Population and Habitat Viability Assessment for the wattled crane *(Bugeranus carunculatus)* in South Africa

Final Report
from the workshop held
31 July – 2 August 2000 in Wakkerstroom, South Africa

Edited by
K. McCann, A. Burke, L. Rodwell, M. Steinacker and U.S. Seal

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Section 1

Introduction and Overview

Population and Habitat Viability Assessment for the Wattled Crane in South Africa

INTRODUCTION AND OVERVIEW

Background

The wattled crane is the only member in the genus *Bugeranus*. This species can be classified as follows :

Class: AVES
Order: GRUIFORMES - Cranes are closely related to the bustards (*Otididae*) in Africa
Suborder: GRUES
Family: GRUIDAE (Cranes)
Subfamilies: Gruinae - These are the "typical" cranes, which include 13 species (*Anthropoides* (2), *Bugeranus* (1), *Grus* (10))
Species: *Bugeranus carunculatus*

The wattled crane (*Bugeranus carunculatus*) is one of three crane species that inhabits South Africa and is the largest and rarest of Africa's cranes. The wattled crane is restricted to Africa with three main subpopulations being recognised. The main subpopulation is found in south-central Africa (Zambia, Botswana, Angola, Zaire, Tanzania and Zimbabwe), while the other two smaller subpopulations are found in Ethiopia and South Africa respectively (Meine & Archibald 1996). Historically this species was widespread and formerly occupied all four "old" provinces of South Africa, being common in the eastern Transvaal, Natal, Orange Free State and extending as far south into the western parts of the Cape Province (Somerset West / Caledon) (Brooke & Vernon 1988). It currently occupies a vastly restricted range within the eastern higher rainfall regions of the country, with concentrations in the Mpumalanga Highlands and the midlands to southern parts of KwaZulu-Natal. Small numbers of breeding pairs are also present within the Wakkerstroom region, the Eastern Cape (3 breeding pairs in the north-eastern region), as well as the north-eastern Free State (2 pairs) (McCann in press a). Wattled cranes are no longer present within the Western Cape and Swaziland, with very infrequent sightings in Lesotho (Brooke & Vernon 1988).

The wattled crane is the most highly wetland-dependent of the crane species as it utilizes this habitat for both foraging and breeding. It feeds mainly on aquatic vegetation, including the bulbs and rhizomes of submerged sedges and wetland plants. Wattled cranes will, however, also eat grain, grass seeds and insects when foraging in open dry habitats surrounding their marshy home (Meine & Archibald 1996). They very rarely utilize agricultural lands, and if they do, they feed mainly on the excess leftover grain in harvested maize fields. Due to their dependence on wetlands, especially for breeding, they are extremely sensitive to disturbance and may abandon their breeding area if the wetland is repeatedly disturbed (Tarboton *et al.* 1987). For this reason, they are good environmental indicators of the health of that habitat, a habitat on which, in most instances, farming communities rely for a healthy water supply for agricultural and household purposes.

Wattled cranes gain maturity at approximately seven to eight years of age. They spend these years in a non-breeding floater flock, learning the traditional feeding areas around their range. At this age individuals find a suitable mate within this social non-breeding flock and then leave the flock in search of breeding territories. This winter-breeding wetland-dependent species has a peak in breeding activity between May and August each year, although breeding activity has been recorded in all months of the year (McCann *et al.,* in press). The threat of hailstorms and nest flooding has been suggested for the wattled cranes' tendency to nest within the winter months (Johnson & Barnes 1992). Active breeding pairs are year-round residents of varying size highland marsh wetlands, sometimes using seasonal wetlands opportunistically or as post-breeding dispersal areas. Pairs are strongly territorial and may defend territories several kilometers in size (McCann & Benn, in prep). These territories are highly specialized, comprising permanently inundated wetlands with predominantly sedge-based vegetation (Meine & Archibald 1996). Large permanent wetlands with minimal human disturbance form appropriate nesting areas for wattled cranes. An open area is utilized within this wetland, where dry vegetation is gathered to construct the nest. A large mound of this vegetation is built up so that a protective moat surrounds it. This design helps to protect that nest and eggs from predators. Nest building forms part of the courtship ritual, which also includes spectacular jumping and dancing displays, with mating following shortly thereafter. The highly extended breeding period allows individuals unsuccessful in their first attempt to re-nest the same season (Johnson & Barnes 1992). The wattled crane's reproductive rate is low, with the average clutch size being the lowest of any of the cranes (Johnsgard 1983). Pairs may lay either 1 or 2 eggs in a clutch, with the majority of the 2-egg clutches occurring in the KwaZulu-Natal population. In both cases only one chick is raised. Incubation period is the longest of any crane, c. 32 – 40 days (Mein & Archibald 1996). Pairs have an 82 % hatching success rate, with the second egg acting as an "insurance policy" against the first not hatching (McCann *et al* 1998). Chicks fledge after 110 – 130 days. Juveniles remain with their parents for almost 12 months, after which they are expelled from the breeding territory or are taken to a non-breeding floater flock (essentially only in KwaZulu-Natal). Juveniles only obtain full adult plumage after the first year.

Status

The distribution of the current wattled crane population is shown in Figure 1. It was recorded in a total of only 31 Quarter-quarter Degree Grid Squares in the country, covering 1,55% of the surface area of the country, a 75,8% reduction in range from the historical distribution. The most significant reduction in the population took place between 1986 and 1994 where the largest reduction in the range occurred in the Mpumalanga region (McCann, in press a).

The wattled crane is endemic to the Afrotropical region, where it occurs in a series of disjunct populations between Ethiopia and South Africa. Due to its historical decline in range and numbers, it was included in the "Red Data" listings for both the *African Red Data Book* (Collar and Stuart 1985), listed as "of special concern" and the *South African Red Data Book* (Brooke 1984), listed as "endangered". Brooke (1984) suggested that the wattled crane "could easily become extinct as a South African breeding species before 2000 AD".

The next assessment of the status of the wattled crane population came in the publication of the IUCN / SSC The Crane : Status survey and Conservation Action Plan (Meine & Archibald 1996), outlining the status of all 15 crane species of the world. In this publication, the overall African population of wattled crane was listed as "Endangered" under the following IUCN categories : A1b,c,d,e; A2c,d,e. However, the individual subpopulations within its entire range were also assessed. The South African population was listed as "Critically endangered" under the following IUCN categories : all of the above mentioned for the overall population as well as D (Meine & Archibald 1996). The recent publication of the latest South African Red Data Book (Barnes 2000) by Birdlife South Africa, also lists the wattled crane as "Critically endangered".

The current population of 235 individuals in South Africa has declined by 38% from its 1980 estimated population size of 380 individuals (McCann, in press a). The KwaZulu-Natal subpopulation has always been the most important core population where the majority of the breeding pairs and floaters were located. In the early 1980's, the Mpumalanga subpopulation formed the second most important population, but has unfortunately shown the most drastic decline of all the regions over the past 2 decades. Since the late 1970's, both the Eastern Cape and Free State populations have always been small. The current population, as of 2000 is structured as follows : 197 individuals in KwaZulu-Natal (65 breeding pairs and 67 non-breeding floaters); 21 individuals in Mpumalanga (8 breeding pairs and 5 non-breeding floaters); 10 individuals in the Eastern Cape (4 breeding pairs and 2 non-breeding floaters); and 7 individuals in the Free State (2 breeding pairs and 3 non-breeding floaters).

