stockdale, Sherri Huntress, Graeme Phipps, Anne Richardson.

RECOMMENDATIONS

All workshop participants were involved in the formulation and development of recommendations.

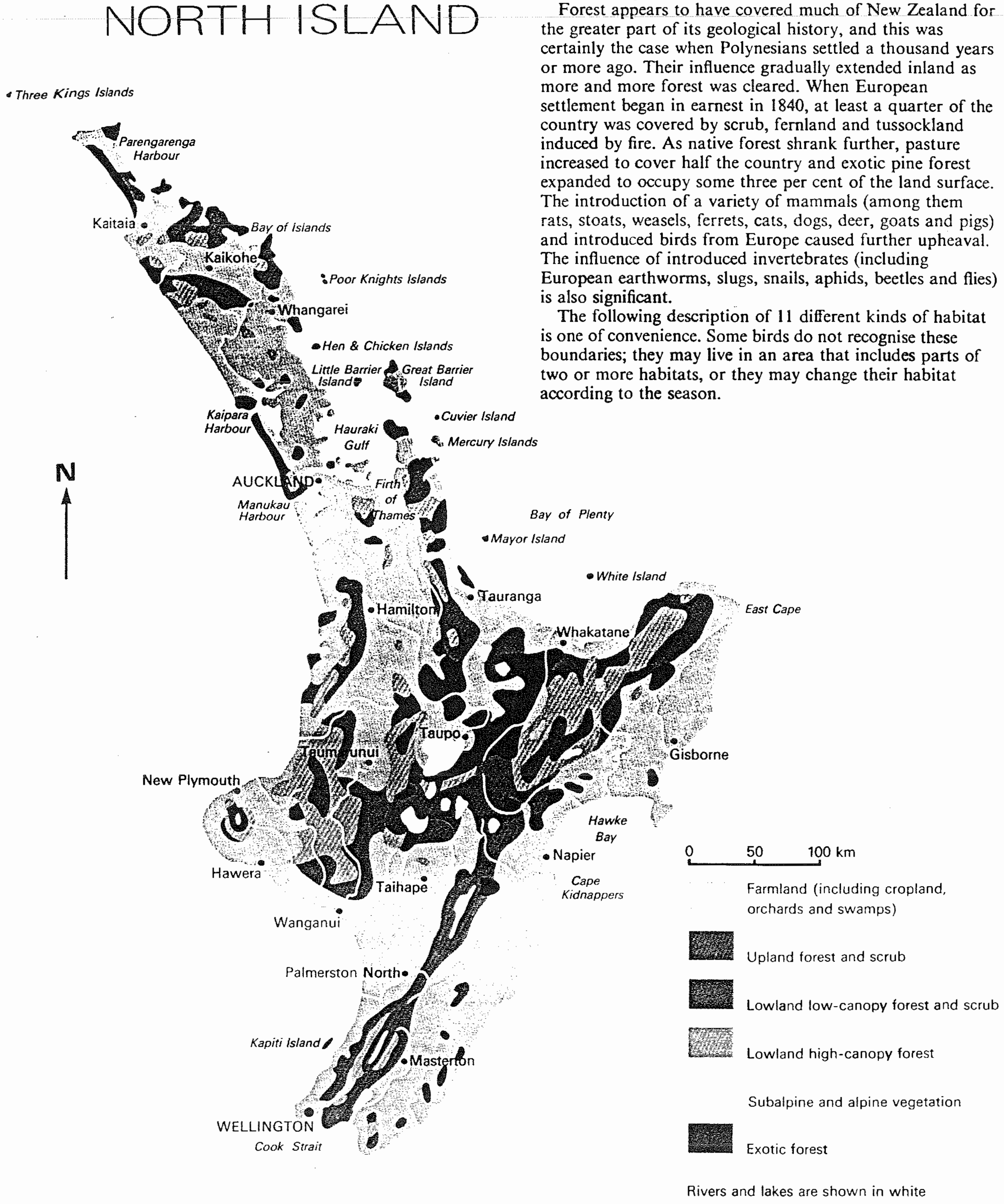
Habitats: where New Zealand birds live

WHERE A BIRD LIVES is intimately related to how it lives. A bird's survival in a particular habitat depends on a number of factors—food resources, nesting and roosting sites, and both the numbers and kinds of predators and food competitors present. Endemic birds that are already rare or which need large territories are those most vulnerable to change in their habitat. The species most likely to survive such changes are those that can adapt to a new habitat because they are not highly specialised.

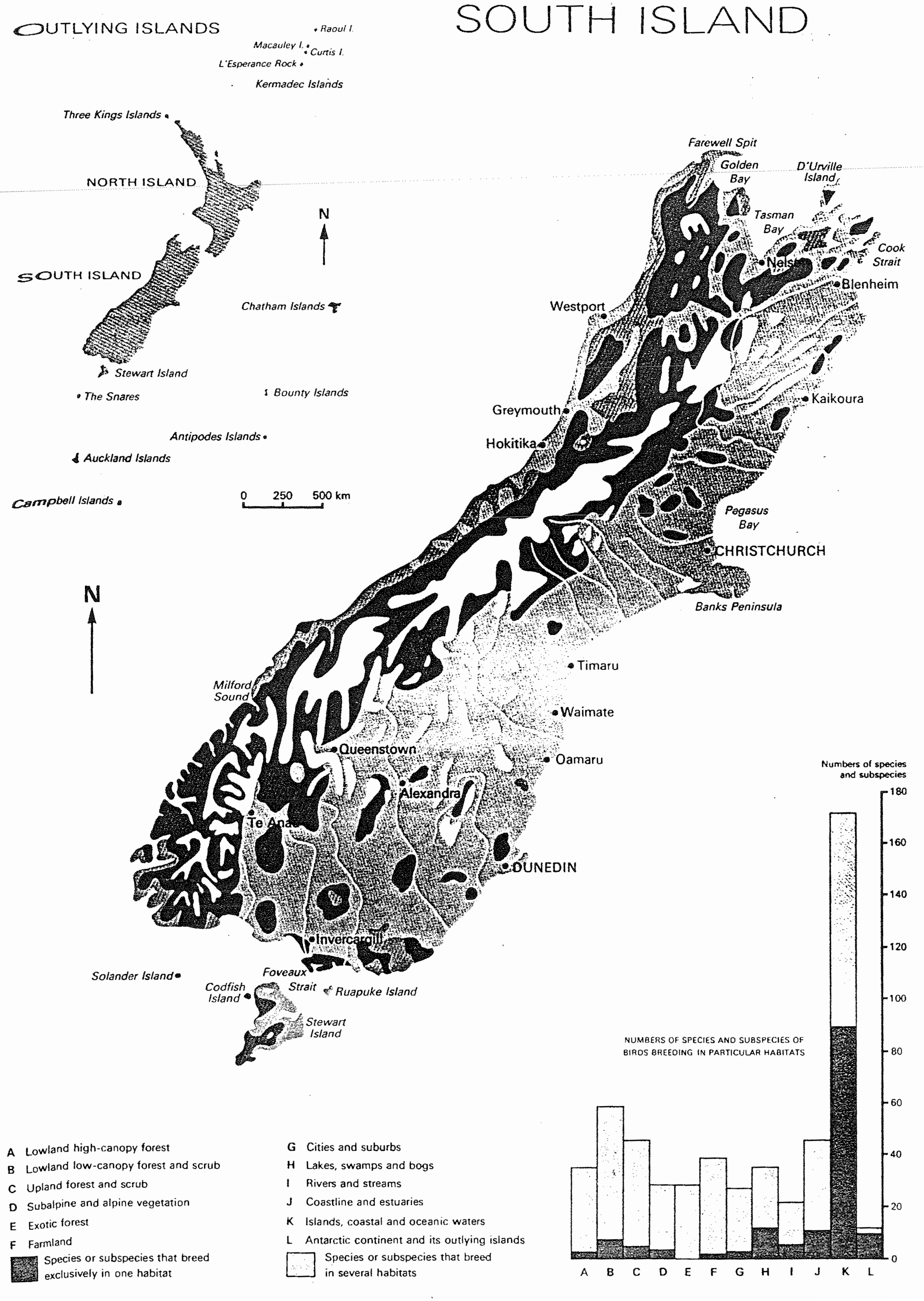
New Zealand is a mountainous country—more than half the land rises above 300 m, and nearly a fifth above 900 m. Most of the country has a rainfall of between 1000 and 2000 mm per annum, but there are widely divergent extremes. The western side of some South Island mountains receives over 10 000 mm, and some eastern areas receive annually only 350 mm.

Forest appears to have covered much of New Zealand for the greater part of its geological history, and this was certainly the case when Polynesians settled a thousand years or more ago. Their influence gradually extended inland as more and more forest was cleared. When European settlement began in earnest in 1840, at least a quarter of the country was covered by scrub, fernland and tussockland induced by fire. As native forest shrank further, pasture increased to cover half the country and exotic pine forest expanded to occupy some three per cent of the land surface. The introduction of a variety of mammals (among them rats, stoats, weasels, ferrets, cats, dogs, deer, goats and pigs) and introduced birds from Europe caused further upheaval. The influence of introduced invertebrates (including European earthworms, slugs, snails, aphids, beetles and flies) is also significant.

The following description of 11 different kinds of habitat is one of convenience. Some birds do not recognise these boundaries; they may live in an area that includes parts of two or more habitats, or they may change their habitat according to the season.



SOUTH ISLAND



NUMBERS OF SPECIES AND SUBSPECIES OF BIRDS BREEDING IN PARTICULAR HABITATS

A	Lowland high-canopy forest
B	Lowland low-canopy forest and scrub
C	Upland forest and scrub
D	Subalpine and alpine vegetation
E	Exotic forest
F	Farmland
G	Cities and suburbs
H	Lakes, swamps and bogs
I	Rivers and streams
J	Coastline and estuaries
K	Islands, coastal and oceanic waters
L	Antarctic continent and its outlying islands
▨	Species or subspecies that breed exclusively in one habitat
☐	Species or subspecies that breed in several habitats

KAKA
(Nestor meridionalis)

POPULATION VIABILITY ANALYSIS
WORKSHOP REPORT

KAKA

1.0 KAKA

1.1. INTRODUCTION TO WILD POPULATIONS

Kaka (Nestor meridionalis) are a large (min. 350 g max. 800 g) forest parrot once common in the temperate rain forests of New Zealand. Two subspecies of kaka are currently recognised:

North Island kaka (Nestor meridionalis septentrionalis, Lorenz)
South Island kaka (N. m. meridionalis, Gmelin).

Both subspecies are classed as threatened.

Kaka populations have been declining in New Zealand since European occupation, largely because of predation and competition from introduced animals (rats, mustelids, possums, ungulates, wasps), forest destruction and fragmentation, and hunting pressure (summarised by O'Donnell & Rasch 1991).

Kaka are now rare on the North and South Island mainlands,, apart from localised concentrations in large native forest remnants and a few offshore islands (Moynihan et al. 1979, Ogle 1982, O'Donnell 1983, Saunders 1983, O'Donnell and Dilks 1986, O'Donnell and Rasch 1991). Large populations of North Island kaka are found on Little Barrier (3000 ha) and Kapiti Island (2000 ha), and of South Island kaka on Codfish Island (1000 ha).

1.2. PREVIOUS ABUNDANCE AND RATES OF DECLINE

Kaka were once abundant in rain forests, throughout much of New Zealand. They were harvested in large numbers by the Maori people and later Europeans (Fulton 1908, Myers 1923, Best 1942). For example, Buller (1877) recorded that between 10,000 and 12,000 Kaka were killed by Maori hunters in the central North Island within a two month period. Such prodigious harvests continued when European arrived. Fulton (1908) reports up to 400 being shot in three days by three men in the Maruia district.

In the 1800s, kaka were still abundant throughout New Zealand. Between 1885 and 1900 they began to decline and were "fast disappearing" in some areas (Potts 1882; Buller 1894; Phillips 1948). By 1930, their distribution had become localised and birds were becoming rare in some districts. Kaka have remained locally common in the North island for decades, some populations crashing as late as the 1960s (eg Northland). A typical rate of decline is reflected in these reports from Northland: 1920s-early 1940s seen in flocks of 200-300 birds, 1960s flocks of 10-20 birds, "fading out" in the 1970s, and only 1-2 birds seen by 1990 (T. Parker, J. Cox, R. Pierce pers. comm.).

Kaka are now absent from most of the North Island and there is evidence that decline is continuing in the two mainland North Island areas with apparently viable populations: West Taupo and Whirinaki/Urewera. In the South Island kaka are still widespread in most indigenous forests, particularly in the west. Numbers have declined greatly, but not as markedly as in the North Island. Two strongholds remain on mainland South Island (South Westland and Waitutu).

The first major research on kaka was initiated in 1984, and there are currently 3 populations being studied: the North Island kaka on Kapiti Island (Moorhouse 1991), and the South Island kaka in Nelson Lakes National Park (Beggs & Wilson 1991) and South Westland (O'Donnell & Dilks 1986). Data from these studies form the basis for the population models.

1.3. CURRENT CAPTIVE POPULATION

North Island Kaka: (From Mick Sibley's annual report of 30 June 1992)
The current captive population is 56 (24.21.11). It has been a productive year with a total of 15 chicks fledging at Auckland, Christchurch and Mt Bruce. One adult female died of old age (35+) whilst 3 other adults died of various causes. Six of the chicks at Auckland Zoo were hand-raised as part of the research into gut flora establishment and lactobacillis supplementation, whilst all others were parent-raised.

At present all kaka at Auckland Zoo are being anaesthetised with blood samples taken to determine relationships (DNA fingerprinting), normal blood values, and sub-specific status. At the same time, detailed weights and measurements are being taken.

Thirteen of birds were originally obtained from the wild, of which 10 are still alive. Six of these founders have produced surviving young.

South Island Kaka: (From Tony Pullar - June 1993)
The current captive population is eight birds, of which six are known to be wild born, mostly brought in as injured birds and are generally not suitable for breeding. One chick successfully handraised last breeding season from captive pair at Dunedin Botanic Gardens. This is the first successful captive breeding for over ten years.

1.4. KAKA POPULATION BIOLOGY AND VIABILITY ANALYSIS

Population Biology Parameters

Three Major Scenarios to model:

1. South Island beech forest (based on Nelson population)
    - virtually no breeding each year because of competition with introduced wasps and possums for important foods.
    - breeding pulse on average every 6 years coinciding with beech mast.
    - mast also precedes significant predation pulse.
2. North Island island population (based on Kapiti island)
    - some breeding every year.
    - some rat predation every year.
    - high annual variation in productivity because of natural variation in food abundance.
    - habitat improving because of eradication of possums.
3. South Island podocarp-beech forest where possums are not yet present but are invading.
    - some breeding every year
    - more regular breeding pulses because of beech mast and podocarp mast.
    - significant breeding pulses.
    - possums now invading so significant reduction in habitat quality predicted.

There is insufficient data to model the fourth scenario, North Island mainland, though inferences can be drawn from the results of the other three scenarios.

Scenario 1 is characteristic of current status in much of the range of kaka, both North and South Island, with habitat quality severely deteriorated because of introduced browsers, and with high periodic predation levels.

Scenario 2 gives us a glimpse of more optimum conditions on an island, although habitat quality is still improving and predation by introduced rats occurs.

Scenario 3 gives us an idea of what is probably happening in the few remaining areas where kaka numbers remain high on the South Island mainland. These populations appear to be surviving, albeit at reduced levels, in the medium term. Colonisation of possums in this habitat is ongoing, and will reduce the quality and quantity of available food.

1.4.1. Values of Variables fed into models:

1. Current Population Size

Current population size of kaka cannot be determined because of the bird's high degree of mobility and variable conspicuousness in time and space. Nevertheless, order of magnitude estimates have been made for the three areas included in the models. The size of the Kapiti Island population was estimated by two different techniques (nests found per area searched and transect bird counts) - both gave a very similar value in the order of 1000 birds. We estimated the size of study populations in Nelson Lakes and South Westland on the basis of 5-minute bird counts, capture data, and the perceived abundance of kaka in these areas relative to Kapiti Island.

2. Carrying Capacity

In all scenarios, carrying capacity was assumed to be higher than the current population level. Kaka populations are known to have been several orders of magnitude higher than present levels. Therefore, we ensured that carrying capacity did not constrain population growth.

3. Reproduction

Records on captive kaka indicate the average age of first reproduction to be 5 years (M.D. Sibley, pers. comm.). Wild kaka are known not to breed under three years of age.

Data on average clutch size, hatching success, brood size and fledging success are available for North Island kaka on Kapiti Island (Moorhouse 1991). The limited data available for South Island kaka (Jackson 1963; Beggs & Wilson 1991; C.F.J. O'Donnell pers. comm.) indicate that they are similar to North Island kaka, but that the maximum brood is 5. However, a brood size of five has never been observed on Kapiti Island, so we regard this as the maximum potential number of young fledged.

The number of pairs that attempt to breed shows marked annual variation in all habitats. The only breeding recorded in Nelson Lakes coincided with a beech seed mast year, which occurs on average every 6 years. In non-mast years no successful breeding was recorded. Despite this observed periodicity in kaka breeding, we have averaged productivity over the time span of our studies to confirm to the format of the model.

4. Mortality

Primary causes of mortality in kaka are predation of eggs, nestlings, young fledglings and incubating females. Rats prey upon on eggs and nestlings (Moorhouse 1991), and stoats are likely to prey upon all these stages (a nesting adult female was killed by a stoat; Beggs & Wilson 1991). Two other hole nesting forest birds (yellowheads and parakeets) are known to suffer nest predation by stoats and ship rats. Our estimate of adult female kaka mortality is based in part on a 50% mortality of incubating female yellowheads during periodic stoat plagues (O'Donnell et al. 1991). Young fledglings are assumed to be vulnerable to stoats because they are flightless for the first few days post fledging.

Starvation of nestlings was found to be a major cause of mortality on Kapiti Island. However, we consider this unimportant in Nelson Lakes (beech) and South Westland (beech/podocarp) forest as kaka only breed in these habitats when there is plenty of food.

Banding studies indicate that, apart from nesting females, kaka have a very low level of adult mortality. We used a conservative value of 3%. Adult mortality in four species of parrot in the wild ranged from 3-8% (Ulysses Seal, pers. comm.).

Kaka are a long-lived species. One female kaka was known to have survived 27 years on Kapiti Island, and kaka in captivity have lived up to 35 years. Therefore, we assume a maximum longevity in the wild of 30 years.

1.4.2. **Scenario One** - South Island beech forest

Notes on data input to Vortex

Input notes

The following is a summary of input data printed from Vortex. For full explanation see Appendix 4, the data input section from the Vortex manual (Lacy & Kreeger, 1992).

Input File: Beggs8.bat

Simulations *** 10
Years *** 100

Reporting Interval *** 10
Populations *** 1
Types of catastrophes *** 1
Inbreeding depression? *** No
Monogamous or polygynous *** M
Female breeding age *** 5 (estimated from captive population)
Male breeding age *** 5
Maximum age *** 30 (clearly long lived birds with max longevity in captivity of35 years)
Sex ratio *** 0.5 (50:50 sex ratio at birth in captivity)
Maximum clutch size *** 5 (confirmed for North and South Island kaka)
Density dependent reproduction? *** No

Population1:Percent clutch size0*** 97.5 (% of s laying no eggs)
Population1:Percent clutch size1*** 0.25 (% of s laying 1 egg, etc)
Population1:Percent clutch size2*** 0.5
Population1:Percent clutch Size3*** 1.0
Population1:Percent clutch Size4*** 0.5
Population1:Percent clutch Size5*** 0.25
EV--Reproduction*** 20%

Note: We assume that in most years there is virtually no breeding because the population is under competitive stress. However, once on average every 6 years there is a breeding pulse based on beech mast. When that happens we estimate (from Nelson Lakes data)that 15 % of adult females breed. The high environmental variance reflects the extreme variability of breeding from year to year.

Female mortality age 0 *** 50% (mortality up to age of 1)
EV--Female mortality***18%

Note: The 50 % mortality derived from 40 % rat or stoat predation and 10 % predation of fledglings on the ground after birds have left the nest. (derived Kapiti Island mortality figures, supported by data on yellowheads which also indicates 50% predation rate in stoat years).

Female mortality at age 1 *** 3 %
EV--female mortality *** 1
Female mortality at age 2 *** 3 %
EV--female mortality *** 1
Female mortality at age 3 *** 3
EV--male mortality*** 1
Adult female mortality*** 5.5
EV--Adult female mortality*** 2

Note: Kaka are long-lived and appear to have very low adult mortality. Under best possible conditions annual mortality was estimated at 3 % per annum. Mortality may be higher than this but more data from banded populations is required. Adult female mortality is higher because we predict 50 % of breeding females will be preyed upon in a predator plague year. Thus if 15% of females breed and 50% are preyed upon, this = an additional 2.5 % mortality averaged over six years.

Male mortality at age 0 *** 50%
EV--Male mortality *** 18%
Male mortality at age 1 *** 3
EV--Male mortality *** 1
Male mortality at age 2 *** 3
EV--Male mortality *** 1
Male mortality at age 3 *** 3
EV--Male mortality *** 1
Adult male mortality *** 3
EV--Adult male mortality *** 3

Note: Males are not subject to predation on nest so mortality remains constant with time.

Probability of catastrophe *** 1.0
Severity on reproduction *** ?
Severity on survival *** ?

Note: Allows for a possible disease outbreak in the population once in a hundred years.

All males breeders? *** yes
Start at stable age distribution? *** yes
Initial population size *** 300 (speculative number for Nelson beech forests)
Carrying capacity (K) *** 1000
EV--K***
Trend in carrying capacity K? *** yes
Years of trend *** 20
Percent change in K *** -1.0

Note: Habitat quality will continue to decline (wasps and possums) slowly over the next 20 years approx. Rate guesstimated at 1%/year.

Harvest? *** No
Supplement? *** No
Density dependent reproduction? *** No

Summary of output from Vortex runs:
Even with a mortality rate of only 3% for most age classes, the population became extinct in an average of 29 years. Female mortality was a crucial variable in determining rate of extinction. Our estimate of adult female mortality due to predation (2.5%) is low, but with so few females breeding in the population each year it was still sufficient to produce the predicted decline. Although many of the variables were estimates, as these were conservative, we consider the simulation realistic. Simulations run with mortality at 5 and 7% showed even more dramatic declines.

Alternative run options:

1) Both inbreeding and not inbreeding options

2) Higher adult mortality rates (6-8 %)

3) Without a disease catastrophe

4) Simulate what would happen with an increase in the frequency and the number of females breeding (ie. simulate the effects of increased reproduction from supplementary feeding).

5) Simulate the effect of removing stoat predation following beech mast years (this will reduce adult female mortality by 2.5 % and increase year 0-1 survival by 10%).

6) Simulate the effect of removing all predation on nestlings and adult females.

1.4.3 **SCENARIO 2** - Kapiti Island

Notes on Data Input to Vortex:

Categories of the model different from scenario 1 are outlined below.

Input filename: Ron2.bat
Population1:Percent brood size0*** 60.00
Population1:Percent brood size1*** 10.00
Population1:Percent brood size2*** 20.00
Population1:Percent brood Size3*** 10.00
Population1:Percent brood Size4*** 0.00
Population1:Percent brood Size5*** 0.00
EV--Reproduction*** 33.00 (based on the estimated proportions of the population breeding in the four years of the study; 80, 40, 40, 0)

Note: A higher proportion of the Kapiti kaka population breed than at Nelson Lakes. We assumed that at least 80% of birds bred in the "boom" 1988/89 season. In the subsequent two years approximately half this number of nests were found, hence the estimate of forty percent of the population breeding in a typical year. This estimate of annual productivity is then split between the different brood size categories on the basis that broods of four and five young were not recorded in a total sample of 48 nests and that two young were the modal brood.

Female mortality age 0 *** 60%
EV--Female mortality*** 16%

Note: This estimate of female mortality is based on the combined losses due to predation and starvation of nestlings plus a very rough estimate of 33% post-fledging mortality up to 1 year. In the 1988/89 season nine nestlings were banded in the vicinity of the Rangatira flat ranger station. Six of these are still alive at present (December 1991). One of the other three is known to have died, the other two can reasonably be presumed dead.

Female mortality at age 1 *** 3 %
EV--female mortality *** 1%
Female mortality at age 2 *** 3 %
EV--female mortality *** 1%
Female mortality at age 3 *** 3%
EV--female mortality*** 1%
Adult female mortality*** 3%
EV--Adult female mortality*** 1%

Note: Female kaka on Kapiti Island are not subject to predation while incubating. We have therefore entered minimal estimates of mortality for adult females in this population. Kaka are long-lived and appear to have very low adult mortality. Under optimal conditions annual mortality was estimated at 3 % per annum. More data from banded populations required to obtain an accurate estimate of female mortality.

Male mortality at age 0 *** 60%
EV--Male mortality *** 16%
Male mortality at age 1 *** 3%
EV--Male mortality *** 1%
Male mortality at age 2 *** 3%
EV--Male mortality *** 1%
Male mortality at age 3 *** 3%
EV--Male mortality *** 1%

Adult male mortality *** 3
EV--Adult male mortality *** 3

Note: Males not subject to predation on nest so mortality remains constant with time.

All males breeders? *** yes
Start at stable age distribution? *** yes
Initial population size *** 1000
Carrying capacity (K) *** 5000?
EV--K*** 500
Trend in carrying capacity K? *** no
Years of trend ***
Percent change in K ***

Note: Habitat quality may continue to increase as the island recovers from possums and regeneration continues. On the other hand,the present diverse mosaic of seral forest may be more favourable to kaka than a homogeneous climax forest. We have therefore not entered any trend in carrying capacity.

<u>Summary of outputs from Vortex:</u>
This population is increasing despite substantial nestling mortality (60%). In this case, the absence of stoat predation on breeding females and the greater frequency of reproduction (due to the absence of possums) would seem to be the important factors contributing to the stability/growth of the population. Lambda would no doubt have been larger in the absence of rat predation on nestlings.

Alternative run options:

1) Increase mortality on year 0 birds to simulate ship rat invasion on the island.

2) Remove predation component due to Norway rats to simulate a predator free environment (this will allow evaluation of the effect on kaka of the proposed eradication of rats from Kapiti Island). The 0-1 age class mortality would then be 20% rather than 60%.

3) Simulate the effect of the former possum density on Kapiti Island to evaluate what would have happened to the kaka population if possums had not been removed. (Ron to check with rangers diary on number of young kaka seen etc.).

4) Run without catastrophe

1.4.4 **Scenario 3.** - South Westland

Notes on data input to Vortex:

Categories of the model different from scenario 1 are outlined below.

Colin1.bat - invasion of possums
Colin2.bat - prior to arrival of possums

Output filename ***

Population1:Percent clutch size0*** 60
Population1:Percent clutch size1*** 5
Population1:Percent clutch size2*** 20
Population1:Percent clutch Size3*** 10
Population1:Percent clutch Size4*** 2.5
Population1:Percent clutch Size5*** 2.5
EV--Reproduction*** 16%

Note: We expect less variance in the proportion of the population breeding each year in South Westland than on Kapiti Island because of more reliable food supplies. Jackson (1963) records a broad size in South island Kaka of 2-5 birds. (Cof mean brood size of 2 on Kapiti Island)

Female mortality age 0 *** 50%
EV--Female mortality*** 18

Note: The estimated 50 % mortality was derived from 40 % rat or stoat predation and 10 % predation of young fledglings on the ground (derived from Kapiti Island mortality figures, supported by data on yellowheads which also indicates a 50% predation rate on nestlings in years of high stoat numbers).

Female mortality at age 1 *** 3 %
EV--female mortality *** 1
Female mortality at age 2 *** 3 %
EV--female mortality *** 1
Female mortality at age 3 *** 3
EV--female mortality*** 1
Adult female mortality*** 3%
EV--Adult female mortality*** 16%

Note: Kaka are long-lived and appear to have very low adult mortality. Under best possible conditions annual mortality estimated at 3 % per annum.

Over estimated adult female predation was derived from 10% predation each year (over 6 yrs), then 50% during stoat plague in 7th year (average 16%). Predation in yellowhead populations in non-stoat plague years is less than 10%. Predation in South Westland is probably higher than in beech forests because the mixed forest supports a higher base population of rats and stoats.

Male mortality at age 0 *** 50%
EV--Male mortality *** 18
Male mortality at age 1 *** 3
EV--Male mortality *** 1
Male mortality at age 2 *** 3
EV--Male mortality *** 1
Male mortality at age 3 *** 3
EV--Male mortality *** 1
Adult male mortality *** 3
EV--Adult male mortality *** 3

Note: Males not subject to predation on nest so mortality remains constant with time.

All males breeders? *** yes
Start at stable age distribution? *** yes
Initial population size *** 3000 (Windbag Valley, South Westland
Carrying capacity (K) *** 4000
EV--K***100
Trend in carrying capacity K? *** yes
Years of trend *** 30
Percent change in K *** -3%

Note: Habitat quality will decrease significantly as possums colonise South Westland forests. Data in Rose et al. (1990) show that kaka numbers decline by 40% within 10 years of colonisation, by 80% 10-30 yrs on and 90% by 30 years.

Summary of Output from Vortex Runs

With the invasion of possums and on-going predation by stoats and rats the population became extinct on average in 33.5 years. Even if the possum invasion did not occur or was able to be managed, the probability of extinction within 100 years was still 0.4, and the average remaining population size was only 77 birds from the original 1000. The prognosis is that the remaining populations would become extinct soon after 100 years. The overall implication is that Kaka populations can't withstand predation of adult females, even with high habitat quality and regular breeding. Enhanced breeding is likely to just slow the extinction rate, but not reverse the overall trend to extinction.

Alternative run options:

1. Run without the decline in carrying capacity brought on by possum colonisation to determine if a 'predator only' population can survive.

1.4.5. Alternative Run Options for all Scenarios

1. Run with inbreeding depression.

2. Run without disease catastrophe.

3. Run with a skewed age structure typical of an ageing population. We think is a likely situation in most mainland Kaka populations.

4. Plot extinction rate, and assume year 1 is 1900, ie. when many of the predators and competitors first became common. Compare this with historical information on the decline of kaka populations nationwide to evaluate the accuracy of the simulation.
5. Run with varying levels of harvesting to simulate effects of poaching.
6. Model long term stability of Codfish Island population given a likely starting population of 300 birds. Codfish may eventually be the only surviving population of South Island kaka and it is therefore essential to evaluate the viability of this population under a range of conditions.
7. Simulate recovery of a kaka population from varying minimum levels.

1.5. RECOMMENDATIONS:

1.5.1. Recommendations for Management in the Wild

1. Develop a management plan for kaka that encompasses both wild and captive populations within the next year.
2. Evaluate supplementary feeding as a means of enhancing kaka productivity in the wild.
3. Evaluate current techniques for control of predators and competitors for their effect on kaka populations. For example, what are the effects of trapping and 1080 poison on kaka?
4. Develop techniques for the reintroduction of captive bred kaka into the wild.
5. Develop techniques for translocation of Kaka from island strongholds onto the Mainland.
6. What is the extent of poaching of kaka for food or the illicit bird trade? Harvesting impacts in the models?

1.5.2. Recommendations for Management in Captivity

North Island Kaka:

1. Establish a 'Nuclear 1 [or2?] captive population (i.e. a captive nucleus to always represent 98% of the wild gene pool).

   Ideally this requires 20 effective founders as the basis for a captive population. 10 males - 10 females (desirable) or 5 males - 15 females (upper limit) - (60 effective founders is the upper limit for maintenance). There is thus,theoretically, a need in the future to accumulate another ten founders of known provenance into the current population. Adjustments will need to be made to maintain the captive population size at about 60 individuals, (achieved through experience and calculated assumptions) and sufficient holders need to be recruited to achieve this.