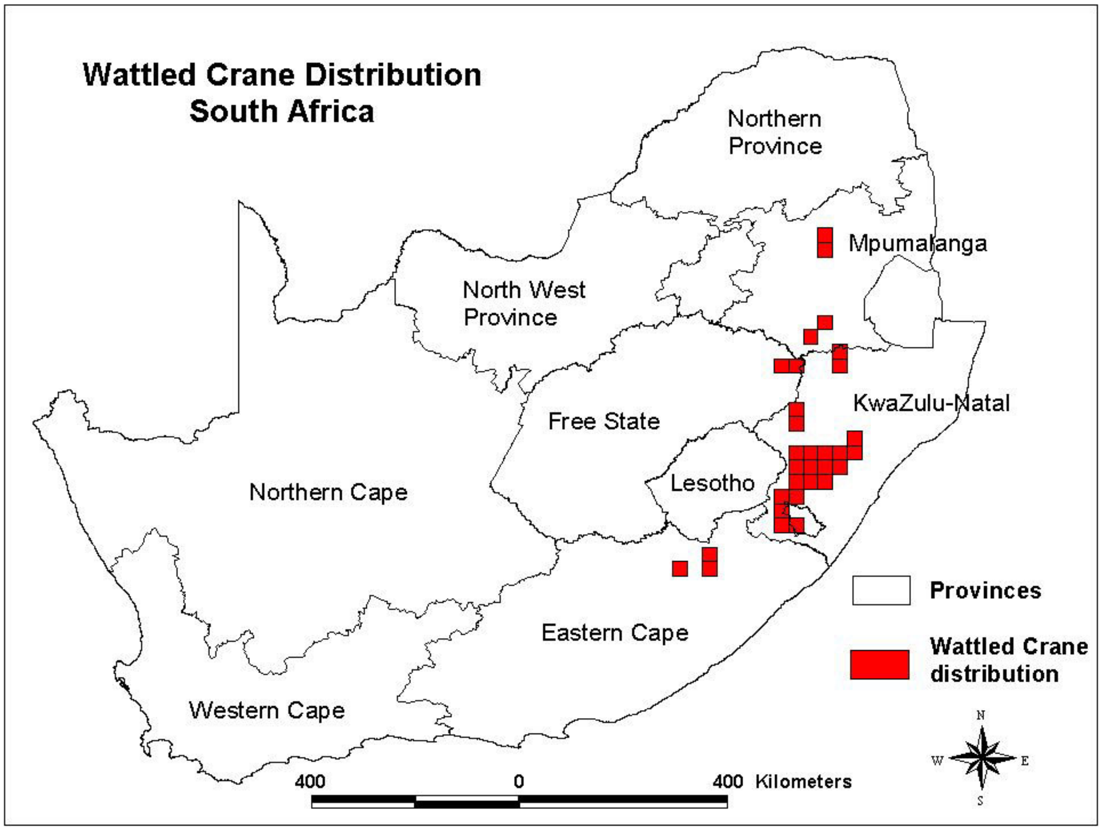

Figure 1 : Map showing the current distribution of the wattled crane in South Africa.

Threats

Loss and degradation of wetland habitats constitute the most significant threat to this species, mainly through the loss of wetlands to intensified agriculture, dam construction and industrialization (Johnson & Barnes 1992). Grassland areas surrounding suitable breeding wetlands are as important to successful breeding as the wetland itself, with these areas undergoing significant transformation through the planting of exotic timber plantations, a land use incompatible with wattled crane survival. In addition, many hundreds of hectares of these grassland habitats are also being converted to intensive agriculture for food production. (Allan 1996) Management of wetland habitats also constitute a threat, with the frequent burning of wetlands as fire-breaks on farmland, and particularly forestry property, during the winter months (peak period for wattled crane breeding activity), leading to the loss of eggs or young unfledged chicks. Wattled cranes, especially first-year inexperienced flying birds, are prone to colliding with powerlines, especially 11 and 22 kV rural distribution powerlines, often located within the territories between roosting and feeding sites (McCann, in press b). Recently, many wattled crane individuals / eggs have been removed from the wild for the international bird trade, which can have a significant affect on a small breeding population, and is expected to increase if measures are not taken to control it internationally.

Conservation Concerns - Why was a PHVA required?

The conservation of the wattled crane in South Africa is faced with a number of compounding factors :

- Firstly, its present breeding range falls wholly within the grassland biome, a region which has undergone and is continuing to undergo massive transformation as a result of intensive agricultural practices, mining exploitation, afforestation, damming for water storage, industrialization and urbanization,
- Secondly, its breeding sites are thinly scattered over a wide area, i.e. there is a high level of fragmentation, a vital factor affecting the conservation of a small population,
- Thirdly, virtually all these sites are located on privately owned farmland.

There is no doubt that the South African wattled crane population has declined dramatically over the past two decades. Initial genetic analysis of the southern African wattled crane subpopulations has tentatively revealed that the South African subpopulation is genetically unique and isolated from the subpopulation in south-central Africa. The resultant serious concern expressed over the decline of this species and its potential genetic uniqueness led to the initiation of a PHVA.

Initiation of the PHVA Process for the Wattled Crane in South Africa

The South African Crane Working Group (a working group of the Endangered Wildlife Trust – see Appendix 1) initiated the PHVA process for the South African wattled crane population, with the aim of ultimately securing the long-term survival of this species. The PHVA process was to analyse different management scenarios on the population dynamics of this species, using all relevant knowledge and expertise, so devise a strategy for the conservation benefit of this species. In addition, the process aimed at identifying gaps in our knowledge which will be vital for the conservation of this species in the long term.

The overall purpose of the workshop was to assess the change in the South African wattled crane population over the past two decades, and to assess the extinction potential of this population under current population conditions. It was, therefore, to result in the development of a conservation management strategy / plan for the wattled crane population which will allow it to survive over the long-term in its natural and man-modified habitats in South Africa, incorporating specific recommendations and priorities for research and management.

The PHVA Process

To allow all participants in the workshop the opportunity to obtain a complete picture regarding the current Wattled Crane population in South Africa, all available information (both published and unpublished information) was synthesized into a Briefing Document. This Briefing Document was made available to all workshop participants two weeks prior to the workshop. This was achieved either through making hard copies available to participants as well as having placed the entire document on the Internet, on the Endangered Wildlife Trust's web page (http://www.ewt.org.za). This allowed all workshop participants to have as complete an understanding of the current knowledge available to us as well as an understanding of the current conservation status of the species, prior to attending the PHVA workshop.

Thirty-eight participants worked for 3 full days in a church hall in Wakkerstroom (Mpumalanga). Participants stayed in local homes and in a few commercial facilities. Meals, lunch and dinner, were provided by ladies of the church. The community had opened its arms to the workshop, reflecting the close working relationship that has been developed between the South African Crane Working Group participants and the community. The location was distant from the homes and offices of all of the participants and provided an hospitable and open environment. The area is famous for its bird watching opportunities.

After the first morning of presentations and introduction to the workshop, the participants were formed into 5 working groups. These groups were formed around themes organized on the basis of comments offered by the participants at the beginning of the workshop, and comprised: Land Use Patterns, Distribution and Habitat, Threats, Captive Population and Supplementation, and Population Dynamics and Modelling. The participants were distributed evenly among the groups based upon knowledge and interests, recognizing that many of the participants had contributions to make to other groups. The workshop process included multiple plenary sessions allowing rapid exchange of information and elimination of redundancies. Individual working group sessions were structured around a systematic rational decision-making process. Times were set for each task, followed by a plenary session and description of the next step in the process. Key controversial questions were discussed during plenary sessions structured to provide constructive questions and comments to a working group for its further analysis. The intention was to provide a basis for building a common understanding of the issue, and eventually to reach an agreed recommendation or to focus remaining concerns on testable questions or assumptions. No votes were taken at any stage.

To obtain the entire picture concerning a species, all the information that could be gathered was discussed by the workshop participants with the aim of first reaching agreement on the state of current information. Where appropriate, these data were then incorporated into a computer simulation model to determine:

1. Risk of local extinction under current conditions,
2. Those factors that make the species vulnerable to extinction, and
3. Which factors, if changed or manipulated, may have the greatest effect on preventing local extinction.

The process assisted in the design of conservation management programmes on the basis of sound scientific and expert knowledge, while allowing new information (that eventually becomes available) to be used to adjust and further refine management practices.

Complementary to the modelling process was a communication process, or deliberation, that takes place during a PHVA. Workshop participants worked together to identify the key issues affecting the conservation of the species. During the PHVA process, participants worked in smaller groups and analysed and discussed key identified issues. Each group produced a report on their topic, which is included in the final PHVA document. A successful workshop depends on determining an outcome where all participants, coming to the workshop with different interests and needs, "win" in developing a management strategy for the species.

Workshop report recommendations are developed by, and are the property of, the local participants.

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Section 2

Executive Summary

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EXECUTIVE SUMMARY

Executive Summaries of the 5 working groups
Results and Recommendations

<u>1) Executive Summary of the Land-use Patterns Group.</u>

The group was tasked to assess the past, present and future land-use patterns and how these have affected and may affect crane habitat and thus crane numbers. The group followed the standard methodology of:

1) identifying the problems related to land-use patterns and habitat;
2) gathering and assessing all available information and unwritten knowledge with respect to crane habitat;
3) setting goals to overcome the problem;
4) the development of tasks and action plans to achieve the goals

Based on sighting figures, the group concluded that wetlands (76%) and grasslands (10%) are the most important components of wattled crane habitat. As breeding only takes place in wetlands, and based on the fact that both total numbers and the number of breeding sites are dropping, the group concluded that breeding habitat (including associated foraging areas) are of vital importance.

The main threats to breeding habitats have been the drainage of wetlands through canalisation, cultivation, direct afforestation, inundation and inflow reduction, amongst others. In the future, it is thought that some historical threats will be mitigated while others, especially stream flow reduction activities, continuing expansion of cultivation and inundation will become more serious.

The group assessed information on rate of habitat decline and concluded that information is scanty, resulting in us having a poor understanding of the rate of decline. We decided to work on the basis that approximately two breeding sites are being lost per year. We also concluded that breeding sites were abandoned because of habitat loss – this being based on the existence of a relatively large floater flock. The following goals were thus set:

<u>Minimum Goal</u>: to reduce the loss of active sites to zero over a five-year period, with a maximum loss not exceeding six sites

<u>Maximum Goal</u>: to halt the loss of active sites immediately, have no further reduction and establish at least one new potential site per year.

In order to achieve this goal, five major tasks with broad action plans were identified. Our recommendations are thus:

TASK 1
Develop an accurate description of what constitutes viable wattled crane habitat - must include breeding habitat and foraging habitat with correct nutrition.

TASK 2
Gain a clear understanding of how fast wetlands are lost in total and in terms of wattled crane requirements (deducing the historical rate of change).

TASK 3 a
Complete a risk assessment of all breeding sites using the following actions.

TASK 3 b
Develop an action plan to reduce the risk at "high risk" sites – thereby ensuring that they are not lost.

TASK 4
Survey all wetlands that fall within the area delineated under Task 2 above, and assess them for breeding suitability. Then classify these wetlands according to their suitability and risk (acquired from task 3).

TASK 5
To heighten the awareness of the plight of the wattled crane using a publicity and awareness programme.

2) Executive Summary of the Distribution and Habitat Group.

The brief of the group was to examine the history of the wattled crane, its habitat characteristics and management, minimum area requirements, food selection and energetics, breeding biology and the establishment of a single database.

Ten courses of action were identified :

1) Document the decline of the wattled crane. This will include description of the ancestral range (the Type Specimen came from the Western Cape) through to the modern fragmentation of the remaining habitat.
2) Create a model of potential habitat for the wattled crane. By overlaying environmental data sets on wattled crane localities its environmental tolerances can be measured. Extrapolation pinpoints areas outside the known range that may yet harbour cranes or be amenable to management for cranes.
3) Determine the biophysical characteristics of wattled crane nest sites. Detailed accounts of many wetlands are already published. Multivariate comparison of current wattled crane sites with abandoned sites and all other documented wetlands should identify vital components.

4) Determine optimum management for wattled crane habitat. Data on burning, grazing and water level regimes can be related to crane presence and breeding success.
5) Determine minimum area requirements for wattled cranes. The measurements required are of nesting wetlands, foraging ranges of breeding pairs and floating ranges of non-breeders.
6) Investigation of hatching failure of full term eggs. Failure of eggs to hatch is not a serious problem, but needs monitoring, for example to detect onset of infertility.
7) Analyze chick productivity as a function of rainfall and other climatic factors. Losses from purely climatic causes need quantification in order to detect and monitor losses from other sources.
8) Investigate the role of predation in chick productivity. About half of hatched chicks die before fledging, most from unknown causes. The role of predators needs quantification, and methods of reducing chick loss may then become apparent.
9) Determine the diet and energy requirements of the wattled crane. Very little is known of food selection, nor of how essential harvest leftovers are for non-breeders. Captive studies will be used to supplement observations in the wild.
10) Central database establishment. It is essential that not only all field data be assembled in one database, but that it also contains a complete bibliography.

Priorities:

1) Determine biophysical characteristics of wattled crane nest sites (Action 3).
2) Determine diet and energy requirements of the wattled crane (Action 9).
3) Central database establishment (Action 10).
4) Determine minimum area requirements for wattled cranes (Action 5).

3. Executive Summary of the Threats Group.

The group was tasked with assessing the threats to the wattled crane population. The threat of impacts on habitat, however, was not assigned to this group, but to the group tasked with habitat loss. There are three sets of data available to assess these threats:

1) Reported incidents of mortality (section 9 of the briefing document);
2) Population data for both breeding and non breeding birds for the years 1982, 1988, 1994, and 1999
3) Independent subset of the reported incidents of known wattled crane individuals.

Reported incidents of mortality: The data set shows that collisions with power lines (mainly 22Kv lines) account for a mortality of 1.04% of the population per annum. The ratio of adults : immature : juveniles killed by power lines is 4,16 : 1 : 1,16. Mortalities through poisoning account for 0,19% of the population per year at an adult : immature : juvenile ratio of 4 : 3 : 0. Collisions with fence lines account for 0,15% mortality of the population. All birds killed were juveniles. Miscellaneous threats (hunting, illegal chick and egg removal, dogs) account for 0.24% of the mortality of the population at an adult : immature : juvenile ratio of 3 : 0 : 5. The accumulated percentage of these threats amounts to less than 2%, which we feel is far too low. The model also supports this in that a 2% mortality does not show a decline in the modelled population.

Population decline versus known mortalities: The loss of adult birds in the population during the periods 1982-1988, 1989-1994 and 1995-1999 was compared with the incidents of known mortality during the same periods. This revealed that virtually all adult mortality remained unexplained; it also suggested that adults may move from breeding sites to floater flocks.

Independent subset of the mortality data: Eight captive bred birds released in Mpumalanga were monitored until their deaths. The causes of their mortality (poisoning, collisions, etc) differed significantly in their relative frequency from the mortalities reported in the first data set.

Before the threats to wattled crane populations can be assessed, a clearer understanding of what causes crane mortality is needed. We recommend that addressing this shortcoming is a priority; we also recommend various mitigating actions in the areas where mortalities have been reported.

Recommendations:

1. There is a proposal to ESKOM to proactively fit mitigating measures to power lines in the vicinity of 36 wattled crane nests. We recommend that this is extended to the other nest sites as well as the areas utilized by the non-breeding flocks.
2. Reduce the mortality caused by fences, by reducing the disturbance around the nest site and making landowners and inhabitants on the farm aware of the problem
3. Accepting that there is a need for the use of agrochemicals, there is definite requirement to reduce the misuse of these chemicals.
4. The reduction of the illegal exploitation of wattled cranes through education and awareness programmes as well as prosecution.
5. Establish an effective network of informants and an efficient reporting procedure to determine the effects of threats on the population in terms of mortality rates and increase the rate of effective reporting of mortalities

4) Executive Summary of the Captive Population and Modeling Group.

The group assessed the validity and need for a supplementation (release) programme and a captive wattled crane breeding programme. The conservation value of these programmes was examined and various management scenarios for both programmes were modeled using Vortex. The issues of maintaining the genetic integrity of the South African population and the development of alternatives to captive breeding were also discussed.

Supplementation

Key question: Can a supplementation program play a significant role in the long-term survival of the wild South African population of wattled cranes?

To answer this question a number of scenarios were modeled with assistance from the Life History, Population Dynamics and Modeling Group using the Vortex software. The management scenario that had the most significant, positive impact on the wild population was the discontinuation of the supplementation programme for a period of 5-8 years. During this period, the size and breeding success of the captive population could be improved and would allow time for other research and field conservation efforts to take effect (e.g. reduction of wild chick / juvenile mortality, habitat restoration / preservation, etc.). After 6-8 years, as many as 6 birds every 3 years could be produced for release from captive produced birds.

Recommendations:

1. Discontinue the supplementation program for the next 5 years.
2. Focus on building the captive program for the next 5 – 8 years.
3. Review and revise the Wattled Crane Recovery Team, strategy, roles, ownership and resource allocation.
4. Develop a mechanism for biannual review of strategy in the light of continuing research into all aspects of wattled crane conservation.

The success of the supplementation program depends on improved knowledge of the wild population with respect to:

1. Hatch and fledge rates of wild birds
2. Future availability of breeding habitat
3. Density dependence effects
4. Age class structure
5. Factors impacting size of non-breeding flock
6. Movements
7. Threats

Captive Breeding

Key question: Is a South African captive breeding program necessary?

This was answered in the affirmative following the Vortex modeling of the supplementation programme. It was recognized that the captive population would need to be larger than the one currently held and strategies to accommodate the increased captive population size and management needs were discussed. Vortex modeling was used to establish optimum captive population size in terms of retained heterozygocity, acceptable inbreeding coefficient, limited resources and its potential to produce enough birds to support a viable supplementation programme.

The management scenario that had the most relevancy based on limited resources for captive breeding in South Africa was to increase the captive flock to 40 birds as quickly as possible using second eggs collected from wild nests. After 8-10 years, carrying capacity will be reached and the flock can begin to produce offspring for a release programme.

The group supports the existence of a captive breeding programme for 2 reasons:

- To serve as a genetic reservoir in the case of catastrophic extinction of birds in the wild.
- To provide birds for a supplementation programme if required in the future.

Recommendations:

1. Replace 2 females in the captive flock (improper sexual imprinting may prevent these individuals from reproducing).
2. Keep all wild, second eggs collected in 2000 as captive stock.
3. Review and redirect resources for the current supplementation programme.
4. Examine the role of the current isolation rearing facility, which includes the role of Mpumalanga Parks Boards' continued participation; resources; personnel; and logistics of transport of chicks in light of the shift in focus from the supplementation programme to building a captive flock.
5. Identify alternative isolation rearing facilities at the KwaZulu-Natal Crane Foundation (KZ-NCF) / Treehaven / Umgeni River Bird Park.
6. Hold workshop to determine KZ-NCF / SACWG roles in light of the PHVA recommendations.
7. Arrange a workshop to review logistics and strategy of maintaining of captive flock issues including:
   - Ownership/directorship of program
   - Memorandum of participation and terms and conditions thereof and management protocols
   - Identification of additional facilities and holding space
   - A biannual review of the captive breeding program as research continues into all aspects of crane conservation

   - Investigate alternative housing of U.S. birds and non-productive adults. It is recommended that the U.S. birds be maintained in pens less suitable for breeding and that other potential uses for them are identified (e.g. used for educational display, foster incubator/parent role, disposition to other captive breeding programmes).