   Every founder needs to be represented equally in the overall population over all generations. Genetic representation should be brought in from the wild at a rate of one productive genetic sample every two generations (approximately 20 years). Possibly optimum would be every 10 years. (Optimum pairing to achieve genetic goals is presently being worked on.)

   Explanation: The aim of establish nuclear captive populations is to provide for a strong genetic base and insurance policy against the collapse of any species in the wild and to provide material for the re-introduction of stock. In theory we aim to manage the population with a 200-year time frame.

2. Follow recommendations of the Captive Species Management Plan under the leadership of the Species Co-ordinator.

   Species Co-ordinator to distribute a standardised data collection from all participants.

   - Holders of specimens must provide data as required by Species Co-ordinater.

   - Programme birds to be permanently identified using leg bands and Trovan implants.

   - Species Co-ordinator to do SPARKS analysis and make recommendations.

- Species Co-ordinator should maintain a photocopy library of relevant literature and keep-up-to date and in communication with developments, also to relate to Regional Conservation Co-ordinator.

3. Stock excess to programme requirements should be made available to research programmes, public advocacy work Export of surplus birds to institutions who will reciprocate with research or other assistance for kaka conservation should be considered.

4. Use captive population as a resource for prioritised research purposes.

   Identified projects (see below) include:

   - Sperm collection and storage (HIGH PRIORITY)
   - Investigation of when males cease spermatogenesis.
   - Nutritional work, comparing wild diets and constructing captive dietary analogues.
   - Investigating disease susceptibility.
   - Investigation of nest site preference to facilitate design of artificial predator-proof nest boxes for wild populations.
   - Bill size/weight/sexual dimorphism and ageing criteria.

5. Provide support for the field programme.

   - Obtain details from DOC.

6. Establish comprehensive husbandry manual.

   Comments:
   The species management team co-ordinator needs to produce a manual to guide participants on all aspects of captive management.

   - Ensure that what items in PVA Data Form as can be addressed in captivity are done. e.g. weights, measurements, egg weights, incubation data etc.

7. Establish comprehensive health profiles for Kaka in the wild and in captivity.
    - Wild animal veterinary assistance is needed.
    - Establishment of normal physiological values.
    - Construction of periodic health screening.
    - Encourage use of regional pathology register.
8. Develop techniques to successfully effect re-introduction with collaborative post-release monitoring.
    - Develop behavioural enrichment projects to encourage juveniles to learn a range of foraging skills.
    - Explore possibilities of training against environmental threats.
9. Explore the value of Kaka as analogues for conservation work on the endangered kakapo Strigops habroptilus.
    - Complete egg incubation studies and hand-rearing studies by 1992.
    - Complete gut flora studies during 1992.
    - Other studies as required.
10. Encourage public advocacy of collaborative work by high profile exhibit interpretation.

    Comments:
    Public exhibition provides opportunity to develop positive community attitudes towards wildlife and the environment. Programmes should be actively interpreted and promoted giving the public clear reporting on what collaborative programmes seek to achieve and where they are up to. This allows an avenue for sponsorship opportunities to generate funds for collaborative programmes.

South Island Kaka

Results of the PVA Workshop indicate particular urgency, and in accordance with IUCN Policy it is recommended that a 'Nuclear 1' captive population be established.

1. Establish a Nuclear 1 population based on 10 10 founders, to be built up to 20.20 within five years.

   Identify stock and acquire from wild sources ASAP. Effect of removing 20 birds from wild population should be simulated by computer. If removal of adults was deleterious to a wild population eggs could be removed instead. This may produce double clutching and therefore have nil effect on the population. South island Kaka eggs could be incubated under North Island kaka.

2. Appoint a captive breeding co-ordinator (Tony Pullar nominated) and prepare a captive management plan.

3. Co-ordinator to urgently identify spaces to hold the founder birds.

4. Develop captive husbandry techniques using North Island sub-species as an analogue and establish comprehensive husbandry manual.

5. Use captive population as a resource for prioritised research purposes (see below).

6. Provide support for the field programme.

7. Establish comprehensive health profiles for Kaka, both in the wild and in captivity.

8. Develop techniques to successfully effect re-introduction with collaborative post-release monitoring.

9. Continue to explore the value of Kaka as analogues for conservation work on Kakapo Strigops habroptilus.

10. Encourage public advocacy of collaborative work by high profile exhibit interpretation.

11. Consider exporting stock excess to programme to institutions which will reciprocate with research assistance for kaka.

1.5.3. Recommendations for Research on Both Taxa

In wild

1. What is the actual mortality of adult females and the interbirth interval?

2. Obtain a standardised index of kaka abundance in key habitats. This is essential for comparisons between habitats, estimating initial population size and evaluation of the success of management practices. Potentially useful indexes could include average flock size seen and standard five minute bird counts. Data from both of these techniques could be compared with historical information and calibrated against the estimated density for Kapiti Island.

3. What is the historic pattern of kaka population decline in different regions and how does this compare to the models predictions?

4. Clarify the respective roles of competitors and predators in the decline of kaka and evaluate the likely success of management options?

5. How does the diet of the kaka vary seasonally and what are the phenology patterns of foods important for breeding? Prediction of years in which most breeding will occur will allow for more efficient use of management resources.

6. Clarify the taxonomy of North and South Island kaka? Are kaka populations genetically and physically distinct and what are the population parameters ?

In Captivity:

1. Promote molecular genetic work to establish taxonomic relationship of North and South Island Kaka populations.

   Comments:
   (a) It is as yet undetermined whether there are two distinct subspecies of Kaka. This information is important in the establishment of management strategies for recovery. Determination urgently needed.

   (b) Sample wild caught (provenanced) captive birds ASAP.

(c) Provide material and analysis to institutions willing to participate.

N. B. Current captive North Island Kakas need to have purity confirmed.

2. Surgically sex stock to confirm existing sexing to establish a group of birds able to provide reliable morphological data. Identify these birds with permanent I.D.

    (a) Then work up ageing and sexing schedule.

    (b) Can check museum specimens having done 2a and 2b.

3. Vet/Health Aspects

    (a) Establishment of normal values.

        - Establish and maintain health profiles, by at least an annual health check - cloacal and blood.

        - Use regional pathology registry

        - Sperm storage - cryostorage

    (b) When do males start and stop producing viable sperm?

4. Connect with Ellen Dierenfeld and do nutritional work.

5. Trial Donna Corp rings & TROVAN implants, to help with wild/Ding.

1.6 CONCLUSIONS

The PVA simulations ran at this workshop confirm that a management strategy for kaka conservation is urgently required. Population modelling suggests that South Island mainland kaka populations face extinction within 100 years and probably within 30-50 years even under optimistic scenarios. While insufficient data were available to model North Island mainland populations, the earlier impact of humans makes it is highly probable that their decline is even more advanced than in the South Island populations. The populations on Little Barrier, Kapiti and Codfish Islands are likely to remain stable provided they escape invasion by introduced predators or browsers.

Kaka are declining on the mainland because of a complex interplay between competition and predation, but primarily because of predation of adult females on the nest. The 4 strongholds of kaka on the New Zealand mainland are under considerable threat because of ongoing colonisation by possums. Despite the vulnerability of kaka the species has high recovery potential due its productivity and longevity. It is essential to implement management strategies within a realistic time frame to effect recovery (i.e. within the next ten years).

The model suggests that the trend to extinction in mainland populations will occur whatever the starting population size. Although we had to estimate this in all scenarios, the overall conclusions are unlikely to alter even if actual population size differed considerably from our estimates.

Thus, the model suggests that under prevailing conditions on the New Zealand mainland, a larger starting population will simply take longer to become extinct that a smaller.

KEA
(Nestor notabilis)

POPULATION VIABILITY ANALYSIS
WORKSHOP REPORT

KEA

2.0. KEA

2.1. INTRODUCTION TO WILD POPULATIONS:

The kea is a endemic alpine parrot found along the Southern Alps of New Zealand's South Island. The kea is in an unenviable position as it is a high profile species:

On one hand it is a very popular and accessible species, most New Zealanders know it well as they have come across them while tramping, on the roadside in alpine areas, at ski fields and seen them in zoos or private and public aviaries. The kea is an intelligent species with personality - most people can tell stories of comical or notable behaviours they have observed, in most cases they relate these with affection or admiration. In addition to this kea are unique to New Zealand and much of their behaviour could be said to be unique to the bird world as well. To many they are the symbol of New Zealand's alpine areas and as such hold a special place in many people's hearts.

On the other hand there are many problems involving kea, and there has built up over the years a strong prejudice against them and much anecdotal information, much of it detrimental and possibly wrong. Kea were totally protected in 1986, prior to this they were partially protected and earlier totally unprotected - in fact the Government paid bounties on kea bills. Between 1860 and 1970 when kea were partially protected about 150,000 kea were killed. The most accurate record of kea killed is from the New Zealand Journal of Agriculture which shows that 29,249 bounties were paid out between 1920-29.

Currently there are five main areas were there are problems which involve kea, they are:

1. Alpine villages and tourist areas where kea congregate because of the human activity and the associated by-products such as rubbish dumps and supplementary food availability. Here there are problems with kea being exposed to dangerous or toxic waste and kea inflicting damage to facilities, gear and installations;

2. Ski-fields once again kea congregate in these areas because of the activity and availability of supplementary food, kea inflict damage to installations, equipment and personal gear which may put at risk human safety and cost a great deal of money to replace;

3. High country sheep runs, kea can injure and kill sheep which can cost the run holder considerable sums of money especially if the damaged or lost stock are valuable stud animals. Kea injure sheep simply by pulling wool or inflicting wounds in their flesh, normally on their backs. The way in which kea kill sheep is more complex and two mechanisms are thought to be the cause

   - infection introduced or initiated by these relatively minor wounds, and
   - severe lacerations and wounding resulting in physical damage and trauma resulting in death.

   The reasons why kea attack sheep are not known;

4. Lowland areas adjacent to kea habitat, there are growing problems with kea inflicting damage to houses, facilities and equipment in areas were kea have not normally be evident. These are areas adjacent to kea habitat in Nelson and the West Coast, kea in these areas are transitory and seem to move into an are for a short time and cause considerable damage. This problem are in a new phenomena and has only been experienced in the past two or three years;

5. Kea in captivity and smuggling. Many kea have been held in captivity because of their past unprotected status and to be used as decoys by run holders to eliminate wild birds on their runs. At present there are many kea in captivity as a result of this, permits have been issued for many but just as many are still being held illegally and some are still being caught and held as call birds. Overseas demand for kea has meant birds have been smuggled out of the country, a number of these are from the abundant captive stock but many are captured from wild flocks. This illegal trade has an unknown effect on the wild population and most of the birds caught die before reaching their destinations.

   Even though the kea is a high profile species which is relatively accessible very little is known about it. There are huge gaps in the information available on all aspects of its biology, ecology, distribution, status and population dynamics. The available information and gaps in kea information are highlighted in table 1.

2.2. SUMMARY OF INFORMATION ON BIOLOGY AND ECOLOGY

Table 1.

KNOWN INFORMATION	UNKNOWN INFORMATION
BREEDING	
* breeding age (3 yrs)	* mean breeding age
* clutch range (1 - 4)	* mean hatching success
* mean clutch (2.5)	* mean fledge, success
* hatch. success (1.9)	* mean fledge age
* fledge. success (1.6)	* incidence of multiple clutches
* laying freq.(12 months)	* hatching sex ratio
* incubation (23-24 d)	* egg fertility
* fledge. age (13 wks)	* reproductive lift span
* life time reproduction	
* % of male/female breeding	
POPULATION	
size	
sex ratio/structure	
social structure -distribution	
juvenile dispersion	
breeding/non-breeding proportion	
age structure	
HABITAT	
breeding (limited)	
non breeding (limited)	
food requirements (limited)	
breeding	
non breeding	
food requirements	
MORTALITY	
% normal adult	
% normal juvenile	
causes natural and unnatural	

It is obvious then that kea conservation is not nor will it be a simple matter. When producing the recovery/management plan we will need to bear in mind that we will have to address not only the biological and ecological areas but the human conflict areas also, these areas will be the most difficult and complex.

2.3 CURRENT CAPTIVE POPULATION(From annual report of Tony Pullar, 30/6/92) The current captive population (for which we have records) is 204 (132.56.16). The PVA in Christchurch identified the need to establish captive population of 20:20 founders. Tony is attempting to identify suitable birds to form this core, whose origins can be traced back to wild-caught ones. The blood analysis currently being undertaken at Auckland Zoo may prove very useful in this and other programmes, allowing determination of unrelated birds to provide a healthy breeding base. Priorities at present are banding and sexing birds. Eleven chicks were raised at Auckland Zoo this season, most being hand-raised to study the establishment of the normal gut flora and the effects of lactobacillis supplementation.

Private owners with kea to be approached. If they will not join the SMP valuable birds for the programme can be removed from these persons. We can then afford to be more selective with regard what birds are returned. Recommended that they be left with single six birds.

Private people can join SMP if they abide by rules/directions.

Follow same strategy as that for Kaka for nuclear and founder stock.

Balance the array of aviary space available for both species.

2.3.1 Kea Strategies

1. 204 kea spaces currently exist.

2. Only sixty spaces required for the nuclear captive population. Therefore identify 10.10 wild caught birds which have bred to act as founders. If 10.10 wild caught founders cannot be located numbers to be made up with wild caught potential founders which will then need to be bred to become founders.

3. Identify progeny of founders to take population up to a maximum of 60.

4. Construct SPARKS breeding programme and manage according to recommendations of the Species Co-ordinator.

5. In order to achieve the above it will be necessary to re-appraise all current holding and may be necessary to move stock according to programme objectiv

Stock excess to programme requirements should be made available to research programmes, public advocacy and consider exporting birds to institutions who will reciprocate with research assistance for Kea.

2.4. POPULATION BIOLOGY AND VIABILITY ANALYSES

2.4.1. Values of Variables Fed into Model

Listing of parameters for Basic Simulation

1 One population based on expectation of gene flow from Kaikoura to Southernmost birds over time. Some population differences expected.

2. There would be no correlation between reproduction and survival.

Inbreeding depression considered insignificant low based on fact that breeding is by a dominant core group and there may be a fair proportion of inbreeding already.

3. Believe kea breeding is monogamous. Information to date shows that male feeds female in nest then shares feeding of chicks - therefore no opportunity.(Jackson 1969 and Wiison data).

4. Age of female starting breeding in the wild (earliest in captivity is three) - Mean age = five.

5. Male same.

6. Maximum age beyond which death occurs = 25 possible range of 25 - 35. Suggestion from Australian that large number of captive birds were brought in the 1940's and are still alive. A 35 year old male is still breeding in captivity in New Zealand.

Males appear to become infertile earlier than females.

7. Sex ratio at birth possibly even (needs to be modelled with 1.5 males to 1 female based on current NZ captive data but this needs more work) and a 2.1 males - 1 female based on collection data (Diamond and Bond).

Sexing can occur with hatchlings also. Query if Wilson data is available.

8. Maximum Fledging litter sizes at 4 based on Captive information of 4 which was N.Z. Wild : 2-3 (Wilson).

9. Maximum clutch size recorded in captivity is 5.

10. Reproduction success not density dependant

    Average year 60% of adult females produce no young (Diamond and Bond - who had a sex ration of 4 male to one female with 1% of males only breed in a year)

    All females that breed are presumed to produce some young.

    Percentage of females producing one young.

    Productivity (JACKSON 1963): Observations of family groups indicate 2 per pair (Wilson and Captive data).

    Jackson Data is best but needs to be checked whether this includes zeros.

11. With 1.7 average had 15% producing 1 young. 2 30% produce 2 young, 5% producing 3 young standard deviation is 5%.

12. Female mortality fledging to year 1 = 40 based on sample size of five (Diamond and Bond).

    Jackson 1969 a second figure of 32 (includes males and females) Standard deviation would be 10.

13. Female mortality 1 - 2 = 10 based on a relatively low figure as adults will still share food with young at this age but no data.

    Have a figure from JACKSON - males and females combined of 80% Problems of separating mortality and dispersal. Standard Deviation of 3.

14. 2-3.

15. 2-4 (All 5% with a SD of 2).

16. 4-5 Data From Captivity of 50% dying in the first 30 days based on Isis data needs interpretation and one out of 14 captive birds that died between fledging and year one (ISIS).

17. Annual percent mortality of adult females - 5 based on no sex specific data.

    JACKSON had a 100% survival from age four on his banding study with SD of 2.

18. Males - same as females.
    <u>Background</u>
    Diamond and Bond reported 11 out of 12 males lost between fledging and year one. Considered a lot of this relates to dispersal as well as mortality.
    Diamond and Bond estimated first year mortality in males "as high as 50%".

    Do we expect male mortality to be higher than females - maybe yes due to cost of dispersal, maybe no if using human supplied food.

19. CATASTROPHE 1 was one in every 25 years weather event.
    Effect on reproduction 0.25.
    Survival .80

20. CATASTROPHE 2 in a hundred.
    Severity of reproduction 0.95.
    Survival .10

21. All adult males not in breeding pool, but 90% were (not based on data, but no indication that males are limited.)

22. Stable age distribution - assumed stable.

23. A thousand individuals in initial population.

24. Carrying capacity 2,000 individuals.

25. Standard Deviation 0.

26. No change in carrying capacity - model with possible reduction in food and management maybe a 20% reduction over 100 years.

27. Harvesting - run with no harvest and later with annual take of 5% or 10% distributed across age and sex.

28. No supplementation to wild population.

```
KEA_base.006    ***Output Filename***
N    ***PlotterFiles?***
N    *** Full Table?***
100    ***Simulations***
100    ***Years***
10    ***Reporting Interval***
1    ***Populations***
N    ***EVcorrelation?***
0    ***Typeso
Catastrophe?***
N    ***Inbreeding Depression?***
M    ***MonogamousOrPolygynous***
5    ***FemaleBreedingAge***
5    ***MaleBreedingAge***
25    ***MaximumAge***
0.500000    ***SexRatio***
4    ***MaximumLitterSize***
N    ***Density dependent reproduction?***
60.000000    ***Population1:PercentLitterSize0***
15.000000    ***Population1:PercentLitterSize1***
20.000000    ***Population1:PercentLitterSize2***
5.000000    ***Population1:PercentLitterSize3***
0.000000    ***Population1:PercentLitterSize4***
5.000000    ***EV--Reproduction***
40.000000    ***FemaleMortalityAtAge0***
10.000000    ***EV--FemaleMortality***
10.000000    ***FemaleMortalityAtAge1***
3.000000    ***EV--FemaleMortality***
5.000000    ***FemaleMortalityAtAge2***
2.000000    ***EV--FemaleMortality***
5.000000    ***FemaleMortalityAtAge3***
2.000000    ***EV--FemaleMortality***
5.000000    ***FemaleMortalityAtAge4***
2.000000    ***EV--FemaleMortality***
5.000000    ***AdultFemaleMortality***
2.000000    ***EV--AdultFemaleMortality***
40.000000    ***MaleMortalityAtAge0***
10.000000    ***EV--MaleMortality***
10.000000    ***MaleMortalityAtAge1***
3.000000    ***EV--MaleMortality***
5.000000    ***MaleMortalityAtAge2***
2.000000    ***EV--MaleMortality***
5.000000    ***MaleMortalityAtAge3***
2.000000    ***EV--MaleMortality***
3.000000    ***MaleMortalityAtAge4***
```

```
2.000000    ***EV--MaleMortality***
5.000000    ***AdultMaleMortality***
2.000000    ***EV--AdultMaleMortality***
N    ***AllMalesBreeders?***
90.000000    ***PercentMalesInBreedingPool***
Y    ***StartAtStableAgeDistribution?***
1000    ***InitialPopulationSize***
2000    ***K***
0.000000    ***EV--K***
N    ***TrendInK?***
N     ***Harvest?***
N    ***Supplement?***
Y    ***AnotherRun?***

VORTEX -- simulation of genetic and demographic stochasticity

KEA_BAS6.RPT
Sat Dec 28 15:51:12 1991
 1 population(s) simulated for 100 years, 100 runs
 No inbreeding depression
 First age of reproduction for females: 5   for males: 5
 Age of senescence (death): 25
 Sex ratio at birth (proportion males): 0.5000

Population 1:
  Reproduction is assumed to be density independent.

   60.00 (EV = 5.00 SD) percent of adult females produce litters of size 0
   15.00 percent of adult females produce litters of size 1
   20.00 percent of adult females produce litters of size 2
    5.00 percent of adult females produce litters of size 3
    0.00 percent of adult females produce litters of size 4

  40.00 (EV = 10.00 SD) percent mortality of females between ages 0 and 1
  10.00 (EV = 3.00 SD) percent mortality of females between ages 1 and 2
   5.00 (EV = 2.00 SD) percent mortality of females between ages 2 and 3
   5.00 (EV = 2.00 SD) percent mortality of females between ages 3 and 4
   5.00 (EV = 2.00 SD) percent mortality of females between ages 4 and 5
   5.00 (EV = 2.00 SD) percent annual mortality of adult females (5 <= age <= 5)
  40.00 (EV = 10.00 SD) percent mortality of males between ages 0 and 1
  10.00 (EV = 3.00 SD) percent mortality of males between ages 1 and 2
   5.00 (EV = 2.00 SD) percent mortality of males between ages 2 and 3
   5.00 (EV = 2.00 SD) percent mortality of males between ages 3 and 4
   5.00 (EV = 2.00 SD) percent mortality of males between ages 4 and 5
   3.00 (EV = 2.00 SD) percent annual mortality of adult males (5 <= age <= 25)
```

```
EVs may have been adjusted to closest values possible for binomial distribution.
EV in mortality will be correlated among age-sex classes but independent from EV
in reproduction.
Monogamous mating; 90.00 percent of adult males in the breeding pool.

 Initial size of Population 1:    (set to reflect stable age distribution)
 Age 1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
17   18   19   20   21   22   23   24   25   Total
   57   48   44   38   35   31   29   26   24   21   20   18   17   14   14   12
12   10    9    9    8    7    6    6    6   521  Males
   58   48   44   38   35   31   27   25   22   19   17   16   14   12   11   10
9    8    7    6    6    5    4    4    3   479  Females

 Carrying capacity = 2000 (EV = 0.00 SD)

Deterministic population growth rate (based on females, with assumptions of  no
limitation of mates and no inbreeding depression):

   r =  0.063     lambda = 1.065     R0 =    2.137
  Generation time for:  females = 12.13    males = 12.81

Stable age distribution:  Age class    females    males
                               0        0.085      0.085
                               1        0.048      0.048
                               2        0.040      0.040
                               3        0.036      0.036
                               4        0.032      0.032
                               5        0.029      0.029
                               6        0.026      0.026
                               7        0.023      0.024
                               8        0.020      0.022
                               9        0.018      0.020
                              10        0.016      0.018
                              11        0.014      0.016
                              12        0.013      0.015
                              13        0.012      0.014
                              14        0.010      0.012
                              15        0.009      0.011
                              16        0.008      0.010
                              17        0.007      0.009
                              18        0.007      0.009
                              19        0.006      0.008
                              20        0.005      0.007
                              21        0.005      0.006
                              22        0.004      0.006
```

```
VORTEX -- simulation of genetic and demographic stochasticity

KEA_BAS6.RPT
Sat Dec 28 20:50:35 1991


 1 population(s) simulated for 100 years, 100 runs

 No inbreeding depression
 First age of reproduction for females: 5   for males: 5
 Age of senescence (death): 25
 Sex ratio at birth (proportion males): 0.5000



Population 1:

  Reproduction is assumed to be density independent.

   60.00 (EV = 5.00 SD) percent of adult females produce litters of size 0
   15.00 percent of adult females produce litters of size 1
   20.00 percent of adult females produce litters of size 2
    5.00 percent of adult females produce litters of size 3
    0.00 percent of adult females produce litters of size 4

  40.00 (EV = 10.00 SD) percent mortality of females between ages 0 and 1
  10.00 (EV = 3.00 SD) percent mortality of females between ages 1 and 2
   5.00 (EV = 2.00 SD) percent mortality of females between ages 2 and 3
   5.00 (EV = 2.00 SD) percent mortality of females between ages 3 and 4
   5.00 (EV = 2.00 SD) percent mortality of females between ages 4 and 5
   5.00 (EV = 2.00 SD) percent annual mortality of adult females (5 <= age <=
25)
  40.00 (EV = 10.00 SD) percent mortality of males between ages 0 and 1
  10.00 (EV = 3.00 SD) percent mortality of males between ages 1 and 2
   5.00 (EV = 2.00 SD) percent mortality of males between ages 2 and 3
   5.00 (EV = 2.00 SD) percent mortality of males between ages 3 and 4
   5.00 (EV = 2.00 SD) percent mortality of males between ages 4 and 5
   3.00 (EV = 2.00 SD) percent annual mortality of adult males (5 <= age <= 25)
   EVs may have been adjusted to closest values possible for binomial distribution.
   EV in mortality will be correlated among age-sex classes
     but independent from EV in reproduction.
 Monogamous mating; 90.00 percent of adult males in the breeding pool.
```

```
 Initial size of Population 1:
   (set to reflect stable age distribution)
 Age 1    2    3    4    5    6    7    8    9    10   11   12   13   14   15   16
17   18   19   20   21   22   23   24   25   Total
   57   48   44   38   35   31   29   26   24   21   20   18   17   14   14   12
12   10    9    9    8    7    6    6    6    521  Males
   58   48   44   38   35   31   27   25   22   19   17   16   14   12   11   10
9    8    7    6    6    5    4    4    3    479  Females

 Carrying capacity = 2000 (EV = 0.00 SD)

Deterministic population growth rate (based on females, with assumptions of no
limitation of mates and no inbreeding depression):

   r =  0.063    lambda = 1.065    R0 =    2.137
  Generation time for:  females = 12.13    males = 12.81

Stable age distribution:

Ratio of adult (> = 5) males to adult (> = 5) females: 1.144

Population1

Year 10
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =    100, P[S] = 1.000
   Population size =          1816.15 (  16.88 SE,  168.83 SD)
   Expected heterozygosity =     0.999 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =     1.000 (  0.000 SE,   0.000 SD)
   Number of extant alleles = 1452.79 (   6.57 SE,   65.67 SD)
Year 20
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =    100, P[S] = 1.000
   Population size =          1998.39 (   1.24 SE,   12.37 SD)
   Expected heterozygosity =     0.999 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =     0.999 (  0.000 SE,   0.001 SD)
   Number of extant alleles = 1107.26 (   3.02 SE,   30.23 SD)
Year 30
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =    100, P[S] = 1.000
   Population size =          2001.34 (   0.91 SE,    9.05 SD)
   Expected heterozygosity =     0.998 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =     0.999 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  876.40 (   2.40 SE,   24.00 SD)
```

```
Year 40
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          1996.62 (  1.14 SE,   11.37 SD)
   Expected heterozygosity =    0.998 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.998 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  729.02 (   2.01 SE,   20.09 SD)
Year 50
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          1997.77 (  1.54 SE,   15.36 SD)
   Expected heterozygosity =    0.997 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.998 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  622.35 (   1.90 SE,   18.97 SD)
Year 60
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          1998.49 (  1.11 SE,   11.13 SD)
   Expected heterozygosity =    0.997 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.997 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  546.22 (   1.71 SE,   17.13 SD)
Year 70
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          1998.26 (  1.17 SE,   11.75 SD)
   Expected heterozygosity =    0.996 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.997 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  484.49 (   1.49 SE,   14.92 SD)
Year 80
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          2000.65 (  1.24 SE,   12.39 SD)
   Expected heterozygosity =    0.996 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.997 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  436.51 (   1.35 SE,   13.47 SD)
Year 90
   N[Extinct] =        0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          2000.19 (  1.37 SE,   13.67 SD)
   Expected heterozygosity =    0.995 (  0.000 SE,   0.000 SD)
   Observed heterozygosity =    0.996 (  0.000 SE,   0.001 SD)
   Number of extant alleles =  396.57 (   1.28 SE,   12.81 SD)
```

```
Year 100
   N[Extinct] =       0, P[E] = 0.000
   N[Surviving] =   100, P[S] = 1.000
   Population size =          1996.54 (   1.47 SE,    14.68 SD)
   Expected heterozygosity =    0.995 (  0.000 SE,    0.000 SD)
   Observed heterozygosity =    0.996 (  0.000 SE,    0.001 SD)
   Number of extant alleles =  362.84 (   1.24 SE,    12.41 SD)

In 100 simulations of 100 years of Population1:
 0 went extinct and 100 survived.

This gives a probability of extinction of 0.0000 (0.0000 SE),
 or a probability of success of          1.0000 (0.0000 SE).

Mean final population for successful cases was 1996.54 (1.47 SE, 14.68 SD)

  Age 1      2      3      4   Adults    Total
 114.31  99.26  85.68  78.92  662.35   1040.52  Males
 114.66  97.59  86.17  78.56  579.04    956.02  Females

Without harvest/supplementation, prior to carrying capacity truncation,
 mean lambda was 1.0639 (0.0004 SE, 0.0419 SD)

Final expected heterozygosity was      0.9950 ( 0.0000 SE,  0.0003 SD)
Final observed heterozygosity was      0.9958 ( 0.0001 SE,  0.0015 SD)
Final number of alleles was          362.84 (   1.24 SE,    12.41 SD)
*************************************************************************
*
```

2.4.2. Summary of Output from Vortex Runs:

Summary of Base Kea Run:

All populations increased to a mean final size of 1996.54 individuals, i.e. to carrying capacity (set at 2000).

Other runs undertaken at workshop:

RUN 2: As base run above but with two catastrophes (weather and disease) CC 2,000, POPN.1,000. Result - all populations survived, average final population size: 1,335.

RUN 3: As Run 2 but sex ratio at birth changed from 1 to 1 to 2 male to one female. Result - two extinctions, average final size of surviving populations 536.

Tabulated summaries of runs undertaken at CBSG following the workshop:

Table 1. The effect of simulated variations in male and female adult mortality on the demographic and genetic characteristics of Kea.

Variables held constant each year in this series of simulations were: density independent reproduction, female reproductive success (60%=0, 15%=1, 20%=2, and 5%=3 hatched chicks), average of first reproduction=5 years, monogamous mating in a given year with 90% of adult males in the breeding pool, no inbreeding effects, sex ratio at birth = 0.50, age of senescence =25 years, no catastrophes, harvesting or supplimentation of the population, equal sex preadult mortality (0-1 =40%, 1-2 =10%, 2-3 =5%, 3-4 =5%, 4-5 =5%, and adult mortality as specified in the table). The size of the initial population was set at 1000 with a K of 2000 and the age and sex distribution that of a stable population. Simulations were run for 100 years and 100 runs were done for each scenario.

Summary:
All populations increased in size to approach the carrying capacity (N = final population size in bold type) with adult mortality varying between 3 and 10% for both sexes.

Table 2. The effect of simulated variations in male and female adult reproductive success on the demographic and genetic characteristics of a Kea population.

Variables held constant each year in this series of simulations were: density independent reproduction, male and female adult mortality (5%), average of first reproduction=5 years, monogamous mating in a given year with 90% of adult males in the breeding pool, no inbreeding effects, sex ratio at birth = 0.50, age of senescence =25 years, no catastrophes, harvesting or supplimentation of the population, equal sex preadult mortality (0-1 =40%, 1-2 =10%, 2-3 =5%, 3-4 =5%, and 4-5 years =5%). The size of the initial population was set at 1000 with a K of 2000 and the age and sex distribution that of a stable population. Simulations were run for 100 years and 100 runs were done for each scenario. None of the simulated populations went extinct in this series.