8. After 5 years, remodel the contribution that a supplementation programme would make to the wild population based on conditions in the wild. If review indicates supplementation would make a significant contribution, resources could be redirected after 3 years into a limited supplementation programme to further refine release techniques.

Genetics

In 1996, 6 adults were imported from the U.S. in an effort to increase the number of captive Wattled Cranes in South Africa. In 1999, 4 chicks were imported. In 1995, South Africa signed the Convention of Biodiversity. In an effort to protect the genetic integrity of South African species, in 1999, the South African CITES authorities placed a moratorium on the import and use wattled cranes and their eggs not of South African origin. In response, SACWG initiated a genetic survey to determine if the South African population exhibits genetic distinctness from populations in other range countries. Samples sizes were too small to make any definitive conclusions but preliminary results indicate that Botswana and Zimbabwe samples show very little divergence, whereas the South African and Zimbabwean populations show significant divergence. It has been recommended that the South African population of wattled cranes should be considered and managed as a distinct population unless future mixing of the populations becomes necessary to maintain viability.

Recommendations:

1. Conduct further genetics research to clarify relationship of wattled crane populations.
2. Consulting geneticists (Ken Jones and Dr. Paulette Bloomer) should meet / communicate to decide upon future strategy, costs, and feasibility of sample collection and analysis.
3. The captive breeding team should regularly review new information emerging from the genetics studies to determine appropriate management strategies.

Alternative Methodologies

Recommendations:

1. Explore cryopreservation of sperm to determine it's potential contribution to wattled crane conservation and feasibility.
2. Monitor development of egg or embryo freezing technology for birds (not available at present).
3. Do not pursue translocation of adult birds from within the South African population. It was decided that this technique would not be supported by the relevant conservation authorities and is inappropriate at this time.

5) Executive Summary of the Life History, Population Dynamics and Modeling Group.

The Modeling Working Group was tasked with developing a baseline model which best approximates the current population dynamics of the wattled crane population in South Africa, taking into account knowledge of the current population parameters, genetic structure and carrying capacity.

The model was then used to predict the outcome of different scenarios on the population so as to improve decision-making in respect of management to maintain a viable wattled crane population. The wattled crane population parameters were modelled using the VORTEX simulation model, a simulation programme designed to aid the understanding of the effects of deterministic, demographic, environmental, and genetic stochastic events on the dynamics of a wild population.

Baseline Model

As recorded mortality data was found to be inadequate to account for the observed decline in the wattled crane population, the post-fledgling mortality rate was estimated by adjusting the mortality rate in the model until the model results mimicked the observed populations sizes from 1980 until 2000. A mortality rate of 6 % resulted in a close fit of the model with the actual wild population data.

Based on the available data, the baseline model was developed with the following criteria : starting population size = 379 individuals (1980 population estimate); age at first breeding = 8 years old; juvenile mortality = 74%; immature and adult mortality at all ages 1 years old to adult = 6%; maximum breeding age = 45 years old; carrying capacity = 500 individuals; and no supplementation.

Notes on the Output Baseline Model

The resulting trend in this population model has shown that a 6% immature / adult mortality rate best approximates the real population trend over the past 20 years, assuming all other population parameters entered in the model are correct. Year 0 in Figure 2 represents the year 1980 while year 20 approximates the current time of year 2000. This population has a negative deterministic growth rate (r = -0.028), indicating that the population is in deterministic decline (the numbers of deaths outpace the numbers of births), and will become extinct even in the absence of any stochastic fluctuations. Following the model simulation, the stochastic growth rate becomes more negative (-0.0347) indicating that stochastic fluctuations further affect the population negatively. In summary, a significant finding of this baseline model is that the South African wattled crane population (without any management of the population) currently has a negative growth rate, and together with stochastic fluctuations, will go extinct in approximately 93 years' time (from 1980).

The baseline model was then used to model different scenarios, including :

- the effect of different mortality rates, and
- the effect of different supplementation strategies

For these scenarios, the sensitivity of the model to the age at first reproduction and age at last reproduction (reproductive senescence) was tested using the following values for these parameters :

Age at first breeding – 7, 8 and 9 years old
Reproductive senescence – 30, 45 and 60 years old

The aim of the modelling was to determine the characteristics of the population which could be manipulated (through management) that would result in the reduction of the decline in the wattled crane population and the ensured survival of the population into the long-term. Therefore, the conservation objectives were as follows :

- Reverse the current negative growth rate, to result in a positive growth rate for the population,
- Have a population that has a greater than 50% chance of survival over the next 100 years,
- Maintain a population with 95% genetic heterozygosity.

Sensitivity Analysis

At mortality rate of 6% (current level):

- Individuals with age of senescence of 30 all lead to extinction, including those at 45 with age at first breeding at 9 years of age (therefore age of senescence is significant).
- At mortality rate of 6% all population iterations maintain a negative growth rate, implying that in all these cases the population will eventually become extinct.

At mortality rate of 5%:

- Irrespective of the age at first breeding, all populations with age of senescence of 30 all become extinct within 100 years.

- At mortality rate of 5%, the only scenarios which generate a positive growth rate is a supplementation of 6 individuals per year after an initial 8 year period.

At mortality rate of 4%:

- Reducing the mortality rate to 4% (with no supplementation) results in a reduced probability of extinction (except for age of first breeding at 9 years of age and age of senescence at 30 years).
- In all cases (except where age of senescence = 30 years) the reduced mortality rate to 4% allows for supplementation of either 4 or 6 to result in a positive growth rate.

VORTEX Modeling of Effect Supplementation Programme has on Wild Population

The goal of the supplementation programme is to significantly increase the number of Wattled Cranes in the wild in South Africa and to develop supplementation techniques in case of catastrophic event. The following scenarios were modeled with assistance from the Life History Modeling Group using VORTEX.

- No supplementation
- Supplementing 4 birds (2 males / 2 females) every year from the first year
- Supplementing 6 birds (3 males / 3 females) every year starting at year 9
- Supplementing 12 birds (6 males / 6 females) every alternate year starting at year 9
- Supplementing 4 birds (2 males / 2 females) every year for the first 20 years
- Supplementing 4 birds (2 males / 2 females) every third year from year 9
- Supplementing 5 birds (2 males / 3 females) every third year from year 9
- Supplementing 6 birds (3 males / 3 females) every third year from year 9

Recommendations Based on Model Results:

- Discontinue the supplementation program for the next 5-8 years and focus current efforts into developing the captive flock as a genetic reservoir.
- After 5 years, the status of the bird in the wild should be reviewed and the contribution a supplementation programme would make should be re-evaluated.
- If modeling indicates supplementation would significantly contribute to the wild flock, then 3 years prior to a full-scale release effort, resources could be directed into the refinement of release methodologies and techniques.
- Length of time needed to continue supplementation should be examined.

Overall Recommendations:

The use of Vortex to model the wattled crane population allows for the interpretation of the effects of different ranges of factors and different management actions on the population. This allows for the setting of conservation management goals, which are more likely to reverse the population decline.

The baseline model shows the current trend of the wild wattled crane population in South Africa, using the most current information on population demographic parameters. This model shows that the population is in steep decline, a process that needs to be reversed in ensure the long-term survival of this wetland-dependent species.

Therefore, the following model shows the overall result of several management actions, which will result in the long-term conservation of the species, i.e. a positive growth rate in the wild wattled crane population.

The factors, which result in this model, are as follows, and form the basis of work required in the future on the wild wattled crane population :

- The reduction of immature / adult mortality by 4 individuals per year, thereby reducing the mortality rate to 4%.
- Implement long-term habitat management plans to safe-guard breeding sites, thereby allowing breeding pairs to successfully occupy a site for up to 45 years (several pairs in the past may have had the potential to utilize sites for longer periods due to their long life spans, but have been prevented through serious habitat degradation where breeding sites have become unsuitable).
- Supplementing the wild population with 6 captively bred individuals every second year, after an initial 8 years where the focus is placed on establishing a viable captive flock within recognised breeding institutions. The modelling of the captive flock has shown that after the initial 8 year period, between 4 and 6 chicks will become available for supplementation every three years. Therefore, this more intensive release of 6 birds every second year will mean that the individuals available from the captive breeding programme will need

to be supplemented with second eggs from the wild to increase the number available for release every second year.

Additional research required into the population to refine our understanding of the species includes :

- Determining the age of reproductive senescence.
- Determining the actual age of first reproduction.

Population and Habitat Viability Assessment for the Wattled Crane (*Bugeranus carunculatus*) in South Africa

Final Report from the Workshop
Held 31 July – 2 August 2000 in Wakkerstroom, South Africa

February 2001

Edited by

K. McCann, A. Burke, L. Rodwell, U.S. Seal and M. Steinacker

Section 3

Working Group Reports

LAND-USE PATTERNS WORKING GROUP REPORT

Participants: Doug Burden, Koos de Wet, Dave Everard, Janis O'Grady, Jon Smallie, Terrence Collier, Geraldine Monroe, Michael Braack.

HISTORIC, PRESENT AND FUTURE IMPACTS ON THE WATTLED CRANE POPULATION IN SOUTH AFRICA

INTRODUCTION

Five working groups were constituted to address various issues. Our group was tasked to assess the historic, present and future land-use patterns, and how these have affected or may have affected certain habitats and therefore the crane population. The objective was to come up with a series of recommendations that will alleviate the problems associated with the degradation of crane habitat, and thus make a significant contribution to reversing the current trend of the declining crane population.

METHODOLOGY

In assessing problems, the group followed the standard PHVA methodology of :

1) identifying the problems related to land-use patterns and habitat;
2) gathering and assessing all available information and unwritten knowledge with respect to crane habitat;
3) setting goals to overcome the problem;
4) developing tasks and action plans to achieve the goals.

1) Initially, all land-use types that may impact on wattled crane populations were identified and problems relating to changes in the land-use types were brainstormed. These problems were then prioritized according to their impact on wattled crane habitat in the past, present and the future. This involved ongoing discussion and brainstorming, and problems were added to the list as they were identified.

2) All information relating to the above problems was then gathered, listed and discussed in an attempt to derive estimates of the extent to which wattled crane habitat has been lost in the past. The problems were also analyzed and discussed further. Several problems were refined or expanded upon where required.

3) Having obtained estimates of the extent to which wattled crane habitat had been lost in the past, explicit goals were set for the future. These involved specifying the extent to which habitat loss would be reduced in the future. Goals were based upon a 5-year period and were divided into a minimum and maximum goal. The minimum goal was taken to be the minimum achievement sought by the group, whilst the maximum goal was the ideal achievement.

4) The tasks needed to achieve each goal were determined and the specific actions making up each task were listed. The actions were then assigned to an organization or individual. The time frame, resources, collaborators and the outcome of each task were also specified in order to ensure that these actions are not simply lost along the way.

RESULTS

As a result of a brainstorming exercise in response to the task set and in order to eventually set attainable goals, the group made the following statements and assumptions :

- habitat loss / change is a major factor contributing to wattled crane population decline
- wattled crane habitat was divided into the following five components:
    - nesting / breeding
    - foraging
    - roosting
    - loafing / floating
    - migration routes

The group decided that breeding habitat (wetlands) is of prime importance to wattled cranes, with grasslands being of secondary importance on the basis of the following information (information obtained from the Briefing Document) :

- Wetlands, including dam edges are used 76% (sightings) of the time
- Grasslands – 10% (sightings) of the time

Land-use threats to these two wattled crane habitats were then identified and ranked. The land-use threats were derived from an identified set of present and historical land-use types : Forestry, Agriculture (cultivation), Urban development, Mining, Industry, Conservation, Grazing, Eco-tourism and Rural Development.

LAND-USE THREATS TO WETLANDS AND GRASSLANDS

Definition of a wetland according to the South African Water Act:
"water dominated area with impeded drainage where soils are saturated with water and where there is characteristic fauna and flora."

Threats to wetlands:

a) Canalisation: for cultivation; settlement; roads & other infrastructure; grazing
b) Cultivation
c) Direct afforestation
d) Inundation (damming)
e) Stream flow reduction: afforestation; irrigation; dams; extraction (domestic / industrial)
f) Alien invasion
g) Burning
h) Grazing
i) Pollution
j) Siltation: catchment degradation; overgrazing; mining; cultivation & harvesting; road & other infrastructure; drainage
k) Lack of Grazing

Land use threats to grasslands:

l) Cultivation
m) Afforestation
n) Settlement (Rural)
o) Development
p) Burning
q) Grazing
r) Alien Invasion
s) Bush encroachment
t) Pollution
u) Harvesting

The information on wetlands at our disposal (Begg 1986 – KZN study 1968-1986; Marnewyk & Grundling 1999 – Dullstroom; Begg 1986 – Umfolozi Catchment) was acknowledged, but did not provide us with an adequate indication of wetland loss within the wattled crane distribution range to date. The information on breeding habitat requirements – ranging from 6ha to 300 ha with an average of 40ha in KZN, and an average of a minimum of 18ha in Mpumalanga was also deemed inadequate (information obtained from the Briefing Document). The group could identify no obvious changes that had affected wattled crane well-being between 1970 to 1990. An exercise to determine future land-use threats to wattled crane survival revealed that as South Africa is a water-deficient country, stream flow reduction and direct utilisation of water from rivers and wetlands could have a huge impact on wattled crane breeding habitat beyond 2000. Some marked differences were noted between the ranking of past land-use threats to wetlands versus future (threats which have changed in rank marked with *):

- stream flow reduction & direct utilization of water (South Africas is a dry country)*
- cultivation
- inundation

- grazing*
- burning
- canalisation
- siltation
- infilling of wetlands
- alien invasion
- pollution
- afforestation
- lack of grazing*

GOALS

Based on the evidence that :

- wattled crane populations are declining at an alarming rate
- wattled crane breeding sites are being abandoned at the rate of 2-4 per year

And the speculation that :

- loss of wetland habitat or change in wetland conditions being the cause of wetland sites being abandoned (large floater flock is an indication that there is no lack of birds to occupy sites), we conclude that breeding habitat loss is a major contributor to population decline. Therefore it is of major importance to stop this loss of breeding sites.

The following goals were thus set :

If approximately 50% of all wetlands in KwaZulu-Natal have disappeared, and the current rate of loss is about 2-4 breeding wetlands per year, and because there is on average only one breeding pair per breeding wetland (1:1), then a minimum goal would be:

- **To reduce the rate of loss of active sites to zero over a five-year period, with maximum loss not exceeding six sites.** (see graph below).

We do believe that there is an opportunity to meet and exceed this minimum goal and feel that a challenging target would be to :

- **Reduce the loss of breeding sites immediately, so that no further loss occurs, and to establish one new potential site per year, eventually at least reaching a maximum of 110 breeding sites (based on the 1981 statistics)** (see Figure 1 below).

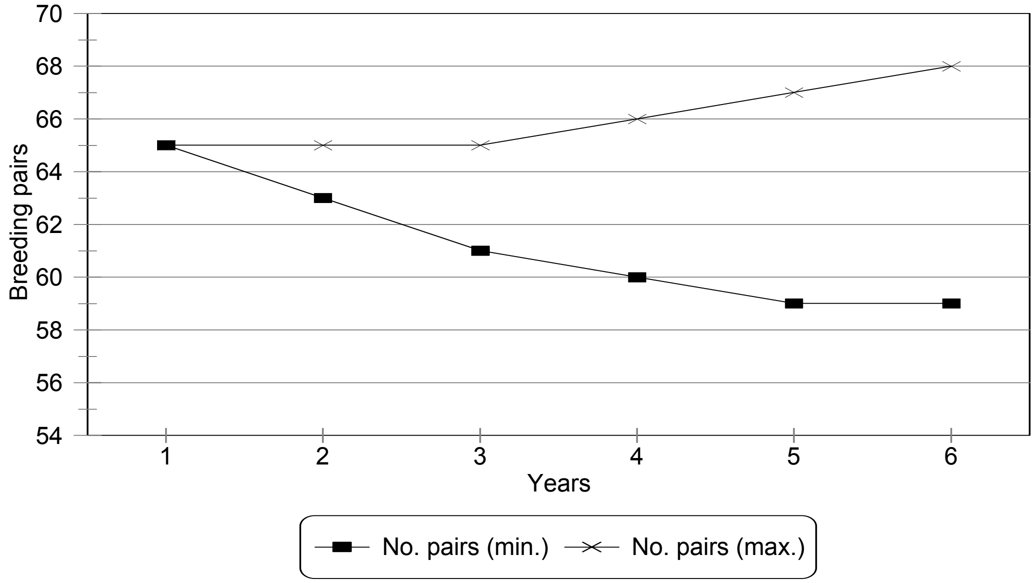

Figure 1 : The minimum and maximum goals for reduction in wattled crane wetland breeding site loss.

RECOMMENDATIONS

A number of tasks which need to be carried out in order to achieve the above goals were identified.