Summary:
All populations increased in size to approach carrying capacity (see N - bold type) if the % of males in the breeding pool ranged from 50 to 100% and chick production between an average of 0.7 - 1.4 per female (from % of females producing different clutch sizes), and if 90% of males were in breeding pool and chick production averaged between 0.4 and 1.6 per female.

Table 3. The effect of simulated variations in male and female adult reproductive success on the demographic and genetic characteristics of a Kea population.

Variables held constant each year in this series of simulations were: density independent reproduction, male and female adult mortality (5%), average of first reproduction=5 years, monogamous mating in a given year with 90% of adult males in the breeding pool, no inbreeding effects, sex ratio at birth = 0.50, age of senescence =25 years, no catastrophes, harvesting or supplimentation of the population, equal sex preadult mortality (0-1 =40%, 1-2 =10%, 2-3 =5%, 3-4 =5%, and 4-5 years =5%). The size of the initial population was set at 1000 with a K of 2000 and the age and sex distribution that of a stable population. Simulations were run for 100 years and 100 runs were done for each scenario. None of the simulated populations went extinct in this series.

Table 4. The effect of varying simulated levels of catastrophe on the demographic and genetic characteristics of a kea population.

Variables held constant each year in this series of simulations were: density independent reproduction, male and female adult mortality (5%), average of first reproduction=5 years, monogamous mating in a given year with 90% of adult males in the breeding pool, no inbreeding effects, sex ratio at birth = 0.50, age of senescence =25 years, harvesting or supplementation of the population, equal sex preadult mortality (0-1 =40%, 1-2 =10%, 2-3 =5%, 3-4 =5%, and 4-5 years =5%). The size of the initial population was set at 1000 with a K of 2000 and the age and sex distribution that of a stable population. Simulations were run for 100 years and 100 runs were done for each scenario.

Summary:
Catastrophes 91 in model) with 50% probability (i.e. once every two years on average), no effects on reproduction, and reducing survival by 20% (SUR = 0.80 on table) to 40% (SUR = 0.6), led kea populations to decline to (or almost to) extinction.

Table 5. The effect of simulated variations in pre-adult mortality on the demographic and genetic characteristics of a Kea population.

Variables held constant each year in this series of simulations were: density independent reproduction, male and female adult mortality (5%), average of first reproduction=5 years, monogamous mating in a given year with 90% of adult males in the breeding pool, no inbreeding effects, sex ratio at birth = 0.50, age of senescence =25 years, no catastrophes, harvesting or supplementation of the population. The size of the initial population was set at 1000 with a K of 2000 and the age and sex distribution that of a stable population. Simulations were run for 100 years and 100 runs were done for each scenario.

Summary:
Setting mortality between fledging and year 1 as 40% an adult mortality at 5%, populations increased with mortality of 5 to 10% in the intervening sub-adult years, remained fairly stable at 20% mortality these years and declined to extinction with mortalities of 30% or higher.

Summary:
With productivity averaging 0.7 birds fledged/female, populations increased with a range of adult mortalities between 3 and 10% of either sex.

2.4.3. Population Factors of Particular Importance (In Priority Order).

1. Population Size
   Affected by all external factors but irrelevant to model. Measurement not achievable but development of indexes high priority.

2. Age Specific Male Mortality
   Affected by all external factors. Little data but considered higher than female. Important to determine relative importance of mortality at different ages using the model.

   Research priority in the wild.

3. Age Specific Female Mortality
   Little data. Research needed on relative importance of mortality of different age groups.

   Research priority in the wild.

4. Productivity
   Little data. Use model to estimate relevant importance.
   Research priority in wild.

5. Carrying Capacity
   Affected by most external factors. Difficult to measure or influence by management.

   Not a priority for research as population considered below carrying capacity.

6. Percentage of Males in Breeding Pool
   Important to model (with 90% in pool population increased, with 30% in pool it crashed). Unimportant in wild as it is not believed that males are limiting.

7. Age of First Breeding
   Not considered important as affected by few external factors and a high confidence placed on estimate used in model. Influence of this variable on model not yet tested.
8. Sex Ratio at Birth
   Not affected by any external factors but maybe important for understanding population dynamics. Influence of this variable on model not yet tested. Priority to obtain better figures from captive population.

9. Age of Senescence
   Considered insignificant in terms of model and the degree to which it is influenced by external factors.

2.4.4. External Factors of Particular Importance (In Priority Order).

1. Habitat Factors
   Changing land use, changing food availability, hazards - i.e. toxins, rubbish, parasites)

   Important to record changes and use model by altering carrying capacity.

   Introduced Browsers and Predators: Not important for management at this stage as considered unlikely to have greater effect than the species has coped with in the past. Reconsider if refinement of model suggests population decline.

2. Kea/Sheep Interaction
   A major advocacy and research issue. Use the model to determine level of resulting kea control that the population can sustain. Assess proportion of population exposed to this factor.

   Catastrophe
   Use model to determine resilience of population (runs to date showed population increase with significant one in a hundred years disease catastrophe and one in twenty year weather catastrophe). Not manageable.

   Serendipity
   Not in model nor influenced by management.

3. Smuggling
   Major advocacy and law enforcement issue. Use model to determine level that is sustainable but considered at this stage not sizeable enough to justify research.

Recognitions
We recognise that:

- a major factor limiting kea population stability is the removal of kea which conflict with humans or human interests (given our current knowledge on kea ecology);

- we lack essential\accurate information on kea demography and ecology (population size\trend, age specific mortality);

- some of this information could easily be obtained from captive populations;

- that conflict exists between different interest groups regarding kea management;

- habitat changes are taking place which may affect the viability of the kea population;

- historically kea have survived intense human persecution and interactions with introduced browsers and predators;

- kea populations in areas not directly effected by humans (protected areas) may be an important source of immigrants to supplement populations depleted through the effect of other factors;

Findings

Finding that:

- modelling the kea population, using our current best estimates of demographic and environmental variables, indicates that the population is able to maintain and possibly expand in the presence of realistic stochastic environmental events.
- that the following variables were of particular significance in influencing population trends generated by the model:
- age specific mortality of males and females
- proportion of males and females breeding in any one year
- reproductive output
- simulations involving the removal of birds from the wild populations indicated that a maximum level of removal [to be modelled] was possible that did not result in population decline although stability was reduced;
- that immigration,as modelled [to be modelled] is an important factor in maintaining the viability of harvested \depleted sub-populations;

2.5. RECOMMENDATIONS

2.5.1. Recommendations for Overall Management and Research:

A key management recommendation is to work to reduce the effects of humans and their activity on kea [these effects are considered to be readily controllable].

- actions to achieve this are identified in "The Kea Management Statement (Draft)"

Research must be undertaken to obtain better estimates of the following kea population features:

- productivity;
- age specific mortality (especially in females);
- the proportion of males and females breeding in any one year;

This must be obtained in both human influenced and non-influenced sub-populations.

That the model be re-run as better estimates of population demographic factors become available;

Develop techniques to:

- obtain population densities in different habitats and then quantify the relative amount of each habitat available/used to estimate the total population and potential carrying capacities (it is recognised that good census data is often the hardest thing to acquire for many threatened species. Therefore we are recommending the use of this technique rather than comprehensive surveys over the full range of the species);

- obtain indices of population size and trends;

Maintain a captive population with good founder representation to assist in:

- research into demographic factors;

- maintaining a protected and representative gene pool;

- developing husbandry skills that may be used to enhance wild populations;

- developing re-introduction and supplementation techniques;

- developing techniques for genome preservation.

That populations in protected areas are not subjected to culling or the un-natural removal of individuals.

That surplus birds from captive populations and birds removed from the wild for management purposes be made available for export to recognised institutions.

KEA MANAGEMENT - PROBLEM AREAS

HIGH COUNTRY RUNS	- advocacy - research - for sound management - research - sheep mortality - research - damage prevention - short term management options
SKIFIELDS AND ALPINE VILLAGES	- advocacy - deter kea congregations - 'kea-proof' buildings
LOWLAND AREAS ADJACENT TO KEA HABITAT	- research - reasons - advocacy
SITES WHERE KEA ARE ADVERSELY AFFECTED BY HUMAN ACTIVITIES	- advocacy - minimising in kea habitat

2.5.2. Issues for Further Discussion

Genetic diversity of wild population

Kea recovery plan

2.5.3. Recommendations for Management of Captive Population:

1. Establish a captive population to protect against catastrophic loss of the species.

   <u>Comments</u>
   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% Heterozygosity 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.

2. Follow recommendations of the Captive Species Management Plan under the leadership of the Species Co-ordinator.

   - Species Co-ordinator to distribute a standardised data collection from all participants.

   - Holders of specimens must provide data as required by Species Co-ordinator.

   - Programme birds to be permanently identified using leg bands and Trovan implants.

   - Species Co-ordinator to do SPARKS analysis and recommendations.

   - Species Co-ordinator should maintain a photocopy library of relevant literature and keep up to date and in communication with developments, also to relate to Regional Conservation Co-ordinator.

3. Use captive population as a resource for prioritised research purposes.

   Comments
   Identified projects include:

   - Sperm collection storage (HIGH PRIORITY)
   - When male cease spermatogenesis.
   - Nutritional work, comparing wild diets and constructing captive dietary analogues.
   - Investigating disease susceptibility.
   - Establishment of next parameters to suggest nest site choices in wild (?)
   - Bill size/weight/sexual dimorphism and ageing criteria.
   - Others as supported by PVA Field Participants.

4. Provide support for the field programme.

   - Obtain details from DOC. Field programmes include DOC and other agencies. Programmes as identified by PVA Field Participants).

5. Establish comprehensive husbandry manual.

   Comments
   The species management team co-ordinator needs to produce a manual to guide participants on all aspects of captive management.

   - Ensure that what items in PVA Data Form as can be addressed in captivity are done. e.g. weights, measurements, egg weights, incubation data etc.

6. Establish comprehensive health profiles for Kea, both in the wild and in captivity.

   - Wild animal veterinary assistance is needed.
   - Establish of normal physiological values.
   - Construction of periodic health screening.
     NB: Use of the Regional Pathology Registry is encouraged.

7. Develop techniques to successfully effect re-introduction with collaborative post-release monitoring.

   - Develop behavioural enrichment projects to encourage juveniles to a range of foraging exercises.

   - Explore possibilities of training against environmental threats.

   (Need to expand to include real interaction with field management programmes, i.e. detailed proposals for release programmes)

8. Explore the value of kea as analogues for Conservation work on kakapo.

   - Complete egg incubation studies and hand-rearing studies by 1992/

   - Complete gut flora studies during 1992.

   - Other studies as required.

9. Encourage public advocacy of collaborative work by high profile exhibit interpretation.

   Comments
   Public exhibition provides opportunity to develop positive community attitudes towards wildlife and the environment. Programmes should be actively interpreted and promoted giving the public clear reporting on what collaborative programmes seek to achieve and where they are up to. This allows an avenue for sponsorship opportunities to generate funds for collaborative programmes

10. Consider exporting stock excess to programme to institutions which will reciprocate with research or other assistance for kea conservation.

   Comments
   A tightly organised strategy needs to be formulated to ensure maximum benefit. m Everyone involved must benefit.

REFERENCES

Beggs, J.R. 1988. Energetics of kaka in a South Island beech forest. Unpubl. MSc thesis, University of Auckland.

Beggs, J.R.; Wilson, P.R. 1987. Energetics of South Island kaka (Nestor meridionalis meridionalis) feeding on the larvae of kanuka longhorn beetles (Ochrocydus huttoni). NZ Journ. Ecology 10: 143-147.

Beggs, J.R.; Wilson, P.R. 1991. The kaka (Nestor meridionalis), a New Zealand parrot, threatened by introduced wasps and mammals. Biological Conservation 56: 23-38.

Buller, W. 1877. Notes on the ornithology of New Zealand. Trans. N.Z. Inst. 10:92

Elliott, G.P.; Ogle, C.C. 1985. Wildlife and wildlife habitat values of Waitutu forest western Southland. Fauna Survey unit Report No. 39. NZ Wildlife Service, Wellington.

Fulton 1908

Lacy, R.C. and T. Kreeger. 1992. Vortex Users Manual - a stochastic simulation of the extinction process. Captive Breeding Specialist Group, Apple Valley, Minnesota.

Moynihan, K.T. 1986. Wildlife and sites of special wildlife interest in the western Waikato region. Fauna Survey Unit Report No. 41. NZ Wildlife Service, Wellington.

O'Donnell, C.F.J. 1983. Wildlife values of State Forests within the Western King Country Management Region. NZ Wildlife Service Fauna Survey Unit Report No. 35. Department of Internal Affairs, Wellington.

O'Donnell, C.F.J. 1991. Application of the wildlife corridors concept to temperate rainforest sites, North Westland, New Zealand. Chapt. 9 In: Nature Conservation 2: The role of corridors. D.A.Saunders & R.J.Hobbs (eds). Surrey Beatty & Sons: Chipping Norton.

O'Donnell, C.F.J.; Dilks P.J. 1986. Forest birds in South Westland - status, distribution and habitat use. New Zealand Wildlife Service. Occasional Publication No 10. Department of Internal Affairs, Wellington.

O'Donnell, C.F.J.; Rasch, G. 1991. Conservation of kaka in New Zealand. A review of status, threats, priorities for research and implications for management. Science & Research Internal Report No. 101. Department of Conservation, Wellington.

Rose, A.B.; Pekelharing, C.J.; Platt, K.H.; O'Donnell, C.F.J.; Hall, G.M.J. 1990. Impact of brush-tailed possums on forest ecosystems, South Westland. Forest Research Institute Contract Report FWE 90/52. FRI, Christchurch.

Saunders, A. 1983. Wildlife and wildlife habitat values of the Mamaku Plateau-an overview. NZ Wildlife Service Fauna Survey Unit Report No. 37. Department of Internal Affairs, Wellington.

Wilson, P.R. 1984. The effects of possums on mistletoe on Mt Misery, Nelson Lakes National Park. Proc. Section A4E, 15th Pacific Sci. Congr. Dunedin, 1983. (P.R.Dingwall compiler). Department Lands and Survey, Wellington.

APPENDICES

POPULATION VIABILITY ANALYSIS WORKSHOP REPORT

APPENDIX 1:

DISEASE IN KEA AND KAKA

(Sherri L Huntress DVM and Peter H. G. Stockdale B. Vet. Med. FRCVS)

There is little published data on disease and causes of death in Keas, with even less on the Kaka. This is not an extensive search but rather a review of some of the necropsy reports of Keas and kakas as well as those diseases which (potentially) could cause serious problems in both captive and wild Kea and Kaka populations.

1. Diseases reported and likely to occur in Nestor spp. can be divided into a number of groups.

   Infectious Diseases

   a) Facultative pathogens: these are diseases that are induced by more or less stress to the birds.

      Examples are:

      Mycoses e.g. aspergillosis, candidiasis
      Bacteria e.g. Salmonella spp.
      Viruses/Rickettsiae e.g. Psitticosis (1)

   b) Diseases that could be spread from domestic birds (particularly psittacosis) in New Zealand to wild psittacines.

      Parasites: Syngamus trachea, Capillaria spp

      Bacteria: Salmonella spp, E. coli, Pasteurella multocida, Yersinia sp.

      Viruses: Psittacine beak and feather disease (PBFD) (2)

      Diseases that could be introduced into New Zealand from overseas:

      (i) Via migratory birds: Virus - Paramyxoviruses of various serotypes, including Newcastle disease,(velogenic form).

      (ii) Via smuggling of psittacines into New Zealand: Viral - Psittacosis(1), PBFD(2), Paramyxoviruses (3), Papovavirus(4), Enteroviruses(5)

2. Ingestion of foreign bodies and toxic substances

   (a) Foreign bodies - reported at necropsy. Kea behaviour makes ingestion of foreign bodies likely (6), S PHILLIPSON (PERS. COMM.) 1981

   (b) Lead poisoning - necropsy reports (Appendix)

In any conservation or recovery programme for Keas and Kakas it is important to include some estimation of the risks of disease for these taxa. This can approach the real situation only by understanding the types and prevalence of diseases in these birds. The opportunity should be taken to obtain normal values for as many physiological variables as possible so that we can better understand disease and its effects when it occurs and data should be collected at necropsy as and when possible to permit better assessment of disease risks for the populations.

Necropsies of Nestor spp

Keas

	Origin	**Diagnosis**
1.	Taronga Zoo	Hepatoma
2.	Lincoln AHL	Kidney (Lead inclusions)
3.	Batchelar AHL	Staphylococcal* arthritis
4.	Mount Bruce	Hepatosis
5.	Mount Bruce	No diagnosis
6.	Mount Bruce	Myopathy
7.	Mount Bruce	No diagnosis

* Similar to the organism causing 'bumble foot'.

Kakas

1.	Invermay AHL	Ovarian adenocarcinoma
2.	Auckland AHL	Splenic necrosis, Septicaemia

REFERENCES:

1. Johnson FWA, Lyon DG, Wilkinson R, Bloomfield P, Philips HL 1984. Isolation of Chlamydia Psittaci from Newly Imported Kea (Nestor Notabilis) Vet.Rec. 114 : 298-299.

2 Pass DA, Perry RA 1985. Psittacine Beak and Feather Disease : An Update Aust. Vet. Practit 15: 55-60.

3. Shortridge KF, Burrows D, Erdei J 1991. Potential Danger of Avian Paramyxovirus Type 3 to Ornithological Collections Vet.Rec. 129 : 363-364.

4. Pass DA 1987. Papovavirus Infections of Birds Aust.Vet. Practit, 17: 77-79.

5. Wylie SL, Pass DA 1989. Investigations of an Enteric Infection of Cockatoos Caused by an Enterovirus-like Agent Aus. Vet. J 66:321-324.

6. J. R. JACKSON 1969. What do Keas Die Of? Notornis 16: 33-44 .

APPENDIX 2:

PVA DATA FORMS - KEA

(Based Primarily on Captive Population)

Species: Nestor notabilis (KEA)

Species distribution:
East & West of the Main divide (Southern Alps)
South Island

Study Taxon (subspecies):
None

Study Population Location:
Captive

Metapopulation - are there other separate populations? Are maps available?: (Separation by distance, geographic barriers?)
None. Suggestion that Kea have crossed Cook Straight to Wellington region, rarely.

Specialized Requirements (Trophic, ecological):
Alpine - to forest lowlands.

Age of first reproduction for each sex (proportion breeding):

a) Earliest: 3 yrs
b) Mean: 4-5 yrs

Clutch size (N, mean, SD, range):
Number fertile: 4)
Number hatched: 4) Captive Pair 1991
Number fledged: 4)

Laying Season:
July - October

Laying Frequency (interclutch interval):

Are multiple clutches possible?
Yes, if first clutch removed or destroyed.

Duration of Incubation:
25 days

Hatchling Sex Ratio:
3 male - 1 female From study pair - normal estimate 50/50

Egg Weights:
(26.6) (24.7) (25.56) (30.7) (30.7) (28.75)
Average of 27.83 (n=6)

Hatchling Weights (male and female):

Age(s) at Fledging:
Captive Fledging -- 90 days

Adult Sex Ratio:

Adult Body Weight of Males and Females:

Reproductive Life-span (Male & Female, Range):
One bird (female) in captivity known to be 35 years old and still actively breeding.

Life Time Reproduction (Mean, Male & Female):
25-40 yrs (estimate)
40 yrs ??

Social structure in terms of breeding (random, pair-bonded, polygyny, polyandry, etc; breeding male and female turnover each year?): Pair - Bonded

Proportion of adult males and females breeding each year:

Dispersal distance (mean, sexes):
Unknown

Migrations (months, destinations):

Territoriality (home range, season):
Captivity - 1 pair per aviary.

Age of Dispersal:

Maximum Longevity:
Captive oldest bird is 35 yrs.

Population census - most recent. Date of last census. Reliability estimate.:
(Captive) 206 130 Males 56 Females 20 Unknown

Projected Population (5, 10, 50 years).:
Past Population Census (5, 10, 20 years - dates, reliability estimates):

Population Sex and Age Structure (young, juvenile, & adults) - time of year.:
Fecundity Rates (by sex and age class):
See SPARKS report.

Mortality Rates and Distribution (by sex and age) (neonatal, juvenile, adult);
Unknown in captive population.

Population Density Estimate. Area of Population. Attach marked map.:

Sources of Mortality-% (natural, poaching, harvest, accidental, seasonal?).:

Habitat Capacity Estimate (Has capacity changed in past 20, 50 years?).:

Present Habitat Protection Status.:

Projected Habitat Protection Status (5, 10, 50 years).:

Environmental Variance Affecting Reproduction and Mortality (rainfall, prey, predators, disease, snow cover ?).:

Is Pedigree Information Available?:

Attach Life Table if available.

Correspondent/Investigator:
Name: Tony Pullar
Kea Captive Breeding Co-ordinater
Dunedin City Council

References:
Snyder, Wiley, & Kepler.

APPENDIX 2:

PVA DATA FORMS - KAKA

(Based Primarily on Captive Population)

Species: Nestor meridionalis (KAKA)

Species Distribution:

Study Taxon (subspecies):
Nestor meridionalis septemtrionalis
North Island Kaka

Study Population Location:
Captive population.

Metapopulation
Are there other separate populations? Are maps available?:
(Separation by distance, geographic barriers?)

Specialized requirements (Trophic, ecological):
Forest Dwelling Species

Age of first reproduction for each sex (proportion breeding):

a) **Earliest:** Historical records unclear but can be extrapolated to < 10 yrs for both sexes.
b) **Mean:** 8 years for one female confirmed.

Clutch size (N, mean, SD, range):
Average 4 occasionally 3, 5. Rarely 6. One laid 3 + 6 eggs during 1990.

Number Fertile:
Fertility in captive birds has been approximately 80%.
High fertility.

Number Hatched:
See SPARKS.

Number Fledged:
See SPARKS.

Laying Season:
Late July to January (Auckland)
October - December   Further South - Hamilton - Christchurch

Laying Frequency (interclutch interval):
Need to do more work on this.

Are multiple clutches possible?
Yes, up to 3 per season if eggs are removed.

Duration of Incubation:
23 days.

Hatchling sex ratio:
50/50

Egg Weights:
Of 10 eggs, average = 22.07 fresh weight. g.
Hatchling weights (male and female):
13/14 g. average

Age(s) at Fledging:
12 weeks (under captive conditions)

Adult Sex Ratio:
50/50

Adult Body Weight of Males and Females:
12 Females = 352 - 469 grams
9 Males = 378 - 505 grams

Reproductive Life-span (Male & Female, Range):
Aged show noticeable decrease in reproductive capability. ie: 20 yrs plus.

Life Time Reproduction (Mean, Male & Female):
? 10 yrs (?) 4 per season (estimate)
Social structure in terms of breeding (random, pair-bonded, polygyny, polyandry, etc; breeding male and female turnover each year?):

Monogamous pairs in captive situation will breed in communal aviary.

Proportion of Adult Males and Females Breeding Each Year:
Mature compatible pairs will breed each season.

Dispersal distance (mean, sexes):

Migrations (months, destinations):

Territoriality (home range, season):

Age of Dispersal:

Maximum Longevity:
35 yrs +

Population Census - Most Recent. Date of Last Census. Reliability estimate.:
Captive Population 21.19.3 (43) In new Zealand 1.1 Overseas

Projected Population (5, 10, 50 years).:
Captive population may be expanded to program requirements.

Past Population Census (5, 10, 20 years - dates, reliability estimates):
50% captive pop under 5 years (30 Sept. 1991). All captive bred.

Population sex and age structure (young, juvenile, & adults) - time of year.:

Fecundity rates (by sex and age class):

Mortality rates and distribution (by sex and age) (neonatal, juvenile, adult);

Population density estimate. Area of population. Attach marked map.:

Sources of Mortality-% (natural, poaching, harvest, accidental, seasonal?).:
Captive birds prone to stress related problems particularly during transit and handling.

Habitat capacity estimate (Has capacity changed in past 20, 50 years?).:

Present habitat protection status.:

Projected habitat protection status (5, 10, 50 years).:

Environmental variance affecting reproduction and mortality (rainfall, prey, predators, disease, snow cover ?).:

Is Pedigree Information Available?:
Yes of captive birds. "SPARKS"

Note:
Wild birds seen in Auckland Suburban Gardens - 6 per year reported to Auckland Zoo. Flying from Great Barrier Island?

Correspondent/Investigator:
Name: Mick Sibley
Kaka Captive Breeding Co-ordinater
Auckland Zoo

REFERENCES:

Snyder, Wiley, & Kepler.

Captive Breeding Specialist Group

Species Survival Commission
IUCN -- The World Conservation Union
U. S. Seal, CBSG Chairman

POPULATION and HABITAT VIABILITY ANALYSIS WORKSHOPS

Objectives and Process

The PHVA workshop provides population viability assessments for each population of a species or subspecies as decided in arranging the workshop. The assessment for each species will undertake an in depth analysis of information on the life history, population dynamics, ecology, and population history of the individual populations. Information on the demography, genetics, and environmental factors pertinent to assessing the status of each population and its risk of extinction under current management scenarios and perceived threats will be assembled in preparation for the PHVA and for the individual populations before and during the workshop.

An important feature of the workshops is the elicitation of information from the experts that is not readily available in published form yet which may of decisive importance in understanding the behavior of the species in the wild. This information will provide the basis for constructing simulation models of each population which will in a single model evaluate the deterministic and stochastic effects and interactions of genetic, demographic, environmental, and catastrophic factors on the population dynamics and extinction risks. The process of formulating information to put into the models requires that assumptions and the data available to support the assumptions be made explicit. This process tends lead to consensus building on the biology of the species, as currently known, and usually leads to a basic simulation model for the species that can serve as for continuing discussion of management alternatives and adaptive management of the species or population as new information is obtained. It in effect provides a means for conducting management programs as scientific exercises with continuing evaluation of new information in a sufficiently timely manner to be of benefit to adjusting management practices.

These workshop exercises are able assist the formulation of management scenarios for the respective species and evaluate their possible effects on reducing the risks of extinction. It is also possible through sensitivity analyses to search for factors whose manipulation may have the greatest effect on the survival and growth of the population(s). One can in effect rapidly explore a wide range of values for the parameters in the model(s) to gain a picture of how the species might respond to changes in management. This approach may also be used to assist in evaluating the information contribution of proposed and ongoing research studies to the conservation management of the species.

Information and Expertise

Short reviews and summaries of new information on topics of importance for conservation management and recovery of the individual populations are also prepared during the workshop. Of particular interest are topics addressing:

(1) factors likely to have operated in the decline of the species or its failure to recover with management and whether they are still important,

(2) the need for molecular taxonomic, genetic heterozygosity, site specific adaptations, and the effects of seed banks on the rate of loss of heterozygosity,

(3) the role of disease, predation, and competition in the dynamics of the wild population, in potential reintroductions or translocations, and in the location and management of captive populations,

(4) the possible role of inbreeding in the dynamics and management of the captive and wild population(s),

(5) the potential uses of reproductive technology for the conservation of the species whether through genome banking or transfer of genetic material between subpopulations,

(6) techniques for monitoring the status of the population during the management manipulations to allow their evaluation and modification as new information is developed,

(7) the possible need for metapopulation management for long term survival of the species,

(8) formulation of quantitative genetic and demographic population goals for recovery of the species and what level of management will be needed to achieve and maintain those goals,

(9) cost estimates for each of the activities suggested for furthering conservation management of the species.

Preparation and Documentation Needs

Information to be included in briefing book:

1. Bibliography - preferably complete as possible and either on disk or in clean copy that we can scan into a computer file.

2. Taxonomic description and most recent article(s) with information on systematic status including status as a species, possible subspecies, and any geographically isolated populations.

3. Molecular genetic articles and manuscripts including systematics, heterozygosity evaluation, parentage studies, and population structure.

4. Description of distribution with numbers (even crude estimates) with dates of information, maps (1:250,000 or better if needed) with latitude and longitude coordinates.

5. Protection status and protected areas with their population estimates. Location on maps. Description of present and projected threats and rates of change. For example, growth rate (demographic analysis) of local human populations and numerical estimates their use of resources (development plans) from the habitat.

6. Field studies - both published and unpublished agency and organization reports (with dates of the field work). Habitat requirements, habitat status, projected changes in habitat. Information on reproduction, mortality (from all causes), census, and distribution particularly valuable. Is the species subject to controlled or uncontrolled exploitation? Collecting?

7. Life history information - particularly that useful for the modelling. Includes: size - stage information, stage transitions, age of first reproduction, mean seed production and germination rates, occurrence and survival of seed banks, life expectancy, stage mortalities, adult mortality, dispersal, and seasonality of reproduction.

8. Published or draft Recovery Plans (National or regional) for the wild population(s). Special studies on habitat, reasons for decline, environmental fluctuations that affect reproduction and mortality, and possible catastrophic events.

9. Management masterplans for the captive population and any genome banks.

11. Color pictures (slides okay) of species in wild - suitable for use as cover of briefing book and final PVA document.

Plans for the Meeting:

1. Dates and location. Who will organize the meeting place and take care of local arrangements? Should provide living quarters and food for the 3 days in a location that minimizes outside distractions. Plan for meeting and working rooms to be available for the evening as well as the day. Three full days and evenings are needed for the workshop with arrival the day before and departure on the 4th day.

2. Average number of participants about 30 usually with a core group of about 15 responsible for making presentations. Observers (up to 20) welcome if facilities available but their arrangements should be their own responsibility. Essential that all with an interest in the species be informed of the meeting. Participants to include: (1) all of the biologists with information on the species in the wild should be invited and expected to present their data, (2) policy level managers in the agencies with management responsibility, (3) NGOs that have participated in conservation efforts, (4) education and PR people for local programs, (5) botanical garden or herbarium biologists with knowledge of the species, (6) experts in plant population biology and needed areas of biological expertise and (7) local scientists with an interest in the species.

3. Preparation of briefing document.

4. Funding (cost analysis available) - primarily for travel and per diem during the meeting, preparation of briefing document and the PVA report, and some personnel costs. CBSG costs are for preparation of the documents, completion of the modelling and report after the meeting, travel of 3-4 people, and their per diem. We estimate that each PHVA Workshop costs CBSG $10,000 to $15,000 depending upon the amount of work required in preparation and after the workshop to complete the report.

5. Preparation of agenda and securing of commitments to participate, supply information, and make presentations needs to have one person responsible and to keep in close contact with CBSG office on preparations.

6. Meeting facilities need to include meeting room for group, break away areas, blackboard, slide projector, overhead projector, electrical outlets for 3+ computers, printer (parallel port IBM compatible), and photocopying to produce about 200-500 copies per day. Have food brought in for lunches. Allow for working groups to meet at night.

SSC MISSION

To preserve biological diversity by developing and executing programs to save, restore and wisely manage species and their habitats.

PHVA WORKSHOPS

Guidelines

Every idea or plan or belief about the Species can be examined and discussed

Everyone participates & no one dominates

Set aside (temporarily) all special agendas except saving the Species

Assume good intent

Yes and ...

Stick to our schedule ... begin and end promptly

Primary work will be conducted in sub-groups

Facilitator can call 'timeout'

Agreements on recommendations by consensus

Plan to complete and review draft report by end of meeting

Adjust our process and schedule as needed to achieve our goals

POPULATION AND HABITAT VIABILTY ASSESSMENT

_ CBSG/SSC/IUCN thanks the 'Host Agency' for the invitation to participate in this Workshop on the conservation of the 'SPECIES'.

- SSC MISSION: To preserve biological diversity by developing and executing programs to save, restore and wisely manage species and their habitats.

- Captive Breeding Specialist Group (CBSG) works as a part of the IUCN Species Survival Commission (SSC) to assist rescue of species.

- CBSG has conducted **Population and Habitat Viability Assessment** (PHVA) workshops for >50 species in 22 countries at the request of host countries.

- **Values of the Workshops** are in:

  * bringing together all groups responsible for the saving and management of the species to build a consensus on actions needed for the recovery of the species;

  * bringing together experts whose knowledge may assist rescue of the species;

  * assembling current information on status of the species and the threats to its survival;

  * providing an objective assessment of the risk of extinction of the species based upon current information;

  * using simulation models to test alternative management actions for rescue of the species and its recovery;

  * producing an objective report which can be used as a basis for the policy and implementation actions that are needed to save the species.

- These Workshops have helped chart a course for saving of many species; we hope that this Workshop will be a help to our colleagues in their work to save the 'Species'.

PHVA DATA NEEDS

MAP OF POPULATION(S) DISTRIBUTION AND FRAGMENTATION

CENSUS AND CHANGES DURING PAST 10-50 YEARS

AVERAGE AGE OF FIRST REPRODUCTION (FEMALE & MALE)

OLDEST AGE (SENESCENCE)

MONOGAMOUS OR POLYGYNOUS

INBREEDING

CATASTROPHES & THREATS

ALL MALES IN BREEDING POOL?

MAXIMUM YOUNG PRODUCED PER YEAR

PROPORTION OF ADULT FEMALES REPRODUCING PER YEAR

PROPORTION OF YOUNG (LITTER/CLUTCH SIZES)

MORTALITY:
- 0 - 1
- JUVENILES
- ADULT

FREQUENCY & SEVERITY OF CATASTROPHES

STARTING POPULATION SIZE (AGE DISTRIBUTION IF KNOWN)

CARRYING CAPACITY AND PROJECTED CHANGES

HARVESTS

SUPPLEMENTATION

ANNUAL RATES AND STANDARD DEVIATIONS IF POSSIBLE

VORTEX

Simulation model of stochastic population change

Written by Robert Lacy
Chicago Zoological Park
Brookfield, IL 60513

Version 5.1, 13 April 1991

Stochastic simulation of population extinction

Life table analyses yield average long-term projections of population growth (or decline), but do not reveal the fluctuations in population size that would result from variability in demographic processes. When a population is small and isolated from other populations of conspecifics, these random fluctuations can lead to extinction even of populations that have, on average, positive population growth. The VORTEX program (earlier versions called SIMPOP and VORTICES) is a Monte Carlo simulation of demographic events in the history of a population. Some of the algorithms in VORTEX were taken from a simulation program, SPGPC, written in BASIC by James Grier of North Dakota State University (Grier 1980a, 1980b, Grier and Barclay 1988). Fluctuations in population size can result from any or all of several levels of stochastic (random) effects. Demographic variation results from the probabilistic nature of birth and death processes. Thus, even if the probability of an animal reproducing or dying is always constant, we expect that the actual proportion reproducing or dying within any time interval to vary according to a binomial distribution with mean equal to the probability of the event (p) and variance given by $Vp = p * (1 - p) / N$. Demographic variation is thus intrinsic to the population and occurs in the simulation because birth and death events are determined by a random process (with appropriate probabilities).

Environmental variation (EV) is the variation in the probabilities of reproduction and mortality that occur because of changes in the environment on an annual basis (or other timescales). Thus, EV impacts all individuals in the population simultaneously -- changing the probabilities (means of the above binomial distributions) of birth and death. The sources of EV are thus extrinsic to the population itself, due to weather, predator and prey populations, parasite loads, etc.

VORTEX models population processes as discrete, sequential events, with probabilistic outcomes determined by a pseudo-random number generator. VORTEX simulates birth and death processes and the transmission of genes through the generations by generating random numbers to determine whether each animal lives or dies, whether each adult female produces broods of size 0, or 1, or 2, or 3, or 4, or 5 during each year, and which of the two alleles at a genetic locus are transmitted from each parent to each offspring. Mortality and reproduction probabilities are sex-specific. Fecundity is assumed to be independent of age (after an animal reaches reproductive age). Mortality rates are specified for each pre-reproductive age class and for reproductive-age animals. The mating system can be specified to be either monogamous or polygynous. In either case, the user can specify that only a subset of the adult male population is in the breeding pool (the remainder being excluded perhaps by social factors). Those males in the breeding pool all have equal probability of siring offspring.

Each simulation is started with a specified number of males and females of each pre-reproductive age class, and a specified number of male and females of breeding age. Each animal in the initial population is assigned two unique alleles at some hypothetical genetic locus, and the user specifies the severity of inbreeding depression (expressed in the model as a loss of viability in inbred animals). The computer program simulates and tracks the fate of each population, and outputs summary statistics on the probability of population extinction over specified time intervals, the mean time to extinction of those simulated populations that went extinct, the mean size of populations not yet extinct, and the levels of genetic variation remaining in any extant populations.

Extinction of a population (or meta-population) is defined in VORTEX as the absence of either sex. (In some earlier versions of VORTEX, extinction was defined as the absence of both sexes.) Recolonization occurs when a formerly extinct population once again has both sexes. Thus, a population would go "extinct" if all females died, and would be recolonized if a female subsequently migrated into that population of males. Populations lacking both sexes are not considered to be recolonized until at least one male and at least one female have moved in.

A population carrying capacity is imposed by a probabilistic truncation of each age class if the population size after breeding exceeds the specified carrying capacity. The program allows the user to model trends in the carrying capacity, as linear increases or decreases across a specified numbers of years.

The user also has the option of modelling density dependence in reproductive rates. I.e., one can simulate a population that responds to low density with increased (or decreased) breeding, or that decreases breeding as the population approaches the carrying capacity of the habitat. To model density-dependent reproduction, the user must enter the parameters (A, B, C, D, and E) of the following polynomial equation describing the proportion of adult females breeding as a function of population size:

$$\text{Proportion breeding} = A + BN + CNN + DNNN + ENNNN,$$

in which N is total population size. Note that the parameter A is the proportion of adult females breeding at minimal population sizes. A positive value for B will cause increasing reproduction with increasing population sizes at the low end of the range. Parameters C, D, and E dominate the shape of the density dependence function at increasingly higher population sizes. Any of the values can be set to zero (e.g., to model density dependence as a quadratic equation, set $D = E = 0$). To determine the appropriate values for A through E, a user would estimate the parameters that provide the best fit of the polynomial function to an observed (or hypothetical) data set. Most good statistical packages have the capability of doing this. Although the polynomial equation above may not match a desired density dependence function (e.g., Logistic, Beverton-Holt, or Ricker functions), almost any density dependence function can be closely approximated by a 4th-order polynomial. After specifying the proportion of adult females breeding, in the form of the polynomial, the user is prompted to input the percent of successfully breeding females that produce litter sizes of 1, 2, etc. It is important to note that with density dependence, percents of females producing each size litter are expressed as percents of those females breeding, and the user does not explicitly enter a percent of females producing no offspring in an average year. (That value is given by the polynomial.)

In the absence of density dependence, the user must specify the percent of females failing to breed, and the percents producing each litter size are percents of all breeding age females (as in earlier versions of VORTEX). Read the prompts on the screen carefully as you enter data, and the distinction should become clear. VORTEX models environmental variation simplistically (that is both the advantage and disadvantage of simulation modelling), by selecting at the beginning of each year the population age-specific birth rates, age-specific death rates, and carrying capacity from distributions with means and standard deviations specified by the user. EV in birth and death rates is simulated by sampling binomial distributions, with the standard deviations specifying the annual fluctuations in probabilities of reproduction and mortality. EV in carrying capacity is modelled by sampling a normal distribution. EV in reproduction and EV in mortality can be specified to be acting independently or jointly (correlated in so far as is possible for discrete binomial distributions).

Unfortunately, rarely do we have sufficient field data to estimate the fluctuations in birth and death rates, and in carrying capacity, for a wild population. (The population would have to be monitored for long enough to separate, statistically, sampling error, demographic variation in the number of breeders and deaths, and annual variation in the probabilities of these events.) Lacking any data on annual variation, a user can try various values, or simply set EV = 0 to model the fate of the population in the absence of any environmental variation.

VORTEX can model catastrophes, the extreme of environmental variation, as events that occur with some specified probability and reduce survival and reproduction for one year. A catastrophe is determined to occur if a randomly generated number between 0 and 1 is less than the probability of occurrence (i.e., a binomial process is simulated). If a catastrophe occurs, the probability of breeding is multiplied by a severity factor specified by the user. Similarly, the probability of surviving each age class is multiplied by a severity factor specified by the user.

VORTEX also allows the user to supplement or harvest the population for any number of years in each simulation. The numbers of immigrants and removals are specified by age and sex. VORTEX outputs the observed rate of population growth (mean of N[t]/N[t-1]) separately for the years of supplementation/harvest and for the years without such management, and allows for reporting of extinction probabilities and population sizes at whatever time interval is desired (e.g., summary statistics can be output at 5-year intervals in a 100-year simulation).

VORTEX can track multiple sub-populations, with user-specified migration among the units. (This version of the program has previously been called VORTICES.) The migration rates are entered for each pair of sub-populations as the proportion of animals in a sub-population that migrate to another sub- population (equivalently, the probability that an animal in one migrates to the other) each year. VORTEX outputs summary statistics on each subpopulation, and also on the meta-population. Because of migration (and, possibly, supplementation), there is the potential for population recolonization after local extinction. VORTEX tracks the time to first extinction, the time to recolonization, and the time to re-extinction.

Overall, VORTEX simulates many of the complex levels of stochasticity that can affect a population. Because it is a detailed model of population dynamics, it is not practical to examine all possible factors and all interactions that may affect a population. It is therefore incumbent upon the user to specify those parameters that can be estimated reasonably, to leave out of the model those that are believed not to have a substantial impact on the population of interest, and to explore a range of possible values for parameters that are potentially important but very imprecisely known. VORTEX is, however, a simplified model of the dynamics of populations. One of its artificialities is the lack of density dependence of death rates except when the population exceeds the carrying capacity. Another is that inbreeding depression is modelled as an effect on juvenile mortality only; inbreeding is optimistically assumed not to effect adult survival or reproduction.

VORTEX accepts input either from the keyboard or from a data file. Whenever VORTEX is run with keyboard entry of data, it creates a file called VORTEX.BAT that contains the input data, ready for resubmission as a batch file. Thus, the simulation can be instantly rerun by using VORTEX.BAT as the input file. By editing VORTEX.BAT, a few changes could easily be made to the input parameters before rerunning VORTEX. Note that the file VORTEX.BAT is over-written each time that VORTEX is run. Therefore, you should rename the batch file if you wish to save it for later use. By using data file input, multiple simulations can be run while the computer is unattended. (Depending on the computer used, the simulations can be relatively quick -- a few minutes for 100 runs -- or very slow.) Output can be directed to the screen or to a file for later printing. I would recommend that VORTEX only be used on a 80386 (or faster) computer with a math co-processor. It should run on slower machines, but it might be hopelessly slow.

The program can make use of any extended memory available on the computer (note: only extended, not expanded, memory above 1MB will be used), and the extra memory will be necessary to run analyses with the Heterosis inbreeding depression option on populations of greater than about 450 animals. To use VORTEX with expanded memory, first run the program TUNE, which will customize the program EX286 (a Dos Extender) for your computer. If TUNE hangs up DOS, simply re-boot and run it again (as often as is necessary). This behavior of TUNE is normal and will not affect your computer. After TUNEing the Dos Extender, run EX286, and then finally run VORTEX. TUNE needs to be run only once on your computer, EX286 needs to be run (if VORTEX is to be used with extended memory) after each re-booting of the computer. Note that EX286 might take extended memory away from other programs (in fact it is better to disable any resident programs that use extended memory before running EX286); and it will release that memory only after a re-boot. If you have another extended memory manager on your system (e.g., HIMEM.SYS), you will have to disable it before using EX286.

VORTEX uses lots of files and lots of buffers. Therefore, you may need to modify the CONFIG.SYS file to include the lines

```
FILES=25
BUFFERS=25
```

in order to get the program to run.

VORTEX is not copy protected. Use it, distribute it, revise it, expand upon it. I would appreciate hearing of uses to which it is put, and of course I don't mind acknowledgement for my efforts. James Grier should also be acknowledged (for developing the program that was the base for VORTEX) any time that VORTEX is cited.

A final caution: VORTEX is continually under revision. I cannot guarantee that it has no bugs that could lead to erroneous results. It certainly does not model all aspects of population stochasticity, and some of its components are simply and crudely represented. It can be a very useful tool for exploring the effects of random variability on population persistence, but it should be used with due caution and an understanding of its limitations.

References

Grier, J. 1980a. Ecology: A simulation model for small populations of animals. Creative Computing 6:116-121.

Grier, J.W. 1980b. Modeling approaches to bald eagle population dynamics. Wildlife Society Bulletin 8:316-322.

Grier, J.W. and J.H. Barclay. 1988. Dynamics of founder populations established by reintroduction. Pages 689-701 in T.J. Cade, J.H. Enderson, C.G. Thelander, and C.M. White, eds. Peregrine Falcon

Populations: Their Management and Recovery. The Peregrine Fund, Boise, Idaho.

Lacy, R.C, Flesness, N.R., and Seal, U.S. 1989. Puerto Rican parrot population viability analysis. Report to the U.S. Fish and Wildlife Service. Captive Breeding Specialist Group, Species Survival Commission, IUCN, Apple Valley, Minnesota.

Lacy, R.C. and T.W. Clark. 1990. Population viability assessment of the eastern barred bandicoot in Victoria. Pages 131-146 in T.W. Clark and J.H. Seebeck (eds.), The Management and Conservation of Small Populations. Chicago Zoological Society, Brookfield, Illinois.

Lindenmayer, D.B., V.C. Thomas, R.C. Lacy, and T.W. Clark. 1991. Population Viability Analysis (PVA): The concept and its applications, with a case study of Leadbeater's Possum, *Gymnobelideus leadbeateri* McCoy. Report to the Forest and Timber Inquiry (Resource Assessment Commission), Canberra, Australia. 170 pp.

Maguire, L.A., R.C. Lacy, R.J. Begg, and T.W. Clark. 1990. An analysis of alternative strategies for recovering the eastern barred bandicoot in Victoria. Pages 147-164 in T.W. Clark and J.H. Seebeck (eds.), The Management and Conservation of Small Populations. Chicago Zoological Society, Brookfield, Illinois.

Seal, U.S. and R.C. Lacy. 1989. Florida panther population viability analysis. Report to the U.S. Fish and Wildlife Service. Captive Breeding Specialist Group, Species Survival Commission, IUCN, Apple Valley, Minnesota.

Seal, U.S. and R.C. Lacy. 1990. Florida Key Deer (*Odocoileus virginianus clavium*) population viability assessment. Report to the U.S. Fish and Wildlife Service. Captive Breeding Specialist Group, Species Survival Commission, IUCN, Apple Valley, Minnesota.

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VORTEX:
A Computer Simulation Model for Population Viability Analysis

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Abstract

Population Viability Analysis (PVA) is the estimation of extinction probabilities by analyses that incorporate identifiable threats to population survival into models of the extinction process. Extrinsic forces, such as habitat loss, over-harvesting, and competition or predation by introduced species, often lead to population decline. Although the traditional methods of wildlife ecology can reveal such deterministic trends, random fluctuations intrinsic to small populations can lead to extinction even of populations that have, on average, positive population growth. Computer simulation modelling provides a tool for exploring the viability of populations subjected to many complex, interacting deterministic and random processes. One such simulation model, VORTEX, has been used extensively by the Captive Breeding Specialist Group (Species Survival Commission, IUCN), by wildlife agencies, and by university classes. The algorithms, structure, assumptions, and applications of VORTEX are described in this paper.

VORTEX models population processes as discrete, sequential events, with probabilistic outcomes. VORTEX simulates birth and death processes and the transmission of genes through the generations by generating random numbers to determine whether each animal lives or dies, to determine the number of progeny produced by each female each year, and to determine which of the two alleles at a genetic locus are transmitted from each parent to each offspring. Fecundity is assumed to be independent of age, after an animal reaches reproductive age. Mortality rates are specified for each pre-reproductive age-sex class and for reproductive-age animals. Inbreeding depression is modelled as a decrease in viability in inbred animals.

The user has the option of modelling density dependence in reproductive rates. As a simple model of density dependence in survival, a carrying capacity is imposed by a probabilistic truncation of each age class if the population size exceeds the specified carrying capacity. VORTEX can model linear trends in the carrying capacity. VORTEX models environmental variation by sampling birth rates, death rates, and the carrying capacity from binomial or normal distributions. VORTEX models catastrophes as sporadic random events that reduce survival and reproduction for one year. VORTEX also allows the user to supplement or harvest the population. VORTEX can track multiple sub-populations, with user-specified migration among the units.

VORTEX outputs summary statistics on population growth rates, the probability of population extinction, the time to extinction, and the mean size and genetic variation in extant populations.

VORTEX necessarily makes many assumptions. The model it incorporates is most applicable to species with low fecundity and long lifespans, such as mammals, birds, and reptiles. It integrates the interacting effects of many of the deterministic and stochastic processes that impact on the viability of small populations, providing opportunity for more complete analysis than is possible by other techniques. PVA by simulation modelling has become an important tool for identifying populations at high risk of extinction, for determining the urgency of action, and evaluating options for management.

Introduction

Many wildlife populations that were once widespread, numerous, and occupying contiguous habitat have been reduced to one or more small, isolated populations. The causes of the original decline are often obvious, deterministic forces, such as over-harvesting, habitat destruction, and competition or predation from invasive introduced species. Even if the original causes of decline are removed, a small isolated population is vulnerable to additional forces, intrinsic to the dynamics of small populations, which may drive the population to extinction (Clark and Seebeck 1990). Of particular impact on small populations are stochastic, or random probabilistic, processes. With the exception of aging, virtually all events in the life of an organism are stochastic. Mating, reproduction, gene transmission between generations, migration, disease, and predation can be described by probability distributions, with individual occurrences being sampled from these distributions. Small samples display high variance around the mean, so the fates of small wildlife populations are often determined more by random chance than by adaptation, or mean birth and death rates.

Although many processes affecting small populations are inherently indeterminate, the average long-term fate of a population and the variance around the expected performance can be studied with computer simulation models. The use of simulation modelling, often in conjunction with other techniques, to explore the dynamics of small populations has been termed Population Viability Analysis (PVA). PVA has been increasingly used to help guide management of threatened species during the past few years. The Resource Assessment Commission of Australia (1991) recently recommended that "estimates of the size of viable populations and the risks of extinction under multiple-use forestry practices be an essential part of conservation planning." Lindenmayer *et al.* (1992) describe generally the use of computer simulation modelling for PVA, and discuss the strengths and weaknesses of the approach as a tool for wildlife management.

In this paper, I present the PVA program VORTEX and describe its structure, assumptions, and capabilities. In an accompanying paper, Lindenmayer *et al.* present a PVA of Leadbeater's possum (*Gymnobelideus leadbeateri*) using VORTEX. VORTEX is presently the most widely used PVA simulation program, and there are numerous examples of its application in Australia, the United States of America, and elsewhere. Although many governmental reports and some scientific papers make use of VORTEX and contain brief descriptions of it, the structure, algorithms, and assumptions of the program have not previously been described in the scientific literature.

The Dynamics of Small Populations

The stochastic processes impacting on small populations have been usefully categorised into demographic stochasticity, environmental variation, catastrophic events, and genetic drift (Shaffer 1981). Demographic stochasticity is the random fluctuation in the observed birth rate, death rate, and sex ratio of a population even if the probabilities of birth and death remain constant (Fig. 1). Demographic stochasticity would follow binomial distributions and will be important to population viability only in populations that are smaller than a few tens of animals (Goodman 1987), in which the frequency of birth and death events and the sex ratio can deviate far from the statistical expectations. Environmental variation is the fluctuation in the probabilities of birth and death that results from fluctuations in the environment. Weather, the prevalence of enzootic disease, the abundances of prey and predators, and the availability of nest sites or other required microhabitats can all vary, randomly or cyclically, over time.

Catastrophic variation is the extreme of environmental variation, but for both methodological and conceptual reasons rare catastrophic events are analysed separately from the more typical annual or seasonal fluctuations. Catastrophes such as epidemic disease, hurricanes, large-scale fires, and floods are outliers in the distributions of environmental variation (see Fig. 1).

As a result, they have quantitatively and sometimes qualitatively different impacts on wildlife populations. (A forest fire is not just a very hot day.) Such events are often the cause of the final decline of wildlife populations to extinction (Simberloff 1986, 1988). For example, one of two populations of whooping crane (*Grus americana*) was decimated by a hurricane in 1940 and soon after went extinct (Doughty 1989). The only remaining population of the black-footed ferret (*Mustela nigripes*) was being eliminated by an outbreak of distemper when the last 18 ferrets were captured (Clark 1989; Seal *et al.* 1989).

Genetic drift is the cumulative and non-adaptive fluctuations in allele frequencies resulting from the random sampling of genes in each generation. This can impede the recovery or accelerate the decline of wildlife populations for several reasons. Inbreeding, not strictly a component of genetic drift but correlated with it in small populations, has been documented to cause loss of fitness in a wide variety of species, including virtually all sexually reproducing animals in which the effects of inbreeding have been carefully studied (Wright 1977; Falconer 1981; O'Brien and Evermann 1988; Ralls *et al.* 1988; Lacy *et al.* 1992). Evidence of loss of fitness includes decreased survival and fecundity and increased susceptibility to disease and other environmental stresses. Even if the immediate loss of fitness of inbred individuals is not large, the loss of genetic variation throughout a population that results from genetic drift will reduce the ability of the population to adapt to future changes in the environment (Fisher 1958; Robertson 1960; Selander 1983).

Thus, the effects of genetic drift and consequent loss of genetic variation in individuals (inbreeding) and populations negatively impact on demographic rates and increase susceptibility to environmental perturbations and catastrophes. Reduced population growth and greater fluctuations in numbers in turn accelerates genetic drift (Crow and Kimura 1970). These synergistic destabilising effects of stochastic process on small populations of wildlife have been described as an "extinction vortex" (Gilpin and Soulé 1986). The size below which a population is likely to be drawn into an extinction vortex can be considered a "minimum viable population" (MVP) (Brussard 1985; Seal and Lacy 1989; Thomas 1990), although Shaffer (1981) first defined a MVP more stringently as a population that has a 99% probability of persistence for 1000 years. The estimation of MVPs or, more generally, the investigation of the probability of extinction of a population constitutes Population Viability Analysis (PVA) (Gilpin and Soulé 1986; Gilpin 1989; Shaffer 1990).

Methods for Analysing Population Viability

An understanding of the multiple, interacting forces that contribute to extinction vortices is a prerequisite for the study of extinction-recolonisation dynamics in natural populations inhabiting patchy environments (Gilpin 1987), the management of small populations (Clark and Seebeck 1990), and the conservation of threatened wildlife (Shaffer 1981, 1990; Soulé 1987; Mace and Lande 1991). Because demographic and genetic processes in small populations are inherently unpredictable, the expected fates of wildlife populations can be described in terms of probability distributions of population size, time to extinction, and genetic variation. These distributions could be obtained in any of three ways: from analytical models derived from probability theory, from empirical observation of the fates of populations of varying size, or from simulation models.

As the processes determining the dynamics of small populations are multiple and complex, there are few analytical formulae for describing the probability distributions (*e.g.*, Goodman 1987; Lande 1988; Reed *et al.* 1988; Burgmann and Gerard 1990). These models have incorporated only few of the threatening processes. No analytical model exists, for example, to describe the combined effect of demographic stochasticity and loss of genetic variation on the probability of population persistence.

A few studies of wildlife populations have provided empirical data on the relationship between population size and probability of extinction (*e.g.*, Belovsky 1987; Griffith *et al.* 1989; Berger 1990; Thomas 1990), but presently only order of magnitude estimates can be provided for MVPs of vertebrates (Shaffer 1987). Threatened species are by their rarity unavailable and inappropriate for collection of sufficient experimental data to determine MVPs precisely, and it is likely that the function relating extinction probability to population size will differ among species, localities, and times (Lindenmayer *et al.* 1992).

Modelling the Dynamics of Small Populations

Because of the lack of adequate empirical data or theoretical and analytical models to allow prediction of the dynamics of populations of threatened species, various biologists have turned to computer simulation techniques for PVA. By randomly sampling from defined probability distributions, computer programs can simulate the multiple, interacting events that occur during the lives of organisms and which cumulatively determine the fates of populations. The focus is on detailed and explicit modelling of the forces impinging on a given population, place, and time of interest, rather than on delineation of rules (which may not exist) that may apply generally to most wildlife populations. Computer programs available to PVA include: SPGPC (Grier 1980a, 1980b; Grier and Barclay 1988), GAPPS (Harris *et al.* 1986), POPDYN (Cox 1988), RAMAS (Ferson and Akçakaya 1989; Akçakaya and Ferson 1990; Ferson 1990), FORPOP (Possingham *et al.* 1991), ALEX (Lindenmayer and Possingham *in press*), and SIMPOP (Lacy *et al.* 1989; Lacy and Clark 1990) and its descendant VORTEX.

SIMPOP was developed in 1989 by converting the algorithms of the simulation program SPGPC (written by James W. Grier of North Dakota State University) from the BASIC programming language to compiled C. SIMPOP was used first in a PVA workshop organized by the Captive Breeding Specialist Group, Species Survival Commission (IUCN The World Conservation Union), the United States Fish and Wildlife Service, and the Puerto Rico Department of Natural Resources to assist in planning and assessing recovery efforts for the Puerto Rican crested toad (*Peltophryne lemur*). SIMPOP was subsequently used in PVA modelling of additional species threatened with extinction, undergoing modification with each application to allow incorporation of more threatening processes and more accurate representation of life histories. The simulation program was renamed VORTEX (in reference to the extinction vortex) when the capability of modelling genetic processes was implemented in 1989. In 1990, a version allowing modelling of multiple populations was briefly named VORTICES. The only version still supported, with all capabilities of each previous version, is named VORTEX (Version 5.0). It is anticipated that the name will remain stable in the future even as the program is updated.

In the past few years, VORTEX (or its antecedents) has been used in PVA to help guide conservation and management of many species, including the Puerto Rican parrot (*Amazona vittata*) (Lacy *et al.* 1989), Javan rhinoceros (*Rhinoceros sondaicus*) (Seal and Foose 1989), Florida panther (*Felis concolor coryi*) (Seal and Lacy 1989), Florida Key deer (*Odocoileus virginianus clavium*) (Seal and Lacy 1990), eastern barred bandicoot (*Perameles gunnii*) (Lacy and Clark 1990; Maguire *et al.* 1990), lion tamarins (*Leontopithecus rosalia* ssp.) (Seal *et al.* 1990), brush-tailed rock wallaby (*Petrogale pencillata pencillata*) (Hill 1991), red wolf (*Canis rufus*) (Parker *et al.* 1991), mountain pygmy possum (*Burramys parvus*), Leadbeater's possum, long-footed potoroo (*Potorous longipes*), orange-bellied parrot (*Neophema chrysogaster*) and helmeted honeyeater (*Lichenostomus melanops cassidix*) (Clark *et al.* 1991), whooping crane (*Grus americana*) (Seal *et al.* 1992) Tana River crested mangabey (*Cercocebus galeritus galeritus*) and Tana River red colobus (*Colobus badius rufomitratus*) (Seal and Lacy 1992*a*), and black rhinoceros (*Diceros bicornis*) (Seal and Lacy 1992*b*). In some of these PVAs, modelling with

VORTEX has made clear the insufficiency of past management plans to secure the future of the species and alternative strategies were proposed, assessed, and implemented. For example, the multiple threats to the Florida panther in its existing habitat were recognized as likely insurmountable, and a captive breeding effort has been initiated for the purpose of securing the gene pool and providing animals for release in areas of former habitat. PVA of the eastern barred bandicoot indicated that population recovery would require implementation of all previously considered management options, on a time scale more rapid than had been considered previously.

PVA modelling with VORTEX has often identified a single population process to which a species is particularly vulnerable. The small but growing population of Puerto Rican parrots was assessed to be secure, except for the risk of population decimation by hurricane. As a result of that PVA, recommendations were made to make available more secure shelter for some captive parrots and to move some of the birds to a site distant from the wild flock, in order to minimise the damage that could occur in a catastrophic storm. These recommended actions were only partly completed when, in late 1989, a major hurricane devastated the habitat and killed many of the wild parrots. The remaining population of about 350 Tana River red colobus, on the other hand, were determined through PVA to be so fragmented that demographic and genetic processes within the 10 subpopulations destabilised population dynamics. Creation of habitat corridors may be necessary to prevent extinction of the taxon. In some cases, PVA modelling has been reassuring to managers: Analysis of black rhinos in Kenya indicated that many of the populations within sanctuaries were recovering steadily. Some could soon be used to provide animals for reestablishment or supplementation of populations previously eliminated by poaching. For some species, such as the Key deer, available data were insufficient to allow definitive PVA with VORTEX. In such cases, the attempt at PVA modelling has made apparent the need for more data on population trends and processes, thereby helping to justify and guide research efforts. In each of the above PVAs, simulation modelling provided a valuable structure for assembling, documenting, and making available to managers hypotheses and data that had been scattered among notebooks, agency reports, the scientific literature, unpublished manuscripts, and the collective experience of field biologists.

Description of VORTEX

Overview

The VORTEX computer simulation model is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental and genetic stochastic events on wildlife populations. VORTEX models population dynamics as discrete, sequential events (*e.g.*, births, deaths, and catastrophes) that occur according to defined probabilities. The probabilities of events are modelled as constants or as random variables that follow specified distributions.

VORTEX simulates a population by stepping through the series of events that describe the typical life cycle of a sexually reproducing, diploid organism. The program was designed to model long-lived species with low fecundity, such as mammals, birds, and reptiles. Although it could and has been used in modelling highly fecund vertebrates and invertebrates, it is awkward to use in such cases as it requires complete specification of the percent of females producing each possible clutch size. Moreover, computer memory limitations often hamper such analyses. VORTEX iterates life events on an annual cycle, although a user could model "years" that are other than 12 months duration. The simulation of the population is itself iterated to reveal the distribution of fates that the population might experience.

Demographic Stochasticity

VORTEX models demographic stochasticity by determining the occurrence of probabilistic events such as reproduction, litter size, sex determination, and death with a pseudo-random number generator. The probabilities of mortality and reproduction are sex-specific and pre-determined for each age class up to the age of breeding. It it is assumed that reproduction and survival probabilities remain constant from the age of first breeding until a specified upper limit to age is reached. Sex ratio at birth is modelled with a user-specified constant probability of an offspring being male. For each life event, if the random value sampled from a specified probability distribution falls above the mean value, the event is deemed to have occurred, thereby simulating a binomial process.

The source code used to generate random numbers uniformly distributed between 0 and 1 was obtained from Maier (1991), based on the algorithm of Kirkpatrick and Stoll (1981). Random deviates from binomial distributions, with mean p and standard deviation s, are obtained by first determining the integral number of binomial trials, N, that would produce the value of s closest to the specified value, according to:

$$N = p\ (1 - p)\ /\ s^2.$$

(Note that binomial distributions are discrete and not all values of s are possible.) N binomial trials are then simulated by sampling from the uniform 0-1 distribution to obtain the desired result, the frequency or proportion of successes. If the value of N determined for a desired binomial distribution is larger than 25, a normal approximation is used in place of the binomial distribution. This normal approximation must be truncated at 0 and at 1 to allow use in defining probabilities, although, with such large values of N, s is small relative to p and the truncation would be invoked only rarely. To avoid introducing bias with this truncation, the normal approximation to the binomial (when used) is truncated symmetrically around the mean. The algorithm for generating random numbers from a unit normal distribution follows Latour (1986).