TASK 1 - Develop an accurate description of what constitutes viable wattled crane habitat : must include breeding habitat and foraging habitat with correct nutrition.

a) Develop hypothesis of what constitutes an ideal site – using the appropriate literature and knowledge, etc.
b) Survey all existing wattled crane breeding sites in terms of range of characteristics from hydrology to biology, etc.
c) Survey abandoned wattled crane breeding sites and “potential” sites.
d) Analyse this data and compare the characteristics.
e) Describe the ideal habitat characteristics.

Time frame: 12 months (from any designated time, preferably during the breeding season of the wattled crane)
Resources: a consultant would have to be found by SACWG – KwaZulu-Natal Nature Conservation Services preferably or someone private but this does not mean that SACWG must pay professional fees.
Collaborators: landowners, KZN NCS, SACWG
Outcome: a robust description of the above process and findings
Cost: R20 000

TASK 2 - Gain a clear understanding of how fast wetlands are lost in total and in terms of wattled crane requirements (deducing the historical rate of change).

a) delineate the entire region of wattled crane breeding sites that meet the five broad criteria used by the KwaZulu-Natal Nature Conservation Services in their Strategic Environmental Assessment (already carried out for DWAF).
b) map and compare wetland distribution from time series remotely sensed data (aerial photography; satellite imagery) during the 1970s, 1980s and late 1990s. This would include changes in surrounding land-use, to help with the identification of the cause of the decline in breeding pairs and their breeding sites (a land cover exercise).
c) The product would indicate the percentage, rate and cause of this loss.

Time frame: three months
Responsibility: SACWG – CSIR remote sensing group (or others!)
Cost: R30 000
Collaborators: SACWG, Consultant, DEAT, landowners

TASK 3a - Complete a risk assessment of all breeding sites using the following actions.

a) rate the causes of wetland loss (refer to list of 12 future threats to wetlands in the wattled crane breeding region above).
b) develop a check sheet or methodology to assess the risk to wetlands in order of priorities that will direct the actions of the person concerned with the welfare of the wattled crane.
c) survey the wetlands and classify them according to the risks to them.

Time: three months
Resources: SACWG and experts for tasks one and two; SACWG fieldworkers for survey co-ordination e.g. Kevin McCann / Ronel Steenkamp (appointed wetland fieldworker at SACWG meeting in May 2000)
Cost: minimal
Outcome/product: 1) a tool to assess the risk to wetlands
2) a list of high risk breeding sites

TASK 3b - Develop an action plan to reduce the risk at "high risk" sites – thereby ensuring that they are not lost.

This would have to be site specific and should include the following :

a) stake-holder involvement
b) publicity and awareness and education
c) appropriate intervention
d) incentives and or law enforcement

This task is dependent on Task 3a, which means that the responsibility falls again on the SACWG co-coordinator and the fieldworkers.
<u>Outcome:</u> site-specific programmes

TASK 4 – Survey all wetlands that fall within the area delineated under Task 2 above, and assess them for breeding suitability. Then classify these wetlands according to their suitability and risk (acquired from task 3).

This focuses on establishing the potential carrying capacity, performing the following :

a) check list / methodology for site suitability.
b) survey wetlands and assess for suitability, and grade into excellent-good-moderate-poor-no good.
c) overlay this information with risk assessment.
d) prioritize findings from this data into excellent and low risk sites, etc.
e) develop action plans to encourage breeding of wattled cranes at the site – attract the birds (possible suggestions - duck pellets and decoy).
f) it is essential to identify other good quality wetlands for a buffer .

<u>Time:</u> start in 12 to 18 months time
<u>Resources:</u> Co-coordinators Kevin McCann and Ronel Steenkamp; fieldworkers,
<u>Collaborators:</u> depending on expertise required (SACWG)
<u>Product:</u> Classification of sites and potential carrying capacities under various scenarios
Programmes for rehabilitation of these sites
Constant monitoring and ongoing research automatically result from this process

TASK 5 - To heighten the awareness of the plight of the wattled crane using a publicity and awareness programme.

Using the following:

a) general public
b) landowners
c) land users
d) decision makers : Transitional Local Councils, Catchment Management Associations, provincial government, regional councils

e) conservation authorities, especially managers
f) NGOs and working groups
g) Large corporates

Through the following actions:

- Mass Media campaign
- Target group communication and individuals – this must be championed and co-coordinated (EWT / SACWG)
- Revitalise local initiatives including conservancies, Crane Custodians, etc; the results of the above proceeding should be incorporated into their goals

<u>Time:</u> Start now – ongoing but with 3 month blitz
<u>Resources:</u> EWT / SACWG co-coordinator, media public relation officers, all of us for target group communication
<u>Cost:</u> expensive (mass media) – EWT

DISTRIBUTION AND HABITAT WORKING GROUP REPORT

Participants: Henry Davies, David Johnson, Kerryn Morrison, Ronel Steenkamp, Patrick Lowry, Glenn Ramke

HISTORY, DISTRIBUTION, HABITAT CHARACTERISTICS, BREEDING AND FEEDING ECOLOGY, AND DEMOGRAPHICS OF ALL POPULATIONS IN SOUTH AFRICA

Task 1: Problem Identification

DISTRIBUTION AND HISTORY

- Diffused and scattered historical literature.
- Unpublished data.
- In many of the older records, there is a lack of species identification, e.g. when looking at farm names.
- Lack of interaction data between the fragmented populations, e.g. movement.
- Non-standard methods in the past (the degree of accuracy was perhaps not ideal)
- There are possibly more unknown wattled cranes around.
- Even though there are 3 fragmented populations, there is further, man-induced fragmentation within these fragments.
- Incomplete historical orthophoto coverage to identify wetlands.

BREEDING AND FORAGING

- Exact habitat parameters for nesting and foraging wetlands are lacking, e.g. are high altitude wetlands necessary for cranes in South Africa? Perhaps these wetlands cannot sustain the cranes, e.g. not enough food supply. Why are they not in other wetlands, e.g. St Lucia (KwaZulu-Natal north coast)?
- Biological and physical aspects of cranes are not well known, e.g. diet.
- Causes of chick mortality, as many chicks are lost where the cause is unknown.
- Do predators pose a threat to breeding in general?

AREA AND DEMOGRAPHICS

- What are the minimum area requirements for nesting, including buffer zones?

PRIORITIES

1. Determining exact habitat requirements, including minimum area and buffer zones for breeding territories.
2. Biological and physical aspects of cranes need to be researched.
   - food source and requirement,
   - habitat structure,
   - time element (degree of permanence and seasonality),
   - hydrology.
3. Establish an easily accessible and central database of literature and unpublished data.

Task 2: DOCUMENTATION OF ALL INFORMATION AVAILABLE

DOCUMENT THE DECLINE OF THE WATTLED CRANE

Record original historical sites and range from historical documents.

- R. Brooke. 1987. (D. Johnson has a copy of the paper)

Plot the retraction and fragmentation of the range up until the present.

- Review factors contributing to the geographic separation into the present sub-populations.
- Review past and ongoing fragmentation within the sub-populations.

Data source :

- check McCann (PHVA – Briefing Document)
- check afforestation, ploughing, mining, and water impoundment permit offices for historical data.

DETERMINATION OF SUITABLE WATTLED CRANE HABITAT

Construct a hypothetical map of potential available habitat throughout the historical range of Wattled cranes.

- KwaZulu-Natal already has a map.
- The other areas will need a map - need to find out if data are available.

Compare extant Wattled crane nesting sites with abandoned and unused wetlands (using all information available and then filling in the gaps). Using the following data will highlight whether other factors need to be investigated in future.

- Kerryn Morrison's thesis
- Carlos Bento's work in Mozambique (Natural History Museum - Maputo)
- Barry Taylor (University of Natal)
- George Begg
- Gary Marneweck's study in Dullstroom and other crane areas
- Donovan Kotze (University of Natal)
- Rennies Wetland Project (David Lindley)
- KwaZulu-Natal Nature Conservation Services data for KwaZulu-Natal

Document and analyze past and present management practices of all wattled crane and other relevant wetlands, i.e.

- Grazing
- Burning
- Drainage

Data source :

- Field workers in each region

Establish minimum area requirements

- Nesting ranges
- Foraging range for breeders
- Foraging range and roost site for floaters, including the area between the two
- Buffer zones

Data source :

- Kevin McCann's and Neil Langley's data on home ranges (Briefing Document)

QUANTIFY KEY ASPECTS OF BREEDING BIOLOGY

- Analyze causes of full-term hatching failure.
- Determine chick productivity as a function of rainfall and other climatic factors.
- Quantify the role of predation on nest site selection and chick survival.
- Determine where adult crane and their chick roost at night.

Data source :

- Review published sources.

DETERMINE THE FEEDING BIOLOGY

- Identify key foods.
- Determine energy budgets.
- Use comparative studies with captive birds.
- Determine the importance of crop residues.

Data source :

- Review published sources.
- Jon Smallie's study on crowned crane crop depredation (north east Cape).