VORTEX can model monogamous or polygamous mating systems. In a monogamous system, a relative scarcity of breeding males may limit reproduction by females. In the polygamous model, only one adult male is required to allow breeding by females. In addition, the user can specify the proportion of the adult males in the breeding pool. Males are randomly reassigned to the breeding pool each year of the simulation, and all males in the breeding pool have an equal chance of siring offspring.

The "carrying capacity", or the upper limit for population size within a habitat, must be specified by the user. VORTEX imposes the carrying capacity via a probabilistic truncation whenever the population exceeds the carrying capacity. Each animal in the population has an equal probability of being removed by this truncation.

Environmental Variation

VORTEX can model annual fluctuations in birth and death rates and in carrying capacity as might result from environmental variation. To model environmental variation, each demographic parameter is assigned a distribution with a mean and standard deviation that is specified by the user. Annual fluctuations in probabilities of reproduction and mortality are modelled as binomial distributions. Environmental variation in carrying capacity is modelled as a normal distribution. The variance across years in the frequencies of births and deaths resulting from the simulation model (and in real populations) will have two components: the demographic variation resulting from a binomial sampling around the mean for each year, and fluctuations in that mean due to environmental variation and catastrophes (Figure 1).

Data on the annual variation in birth and death rates is important in determining the probability of extinction, as it influences population stability. Unfortunately, such field information is rarely available (but see Figure 1). VORTEX allows a population to be modelled in the absence of any environmental variation, or any plausible range of variation that might be usefully examined. Sensitivity testing, the examination of a range of values when the precise value of a parameter is unknown, can help to identify whether the unknown parameter is likely to be important in the dynamics of a population. This can guide research priorities and indicate where management actions can ameliorate factors that put a population at risk.

Catastrophes

Catastrophes are modelled in VORTEX as random events that occur with specified probabilities. Any number of types of catastrophes can be modelled. A catastrophe will occur if a randomly generated number between zero and one is less than the probability of that occurrence (*i.e.*, a binomial process is simulated). Following a catastrophic event, the chances of survival and successful breeding for that simulated year are multiplied by severity factors. For example, forest fires might occur once in 50 years, on average, killing 25% of a population, and reducing breeding by survivors 50% for the year. Such a catastrophe would be modelled as a random event with 0.02 probability of occurrence each year, and severity factors of .75 for survival and .50 for reproduction.

Genetic Processes

Genetic drift is modelled in VORTEX by simulation of the transmission of alleles at a hypothetical locus. At the beginning of the simulation, each animal is assigned two unique alleles. Each offspring is randomly assigned one of the alleles from each parent. Inbreeding depression is modelled as a loss of viability during the first year amongst inbred animals. The impacts of inbreeding on the population are determined by using one of two models available within VORTEX: a Recessive Lethals model or a Heterosis model.

In the Recessive Lethals model, each founder starts with one unique recessive lethal allele and a unique, dominant non-lethal allele. This model approximates the effect of inbreeding if each individual in the starting population had one recessive lethal allele in its genome. The fact that the simulation program assumes that all the lethal alleles are at the same locus has a very minor impact on the probability that an individual will die because of homozygosity for one of the lethal alleles. In the model, homozygosity for different lethal alleles are mutually exclusive events, whereas in a multi-locus model an individual could be homozygous for several lethal alleles simultaneously. By virtue of the death of individuals that are homozygous for lethal alleles, such alleles would be removed slowly by natural selection during the generations of a simulation. This reduces the genetic variation present in the population relative to the case with no inbreeding depression, but also diminishes the subsequent probability that inbred individuals will be homozygous for a lethal allele. This model gives an optimistic reflection of the impacts of inbreeding on many species, as the median number of lethal equivalents per diploid genome for mammalian populations is approximately three (Ralls *et al.* 1988).

The expression of fully recessive deleterious alleles in inbred organisms is not the only genetic mechanism that has been proposed as a cause of inbreeding depression. Some or most of the effects of inbreeding may be a consequence of superior fitness of heterozygotes (heterozygote advantage or "heterosis"). In the Heterosis model, all homozygotes have reduced fitness compared with heterozygotes. Juvenile survival is modelled according to the logarithmic model developed by Morton *et al.* (1956):

$$\ln(S) = A - BF$$

in which S is survival, F is the inbreeding coefficient, A is the logarithm of survival in the absence of inbreeding, and B is a measure of the rate at which survival decreases with inbreeding. B is termed the number of "lethal equivalents" per haploid genome. The number of lethal equivalents per diploid genome, $2B$, estimates the number of lethal alleles per individual in the population if all deleterious effects of inbreeding were due to recessive lethal alleles. A population in which inbreeding depression is one lethal equivalent per diploid genome may have one recessive lethal allele per individual (as in the RECESSIVE LETHAL model, above), it may have two recessive alleles per individual, each of which confer a 50% decrease in survival, or it may have some other combination of recessive deleterious alleles which equate in effect with one fully lethal allele per individual.

Unlike the situation with fully recessive deleterious alleles, natural selection does not remove deleterious alleles at heterotic loci, because all alleles are deleterious when homozygous and beneficial when present in heterozygous combination with other alleles. Thus, under the Heterosis model, the effects of inbreeding are unchanged during the repeated generations of inbreeding.

Deterministic Processes

VORTEX can incorporate several deterministic processes. Reproduction can be specified to be density-dependent. The function relating the proportion of adult females breeding each year to the total population size is modelled as a fourth-order polynomial, which can provide a close fit to virtually any plausible density dependence curve. Populations can be supplemented or harvested for any number of years in each simulation. The numbers of additions and removals are specified according to the age and sex of animals. Trends in the carrying capacity can also be modelled in VORTEX. These are specified as an annual percentage change. Thus, a reduction in habitat carrying capacity is incorporated in VORTEX as a linear decrease rather than a geometric decline.

Migration among Populations

VORTEX can model up to 20 populations, with specification of each pairwise migration rate as the probability of an individual moving from one population to another. This probability is independent of the age and sex. Because of between-population migration and managed supplementation, populations can be recolonised. VORTEX tracks the dynamics of local extinctions and recolonisations through the simulation.

Output

In summary, VORTEX simulates many of the processes which influence the size, behaviour and viability of populations. Its output lists: (1) the probability of the extinction at specified intervals (*e.g.*, every 10 years during a 100 year simulation), (2) the median time to extinction, if the population went extinct in at least 50% of the simulations, (3) the mean time to extinction of those simulated populations that became extinct, and, (4) the mean size of, and genetic variation within, extant populations (see Appendix 1 and Lindenmayer *et al.* 1992).

Standard deviations across simulations and standard errors of the mean are reported for population size and the measures of genetic variation. Also reported is the standard error of the probability of extinction, given by:

$$SE(p) = \sqrt{(p \times [1 - p] / n)},$$

in which the frequency of extinction was p over n simulated populations. Demographic and genetic statistics are calculated and reported for each subpopulation and for the metapopulation.

Availability of the VORTEX Simulation Program

VORTEX is written in the C programming language and compiled with the Lattice 80286C Development System (Lattice Inc.) for use on microcomputers using the MS-DOS

(Microsoft Corp.) operating system. Copies of the compiled program and a manual for its use are available for nominal distribution costs from the Captive Breeding Specialist Group (Species Survival Commission, IUCN), 12101 Johnny Cake Ridge Road, Apple Valley, Minnesota 55124, USA. The program has been tested by a variety of workers, but it cannot be guaranteed to be without errors. Each user retains the responsibility for the ensuring that the program does what is intended for each analysis.

Sequence of Program Flow

(1) The seed for the random number generator is initialised with the number of seconds elapsed since the beginning of the 20th century.

(2) The user is prompted for input and output devices, population parameters, duration of simulation, and number of iterations.

(3) The maximum allowable population size (necessary for preventing memory overflow) is calculated as:

$$N_{max} = (K + 3s) \times (1 + L)$$

in which K is the maximum carrying capacity (carrying capacity can be specified to change linearly for a number of years in a simulation, so the maximum carrying capacity can be greater than the initial carrying capacity), s is the annual environmental variation in the carrying capacity expressed as a standard deviation, and L is the specified maximum litter size. It is theoretically possible, but very unlikely, that a simulated population will exceed the calculated N_{max}. If this occurs then the program will give an error message and abort.

(4) Memory is allocated for data arrays. If insufficient memory is available for data arrays then N_{max} is adjusted downward to the size that can be accommodated within the available memory and a warning message is given. In this case it is possible that the analysis may have to be terminated because the simulated population exceeds N_{max}. Because N_{max} is often several-fold greater than the likely maximum population size in a simulation, a warning that it has been adjusted downward because of limiting memory often will not hamper the analyses. Except for limitations imposed by the size of the computer memory (VORTEX can use extended memory, if available), the only limit to the size of the analysis is that no more than 20 populations exchanging migrants can be simulated.

(5) The expected mean growth rate of the population is calculated from mean birth and death rates that have been entered. Algorithms follow cohort life-table analyses (Ricklefs 1979). Generation time and the expected stable age distribution are also estimated. Life-table estimations assume no limitation by carrying capacity, no limitation of mates, and no loss of fitness due to inbreeding depression, and the estimated intrinsic growth rate assumes that the population has already reached the stable age distribution. The effects of catastrophes are incorporated into the life table analysis by using birth and death rates that are weighted averages of the mean values in years with and without catastrophes, weighted by the probability of a catastrophe occurring or not occurring.

(6) Iterative simulation of the population proceeds via steps 7 through 26 below. For exploratory modelling, 100 iterations is usually sufficient to reveal gross trends among sets of simulations with different input parameters. For more precise examination of population behaviour under various scenarios, 1000 or more simulations should be used to minimise standard errors around mean results.

(7) The starting population is assigned an age and sex structure. The user can specify the exact age-sex structure of the starting population, or can specify a total initial population size and request that the population be distributed according to the stable age distribution calculated from the life table. Individuals in the starting population are assumed to be unrelated. Thus, inbreeding

can occur in second and later generations.

(8) Two unique alleles at a hypothetical genetic locus are assigned to each individual in the starting population and to each individual supplemented to the population during the simulation. The simulation therefore uses an infinite alleles model of genetic variation. The subsequent fate of genetic variation is tracked by reporting the number of extant alleles each year, the expected heterozygosity or gene diversity, and the observed heterozygosity. The expected heterozygosity, derived from the Hardy-Weinberg equilibrium, is given by

$$H_e = 1 - \Sigma(p_i 2),$$

in which p_i is the frequency of allele *i* in the population. The observed heterozygosity is simply the proportion of the individuals in the simulated population that are heterozygous. Because of the starting assumption of two unique alleles per founder, the initial population has an observed heterozygosity of 1.0 at the hypothetical locus, only inbred animals can become homozygous, and the probability that an individual is homozygous is equal to the inbreeding coefficient of that individual.

(9) The user specifies one of three options for modelling the effect of inbreeding: (a) no effect of inbreeding on fitness, *i.e.*, all alleles are selectively neutral, (b) each founder individual has one unique lethal and one unique non-lethal allele (Recessive Lethals option), or (c) first-year survival of each individual is exponentially related to its inbreeding coefficient (Heterosis option). The first case is clearly an optimistic one, as almost all diploid populations studied intensively have shown deleterious effects of inbreeding on a variety of fitness components (Wright 1977, Falconer 1981). Each of the two methods of modelling inbreeding depression may also be optimistic, in that inbreeding is assumed to impact only first-year survival. The Heterosis option allows, however, for the user to specify the severity of inbreeding depression in juvenile survival.

(10) The years of the simulation are iterated via steps 11 through 25 below.

(11) The probabilities of females producing each possible size litter are adjusted to account for density dependence of reproduction (if any).

(12) Birth rate, survival rates, and carrying capacity for the year are adjusted to model environmental variation. Environmental variation is assumed to follow binomial distributions for birth and death rates and a normal distribution for carrying capacity, with mean rates and standard deviations specified by the user. At the outset of each year a random number is drawn from the specified binomial distribution to determine the percent of females producing litters. The distribution of litter sizes among those females that do breed is maintained constant. Another random number is drawn from a specified binomial distribution to model the environmental variation in mortality rates. If environmental variation in reproduction and mortality are chosen to be correlated, the random number used to specify mortality rates for the year is chosen to be the same percentile of its binomial distribution as was the number used to specify reproductive rate. Otherwise, the new random number is drawn independently to specify the deviation of age- and sex-specific mortality rates from their means. Environmental variation across years in mortality rates is always forced to be correlated among age and sex classes.

The carrying capacity (*K*) for the year is determined by first incrementing or decrementing the carrying capacity at year 1 by an amount specified by the user to account for linear changes over time. Environmental variation in *K* is then imposed by drawing a random number from a normal distribution with appropriate values for the mean and standard deviation.

(13) Birth rates and survival rates for the year are adjusted to model any catastrophes determined to have occurred in that year of the simulation.

(14) Breeding males are selected for the year. A male of breeding age is placed into the pool of potential breeders for that year if a random number drawn for that male is less than the proportion of breeding age males specified to be breeding.

(15) For each female of breeding age, a mate is drawn at random from the pool of breeding males for that year. The size of the litter produced by that pair is determined by comparing the probabilities of each potential litter size (including litter size of 0, no breeding) to a randomly drawn number. The offspring are produced and assigned a sex by comparison of a random number to the specified birth sex ratio. Offspring are assigned, at random, one allele at the hypothetical genetic locus from each parent.

(16) If the Heterosis option is chosen for modelling inbreeding depression, the genetic kinship of each new offspring to each other living animal in the population is determined. The kinship between new animal *A*, and another existing animal, B, is

$$r_{AB} = 0.5 \times (r_{MB} + r_{PB})$$

in which r_{ij} is the kinship between animals *i* and *j*, *M* is the mother of *A*, and *P* is the father of *A*. The inbreeding coefficient of each animal is equal to the kinship between its parents, $F = r_{MP}$, and the relationship of an animal to itself is $r_{AA} = 0.5 \times (1 + F)$. (See Ballou 1983 for a detailed description of this method for calculating inbreeding coefficients.)

(17) The survival of each animal is determined by comparing a random number to the survival probability for that animal. In the absence of inbreeding depression, the survival probability is given by the age and sex-specific survival rate for that year. If the HETEROSIS model of inbreeding depression is used and an individual is inbred, the survival probability is multiplied by e^{-bF} in which b is the number of lethal equivalents per haploid genome. If the RECESSIVE LETHALS model is used, all offspring that are homozygous for the lethal allele (half of all founder alleles are recessive lethals) are killed.

(18) The age of each animal is incremented by 1, and any animal exceeding the maximum age is killed.

(19) If more than one population is being modelled, migration among populations is occurs stochastically with specified probabilities.

(20) If population harvest is to occur that year, the number of harvested individuals of each age and sex class are chosen at random from those available and killed. If the number to be harvested do not exist for an age-sex class, the program continues but reports that the harvest was incomplete.

(21) Dead animals are removed from the computer memory to make space for future generations.

(22) If population supplementation is to occur in a particular year, new individuals of the specified age-class are created. Each immigrant is assigned two unique alleles, one of which will be a recessive lethal in the RECESSIVE LETHALS model. Each immigrant is assumed to be genetically unrelated to all other individuals in the population.

(23) The population growth rate is calculated as the ratio of the population size in the current year to the previous year.

(24) If the population size (*N*) exceeds the carrying capacity (*K*) for that year, additional mortality is imposed across all age and sex classes. The probability of each animal dying during this carrying capacity truncation is set to $(N - K)/N$, so that the expected population size after the additional mortality is *K*.

(25) Summary statistics on population size and genetic variation are tallied and reported. A simulated population is determined to be extinct if either sex has no representatives.

(26) Final population size and genetic variation are determined for the simulation.

(27) Summary statistics on population size, genetic variation, probability of extinction, and mean population growth rate are calculated across iterations and output.

Assumptions underpinning VORTEX

It is impossible to simulate the complete range of complex processes and dynamics typical of a wild populations. As a result there are necessarily a range of mathematical and biological assumptions which underpin any PVA program. Some of the more important assumptions in VORTEX include:

(1) Survival probabilities are density independent when the population size is less then carrying capacity. Additional mortality imposed when the population exceeds *K* affects all age and sex classes equally.

(2) The relationship between changes in population size and genetic variability are examined for only one locus. Thus, potentially complex interactions between genes located on the same chromosome are ignored. Such interactions (*e.g.*, linkage disequilibrium) are typically associated with genetic drift in very small populations, but it is unknown if, or how, they would affect population viability.

(3) All animals of reproductive age have an equal probability of breeding. This ignores the likelihood that some animals within a population may have a greater probability of breeding successfully, and breeding more often, than other individuals. If breeding is not at random among those in the breeding pool, then decay of genetic variation and the consequent inbreeding will occur more rapidly than in the model.

(4) The life-history attributes of a population (birth, death, migration, harvesting, supplementation) are modelled as a sequence of discrete and therefore seasonal events. However, such events are often continuous through time and the model ignores the possibility that they may be aseasonal or only partly seasonal.

(5) The genetic effects of inbreeding on a population are determined in VORTEX using one of two possible models: the Recessive Lethals model and the Heterosis model. Both models have attributes likely to be typical of some populations, but these will vary between species (Brewer *et al.* 1990). Given this, it is probable that the impacts of inbreeding will fall between the effects of these two models. Inbreeding is assumed to depress only one component of fitness, first-year survival. Effects on reproduction could be incorporated into this component, but longer-term impacts such as increased disease susceptibility or decreased ability to adapt to environmental change are not modelled.

(6) The probabilities of reproduction and mortality are constant from the age of first breeding until an animal reaches the maximum longevity. This assumes that animals continue to breed until they die.

(7) A simulated catastrophe will have an effect on a population only in the year that the event occurs.

(8) Migration rates among populations are independent of age and sex.

(9) Complex, inter-species interactions are not modelled, except in that such community dynamics might contribute to random environmental variation in demographic parameters. For example, cyclical fluctuations caused by predator-prey interactions cannot be modelled by VORTEX.

Discussion

Uses and Abuses of Simulation Modelling for PVA

Computer simulation modelling is a tool that can allow crude estimation of the probability of population extinction, and the mean population size and amount of genetic diversity, from data on diverse interacting processes. These processes are too complex to be integrated intuitively and no analytic solutions presently, or are likely to soon, exist. PVA modelling focusses on the specifics of a population, considering the particular habitat, threats, trends, and time frame of interest, and can only be as good as the data and the assumptions input to the model (Lindenmayer *et al.* 1992). Yet the use of even simplified computer models for PVA will provide more accurate predictions about population dynamics than the even more crude techniques available previously, such as calculation of expected population growth rates from life tables. For the purpose of estimating extinction probabilities, methods that assess only deterministic factors are almost certain to be inappropriate, because populations near extinction will commonly be so small that random processes dominate deterministic ones. The suggestion by Mace and Lande (1991) that population viability be assessed by the application of simple rules (*e.g.*, a taxon be considered Endangered if the total genetically effective population size is below 50 or the total census size below 250) should be followed only if knowledge is insufficient to allow more accurate quantitative analysis. Moreover, such preliminary judgements, while often important in stimulating appropriate corrective measures, should signal, not obviate, the need for more extensive investigation and analysis of population processes, trends, and threats.

Several good population simulation models are available for PVA. They differ in capabilities, assumptions, and ease of application. The ease of application is related to the number of simplifying assumptions and inversely related to the flexibility and power of the model. It is unlikely that a single or even a few simulation models will be appropriate for all PVAs. The VORTEX program has some capabilities not found in many other population simulation programs, but is not as flexible as are some others (*e.g.*, GAPPS: Harris *et al.* 1986). VORTEX is user-friendly and can be used by those with relatively little understanding of population biology and extinction processes. This is both an advantage and a disadvantage.

Testing Simulation Models

Because many population processes are stochastic, a PVA can never specify what will happen to a population. Rather, PVA can provide estimates of probability distributions describing possible fates of a population. The fate of a given population may happen to fall at the extreme tail of such a distribution even if the processes and probabilities are assessed precisely. Therefore, it will be often be impossible to empirically test the accuracy of PVA results by monitoring of one or a few threatened populations of interest. Presumably, if a population followed a course that was well outside of the range of possibilities predicted by a model, that model could be rejected as inadequate. Often, however, the range of plausible fates generated by PVA is quite broad.

Simulation programs can be checked for internal consistency. For example, in the absence of inbreeding depression and other confounding effects, does the simulation model predict an average long-term growth rate similar to that determined from a life table calculation? Beyond this, some confidence in the accuracy of a simulation model can be obtained by comparing observed fluctuations in population numbers to those generated by the model, thereby comparing a data set consisting of tens to hundreds of data points to model results. For example, from 1938 through 1991, the wild population of whooping cranes had grown at a mean exponential rate of $r = 0.040$, with annual fluctuations in the growth rate of $SD(r) = 0.141$ (Seal *et al.* 1992). Life table analyses of the whooping crane predicted a mean population growth rate of $r = 0.052$. Simulations using VORTEX predicted a mean population growth rate of $r = 0.046$ into the future, with $SD(r) = 0.081$. The lower growth rate projected by the stochastic model reflects the effects of inbreeding and perhaps imbalanced sex ratios among breeders in the simulation, factors that are not considered in deterministic life table calculations. Moreover, life table analyses use mean birth and death rates to calculate a single estimate of the population growth rate. When birth and death rates are fluctuating, it is more appropriate to average the population growth rates calculated separately from birth and death rates for each year. This mean growth rate would be lower than the growth rate estimated from mean life table values.

When the simulation model was started with the 18 cranes present in 1938, it projected a population size in 1991 (N = 151 ± 123 SD) almost exactly the same as that observed (N = 146). The model slightly under-predicted the annual fluctuations in population growth (model SD(r) = .112 vs. actual SD(r) = .141). This may reflect a lack of full incorporation of all aspects of stochasticity into the model, or it may simply reflect the sampling error inherent in stochastic phenomena. Because the data input to the model necessarily derive from analysis of past trends, such retrospective analysis should be viewed as a check of consistency, not as proof that the model correctly describes current population dynamics. Providing another confirmation of consistency, both deterministic calculations and the simulation model project an over-wintering population of whooping cranes consisting of 12% juveniles (less than 1 year old), while the observed frequency of juveniles at the wintering grounds in Texas has averaged 13%.

Convincing evidence of the accuracy, precision, and usefulness of PVA simulation models would require comparison of model predictions to the distribution of fates of many replicate populations. Such a test probably cannot be conducted on any endangered species, but could and should be examined in experimental non-endangered populations. Once simulation models are determined to be sufficiently descriptive of population processes, they can guide management of threatened and endangered species (see above and Lindenmayer *et al.* 1992). The use of PVA modelling as a tool in an adaptive management framework (Holling 1978; Clark *et al.* 1990) can lead to increasingly effective species recovery efforts as better data, better models, and more thorough analyses become available.

Directions for Future Development of PVA Models

The PVA simulation programs presently available model life histories as a series of discrete (seasonal) events, yet many species breed and die throughout much of the year. Continuous-time models would be more realistic and could be developed by simulating the time between life history events as a random variable. Whether continuous-time models would significantly improve the precision of population viability estimates is unknown. Even more realistic models might treat some life history events (*e.g.*, gestation, lactation) as stages of specified duration, rather than as instantaneous events.

Most PVA simulation programs were designed to model long-lived, low fecundity (K-selected) species such as mammals, birds, and reptiles. Relatively little work has been devoted to developing models for short-lived, high fecundity (r-selected) species such as many amphibians and insects. Yet, the viability of populations of r-selected species may be highly subjected to stochastic phenomena, and r-selected species may have much greater minimum viable populations than do most K-selected species. Assuring viability of K-selected species in a community may also afford adequate protection for r-selected species, however, because of the often greater habitat area requirements of large vertebrates. Populations of r-selected species are probably less affected by intrinsic demographic stochasticity because large numbers of progeny will minimize random fluctuations, however they are more affected by environmental variations across space and time. PVA models designed for r-selected species would probably model fecundity as a continuous distribution, rather than as a completely specified discrete distribution of litter or clutch sizes; they might be based on life history stages rather than time-increment ages; and they would probably require more detailed and accurate description of environmental fluctuations than might be required for modelling K-selected species.

The range of PVA computer simulation models becoming available is important because the different assumptions of the models provide capabilities for modelling diverse life histories. Because PVA models always simplify the life history of a species, and because the assumptions of no model is likely to match exactly our best understanding of the dynamics of a population of interest, it will often be valuable to conduct PVA modelling with several simulation programs and to compare the results. Moreover, no simulation program (or any computer program) can be guaranteed to be free of errors in code. There is a need for researchers to compare the results from different PVA models when applied to the same analysis, to determine whether how the different assumptions affect conclusions and to cross-validate algorithms and computer code.

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References

Akçakaya, H.R., and Ferson, S. (1990). 'RAMAS/space User Manual. Spatially Structured Population Models for Conservation Biology.' (Applied Biomathematics: Setauket, New York.)

Ballou, J. (1983). Calculating inbreeding coefficients from pedigrees. In 'Genetics and Conservation: A Reference for Managing Wild Animal and Plant Populations'. (Eds. C.M. Schonewald-Cox, S.M. Chambers, B. MacBryde, and W.L. Thomas.) pp. 509-20. (Benjamin/Cummings: Menlo Park, California.)

Belovsky, G.E. (1987). Extinction models and mammalian persistence. In 'Viable populations for conservation.' (Ed. M.E. Soulé.) pp.35-57. (Cambridge University Press: Cambridge.)

Berger, J. (1990). Persistence of different-sized populations: an empirical assessment of rapid extinctions in bighorn sheep. *Conservation Biology* 4, 91-8.

Brewer, B.A., Lacy, R.C., Foster, M.L., and Alaks, G. (1990). Inbreeding depression in insular and central populations of Peromyscus mice. *Journal of Heredity* **81**, 257-66.

Brussard, P. (1985). Minimum viable populations: how many are too few? *Restoration and Management Notes* **3**, 21-5.

Burgmann, M.A., and Gerard, V.A. (1990). A stage-structured, stochastic model for giant kelp *Macrocystis pyrifera. Marine Biology* **105**, 15-23.

Clark, T.W. (1989). 'Conservation Biology of the Black-footed Ferret. Special Scientific Report.' (Wildlife Preservation Trust International: Philadelphia.)

Clark, T.W., Backhouse, G.N., and Lacy, R.C. (1991). Report of a workshop on population viability assessment as a tool for threatened species management and conservation. *Australian Zoologist* **27**, 28-35.

Clark, T.W., and Seebeck, J.H. (eds.) (1990). 'Management and conservation of small populations.' (Chicago Zoological Society: Brookfield, Illinois.)

Clark, T.W., Warneke, R.M., and George, G.G. (1990). Management and conservation of small populations. In 'Management and Conservation of Small Populations.' (Eds. T.W. Clark and J.H. Seebeck.) pp.1-18. (Chicago Zoological Society: Brookfield, Illinois.)

Cox, J. (1988). Viability estimates for small gopher tortoise (*Gopherus polyphemus*) populations. Proceedings annual gopher tortoise council meeting. October 1986.

Crow, J.F. and Kimura, M. (1970). 'Introduction to Population Genetics Theory.' (Harper and Row: New York.)

Doughty, R.W. (1989). 'Return of the Whooping Crane.' (University of Texas Press: Austin.)

Falconer, D.S. (1981). 'Introduction to Quantitative Genetics.' 2nd Edn. (Longman: New York.)

Ferson, S. (1990). 'RAMAS/stage. Generalized Stage-based Modeling for Population Dynamics.' (Applied Biomathematics: Setauket, New York.)

Ferson, S., and Akçakaya, H.R. (1989). 'RAMAS/age User Manual. Modeling Fluctuations in Age-structured Populations.' (Applied Biomathematics: Setauket, New York.)

Fisher, R.A. (1958). 'The genetical theory of natural selection.' 2nd Edn. (Dover: New York.)

Gilpin, M.E. (1987). Spatial structure and population vulnerability. In 'Viable populations for conservation'. (Ed. M.E. Soulé.) pp. 125-39. (Cambridge University Press: Cambridge.)

Gilpin, M.E. (1989). Population viability analysis. *Endangered Species Update* **6**, 15-18.

Gilpin, M.E., and Soulé, M.E. (1986). Minimum viable populations: processes of species extinction. In 'Conservation biology: the science of scarcity and diversity'. (Ed. M.E. Soulé.) pp. 19-34. (Sinauer: Sunderland, Massachusetts.)

Goodman, D. (1987). The demography of chance extinction. In 'Viable populations for conservation'. (Ed. M.E. Soulé.) pp.11-34. (Cambridge University Press: Cambridge.)

Grier, J.W. (1980a). A simulation model for small populations of animals. *Creative Computing* **6**, 116-121.

Grier, J.W. (1980b). Modeling approaches for bald eagle population dynamics. *Wildlife Society Bulletin* **8**, 316-322.

Grier, J.W., and Barclay, J.H. (1988). Dynamics of founder populations established by re-introduction. In 'Peregrine falcon populations: their management and recovery'. (Eds. T.J. Cade, J.H. Enderson, C.G. Thelander, and C.M. White.) pp. 689-701. (The Peregrine Fund: Boise, Idaho.)

Griffith, B., Scott, J.W., Carpenter, J.W., and Reed, C. (1989). Translocation as a species conservation tool: status and strategy. *Science* **245**, 477-480.

Harris, R.B., Metzger, L.H., and Bevins, C.D. (1986). 'GAPPS. Version 3.0'. (Montana Co-operative Research Unit, University of Montana: Missoula, Montana.)

Hill, F.A.R. (1991). A research recovery plan for the brush-tailed rock wallaby *Petrogale pencillata* (Gray 1825). Report to Australian National Parks and Wildlife Service. (Department of Conservation and Environment: Melbourne.)

Holling, C.S. (ed.) (1978). 'Adaptive environmental assessment and management.' International Series on Applied Systems Analysis 3, International Institute for applied systems analysis. (John Wiley and Sons: Toronto.)

Kirkpatrick, S, and Stoll, E. (1981). A very fast shift-register sequence random number generator. *Journal of Computational Physics* **40**, 517.

Lacy, R.C., and Clark, T.W. (1990). Population viability assessment of eastern barred bandicoot. In 'The management and conservation of small populations'. (Eds. T.W. Clark and J.H. Seebeck.) pp.131-46. (Chicago Zoological Society: Brookfield, Illinois.)

Lacy, R.C., Flesness, N.R., and Seal, U.S. (1989). Puerto Rican parrot population viability analysis. Report to the U.S. Fish and Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.)

Lacy, R.C., Petric, A.M., and Warneke, M. (1992). Inbreeding and outbreeding depression in captive populations of wild species. In 'The Natural History of Inbreeding and Outbreeding'. (Ed. N.W. Thornhill.) (University of Chicago Press: Chicago.) (In press.)

Lande, R. (1988). Demographic models of the northern spotted owl (*Strix occidentalis caurina*). *Oecologia* **75**, 601-7.

Latour, A. (1986). Polar normal distribution. *Byte* August 1986, 131-2.

Lindenmayer, D.B., Clark, T.W., Lacy, R.C., and Thomas, V.C. (1992). Population viability analysis as a tool in wildlife management: A review with reference to Australia. Submitted to *Environmental Management.*

Mace, G.M., and Lande, R. (1991). Assessing extinction threats: toward a reevaluation of IUCN threatened species categories. *Conservation Biology* 5, 148-157.

Maguire, L.A., Lacy, R.C., Begg, R.J., and Clark, T.W. (1990). An analysis of alternative strategies for recovering the eastern barred bandicoot. In 'The management and conservation of small populations'. (Ed. T.W. Clark and J.H. Seebeck.) pp. 147-64. (Chicago Zoological Society: Brookfield, Illinois.)

Maier, W.L. (1991). A fast pseudo random number generator. *Dr. Dobb's Journal* May **1991**, 152-7.

Morton, N.E., Crow, J.F., and Muller, H.J. (1956). An estimate of the mutational damage in man from data on consanguineous marriages. *Proceedings of the National Academy of Sciences, U.S.A.* **42**, 855-63.

O'Brien, S.J. and Evermann, J.F. (1988). Interactive influence of infectious diseases and genetic diversity in natural populations. *Trends in Ecology and Evolution* **3**, 254-9.

Parker, W., Smith, R., Foose, T.J., and Seal, U.S. (1991). The red wolf recovery/species survival plan. (U.S. Fisheries and Wildlife Service: Atlanta, Georgia.)

Possingham, H., Davies, I., and Noble, I.R. (1991). An evaluation of population viability analysis for assessing the risk of extinction. Report to the Resource Assessment Commission. (Resource Assessment Commission: Canberra.)

Ralls, K., Ballou, J.D., and Templeton. A.R. (1988). Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conservation Biology* **2**, 185-93.

Reed, J.M., Doerr, P.D., and Walters, J.R. (1988). Minimum viable population size of the red-cockaded woodpecker. *Journal of Wildlife Management* **52**, 385-391.

Resource Assessment Commission. (1991). Forest and timber inquiry. Draft report. Volume 2. July 1991. (Australian Government Publishing Service: Canberra.)

Ricklefs, R.E. (1979). 'Ecology'. 2nd Edn. (Chiron: New York.)

Robertson, A. (1960). A theory of limits in artificial selection. *Proceedings Royal Society of London* **153B**, 234-49.

Seal, U.S., Ballou, J.D., and Padua, C.V. (1990). *Leontopithecus* population viability analysis workshop report. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.)

Seal, U.S., and Foose, T.J. (1989). Javan rhinoceros population viability analysis and recommendations. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.)

Seal, U.S., and Lacy, R.C. (1989). Florida panther population viability analysis. Report to the U.S. Fish and Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.)

Seal, U.S., and Lacy, R.C. (1990). Florida Key deer. Report to the U.S. Fish and Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.)

Seal, U.S., and Lacy, R.C. (1992a). Tana River primate population and habitat viability analysis. Report to the Kenya Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.) (In press.)

Seal, U.S., and Lacy, R.C. (1992b). Kenyan black rhinoceros population viability analysis. Report to the Kenya Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.) (In press.)

Seal, U.S., Mirande, C., and Lacy, R.C. (1992). Whooping crane population viability analysis. Report to the U.S. Fish and Wildlife Service. (Captive Breeding Specialist Group, Species Survival Commission, IUCN: Apple Valley, Minnesota.) (In press.)

Seal, U.S., Thorne, E.T., Bogan, M.A., and Anderson, S.H. (1989). (eds.) 'Conservation biology and the black-footed ferret'. (Yale University Press: New Haven, Connecticut.)

Selander, R.K. (1983). Evolutionary consequences of inbreeding. In 'Genetics and Conservation: A Reference for Managing Wild Animal and Plant Populations'. (Eds. C.M. Schonewald-Cox, S.M. Chambers, B. MacBryde, and W.L. Thomas.) pp. 201-215. (Benjamin/Cummings: Menlo Park, California.)

Shaffer, M.L. (1981). Minimum population sizes for species conservation. *BioScience* **31**, 131-4.

Shaffer, M.L. (1987). Minimum viable populations: Coping with uncertainty. In 'Viable populations for conservation'. (Ed. M.E. Soulé.) pp. 69-86. (Cambridge University Press: Cambridge.)

Shaffer, M.L. (1990). Population viability analysis. *Conservation Biology* **4**, 39-40.

Simberloff, D.A. (1986). The proximate causes of extinction. In 'Patterns and processes in the history of life'. (Eds. D.M. Raup and D. Jablonski.) pp. 259-76. (Springer-Verlag: Berlin.)

Simberloff, D.A. (1988). The contribution of population and community biology to conservation science. *Annual Review of Ecology and Systematics* **19**, 473-511.

Soulé, M.E. (ed). (1987). 'Viable populations for conservation'. (Cambridge University Press: Cambridge.)

Thomas, C.D. (1990). What do real population dynamics tell us about minimum population sizes? *Conservation Biology* 4, 324-7.

Wright, S. (1977). 'Evolution and the genetics of populations. Vol. 3. Experimental Results and Evolutionary Deductions'. (University of Chicago Press: Chicago.)

Figure 1. Frequency histogram of proportion of whooping cranes surviving each year, 1938-1990. The broadest curve is the normal distribution that most closely fits the overall histogram. Statistically, this curve fits the data poorly. The second highest and second broadest curve is the normal distribution that most closely fits the histogram excluding the five leftmost bars (7 outlier "catastrophe" years). The narrowest and tallest curve is the normal approximation to the binomial distribution expected from demographic stochasticity. The difference between the tallest and second tallest curves is the additional variation in annual survival due to environmental variation.

Appendix 1 - Sample output from VORTEX.

Explanatory comments are added in italics.

```
VORTEX -- simulation of genetic and demographic stochasticity
TEST
Fri Dec 20 09:21:18 1991
  2 population(s) simulated for 100 years, 100 runs
```

Simulation label and output file name

VORTEX first lists the input parameters used in the simulation:

```
  HETEROSIS model of inbreeding depression
        with  3.14 lethal equivalents per diploid genome

  Migration matrix:
          1       2
   1   0.9900  0.0100
   2   0.0100  0.9900
```

i.e., 1% probability of migration from population 1 to 2, and from 2 to 1

```
  First age of reproduction for females: 2   for males: 2
  Age of senescence (death): 10
  Sex ratio at birth (proportion males): 0.5000

Population 1:
  Polygynous mating; 50.00 percent of adult males in the breeding pool.
  Reproduction is assumed to be density independent.
   50.00 (EV = 12.50 SD) percent of adult females produce litters of size 0
   25.00 percent of adult females produce litters of size 1
   25.00 percent of adult females produce litters of size 2
```

EV is environmental variation

```
   50.00 (EV = 20.41 SD) percent mortality of females between ages 0 and 1
   10.00 (EV = 3.00 SD) percent mortality of females between ages 1 and 2
   10.00 (EV = 3.00 SD) percent annual mortality of adult females (2<=age<=10)
   50.00 (EV = 20.41 SD) percent mortality of males between ages 0 and 1
   10.00 (EV = 3.00 SD) percent mortality of males between ages 1 and 2
   10.00 (EV = 3.00 SD) percent annual mortality of adult males (2<=age<=10)
         EVs may have been adjusted to closest values possible
                 for binomial distribution
    EV in reproduction and mortality will be correlated.

  Frequency of type 1 catastrophes: 1.000 percent
    with 0.500 multiplicative effect on reproduction
     and 0.750 multiplicative effect on survival
  Frequency of type 2 catastrophes: 1.000 percent
    with 0.500 multiplicative effect on reproduction
     and 0.750 multiplicative effect on survival
```

```
Initial size of Population 1:  (set to reflect stable age distribution)
Age 1    2    3    4    5    6    7    8    9    10   Total
  1    0    1    1    0    1    0    0    1    0      5  Males
  1    0    1    1    0    1    0    0    1    0      5  Females
Carrying capacity = 50 (EV = 0.00 SD)
  with a 10.000 percent decrease for 5 years.
Animals harvested from population 1, year 1 to year 10 at 2 year intervals:
  1 females 1 years old
  1 female adults (2 <= age <= 10)
  1 males 1 years old
  1 male adults (2 <= age <= 10)
Animals added to population 1, year 10 through year 50 at 4 year intervals:
  1 females 1 years old
  1 females 2 years old
  1 males 1 years old
  1 males 2 years old
```

VORTEX now reports life table calculations of expected population growth rate

```
Deterministic population growth rate (based on females, with assumptions of
   no limitation of mates and no inbreeding depression):
    r =  -0.001     lambda = 0.999     R0 =      0.997
  Generation time for:  females = 5.28     males = 5.28
```

Note that the deterministic life table calculations project approximately zero population growth for this population.

```
Stable age distribution:  Age class    females    males
                              0          0.119      0.119
                              1          0.059      0.059
                              2          0.053      0.053
                              3          0.048      0.048
                              4          0.043      0.043
                              5          0.038      0.038
                              6          0.034      0.034
                              7          0.031      0.031
                              8          0.028      0.028
                              9          0.025      0.025
                             10          0.022      0.022
Ratio of adult (>= 2) males to adult (>= 2) females: 1.000
```

```
Population 2:
```

Input parameters for population 2 were identical to those for population 1. Output would repeat this information from above.

Simulation results follow ...

```
Population1
Year 10
    N[Extinct] =        0, P[E] = 0.000
    N[Surviving] =    100, P[S] = 1.000
    Population size =              4.36 (  0.10 SE,    1.01 SD)
    Expected heterozygosity =    0.880 (  0.001 SE,   0.012 SD)
    Observed heterozygosity =    1.000 (  0.000 SE,   0.000 SD)
    Number of extant alleles =    8.57 (   0.15 SE,    1.50 SD)
```

...

Population summaries given, as requested by user, at 10-year intervals.

...

```
Year 100
    N[Extinct] =       86, P[E] = 0.860
    N[Surviving] =     14, P[S] = 0.140
    Population size =              8.14 (   1.27 SE,    4.74 SD)
    Expected heterozygosity =    0.577 (  0.035 SE,   0.130 SD)
    Observed heterozygosity =    0.753 (  0.071 SE,   0.266 SD)
    Number of extant alleles =    3.14 (   0.35 SE,    1.29 SD)

In 100 simulations of 100 years of Population1:
  86 went extinct and 14 survived.
This gives a probability of extinction of 0.8600 (0.0347 SE),
  or a probability of success of          0.1400 (0.0347 SE).

99 simulations went extinct at least once.
Median time to first extinction was 5 years.
Of those going extinct,
   mean time to first extinction was 7.84 years (1.36 SE, 13.52 SD).
123 recolonizations occurred.
Mean time to recolonization was 4.22 years (0.23 SE, 2.55 SD).
110 re-extinctions occurred.
Mean time to re-extinction was 54.05 years (2.81 SE, 29.52 SD).

Mean final population for successful cases was 8.14 (1.27 SE, 4.74 SD)
   Age 1   Adults    Total
    0.14    3.86     4.00  Males
    0.36    3.79     4.14  Females

During years of harvest and/or supplementation
  mean growth rate (r) was 0.0889 (0.0121 SE, 0.4352 SD)
Without harvest/supplementation, prior to carrying capacity truncation,
  mean growth rate (r) was -0.0267 (0.0026 SE, 0.2130 SD)
```

Population growth in the simulation (r = -0.0267) was depressed relative to the projected growth rate calculated from the life table (r = -.001) because of inbreeding depression and occasional lack of available mates.

```
Note: 497 of 1000 harvests of males and 530 of 1000 harvests of females
      could not be completed because of insufficient animals.

Final expected heterozygosity was      0.5768 ( 0.0349 SE,  0.1305 SD)
Final observed heterozygosity was      0.7529 ( 0.0712 SE,  0.2664 SD)
Final number of alleles was            3.14 (   0.35 SE,     1.29 SD)

Population2
```

Similar results for Population 2, omitted from this Appendix, would follow...

```
 ********  Meta-population Summary  ********
Year 10
    N[Extinct] =        0, P[E] = 0.000
    N[Surviving] =    100, P[S] = 1.000
    Population size =             8.65 (   0.16 SE,     1.59 SD)
    Expected heterozygosity =    0.939 (  0.000 SE,   0.004 SD)
    Observed heterozygosity =    1.000 (  0.000 SE,   0.000 SD)
    Number of extant alleles =  16.92 (   0.20 SE,     1.96 SD)
```

...

Meta-population summaries given at 10-year intervals.

...

```
Year 100
    N[Extinct] =       79, P[E] = 0.790
    N[Surviving] =     21, P[S] = 0.210
    Population size =            10.38 (   1.37 SE,     6.28 SD)
    Expected heterozygosity =    0.600 (  0.025 SE,   0.115 SD)
    Observed heterozygosity =    0.701 (  0.050 SE,   0.229 SD)
    Number of extant alleles =   3.57 (   0.30 SE,     1.36 SD)

In 100 simulations of 100 years of Meta-population:
  79 went extinct and 21 survived.
This gives a probability of extinction of 0.7900 (0.0407 SE),
  or a probability of success of          0.2100 (0.0407 SE).

97 simulations went extinct at least once.
Median time to first extinction was 7 years.
Of those going extinct,
   mean time to first extinction was 11.40 years (2.05 SE, 20.23 SD).

91 recolonizations occurred.
Mean time to recolonization was 3.75 years (0.15 SE, 1.45 SD).
73 re-extinctions occurred.
Mean time to re-extinction was 76.15 years (1.06 SE, 9.05 SD).
```

Small Population Biology
&
Population and Habitat Viability Assessment

Robert Lacy, Tom Foose,
Jon Ballou and Jan Eldridge

January 1992

Many wildlife populations that were once large and continuous have been reduced to small, fragmented isolates in remaining natural areas. The final extinction of these populations usually is a matter of chance, resulting from one or a few years of bad luck--even if the causes of the original decline were quite preventable, such as over-hunting and habitat destruction. Few endangered species have recovered adequately and some have gone extinct in spite of protection. This reveals the acute risks faced by small populations and the need for a more intensive, systematic approach to recovery. The purpose of Population and Habitat Viability Analyses (PHVA's) is to help managers understand the risks facing small populations, to identify the relative importance of the factors that put a small population at risk, and to evaluate the effectiveness of various management strategies.

When populations get very small, evolutionary and ecological processes change. All of the things we know about general population management no longer apply. The classic approach to understanding a large population is a life table analysis. The problem with using life tables for small populations is that even if the population is growing (in good shape according to the life table analysis), it will fluctuate wildly, so it could still go extinct at any time. The stochasticity in small populations is categorized according to four causes: demographic fluctuation, environmental variation, catastrophic events, and genetic drift.

1. Demographic Fluctuation - luck of the draw. Flux in all populations occurs even if the environment is constant, and all animals have the same chance. This means that the probability of being male and female, alive or dead, is a coin toss. In a large population this kind of variation all evens out in the end and doesn't really matter, but in small populations it could be important. It is possible, by bad luck, to have every animal happen to die one year. A classic example of this kind of bad luck is the dusky seaside sparrow where all six of the last birds were male.

2. Environmental Variation - flux in demographic probabilities. This is the externally imposed variation in the probability of birth and death. In one year, mortality may be 10%, the next year because of drought, 90%. The same environmentally induced variance may occur in reproductive rates, mortality rates, or carrying capacity.

3. Catastrophic Events - the extreme of environmental variation. We consider it separately for a couple of reasons. If you look at the typical distribution of environmental flux, catastrophes are outliers. You wouldn't predict hurricanes by studying average wind patterns. It is usually so far out, it doesn't fit the normal day to day, year to year variation. The impact on the population may be very sever. The population could be adapted to year to year "normal" variation but not to catastrophe. Often catastrophes will wipe out the species. A species may hang on and then get hit by a catastrophe. We think of them as aberrant events but over a long time period, they are predictable, hurricanes hit at one out of every 30 years, forest fires hit with some probability. Catastrophes include storms, fires, disease, and The Unexpected.

4. Genetic Drift & Inbreeding. Small populations fluctuate genetically just as they do in numbers. It is a sampling problem. In a large population each generation is a good sample of the one that existed before. In a small population each generation is a poor example of the others. Genes that are in flux could hit 0 and so alleles are lost, over time there is a significant loss of genetic diversity. So, the longer the population is small, the greater the loss. Inbreeding also increases as populations become smaller. Loss of genetic diversity has been associated with an increase in vulnerability and susceptibility to environmental problems, reproductive difficulties, and disease -- it affects each species differently. Genetic drift can decrease and worsen the demographic situation. In general, in mammals 1% loss of genetic diversity means 1% loss in reproductive fitness. Loss of genetic diversity will also limit the ability of populations to adapt as environments change.

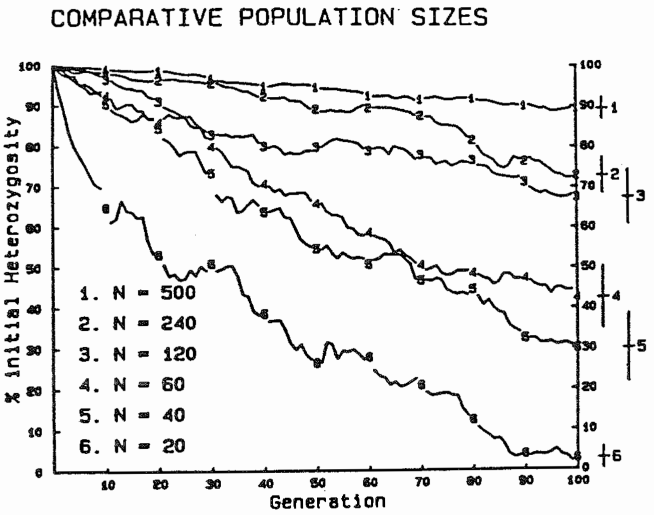

Figure 1. The average losses of genetic variation (measured by heterozygosity or additive genetic variation) due to genetic drift in 25 computer-simulated populations of 20, 50, 100, 250, and 500 randomly breeding individuals. Figure from Lacy 1987a.

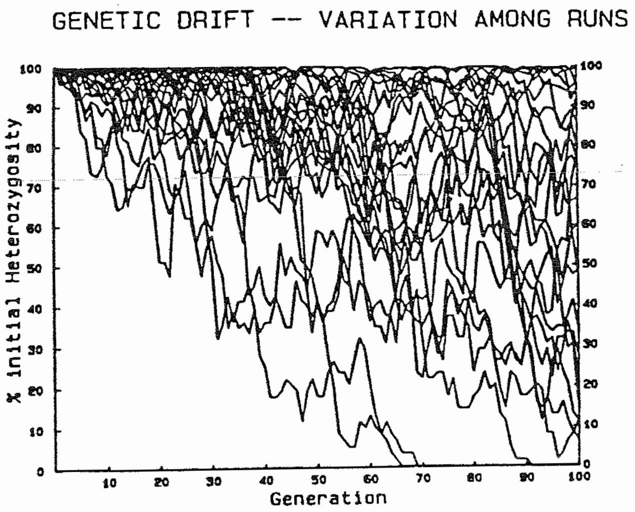

Figure 2. The losses of heterozygosity at a genetic locus in 25 populations of 120 randomly breeding individuals, simulated by computer. Figure from Lacy 1987a.

All of these characteristics feed back on each other in a nasty way...in what is called an extinction vortex. External force (hunting, habitat loss), cause the original decline but when a population becomes very small, you set into motion a series of problems that can spiral down into an extinction vortex. The fluctuation of population size makes inbreeding worse than if size were constant, the demographic fluctuations can negatively impact the population and cause further stochasticity, etc. The spiral is fast unless management is very aggressive. Part of the management problem is to keep populations out of the vortex. The size below which a population is likely to get sucked into the extinction vortex has been called the Minimum Viable Population size (or MVP).

Recently, techniques have been developed to permit the systematic examination of many of the processes that put small populations at risk. By a combination of modeling techniques, the probability of a population persisting a specified time into the future can be estimated. The population models used in PHVA's allow you to do "what-if" scenarios by looking at the data, and management schemes, to try to mitigate the probability of loss.

There are several approaches to modeling the variability of population extinction. One approach is to develop a mathematical formula, based on various population parameters; two examples of this approach are Goodman (1987), and Dennis et. al, (in prep.). There are advantages to a mathematical formula--- it looks precise because you get a number at the end. The disadvantage is that the number may not mean much. Usually the models have a very limited number of factors (exponential growth rate, variance, maximum population size). They suffer from being too simple; they do not include important factors; for example, Dennis et. al. assumes no carrying capacity, exponential growth, no genetic events, and no catastrophes. All models make assumptions, it is important to think about those assumptions.

The approach used in a stochastic models such as VORTEX is to try to understand the extinction vortex. It doesn't depend on a complicated mathematical formula; instead, the program makes the computer think it is the population. Computers are very good at flipping coins, determining the probability is "x" of something happening. The model combines information on life history, distribution, genetics, estimates of disease and catastrophic events (natural and man induced) in a computer simulation that allows rapid evaluation of critical factors for small population recovery. VORTEX was developed by Robert Lacy of the Chicago Zoological Park, based on original programs written by James Grier of North Dakota State University (Grier 1980a, 1980b, Grier and Barclay 1988).

The driving questions behind the model are: How small is critical, how big is enough? These are important questions and the strategy for using the model requires that managers set some goals. For example:

Goal 1. The probability of survival desired for the population (e.g., managers may want 95% probability of survival, or they may settle for a 50% chance)

Goal 2. The percentage of the genetic diversity to be preserved (managers can predetermine what level of diversity they are willing to tolerate, for example, 90%, means that they will only tolerate a loss in heterozygosity of 10%).

Goal 3. The period of time over which demographic security and genetic diversity are to be sustained (e.g., 50 years, 200 years).

An example of a management strategy for an endangered species could start with the question; What is the minimum population size necessary to ensure a 95% probability of survival for 200 years with 95% of the average genetic heterozygosity retained?

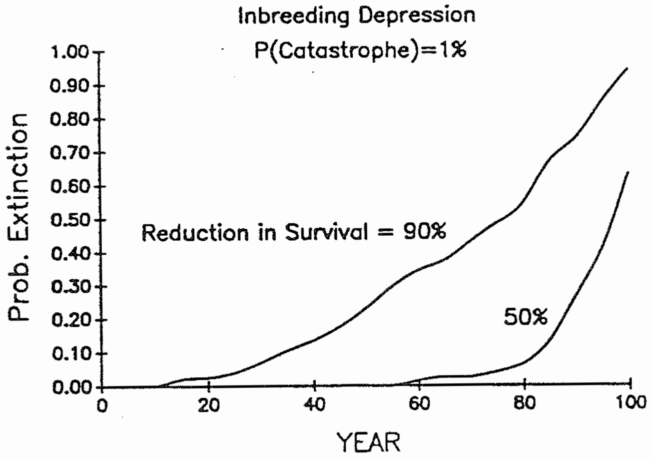

Figure 3. Hypothetical example of population extinction results from the VORTEX PVA model. The model includes negative effects of inbreeding and a catastrophe probability of 1%. The probability of extinction is shown over time for two different levels of catastrophe severity: a 90% reduction in survival vs 50% reduction in survival.

The advantage of simulation models like Vortex is that they can get bigger and bigger by adding things on. The model asks the user to input a lot of population parameters. The model is dependent on knowledge, you need to know sex ratios, birth and death rates, etc.; without this information, you can't do anything. You must recognize where data are weak so you can test the sensitivity of the model. This indicates where you need more data.

The primary use of the model in developing conservation strategies is in conducting "what if" analyses. For example, what if survival were decreased in the wild population as a result of a disease outbreak? How would that effect the extinction of the population and retention of genetic diversity. These "what if " analyses can also be used to evaluate management recommendations. For example, how would probability of population extinction change if the carrying capacity of the reserve holding the animals were increased by 10%.

The key to success of the PHVA approach is that it is accessible. The PHVA workshops conducted by CBSG bring management and expertise together to form a consensus on the priorities for species recovery. It is done in a way that makes information and assumptions explicit. The technique does not rely on "intuition" and it is valuable because everyone has access to the information that is used for management recommendations.

DEFINITIONS

Population and Habitat Viability Analysis. A systematic evaluation of the relative importance of factors that place populations at risk. It is an attempt to identify the most important factors for the survival of the population. In some cases, this may be easy - habitat destruction is often a critical factor for most endangered species. But at other times, the effects of single factors, and the interaction between factors, are more difficult to predict. To try to gain a more quantitative understanding of the effects of these factors, computer models have been developed that apply a combination of analytical and simulation techniques to model the populations over time and estimate the likelihood of a population going extinct.

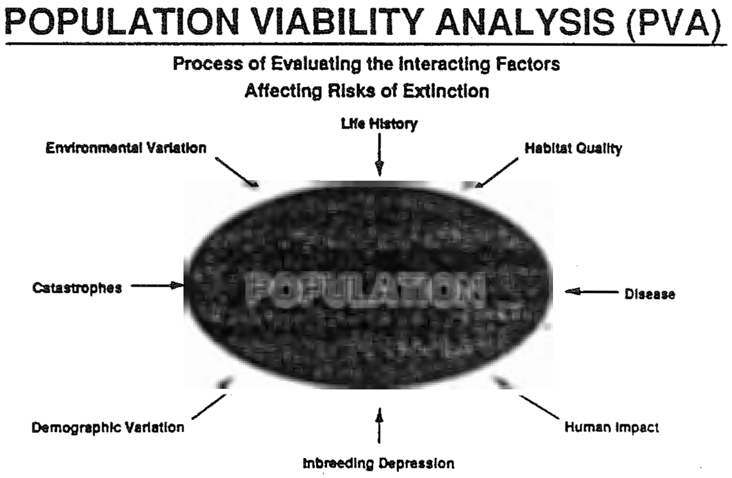

Figure 4. Population Viability Analyses (PVA) model the effects of different life-history, environmental and threat factors on the extinction and retention of genetic diversity in single populations.

Demographic Fluctuation - luck of the draw. Flux in all populations occurs even if the environment is constant, and all animals have the same chance. This means that the probability of being male and female, alive or dead, is a coin toss. In a large population this kind of variation all evens out in the end and doesn't really matter, but in small populations it could be important. It is possible, by bad luck, to have every animal happen to die one year. A classic example of this kind of bad luck is the dusky seaside sparrow where all six of the last birds were male.

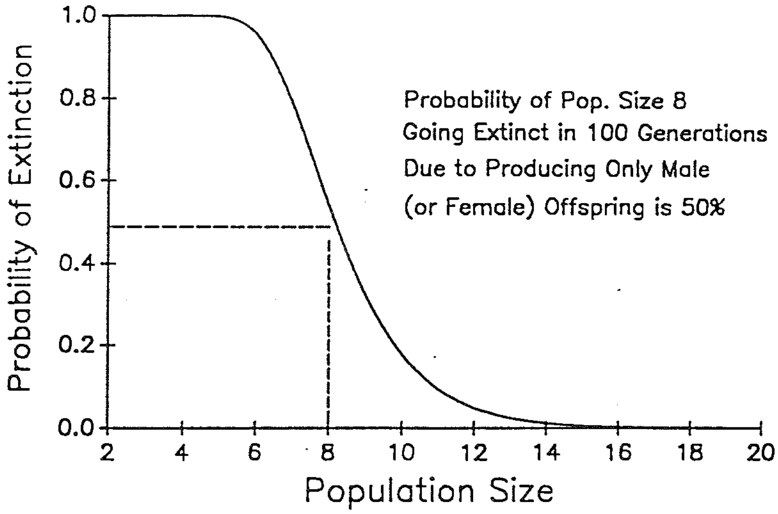

Figure 5. Example of demographic variation: Probability of extinction by 100 generations due solely to producing only one sex of offspring during a generation.

Environmental Variation - flux in demographic probabilities. This is the externally imposed variation in the probability of birth and death. In one year, mortality may be 10%, the next year because of drought, 90%. The same environmentally induced variance may occur in reproductive rates, mortality rates, or carrying capacity.

Catastrophic Events - the extreme of environmental variation. We consider it separately for a couple of reasons. If you look at the typical distribution of environmental flux, catastrophes are outliers. You wouldn't predict hurricanes by studying average wind patterns. It is usually so far out, it doesn't fit the normal day to day, year to year variation. The impact on the population may be very sever. The population could be adapted to year to year "normal" variation but not to catastrophe. Often catastrophes will wipe out the species. A species may hang on and then get hit by a catastrophe. We think of them as aberrant events but over a long time period, they are predictable, hurricanes hit at one out of every 30 years, forest fires hit with some probability. Catastrophes include storms, fires, disease, and The Unexpected.

Genetic Diversity. Expected heterozygosity (proportion of individuals in the population that carry functionally different alleles at a locus) in progeny produced by random matings.

Genetic Drift. Small populations fluctuate genetically just as they do in numbers. It is a sampling problem. In a large population each generation is a good sample of the one that existed before. In a small population each generation is a poor example of the others. Genes that are in flux could hit 0 and so alleles are lost, over time there is a significant loss of genetic diversity. So, the longer the population is small, the greater the loss. Loss of genetic diversity has been associated with an increase in vulnerability and susceptibility to environmental problems, reproductive problems, and disease -- it affects each species differently. Genetic drift can decrease and worsen the demographic situation. In general, in mammals 1% loss of genetic diversity means 1% loss in reproductive fitness. (Refer to figures 1-2).

Inbreeding and Inbreeding Depression- mating between relatives. When numbers of breeding animals become very low, inbreeding becomes inevitable and common. Inbred animals often have a higher rate of birth defects, slower growth, higher mortality, and lower fecundity (inbreeding depression). Inbreeding depression results from two effects: 1) the increase in homozygosity allows deleterious recessive alleles in the genome to be expressed (whereas they are not in non-inbred, more heterozygous individuals); and 2) in cases where heterozygotes are more fit than homozygotes simply because they have two alleles, the reduced heterozygosity caused by inbreeding reduces the fitness of the inbred individuals. In both cases, the loss of genetic variation due to inbreeding has detrimental effects on population survival.

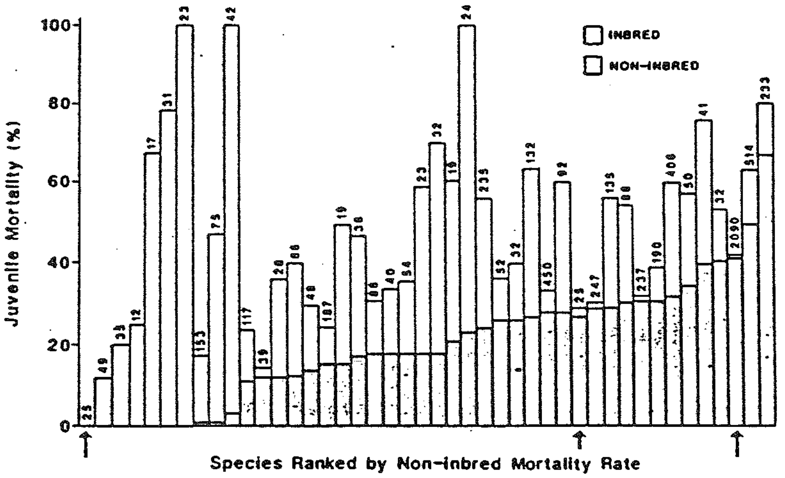

Figure 6. Effects of inbreeding on juvenile mortality in 45 captive mammal populations (From Ralls and Ballou, 1987).3

Extinction Vortex. The genetic and demographic process that come into play when a population becomes small and isolated feed back on each other to create what has been aptly but depressingly described as an extinction vortex. The genetic problems of inbreeding depression and lack of adaptability can cause a small population to become even smaller -- which in turn worsens the uncertainty of finding a mate and reproducing -- leading to further decline in numbers and thus more inbreeding and loss of genetic diversity. The population spirals down toward extinction at an ever accelerated pace.