CENTRAL DATABASE ESTABLISHMENT

- Michelle Steinacker and / or Kevin McCann have a central database.
- Solicit crane data from all other relevant organizations, e.g. Sappi, Mondi, etc.
- Compile a bibliography, including all media articles.

Task 3: GOALS AND ACCOMPLISHMENTS TO BE MET WITHIN EACH GOAL

DOCUMENT THE DECLINE OF THE WATTLED CRANE

1. Analyze the decline in range and numbers of the Wattled crane,
    - Minimum : with the publication of a paper using all conventional publications up to and including the present day, to be completed by July 2001.
    - Maximum : with a more detailed report, emphasizing habitat fragmentation, incorporating all recent land transformation data using afforestation, ploughing, mining, water impoundment permits and any other relevant sources, to be completed by December 2002.

DETERMINATION OF SUITABLE WATTLED CRANE HABITAT

2. Create a model of the potential habitat of the Wattled crane, using available environmental data sets,
    - Minimum : of the current range, to be completed by July 2001.
    - Maximum : of the historical range, to be completed by December 2002.
3. Compare extant Wattled crane nesting sites with abandoned sites and unused wetlands,
    - Minimum : by assembling all available wetland data into a single database, to be completed by July 2001. Database assembling task team - pack of vac undergraduate students.
    - Intermediate : by preliminary analysis of the database to identify major omissions and to collect the necessary data, to be completed by July 2002. The crane field workers within each crane area can achieve this goal.
    - Maximum : by publishing a multivariate analysis of all wetlands for which data are available, to establish which habitat factors are vital for Wattled crane nesting, to be completed by December 2003.
4. Determine optimum management for Wattled crane habitat,

- Minimum : by creating a database of known management practices pertaining to extant and former Wattled crane sites, to be completed by July 2001.
- Maximum : by analyzing the database and producing a habitat management manual, to be completed by December 2002.

5. Determine minimum area requirements for Wattled cranes,
   - Minimum : by collecting all available and derivable data, and increasing the available sample size, pertaining to nesting wetland size and home range of breeders and floaters, to be completed by July 2001.
   - Maximum : by analyzing and publishing the available data and incorporating land transformation and disturbance factors, with a special reference to buffer requirements, to be completed by December 2001.

QUANTIFY KEY ASPECTS OF BREEDING BIOLOGY

6. Investigate hatching failure of full term eggs.
   Minimum : by collecting and analyzing all existing data, to be completed by December 2000.
   - Maximum : by supplementing existing data over the next 5 years, and analyze and publish results, to be completed by December 2006.
7. Analyze chick productivity as a function of rainfall and other climatic factors,
   - Minimum : by collecting, analyzing and publishing all available data, to be completed by December 2000.
   - Maximum : by supplementing existing data by further collection and analysis, in order to produce a more complete long term picture by the year 2004.
8. Investigate the role of predation in chick productivity,
   - Minimum : by initial survey of potential predators around Wattled crane nesting sites, to be completed by December 2001.
   - Maximum : by quantifying the loss of eggs and chicks to identified predators, and the role of roosting sites, to be completed by December 2004.

DETERMINE THE FEEDING BIOLOGY

9. Determine the diet and dietary requirements of the Wattled crane,
   - Minimum : by identifying all food species and items, to be completed by December 2001.
   - Maximum : and by quantifying the food intake and energy budget, to be completed by December 2004.

CENTRAL DATABASE ESTABLISHMENT

10. Establish a central database,
    - Minimum : by developing a database system and collecting all available and ongoing field data, the database system to be completed by July 2001.
    - Maximum : by soliciting all other crane-orientated data and a complete bibliography, to be completed by July 2004.

Task 4: COURSES OF ACTION (TARGETS)

(The numbering within Task 4 corresponds with Task 3)

Facilities have been taken to include automatically an office with a computer, fax machine, telephone, photocopy machine and access to email. Also, access to a library is assumed to be a necessity.
Financial costs are assumed to exclude salaries of established posts and general administration fees.

DOCUMENT THE DECLINE OF THE WATTLED CRANE

1. Analyze the decline in range and numbers of Wattled cranes:
   Responsibility: Kevin McCann (SACWG)
   Collaborators: Dave Johnson, Warwick Tarboton, Carl Vernon, David Allan
   Minimum resources:
      People and time: 1 person
      Facilities: GIS, inter-library loan
      Financial: publication costs
      Deadline: July 2001
   Maximum resources:
      People and time: as above
      Facilities: as above
      Financial: as above + transport to government, etc. offices
      Deadline: December 2002

DETERMINATION OF SUITABLE WATTLED CRANE HABITAT

2. Create a model of the potential habitat of the Wattled crane
   Responsibility: Kevin McCann (SACWG)
   Collaborators: Dave Johnson, Neil Langley, Ann Scott, Kerryn Morrison
   Minimum resources:
      People and time: 1 person
      Facilities: GIS
      Financial: printing
      Deadline: July 2001

Maximum resources:
People and time: 1 person
Facilities: as above
Financial: as above
Deadline: December 2002

3. Compare extant Wattled crane nesting sites with abandoned sites and unused sites
Responsibility: Kevin McCann (SACWG)
Collaborators: Dave Johnson, Warwick Tarboton, Kerryn Morrison, Dave Allan
Minimum resources:
People and time: 8 students, 1 supervisor, 3 months
Facilities: GIS, 8 computers
Financial: 480 days at student rates, printing
Deadline: July 2001
Intermediate resources:
People and time: Supervisor + n part-time field workers
Facilities: GIS
Financial: printing
Deadline: July 2002
Maximum resources:
People and time: 1 student + 1 supervisor
Facilities: multivariate software
Financial: printing + 240 days at student rates
Deadline: December 2003

4. Determine optimum management for Wattled crane habitat
Responsibility: Dave Johnson (Provincial Conservation Agencies)
Collaborators: Donovan Kotze, Barry Taylor, Warwick Tarboton, Kevin McCann
Minimum resources:
People and time: 1 person + n fieldworkers + 1 student
Facilities:
Financial: limited transport funds, printing, 80 hours at student rates
Deadline: July 2001
Maximum resources:
People and time: 1 person
Facilities: multivariate software
Financial: printing
Deadline: December 2002

5. Determine minimum area requirements for Wattled cranes
Responsibility: Kevin McCann (SACWG)
Collaborators: Dave Johnson, Warwick Tarboton, Kerryn Morrison

Minimum resources:
People and time: 1 person + 1 student + n fieldworkers
Facilities: GIS
Financial: printing, 80 days at student rates
Deadline: July 2001
Maximum resources:
People and time: 1 person
Facilities: as above
Financial: printing, limited transport costs
Deadline: December 2001

QUANTIFY KEY ASPECTS OF BREEDING BIOLOGY

6. Investigate hatching failure of full term eggs.
Responsibility: Ronel Steenkamp
Collaborators: Mark Penning, Peter Buss, Kevin McCann
Minimum resources:
People and time: 1 person
Facilities:
Financial: printing
Deadline: December 2000
Maximum resources:
People and time: 1 person + n fieldworkers
Facilities:
Financial: printing, transport costs
Deadline: December 2006

7. Analyze chick productivity as a function of rainfall and other climatic factors
Responsibility: Kevin McCann (SACWG)
Collaborators: Warwick Tarboton, Kerryn Morrison
Minimum resources:
People and time: 1 person
Facilities: multivariate software
Financial: printing
Deadline: December 2000
Maximum resources:
People and time: 1 person + n fieldworkers
Facilities: as above
Financial: printing, limited transport
Deadline: December 2004

8. Investigate the role of predation in chick productivity
Responsibility: Jon Smallie
Collaborators: Ronel Steenkamp, Gus Mills, Peter Taylor

Minimum resources:
People and time: 1 person + n fieldworkers
Facilities: laboratory,
Financial: lab costs, transport costs, printing
Deadline: December 2001
Maximum resources:
People and time: as above
Facilities: as above
Financial: as above
Deadline: December 2004

DETERMINE THE FEEDING BIOLOGY

9. Determine the diet and energy requirements of the Wattled crane
Responsibility: Kevin McCann (SACWG)
Collaborators: Ann Burke, Carlos Bento, Nadia Kraukamp, Donovan Kotze
Minimum resources:
People and time: 1 person + 1-2 field assistants
Facilities: laboratory, herbarium
Financial: lab costs, transport costs, printing, assistants' salaries
Deadline: December 2001
Maximum resources:
People and time: as above
Facilities:
Financial: transport costs, printing, assistants' salaries
Deadline: December 2004

CENTRAL DATABASE ESTABLISHMENT

10. Establish a central database
Responsibility: Kevin McCann (SACWG)
Collaborators: Janis O'Grady, Michelle Steinacker, Mark Penning Kotze
Minimum resources:
People and time: 1 person
Facilities:
Financial: printing,
Deadline: July 2001
Maximum resources:
People and time: as above
Facilities: inter library loan
Financial: library loan costs, printing,
Deadline: July 2004

Figure 1 : Distribution and Habitat Working Group members at work during the Wattled Crane PHVA (Wakkerstroom).