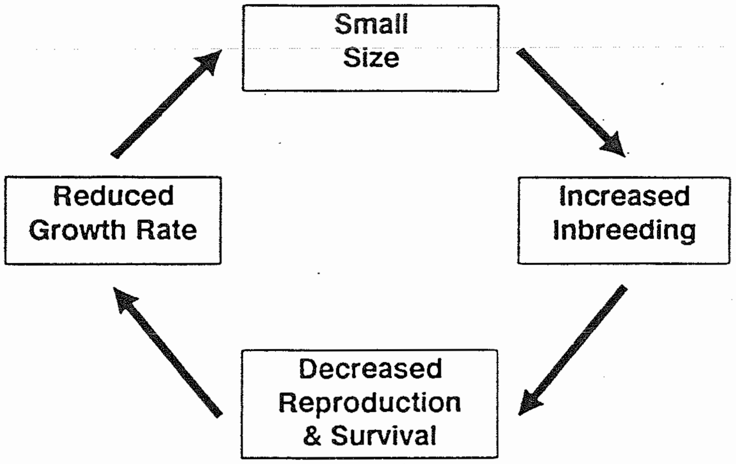

Figure 7. "Extinction Vortex" caused by negative feedback effects of inbreeding in small populations.

Minimum Viable Population Size. Populations large enough to permit long-term persistence despite the genetic, demographic, and environmental problems. Below this size, a population is likely to get sucked into the extinction vortex. There is no single magic number that constitutes an MVP for all species, or for any one species all the time. MVP depends on both the genetic and demographic objectives of a program and the biological characteristics of the population. An analysis can suggest ranges of population sizes that will provide calculated protection against stochastic problems.

The following are important biological factors for Minimum Viable Population Size:

Effective Population Size (N_e). The effective population size is a measure of the way animals reproduce and transmit genes to the next generation. It is important when you need to calculate the rate of genetic loss from generation to generation. Populations where all males and females reproduce are "effectively" larger and lose genetic diversity at a slower rate than a population where only some reproduce even though the census size of both populations is the same. An unequal sex ratio of breeding animals, greater than random variance in lifetime reproduction, and fluctuating population sizes all cause more rapid loss of variation than would occur in a randomly breeding population, and thus depress the effective population size. There is extensive literature on how to estimate a population's effective size; however, the number of animals contributing to the breeding pool each generation can be used as a very rough estimate of the effective size. The effective size of the population is usually much less than the actual number of animals; estimates suggest that Ne is often only 10 to 30% of the total population. Seemingly large populations will lose significant levels of genetic diversity if their effective sizes are small. As a consequence, if the genetic models prescribe an Ne of 500 to achieve some set of genetic objectives, the MVP might have to be 2000.

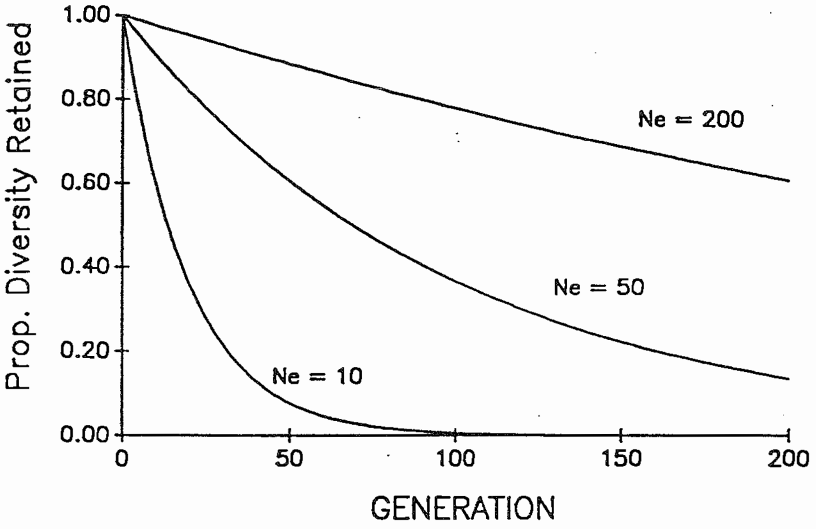

Figure 8. Loss of genetic diversity over 200 generation in populations with different effective sizes (N_e).

Generation Time. Genetic diversity is lost generation by generation, not year by year. Hence, species with longer generation times will have fewer opportunities to lose genetic diversity within the given period of time selected for the program. As a consequence, to achieve the same genetic objectives, MVP's can be smaller for species with longer generation times. Generation time is qualitatively the average age-specific survivorships and fertilities of the population which will vary naturally and which can be modified by management, e.g., to extend generation time.

The Number of Founders - A founder is defined as an animal from a source population that establishes a derivative population. To be effective, a founder must reproduce and be represented by descendants in the existing population. Technically, to constitute a full founder, an animal should also be unrelated to any other representative of the source population and non-inbred.

Basically, the more founders, the better, i.e., the more representative the sample of the source gene pool and the smaller the MVP required for genetic objectives. There is also a demographic founder effect; the larger the number of founders, the less likely is extinction due to demographic stochasticity. However, for larger vertebrates, there is a point of diminishing returns, at least in genetic terms. Hence, a common objective is to obtain 20-30 effective founders to establish a population. If this objective can not be achieved, then a program must do the best with what is available.

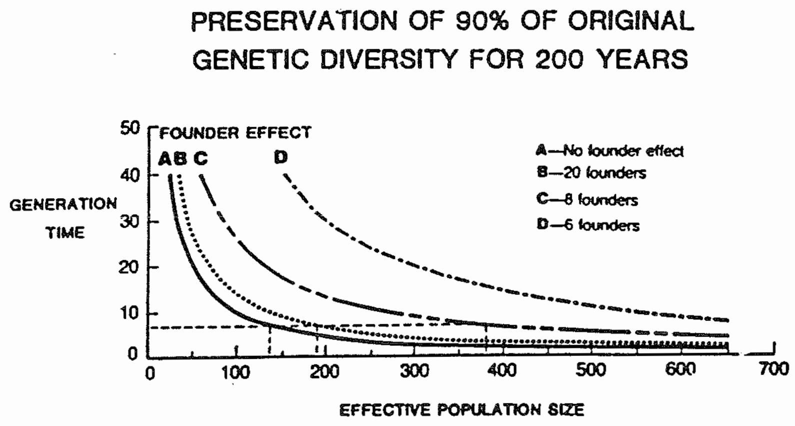

Figure 9. Interaction of number of founders, generation time of the species, and effective population size required for preserving 90% of the starting genetic diversity for 200 years.

Growth rate. The higher the growth rate, the faster a population can recover from small size, thereby outgrowing much of the demographic risk and limiting the amount of genetic diversity lost during the so-called "bottleneck". It is important to distinguish MVP's from bottleneck sizes.

Metapopulations and Minimum Areas

MVP's imply minimum critical areas of natural habitat, that may be difficult or impossible to maintain single, contiguous populations of the thousands required for viability.

However, it is possible for smaller populations and sanctuaries to be viable if they are managed as a single larger population (a metapopulation) whose collective size is equivalent to the MVP. Actually, distributing animals over multiple "subpopulations" will increase the effective size of the total number maintained in terms of the capacity to tolerate the stochastic problems. Any one subpopulation may become extinct or nearly so due to these causes; but through recolonization or reinforcement from other subpopulations, the metapopulation will survive. Metapopulations are evidently frequent in nature with much local extinction and recolonization of constituent subpopulations occurring.

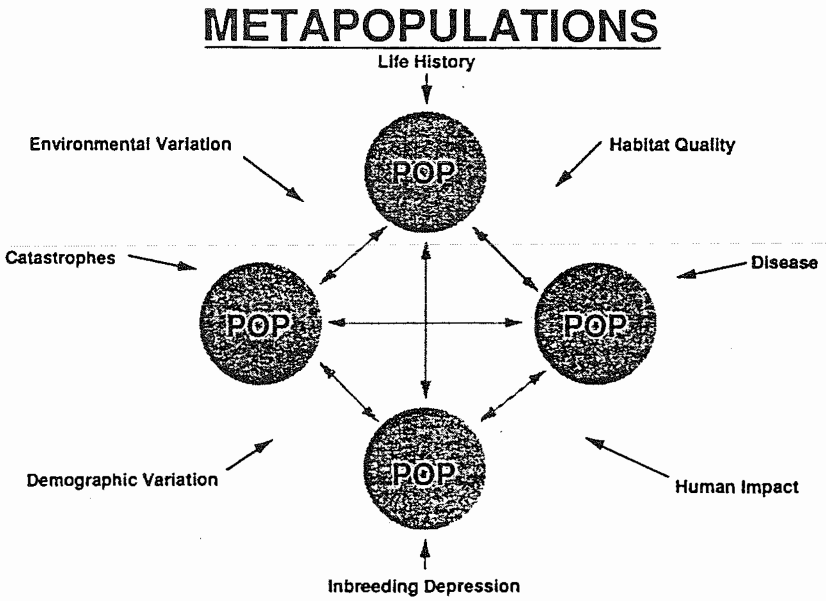

Figure 10. The interaction between population 'patches' results in a Metapopulation structure. Conservation strategies must consider the spatial distribution of the patches and its effect on correlated extinctions and recolonization between patches.

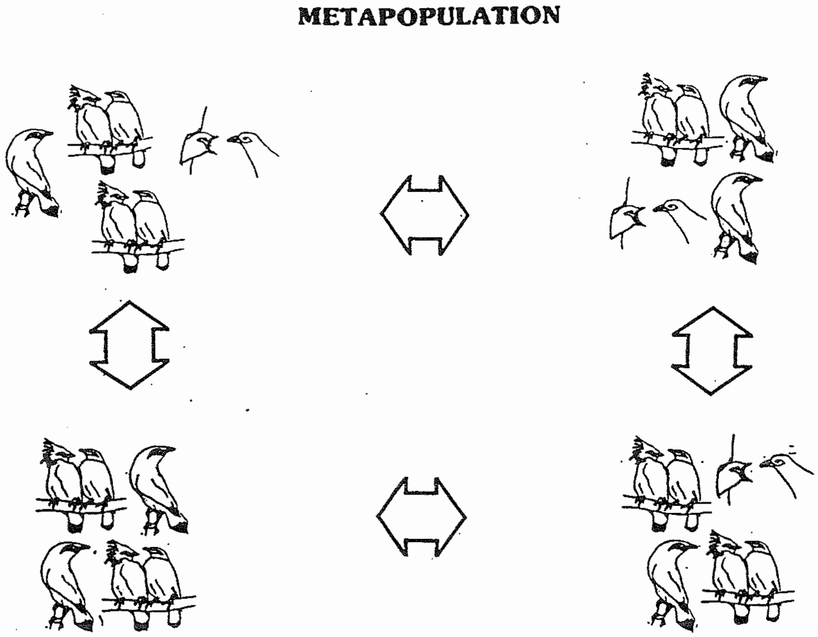

Figure 11. Multiple subpopulations as a basis for management of a metapopulation for survival of a species in the wild.

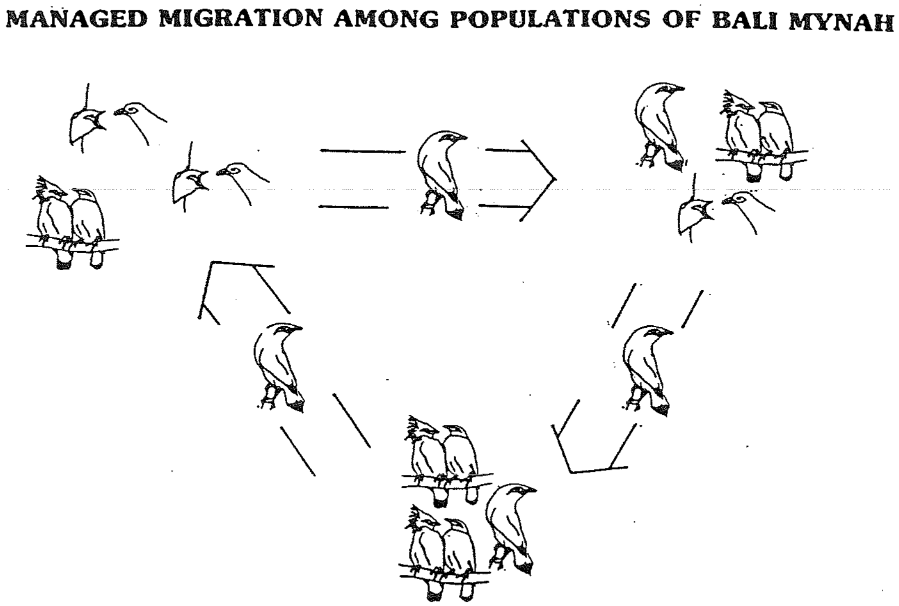

Figure 12. Managed migration among subpopulations to sustain gene flow in a metapopulation.

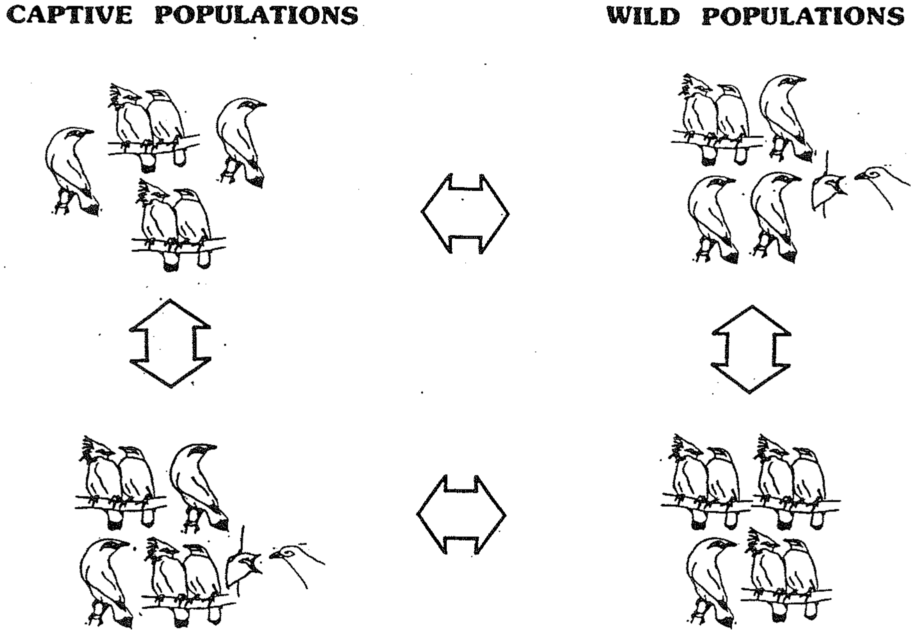

Figure 13. The use of captive populations as part of a metapopulation to expand and protect the gene pool of a species.

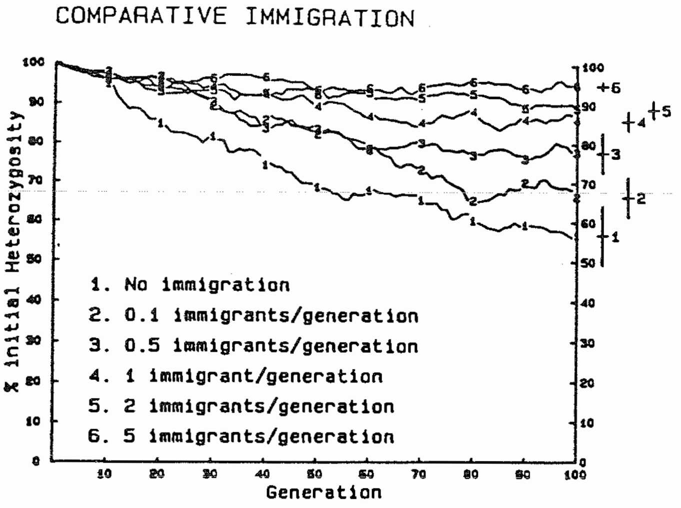

Figure 14. The effect of immigration from a large source population into a population of 120 breeding individuals. Each line represents the mean heterozygosity of 25 computer-simulated populations (or, equivalently, the mean heterozygosity across 25 non-linked genetic loci in a single population). Standard error bars for the final levels of heterozygosity are given at the right. Figure from Lacy 1987a.

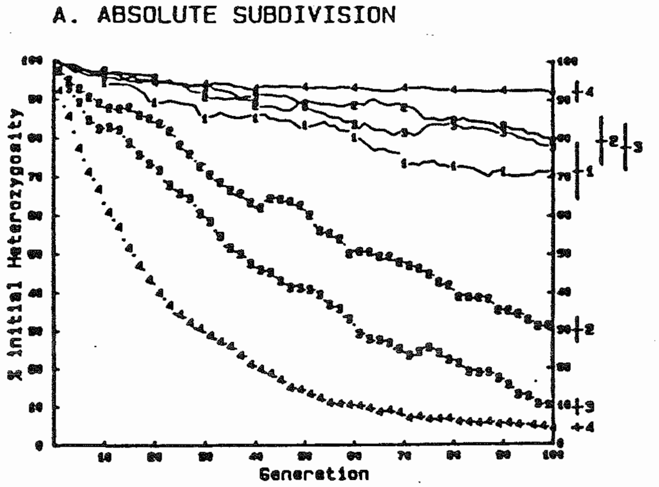

Figure 15. The effect of division of a population of 120 breeders into 1, 3, 5, or 10 isolated subpopulations. Dotted lines (numbers) indicate the mean within-subpopulation heterozygosities from 25 computer simulations. Lines represent the total gene diversity within the simulated metapopulation. Figure from Lacy 1987a.

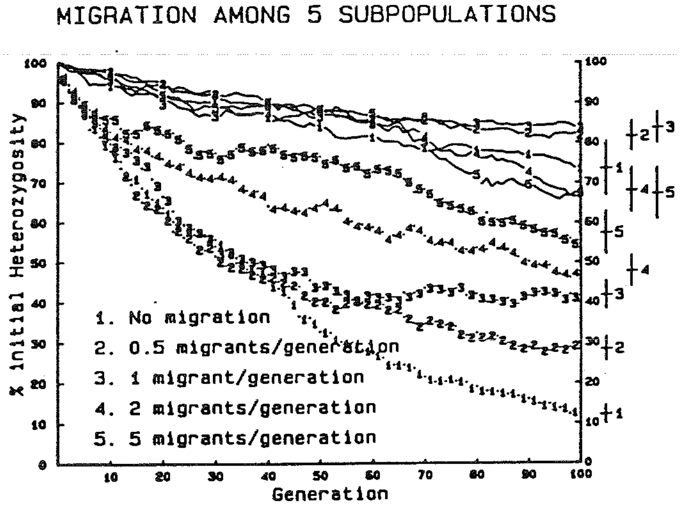

Figure 16. The effect of migration among 5 subpopulations of a population of 120 breeders. Dotted lines (numbers) indicate the mean within-subpopulation heterozygosities from 25 simulations. Lines represent the total gene diversity within the metapopulation. Figure from Lacy 1987a.

WILD KEA MANAGEMENT STATEMENT

Canterbury Conservancy Miscellaneous Report Series No. 4

CONSERVATION
TE PAPA ATAWHAI

WILD KEA
MANAGEMENT STATEMENT

Prepared by

Andrew Grant

In consultation with all South Island DOC Conservancies

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INDEX

INTRODUCTION

The Wild Kea Management Statement provides a guide on how the Department of Conservation (DOC) should deal with the various problem areas which involve kea.

Whenever dealing with problems involving kea a number of key points need to be borne in mind:

- the kea population may be declining;
- kea are an endemic species, i.e. naturally only found in New Zealand;
- kea are an absolutely protected species;
- kea were unprotected outside conservation areas until 1986;
- kea are highly inquisitive and the results of their investigations may be destructive;
- kea are considered pests by some groups of people;
- DOC's aim is to encourage people with problems involving kea to come to DOC for solutions rather than take actions themselves.

GOAL:

Long-term conservation of the wild kea population.

OBJECTIVES:

1. **To obtain baseline ecological information for the conservation management of kea.**
2. **To promote kea conservation, and to enhance the public's perception of kea.**
3. **To appropriately manage problems involving kea.**

ACHIEVING THE OBJECTIVES:

Objective 1 : To obtain baseline ecological information for the conservation management of kea.

Background

Because very little is known about the kea (its biology, status, movements, social structure, and actual, as opposed to anecdotal, impacts) past management has been based on emotive arguments and supposition. To allow a more professional and responsible management approach it is important to initiate some research programmes.

Current and recently completed areas of research

(i) Abundance, movements and social behaviour of the kea. (Kerry-Jane Wilson - Lincoln University - this study is in its sixth year).

(ii) Diet and feeding behaviour of kea at Craigieburn Forest Park (Brejaart, R. 1988).

(iii) Human/kea interactions in Arthur's Pass National Park (Brejaart, R. 1992).

(iv) Social behaviour and the ontogeny of kea foraging (Diamond J., and A.B. Bond, 1991).

(v) Sexual dimorphism of kea (Bond A.B., K.-J. Wilson, and J. Diamond 1991).

(vi) Ria Brejaart is currently in the process of producing an annotated bibliography on kea.

(vii) Kea ecology and interactions with sheep and humans (Graeme Elliott has just commenced this study on a DOC Science and Research contract).

Information Required

Several studies are necessary to enable objective management decisions to be made and provide sufficient facts to allow improved advocacy. The following list identifies what areas need to be investigated, with an indication of who could undertake this work:

(a) <u>Kea/human interactions</u>

- How do areas associated with human occupation (ski fields, villages, camps, rubbish dumps, and tourist "stop-off points" in the high country; and, camps, farms and industry in lowland areas frequented by kea) affect the biology, behaviour, distribution and dynamics of the kea population? [University, **Science and Research Directorate, DOC (S&R)**];

- what can be done to reduce the adverse impacts of kea on these human use sites, and the sites on the kea population? [University, S&R].

(b) Kea/sheep interactions

- what is the true extent of kea interaction with sheep? **[Conservancy/Field Centre (DOC), Contract]**;
- which portion of the kea population is involved in incidents and are we targeting these with our management methods? **[Conservancy/Field Centre (DOC), Contract, S&R]**;
- what are the local population dynamics of kea and how does the removal of individuals affect this? **[University, Conservancy/Field Centre (DOC), Contract, S&R]**;
- what happens to kea released into a new area well away from their natal area, natural range or habitat? What impact does this removal of individual kea have on the kea population in the release area as well as the removal area? **[Conservancy /Field Centre (DOC), Contract, S&R]**;
- an investigation into the factors which trigger kea attacks on sheep and how these contribute to the magnitude of the attacks (e.g. behaviour, nutrition, environmental, population dynamics, inter-run differences, weather and moon phase) **[Conservancy/Field Centre (DOC), S&R, Contract]**;
- what are the implications to kea biology and ecology from the changing vegetation compositions brought about through various farming regimes? **[Contract].**

(c) Sheep mortality in the South Island high country

- what is the relative magnitude of deaths caused by kea in relation to the overall mortality of high country sheep? **[University]**;
- what are the dynamics of malignant oedema (blood poisoning) and the bacteria species *Clostridium* which cause this? What is the role of the kea in initiating this disease? Are there factors which make sheep more prone to the disease? **[Massey University Veterinary School, Contract]**;

(d) Kea biology and ecology

- what is the sex ratio of kea offspring, considering the seeming preponderance of males being caught or observed during kea operations? **[University]**.

- an investigation into the population dynamics of kea (habitat requirements, population range, bio-energetics, abundance, productivity, mortality etc.) **[S&R, Universities as a whole or subdivided for a series of smaller studies]**;

- considering the sexual dimorphism in kea bill size investigate the foraging differences between sexes, in the population as a whole and within pair breeding units **[University, S&R]**;

ACTIONS

(i) As much of this information is to be obtained from field centre and conservancy offices it is proposed that the attached questionnaire (appendix 1), which aims to obtain information to help answer some of the questions listed above, is used by all South Island conservancies. These questionnaires will be filled in for each kea incident attended as well as during normal contact with high country run-holders. It is essential that each operation base maintains a kea incident field log to record all actions, observations and events. The Waimakariri Field Centre (Canterbury Conservancy) will be responsible for co-ordinating this study. Analysis of the results will be undertaken as information is collected;

(ii) South Island conservancies co-ordinate their approach to universities and research contractors to ensure that all aspects of kea research are covered and areas of research are not duplicated;

(iii) All banding of wild kea should be carried out under one banding permit so that all colour combinations are unique. Also, a single office should be responsible for all returns of information. It is suggested that this role is carried out by the Canterbury Conservancy office (since the Canterbury Conservancy already has a kea band database which contains all DOC and Lincoln University records).

Objective 2 : To promote kea conservation and enhance the public's perception of kea.

Background

Kea have been considered pests by many high country run holders, ski field operators, and a number of other users of alpine areas for a long time (also of some lowland areas frequented by kea, e.g. Franz Joseph and Fox Glacier). Kea gained absolute protection in 1986. Prior to 1986 kea were indiscriminately killed - the Government was still paying a bounty for kea beaks in 1971, a year after they were given partial protection. These attitudes still persist in many people's minds, but are slowly changing. To ensure these attitudes continue to change the following actions are proposed.

ACTIONS

(i) Vigorous conservation advocacy, through a variety of media as well as through the day to day activities of conservation officers.

Areas to emphasise are that:
- kea are endemic to New Zealand;
- kea are unique to the South Island high country;
- the kea is the world's only alpine parrot;
- kea are fully protected by the Wildlife Act 1953;
- kea impacts can be minimised by positive action;
- kea impacts are relatively minor compared with other problems of the high country, and should be considered as yet another hazard of the back country and high country.

(ii) Encourage or contract a suitable vet to write articles in various magazines, such as "New Zealand Farmer", explaining the reasons why sheep die from malignant oedema (blood poisoning) and how the effects of this disease can be minimised.

(iii) Actively encourage the inclusion of articles in widely read publications on all aspects of kea, as the information becomes available.

(iv) Develop and promote programmes to advocate kea and kea conservation in a planned and active manner. An example of this is "The Kea Campaign a Public Relations Strategy for the Canterbury Region" (appendix 2).

Objective 3 : To appropriately manage problems involving kea.

There are four main areas where there are problems involving kea:

1. high country runs;
2. ski-fields and alpine villages;
3. lowland areas of kea habitat;
4. other human use sites where kea are adversely affected.

1. High country runs

Background

The main problem in this area is the view held by some run holders, that kea cause high stock losses. However, kea are often the scapegoats for a proportion of sheep mortality that may be due to a variety of other factors (e.g. starvation, accident and disease). Kea do cause some sheep mortality, however the extent of this mortality is not fully known and seems to vary from year to year. The incidence of kea/sheep problems seems to be dependent on a wide range of factors, such as weather, kea population dynamics, adjacent ski-field activity and lunar cycles (the influence of each factor needs to be carefully researched and analysed).

There are two ways in which kea are known to kill sheep, by:

(a) Causing or initiating malignant oedema (blood poisoning caused by *Clostridium* spp. of bacteria). The dynamics of this disease are unknown but two main mechanisms are thought to operate:

   i. the organism which causes malignant oedema is widespread over pasture and is ingested during grazing. Once ingested it remains within a sheep's system usually without causing any ill effects. However, when a sheep is under physiological stress (from poor nutrition and cold conditions) any small scratch or tear in its skin can cause malignant oedema to manifest itself. Kea do pull wool from live sheep and inflict flesh wounds, therefore if the animal is in poor condition it may develop malignant oedema and die. The warm, humid wool/skin interface may be an ideal incubation site for this organism;

   ii. during normal feeding kea spend a great deal of time grubbing in the soil. As a consequence dirt particles which contain *Clostridium* spp. spores adhere to the bill. The kea then inoculates the sheep with the disease when it pulls wool or pecks the sheep. This mechanism is the one supported by the majority of high country run holders.

   Vaccination of sheep flocks can minimise or eliminate mortality from this disease.

(b) Causing trauma, physical damage and/or associated infection from wounding. The trauma from these wounds and the associated infection can kill the sheep. The severity of these wounds vary from minor skin lacerations to severe flesh wounds that penetrate the muscle and underlying tissue. All the wounds so far recorded have been on the sheep's back and rump, where the kea can easily land and hold on.

ACTIONS

(i) All runs where there is a potential for sheep/kea conflict should be visited to explain in advance what the Department's policy and approach will be if the run holders experience any problems involving kea. It is recommended that each conservancy make up an information package and present this to the run holder during these visits.

(ii) Following a report of damage to sheep by kea the following action path should be followed:

1. Talk to the run holder(1).

2. Inspect the area and investigate the situation(2).

3. Identify kea responsible by:

    a. carrying out a colour banding programme(3);

    b. observation of the affected flock(4).

4. Once kea responsible are identified there are four main courses of action which can be taken, depending on the circumstances(5):

    a. catch and re-locate;

    b. catch and place into captivity permanently;

    c. catch and place temporarily into captivity for later re-location (when habitat conditions are less severe and/or when it is possible to release them into an area where the likelihood of conflict is less);

    d. destroy.

    Where kea are destroyed appropriate plans will be made for the distribution of feathers and/or study skins. Feathers can be used for traditional weaving, for example.

Explanations

(1) Talk to the run holder, explaining that kea are totally protected and that DOC has a statutory responsibility to conserve kea in its natural habitat. Explain that, in exceptional circumstances DOC has authority to act beyond this. A full explanation of the DOC's total research and management strategy should also be given.

Explanations cont.

A totally honest approach is required. Quite often the situation will be confrontational and will need to be diffused - staff need to be positive ("we can alleviate this problem") but firm ("we will do it in a way which may not necessarily mean removing all or any of the kea"). It is important to stress that as the situation needs a co-operative approach there will need to be some compromises made by both parties.

(2) An inspection of the area is necessary to determine the nature of the problem. Quite often run holders notice "flagged" (a sheep with a tuft of wool protruding above the fleece on it's back) sheep following a muster - this means kea have attacked sheep at some time but may not be doing so at present. This situation can normally be resolved by embarking on a colour banding programme, or action can be deferred after careful discussion. The more serious situation is where attacks are taking place and there is evidence of freshly killed or wounded sheep. In these cases it is necessary to **immediately** carry out intensive observations on the affected flocks to identify kea responsible.

(3) Band as many kea as possible in the area with a metal band and a unique colour band combination (using combinations provided by Canterbury Conservancy). This is to enable the positive identification of the birds causing problems. Farmers and DOC staff will need to keep a lookout for these marked birds and identify which of the them are causing damage to the sheep.

(4) Stake out the area where sheep have been injured or killed and maintain a watch. The most productive time to do this is at night, when kea seem to attack sheep more than any at other time. During moonlit nights it is possible to observe kea quite easily - if there is no moon spotlights need to be used. Kea which are observed on the backs of sheep need to be caught.

(5) Once properly identified DOC officers will need to decide on a course of action which could be one or more of the following:

- capture the bird(s) and place temporarily in an appropriate aviary until summer, when there is more natural food available, and then release back into the wild. (This has not been tried as yet, thus its effectiveness is unknown. It is also necessary to investigate and organise appropriate aviaries well in advance.);

- capture the bird(s) and place in an appropriate aviary (when there is no doubt that the kea was attacking sheep);

- it may be necessary to shoot kea which cannot be caught and which are definitely known to attack sheep. This option should only be used as a last resort;

Explanations cont.

- if there is any doubt as to whether a bird has been responsible for attacking sheep (it may be associated with a group/individual which is attacking sheep but is not itself showing any convincing evidence of being a real threat) then it should be caught, banded, then released in an area where there are no sheep and at least 20km (as a kea flies) distance from the capture area. It should be noted that some birds in the area may be there out of curiosity as a result of increased human activity.

- one possible option, which may be necessary when a run has had a past history of kea attacks and there are circumstances which indicate that such attacks may take place again, is to relocate kea before any sheep are attacked. This option should only be contemplated if a pre-determined "kea exclusion" zone has been discussed and agreed upon, and is adjacent to farm buildings and involves valuable stud animals.

(iii) Encourage farmers to maintain an active inoculation programme against blood poisoning.

(iv) Removal of token birds is not a solution and will not be undertaken.

(v) An active programme of visiting all farmers holding kea both as pets and call birds will be undertaken. Any who wish to continue holding birds as pets only will be given an application form to apply for a permit. To obtain a permit aviaries will need to meet the required minimum specification. No birds will be allowed to be held as call birds. Any person who does not wish to abide by the minimum aviary specifications and conditions will have his/her birds confiscated. A minimum period of two months will be given to upgrade aviaries.

(vi) Investigate the possibility of making losses or damage to sheep flocks a legitimate claim for tax deduction, as is currently permitted for losses incurred by other natural hazards such as weather and flooding.

2. Ski-fields and alpine villages

Background

The main problems in these areas arise from kea congregating because of human activity and the availability of food scraps. A number of theories suggest how this might bring kea into conflict with people:

- the available food is usually of higher calorific value than that naturally available and quickly provides kea with their daily requirements. Under natural conditions these requirements can take up to a full day's foraging to acquire. The "spare" time is spent investigating the multitude of interesting things associated with sites used by humans;

- kea have a number of adaptive strategies which alow them to survive in the harsh alpine environment - one of these is an inquisitiveness to investigate anything within their environment to see if it is a resource which can be utilised. The kea's bill is a very powerful manipulative tool which can be used to rip, tear, shred or cut. Human-made structures and associated items and objects are just other possible resources to investigate;

- recent research has indicated that the manipulation of objects is part of a kea's growing up process, so even in the wild young birds may manipulate unpalatable/inedible objects.

Whatever the reasons, kea can cause considerable damage to fittings, fixtures, structures and virtually anything humans build in or take into the alpine environment.

ACTIONS

The following actions are to be taken to overcome these problems.

(i) A "Don't Feed The Kea" campaign will be instigated. Signs and an accompanying pamphlet have been produced (appendices 3 and 4). The signs will be placed on ski-fields, car parks, information centres and in all conservation areas with high public use. Pamphlets will be made available to ski-shops, information centres and handed out at ski-road toll gates.

(ii) Visits will be made to all ski-fields to determine areas where the operation needs to make changes to protect plant and equipment from damage. Advice will also be provided as to how to make the area less attractive for kea, and how to discourage them from congregating (appendix 5). Some key actions are:

- permanent display of "Don't Feed The Kea" signs;

- ensure adequate provision is made for rubbish disposal - that there are plenty of secure bins for litter and scraps and that bulk rubbish is regularly and completely removed from the area. Any open rubbish pits or dumps still in use must be closed and covered over;

- protect obviously sensitive areas, such as exposed wiring, plastic and rubber fittings and fixtures.

(iii) A colour banding programme will be instigated in areas where problems persist, or where there is a good chance that problems may occur in the future. This will be in association with regular visits to assess the situation. Banding will help to identify where the birds are coming from and their general movements. It will also identify if there are specific kea causing problems. Kea in these areas will only be removed in **exceptional** circumstances. The first approach will be to get the facilities or situation sorted out so that they are 'kea-proof'.

(iv) A building code amendment aimed at minimising the impacts of kea investigations will be drawn up. District councils will be encouraged to apply this to future building permit applications within kea habitat.

(v) During the process of re-licensing activities on the DOC estate (e.g. ski-fields) the facilities will be carefully scrutinised to see if improvements can be made to avoid future conflicts with kea. These then need to be rectified before a licence renewal is granted.

(vi) A way which may be effective in diverting the attention of kea from buildings and equipment is to provide an area full of objects which may be of interest to kea. This would only be effective if absolutely no food was available. That being so this "play" area may occupy them until they get hungry and move off.

(vii) The possibility of damage inflicted by kea becoming a legitimate claim as a tax deduction for ski-field operators will be investigated. Such a claim would only be applicable if preventative measures have been taken.

3. Lowland areas of habitat

A number of other areas do have problems with kea causing damage to building fittings, equipment and various other fixtures. These are normally lowland areas adjacent to the alpine zone. There seems to be two main types: areas which have a permanent population of kea (Fox and Franz Joseph glaciers), and those where kea are virtually never seen and are well away from what is considered normal kea habitat, as currently defined. It may be that kea originally had a much broader habitat range than they currently occupy.

Although nationally the kea population may be declining, it appears that kea in some localities are more often visiting areas outside their normal habitat. The reasons for this dispersal are not known. These incidents are irregular and normally take place during winter months. Because many of these incidents are irregular, people involved are normally fairly good-natured about them. There are indications, though, that in some areas such incidents may become more regular.

ACTIONS

In response to a report of kea causing damage the following actions need to be taken:

(i) The contractor, landowner or resident will be talked to, and informed that kea are totally protected and that the DOC has a statutory responsibility to ensure their conservation. The DOC's management and research strategy will be explained.

(ii) Visits will be made as soon as possible after notification. Where appropriate, advice will be given on how to make equipment less vulnerable to damage and the area less attractive to kea. In exceptional circumstances, kea which consistently prove to be a nuisance will be captured, colour banded and relocated into an appropriate area well away from the capture site. Released birds will, if possible, need to be monitored.

(iii) "Don't Feed The Kea" signs will be placed in areas where there is significant interaction between kea and humans. Other publicity material will be distributed.

(iv) Areas with established populations of kea need to take note of actions detailed in the "Ski fields and Alpine Villages" section.

4. Sites where kea are adversely affected by human activities

Certain sites created by humans in kea habitat have a detrimental effect on the kea population. The most detrimental are open rubbish dumps; these areas attract kea, causing unnatural congregations, as well as provide a number of hazards to kea.

ACTIONS

(i) Identify all sites in kea habitat which may effect kea detrimentally. Advocate ways by which these sites can be made less hazardous.

(ii) Aim to phase out all open rubbish dumps and pits in areas frequented by kea. On private land this will need to be done by an active advocacy campaign. On conservation land dumps must be phased out as soon as is practicable.

SUMMARY

The aim of this document is to provide management guidelines on how the Department of Conservation should deal with the various problem areas which involve kea. All the main areas where there are conflicts which involve kea are outlined and a number of actions are detailed which provide a method for Departmental officers to deal with these situations.

The conservation of kea is based on a number of key themes. These are:

- kea are a unique and important feature of the New Zealand alpine environment;
- there are actual and potential conflicts which require management in the interests of both kea conservation and farming;
- to encourage people who have problems which involve kea to get the Department of Conservation to deal with them and not to deal with them themselves, as has been the case in the past;
- to avoid providing kea with supplementary food (intentionally or unintentionally), and discourage them from congregating in areas of human use.

REFERENCES

Bond, A.B.; Wilson, K.-J.; and Diamond, J. 1991. Sexual dimorphism in the kea (*Nestor notabilis*). *Emu* 91:12-19.

Brejaart, R. 1988. Diet and feeding behaviour of the kea (*Nestor notabilis*). Dissertation Diploma Parks and Recreation Management, Lincoln University.

Brejaart, R. in prep. The kea (*Nestor notabilis*): a bibliography.

Diamond, J.; Bond, A.B. 1991. Social behaviour and the ontogeny of foraging in the kea (*Nestor notabilis*). *Ethology* 88:128-144.

OTHER READING

Anderson, J. 1963. A plea for the kea. *New Zealand Wildlife* issue 3.

Anderson, R. 1986. Keas for keeps. *Forest and Bird* 17:2-5.

Benham, W.B. 1906. Notes on the flesh eating propensities of the kea (*nestor notabilis*). *TNZI* Vol.39:71-89.

Butler, D. (ed.) in prep. Captive Breeding Specialist Group. 1992. Population viability analysis - kea and kaka. Results of a workshop in Christchurch, New Zealand, 2-5 december 1991. CBSG, Minnesota, US.

Clarke, C.M.H. 1970. Observations on the popular movements of kea. *Notornis* Vol. 17:105-114.

Harding, M. 1988. The kea - New Zealand's alpine parrot. *Centennial contact* No.11.

Jackson, J.R. 1960. Keas at Arthurs Pass. *Notornis* Vol. 9:39-58.

Jackson, J.R. 1962. Do keas attack sheep. *Notornis* Vol. 10:33-38.

Jackson, J.R. 1963. The nesting of keas. *Notornis* Vol. 10:319-326.

Jackson, J.R. 1969. What do keas die of? *Notornis* Vol. 16:33-44.

Kubat, S. 1990. The role of oddity, novelty, and social structure for object manipulation in keas *Nestor notabilis*. *Acta XX Congress Internationalis Ornithologici Supplement:* 476.

Marriner, J.R. 1906. Notes on the natural history of the kea, with special reference to it's reputed sheep-killing propensities. *TNZI* Vol. 39:271-305.

Marriner, J.R. 1908. The kea, a New Zealand problem. Marriner Bros., Christchurch.

Meyers, J.G. 1923. The kea or mountain parrot. *NZ Journal of Agriculture* Vol. 29:25-35.

Meyers, J.G. 1924. The relation of birds to agriculture in New Zealand. X. The kea or mountain parrot. *NZ Journal of Agriculture.* Vol. 29:25-35.

Wilson, K.J. 1990a. Kea - a creature of curiosity. *Forest and Bird* Vol. 21:20-26.

Wilson, K.J. 1990b. The mating system and movements of kea. *Acta XX Congress. Internationalis Ornithologici Supplement:* 468.

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The North Canterbury and Aoraki Conservation Boards provided advice which assisted the department in preparing this report.

APPENDIX 1 Kea incident questionnaire

KEA HOTLINE - ACTION SHEET

(A) Kea - Sheep conflict

Following a request for assistance from a run holder or a report of a kea - sheep conflict, the following action should be taken.

Name of sheep station:

Owner/Manager:

Date reported:

(1) Obtain the following information (or as much as possible)

1. The number of sheep dead and/or injured.

2. The type and extent of injuries, e.g. a small or large hole in kidney area, extensive damage to body or both.

3. The location of the sheep (preferably with a grid reference).

4. The date the sheep were found and who found them.

5. An estimate of the time since death or injury.

6. Were the injured/dead sheep ewes, rams, wethers or lambs?

7. Were the sheep unshorn or recently shorn?

8. If the sheep were found injured, get an indication of the recent weather, i.e. mild-cold, dry-wet, snow, etc.

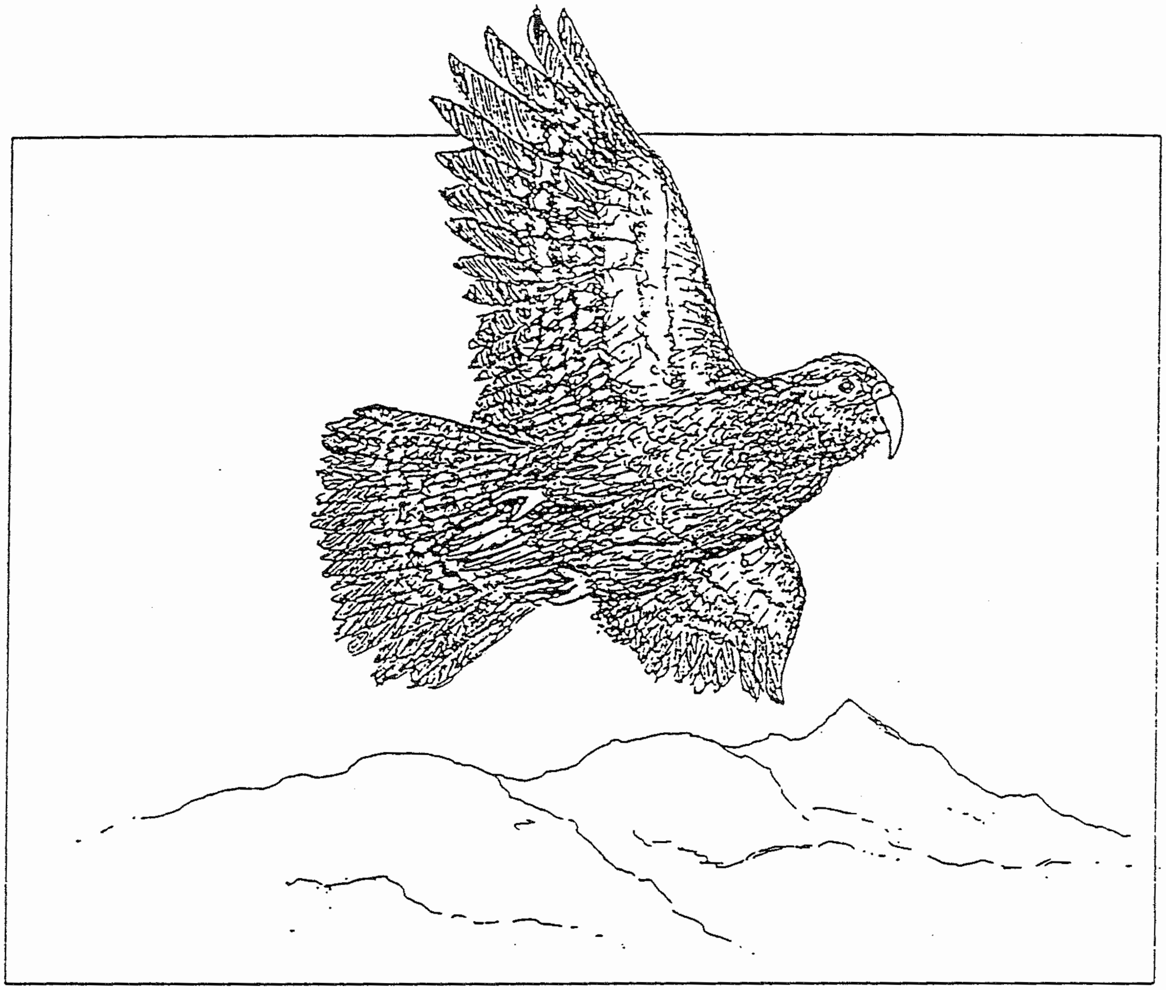
9. Have the stock been moved since the dead/injured sheep were found and if so from where to where?

10. Have the sheep been inoculated against blood poisoning?

11. Have kea been seen in the area? if so, include: where they were seen, when, who saw them, number of kea seen (approx), whether any birds were banded, and if so what bands, and if possible give the age (adult/juvenile) and sex of the birds seen.

<u>Additional Notes</u>:

THE KEA CAMPAIGN



Publicity Strategy for the Canterbury Region.

CONSERVATION

THE KEA CAMPAIGN

Publicity Strategy for the Canterbury Region.

Introduction

This strategy has been produced as an effort to take a planned approach to the public relations work required help protect a species that is believed to be threatened - the kea. The strategy is directly linked with the Wild Kea Management Statement's second objective which is "to promote kea conservation and enhance the publics perception of kea."

The kea has always been well known to the people of the South Island high country with its clown like antics and mischievous behavior. Unfortunately this behavior can lead to the destruction of peoples property and has been linked with the death of sheep. For many years the kea has been slaugtered and even since it became fully protected in 1985 birds have still been killed.

Many people are not aware that this bird is at risk and this strategy has been designed to increase public awareness of the kea's plight and increase the publics empathy to the kea.

There are two seperate issues dealt with in this campaign. The first is to stop people feeding the kea which attracts it to areas of human habitation and can lead to the destruction of property. The other is to educate farmers about the myths and truths of kea attacking and killing sheep.

If possible the campaign, or parts thereof, will be expanded to the other regions in the South Island as they also have kea problems to deal with. Financial assistance will be sought from these regions if they are prepared to support the projects.

Main Goals

* To increase public awareness of the vulnerability of kea.

* To stop the public feeding kea.

* To prevent kea damage to property.

* To educate farmers about kea attacking sheep.

Time Period for Campaign

An initial time period of two years is proposed - running from January 1989 through to January of 1991.

Target Publics

* High country recreational users.

* Tourists.

* Local residents in the high country.

* DOC staff.

* Skiers.

* Summer holiday makers/campers.

* Run holders/farming staff.

* Tourist Operators.

Degree of Possible Negative Reaction to be Expected from Target Publics.

Minimal for:

- tourists;
- DOC staff;
- high country recreational users;
- summer holiday makers/campers;
- local residents.

Higher for:

- run holders/farming staff;
- tourist operators.

For the group listed in the minimal category the task of the campaign is primarily one of education to change simple actions. Little or no cost is involved for these publics except that they may see fewer kea in populated areas and get fewer photos of the birds at close range.

For the group in the higher category some cost is involved. They will have to change some of their management policies and adapt stuctures to be able to cope with kea. Farmers may lose a few more sheep.

Publicity

This must be effective in reaching the target publics.

Pamphlets.

1. Produce a "Don't Feed Kea" pamphlet.

Distribution of pamphlet 5000 copies

* Forest and Bird Canterbury members	300
* Local tramping/mountaineering clubs	500
* Outdoor Recreation Information Centre	100
* Arthur's Pass National Park	500
* Craigieburn Forest Park	200
* Hanmer Forest Park	100
* Mt Cook National Park	500
* North Canterbury District Office	100
* South Canterbury District Office	100
* Waitaki District Office	100
* Peel Forest Park	50
* Mt Thomas Forest	50
* Tourist outlets	500
* Outdoor equipment shops	300
* Newspapers/media	10
* Campervan/Rental car outlets	400
* Camping grounds near the high country	200
* Mt Cook Youth Hostel	50
* Arthur's pass Youth Hostel	50
* Mt Cook retailers	50
* Arthur's Pass retailers	50
* Hotels/motels Arthur's Pass and Mt Cook	100
TOTAL	4310

Aim to have these printed and in outlets by January 1989.
They are purely a public education pamphlet and therefore are to be free.

2. Produce a colour pamphlet about kea in general.

* Obtain sponsorship for production costs.
* Contract professional graphic designer for the artwork.
* Graham Wilson and Ria Brejaart have offered to produce the text.
* Run 10,000+ copies.
* Distribute free to similar outlets to the "Don't Feed Kea" pamphlet.

3. Second print run of the "Don't Feed Kea " pamphlet to be handed out at ski field road toll gates.

Pamphlets should also be inserted into park handbooks and could be put in other relevent publications such as Phillip Temples kea book..

Don't Feed Kea Signs.

Displayed at:

Arthur's Pass;
Craigieburn;
Mt Cook;
Hanmer;
Mt Hutt ski field;
Porter Heights ski field;
Craigieburn ski field;
Broken River ski field;
Temple Basin ski field;
Tekapo ski field.

Newspaper/Magazines.

- Press releases on production of brochures when they are distributed
- Produce a feature page for The Press with sponsorship from outdoor shops.
- Press release when signs are put in and when other management objectives are acheived - including positive steps taken by tourist operators.
- Articles to be written by researchers for various magazines such as Forest and Bird, The Listener, Tussock Grasslands and Mountainlands etc. N.B. Graham Wilson is already working towards this.

Television

- Items on The Mainland Touch regional news programme and national news if possible.
- Wildtrack programme item - contact Guy Marris, Natural History Film Unit, Television New Zealand, Dunedin.
- Any opportunities for television coverage should be taken, providing they present a positive veiwpoint.

Direct Public Contact

- DOC kea seminar.
- Include in summer holiday programmes:
  - kea talked about by interpreters;
  - topic of evening talks.
- Speaking to recreational user groups.

- Letters to recreational user groups with the pamphlets.
- Letters to all tourist agencies operating tours through high country areas.
- Letters and pamphlets sent to local residents and run holders.
- Staff talking to individual farmers and tourist operators in line with the management policy.
- Put together a slide set for talks to groups showing kea damage, behavior and simple ways of preventing kea damage. (Ria Brejaart has ideas on this.)
- "Don't Feed Kea" colouring competition either run through the childrens page at the newspapers or handed out during holiday periods at the visitor centres.
- Idea brought into school outdoor recreation programmes when in the high country. Also educate student teachers at Teacher's College about the problem.
- Ask hut visitors to comment on kea in the area.

Radio

Interview on national and local radio stations with:
Andy Grant;
Peter Simpson;
Ria Breejart;
Graham Wilson.

Displays

Produce a mobile display to be moved around shopping centres, shop windows, outdoor shops, visitor centres etc.

Monitoring the Performance of the Campaign.

It is essential that the performance of the campaign is monitored to establish the effectiveness of the publicity in reaching the target publics and in changing attitudes and actions.

Methods of Monitoring.

* Reports of kea damage occuring or not occuring.

* DOC staff to report people seen feeding kea, the category of publics they fit into, and the area.

* Note any letters to the editor in newspapers. Are the responses positive or negative?

* Note any comments made in visitor books.

* Report on kea hanging around particular areas.

* Are farmers and tourist operators taking the appropriate positive management action?

* Are farmers still killing kea?

* Survey recreational users to gauge if the message is getting through.

The campaign should be evaluated every 3 months and discussions held with IPA and management staff to make any changes or modifications to the campaign in order to continue reaching the target publics as effectively as possible.

Finance for the Campaign.

It would be good to obtain sponsorship to cover all the costs of the campaign. This may best be achieved by contracting a Public Relations consultancy to produce a sponsorship package. However sponsorship can be hard to get in these days were finances in many businesses are short and the effort and time that it would require may not be worth trying for.

Estimated costs are:	$$$
Don't Feed Kea pamphlet	600.00
Colour kea pamphlet	3000.00
Don't Feed Kea pamphlet rerun	1200.00
Displays	2000.00
Additional signs	1000.00
Miscellaneous costs	500.00
Vehicle running	500.00
Slide set	100.00
Conservation Officer (IPA) time @ 6 weeks	3000.00
TOTAL	11900.00

Craig Robertson
CO (IPA)
Canterbury Region

15/12/88

DON'T FEED KEA

Feeding attracts kea to areas of man use, such as skifields, villages d car parks. Once in these areas they ill damage cars, tents, installations, rsonal gear and equipment......if it's ft, rippable, or brightly coloured, then s fair game!

Natural food for kea is mainly plant aterial such as berries, roots, shoots, d insect larvae. Human food is obably bad for kea. Kea eating our od is like you living off junk food ery day.

Why?

- Because human food has a higher energy value than the kea's natural food, a small quantity may provide a kea with its total energy requirements for a day - like you having breakfast, lunch and dinner all at once! (In a natural situation a kea would need to forage for a large part of the day to obtain its daily requirements.) This gives them plenty of spare time which is spent satisfying their natural curiosity. To kea, this can mean pulling to bits your possessions and equipment. Their "toys" include: boots, tents, packs, windscreen rubber seals, car wiper blades, ski roof racks, car aerials, parkas, jackets, protective pads around the base of ski-tow towers, wiring for lights, vehicles, ski-tow early warning systems, loudspeakers, and so on.

- Feeding young kea discourages them from looking for and learning about natural foods. They can become dependent on human scraps. Young kea often flock together which makes the situation worse.

- By not feeding kea they will often move away from areas of human activity to forage for natural food elsewhere in the mountains leaving you and your possessions alone.

How to minimise the damage

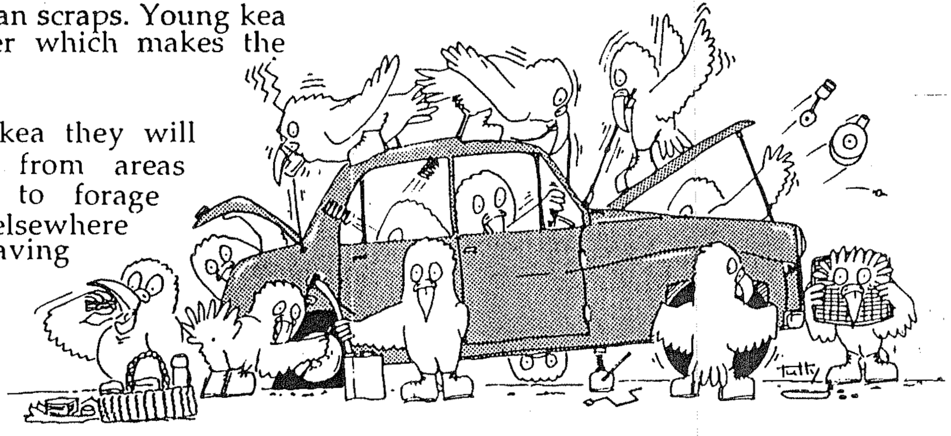
- Do not encourage kea by feeding them. (Very tempting when you want a good photo!)

- Discourage kea away from vehicles and property by "shooing" them off - but DON'T HURT THEM and it is illegal to throw anything at them.

- Do not leave easily damaged articles or equipment in the open.

- Cover up easily damaged areas like wires and rubber seals.

- When in the mountains, don't litter or leave things strewn about.



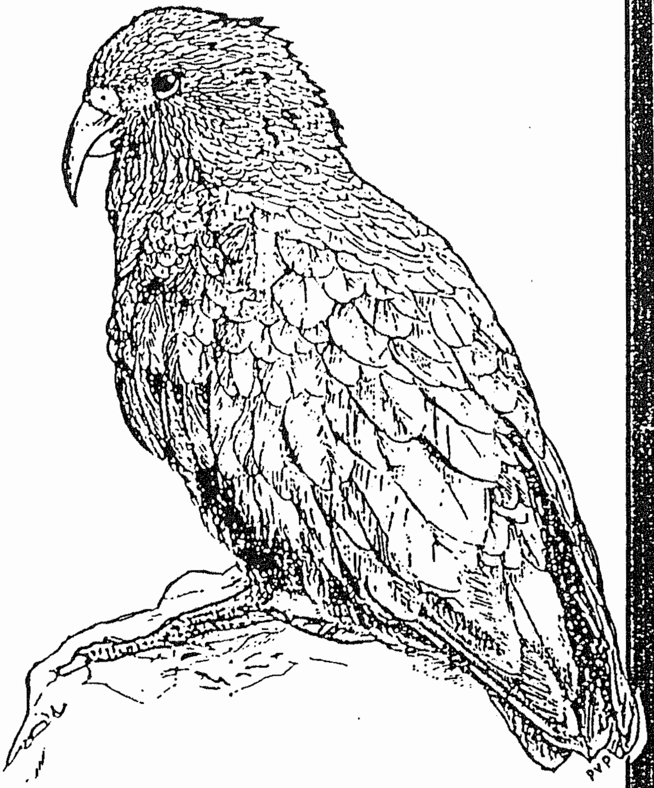
Why are Kea so effective at causing damage?

- They are naturally inquisitive.
- They are highly intelligent.
- Like all parrots a kea can move both parts of its beak, hence it is very flexible and manipulative. This, coupled with strength, makes its beak a very effective tool.
- Its feet are very versatile. With their sharp claws they can grasp and hold most effectively.
- With both claw and beak a kea can old, manipulate, pull, push and tear.
- To live in its harsh and unpredictable nvironment kea must be able to adapt o a wide range of conditions and make he most of any opportunity.
- As kea have no natural enemies they o not have an inbuilt fear and are quite heeky. Their inquisitive nature is ssential for their survival in the wild.

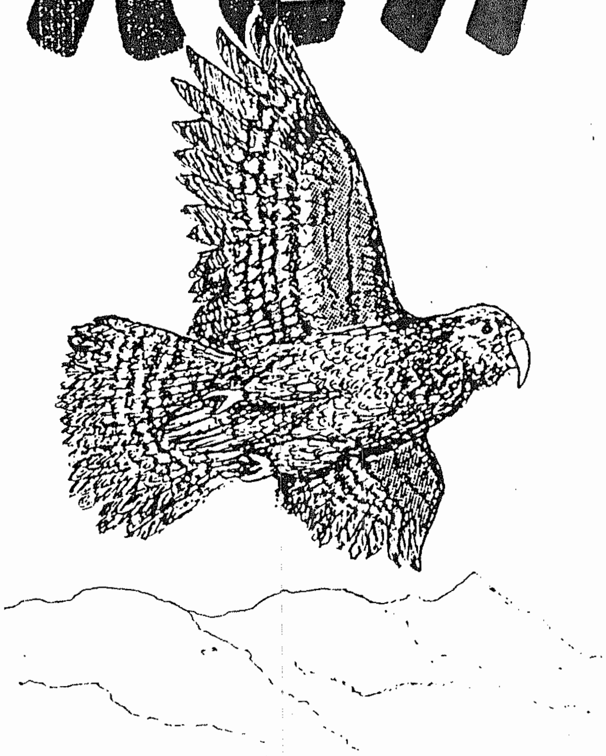
Produced by the
Department of Conservation
Canterbury Conservancy
1989

Kea-our heritage

Kea are a unique feature of the South Island alpine environment and part of our heritage. They belong in the mountains and were there long before us. We must show the tolerance and intelligence necessary to share the mountains with them. Kea have been persecuted by people for over 100 years - it's time to give this mischievous clown of the mountains a chance.



KEA



KEA are found only in the high country and mountains of New Zealand's South Island.

KEA are the world's only alpine parrots.

KEA are fully protected.

KEA are a special part of the alpine environment, adding to its character and atmosphere.

KEA are probably a threatened species.

APPENDIX 4 "Don't feed the kea" sign

Please do NOT feed the Kea.

APPENDIX 5 Information sheet for ski-fields - Waimakariri Field centre

KEA CONSERVATION AND SKI FIELDS

Suggestions for reducing damage to property caused by kea.

1. Don't feed kea

Discourage skiers from feeding kea by displaying DOC "Don't feed kea" signs and posters (available from DOC), distributing DOC kea pamphlets, giving on-field talks about kea, writing kea articles for club newsletters (DOC can provide information on kea) and printing kea warnings on road toll or lift tickets (see following example for Porter Heights Ski Field). An active education programme to dissuade skiers from either deliberately or inadvertently feeding kea will reduce the number of kea congregating at ski-fields and hence damaging property.

PORTER HEIGHTS
SKI AREA

ROAD
TOLL

KEA

- **kea are protected native parrots**
- **To avoid kea damage;**
  - **don't feed kea**
  - **don't leave belongings unattended**

All persons using this ski area do so at their own risk

No 601

Providing the public with information on kea reduces damage to belongings and complaints to ski-field, staff while raising awareness about our native birds

2. Rubbish

Disposal of ski-field rubbish should be outside of kea habitat. Rubbish containers must be kea proof. If kea have access to human food scraps the local population of kea may be higher than if only wild food was available. An artificially high number of kea is likely to mean increased damage to property.

3. Equipment storage

Provide adequate covered storage for skis, boots, poles and clothing. Brightly coloured equipment attracts kea. If there are fewer things for kea to investigate there will be fewer things damaged. When equipment must be left out in the open somebody should keep a close watch for kea.

4. Vehicles

The presence of vehicles attracts kea. Encourage skiers, where possible, to remove; windscreen wipers, easily damaged roof racks (especially foam padding on roof racks) and rubber stretchies from chains and roof racks and ensure that all windows, doors and boots are closed. Owners of vinyl-topped and soft-topped cars should be discouraged from leaving their vehicles unattended. Nets securely tied to vehicles may prevent kea from damaging rubber and plastic fittings (Craigieburn Ski-field hire car nets to skiers - made by 'Fishwell" in Lyttelton).

5. Ski-field Structures

When designing structures for ski fields the potential for kea damage should be considered. DOC staff can offer advice on methods for kea-proofing. New and existing buildings can be made more kea resistant by ensuring that external doors an windows close properly (automatic door closers could be fitted). Doors and windows windows which need to be left open or partially open should have mesh screens. All should have appropriate signs warning people to close them. Lead flashings should be covered with netting or else larger flat galvanised flashings used, exterior electrical wiring should be out of reach from kea. We strongly recommend that the basements of all buildings are enclosed to exclude kea. Rocks, timber or wire netting would be suitable materials. This will prevent damage to fittings and eliminate potential roosting sites. Imported ski field equipment may require minor modification prior to installation. Porter Heights recently modified snow making equipment to take account of kea.

For more information on kea, contact;

Department of Conservation
Waimakariri Field Centre
P O Box 8
ARTHUR'S PASS

Phone Arthur's Pass (03) 318 9211