SUMMARY

The brief of the group was to examine the history of the Wattled crane, its habitat characteristics and management, minimum area requirements, food selection and energetics, breeding biology and the establishment of a single database.

Ten courses of action were identified.

1. Document the decline of the Wattled crane. This will include description of the ancestral range (the Type Specimen came from the Western Cape) through to the modern fragmentation of the remaining habitat.
2. Create a model of potential habitat for the Wattled crane. By overlaying environmental data sets on Wattled crane localities its environmental tolerances can be measured. Extrapolation pinpoints areas outside the known range that may yet harbour cranes or be amenable to management for cranes.
3. Determine the biophysical characteristics of Wattled crane nest sites. Detailed accounts of many wetlands are already published. Multivariate comparison of current Wattled crane sites with abandoned sites and all other documented wetlands should identify vital components.
4. Determine optimum management for Wattled crane habitat. Data on burning, grazing and water level regimes can be related to crane presence and breeding success.

5. Determine minimum area requirements for Wattled cranes. The measurements required are of nesting wetlands, foraging ranges of breeding pairs and floating ranges of non-breeders.
6. Investigation of hatching failure of full term eggs. Failure of eggs to hatch is not a serious problem, but needs monitoring, for example to detect onset of infertility.
7. Analyze chick productivity as a function of rainfall and other climatic factors. Losses from purely climatic causes need quantification in order to detect and monitor losses from other sources.
8. Investigate the role of predation in chick productivity. About half of hatched chicks die before fledging, most from unknown causes. The role of predators needs quantification, and methods of reducing chick loss may then become apparent.
9. Determine the diet and energy requirements of the Wattled crane. Very little is known of food selection, nor of how essential harvest leftovers are for non-breeders. Captive studies will be used to supplement observations in the wild.
10. Central database establishment. It is essential that not only all field data be assembled in one database, but that it also contains a complete bibliography.

PRIORITIES:

1. Determine the biophysical characteristics of Wattled crane nest sites (Action 3).
2. Determine the diet and energy requirements of the Wattled crane (Action 9).
3. Central database establishment (Action 10).
4. Determine minimum area requirements for Wattled cranes (Action 5).

THREATS WORKING GROUP REPORT

Participants: Vicki Hudson, Nadia Kraucamp, Andre Marais, Kevin Shaw, Warwick Tarboton, Richard Schutte, Shawn Catterall.

ANALYSIS OF THE ISSUES AND IMPACTS OF DIFFERENT THREATS ON THE SOUTH AFRICAN WATTLED CRANE POPULATION

INTRODUCTION

The group was tasked with identifying all known threats to wattled cranes and to quantify these threats. For the purpose of this exercise, threats were defined as "any factor that has a negative affect on the population and its survival". Amongst others this also includes anthropogenic impacts on habitat. This particular threat will, however, not be discussed under this section as a complete section has been dedicated to this threat.

IDENTIFICATION OF THREATS

The following four threats were identified:

1. COLLISIONS

All known incidents of collisions have occurred either on power lines or fence lines.

2. POISONING

Two categories were identified

a) Intentional poisoning: defined as where the species is targeted specifically.
Generally cranes are poisoned because they are perceived to cause crop damage or as a source of food. It is doubtful whether wattled cranes are targeted specifically as a source of food.

b). Accidental poisoning: defined as where the cranes are unintentionally poisoned.
Cranes are poisoned accidentally where another bird species is targeted as a source of food. Another possibility is the poisoning of birds through seed dressings, where seeds have been treated with agrochemicals to minimize fungus and / or insect damage.

3. EXPROPRIATION

Defined as the removal of eggs, chicks or adult birds from the wild, through hunting, domestic dogs, poisoning, and natural predators. Where possible, individual threats were analysed separately, otherwise they were analysed together under miscellaneous threats.

4. LACK OF KNOWLEDGE

Despite the apparent amount of data, there are discrepancies between the various data sets. The group also feels that there is an under-reporting of incidents and possibly a bias towards certain threats due to intensive monitoring of these threats.

QUANTIFICATION OF THREATS

To model the effects of threats to the wattled crane population, the threats need to be quantified. Data on the various threats is therefore required, and unfortunately in some cases the data is non-existent (illegal removal of chicks and eggs). Furthermore before these threats can be modelled it is necessary to understand and / or make certain assumptions concerning the existing data. The following line of thinking was adopted during this process:

a) All egg losses and chick mortalities before fledgling are incorporated into the breeding productivity figure. This includes the effects of wetland burning on chick mortality. Breeding productivity is covered in the section "distribution history and breeding ecology".
b) Where mortality was assigned to juveniles, we assumed that these were birds at the post fledgling stage.
c) Only used immature and adult bird mortalities.
d) Juvenile birds are defined as those birds that are still with the parents, but are fully flighted; in other words, between the age of 4 months and 1 Year.
e) Immature birds are those birds that have left their parents and have joined non-breeding flocks. Age between 1 to 8 Years.
f) Adult birds are those birds that form the breeding population and are 8 years and older.
g) Averages and ranges are for the years 1982, 1988, 1994 and 1999.
h) Originally an attempt was made to analyse the data for the two populations, namely KwaZulu-Natal and Mpumalanga separately. The number of incidents were, however, too low to allow an analysis of this kind.

1. POWER LINE COLLISIONS

- Assumptions

    a) Extensive surveys were done in the period 1994 – 1996 and therefore we assume that the figures for these years are the most representative.
    b) Furthermore, as this survey was done for KwaZulu-Natal, we assume that the mortality as a percentage of the KwaZulu-Natal population would be the same as for the Mpumalanga population.

- Most collisions occurred on 11-22 kV distribution powerlines

- Adult : immature : juvenile ratio of birds killed to power lines was 4.16 : 1 : 1.16

- 1.04% of the population dies from collisions on an annual basis.

2. FENCES

- The average proportion of birds killed annually was 0.15% (of the total known annual mortality incidents), with a range of between 0 and 0.28%

- All birds killed were juveniles

3. POISONS

- The number of incidents was so low that it was not feasible to split it up into the various sub-populations.

- Adult : immature : juvenile ratio was 4 : 3 : 0

- The average proportion of birds killed annually was 0.19% (of the total known annual mortality incidents) with a range of between 0.1% and 0.37%.

- It was felt that this is a substantial underestimate of the effect of poisons on the species and recommend that the model run at 5% and 10% mortality.

4. OTHER THREATS (Captured, shot or dog predation)

- Average of 0.24% mortality annually with a range between 0 and 0.45%

- Ratio of adults : immatures : juveniles was 3 : 0 : 5
- The working group, however, felt that this is too low, and recommend a mortality percentage of 10%

5. NATURAL THREATS

This includes wind, fire, hail, floods, disease, extreme temperatures and drought. We assume that this happens 1 in 10 years and affects 5% of the population with a range of 0-100%.

ALTERNATIVE ANALYSIS OF THE AFFECTS OF MORTALITIES USING OTHER DATA SETS

In an attempt to analyse the data, a number of discrepancies were noted. This section briefly sets out the discrepancies, as well as the two possible data sets that could be used, and the reasoning for the selection of the particular data set used

Reported incidents do not satisfy the change in population numbers as reported in the 1982, 1988, 1994, and 1999 censuses (Figure 1 and 2). The number of mortalities between 1982–1988 for KwaZulu-Natal was one adult loss due to hunting, yet population figures indicate a loss of 58 adult birds. Possible under-reporting of mortalities is suspected. Likewise the number of mortalities between 1988–1994 for KwaZulu-Natal was 20 adult birds (19 collisions and 1 unknown), but population figures show a loss of only 4 adult birds. Similarly number of mortalities between 1994 and 1999 for KwaZulu-Natal were 2 adults (1 poison and 1 collision), yet population figures for the same period show a decline of 22 adults. Mortalities for Mpumalanga for the same periods were 1 (poison), 8 (1 poison, 5 collisions, 2 unknown) and 3 (hunted). However, the feeling is that the adult : immature : juvenile mortality ratios expressed under the threats identified were a fair reflection of the real situation.

Comparing the population figures for breeding cranes (figure 1) and non breeding birds (figure 2), some of the discrepancies between reported mortalities and actual numbers of birds lost can possibly explained by the interaction of breeding birds and non breeding birds in the KwaZulu-Natal population. The increase of 27 birds in the non-breeding flock between 1994 and 1999 corresponds to the loss of 22 breeding birds taking into consideration the reported mortality of two birds (obtained from the % mortalities on the entire population) for the same period. This, however, does not take into account recruitment into the breeding flock of young birds.

Another data set that could be used is that of the mortalities of 10 released captive bred Wattled cranes between 1996 and 1999 in Mpumalanga. Only two birds survived with the rest succumbing to poison (3 birds), collision (2 birds), natural predators (2 birds) and fence lines (1 bird).

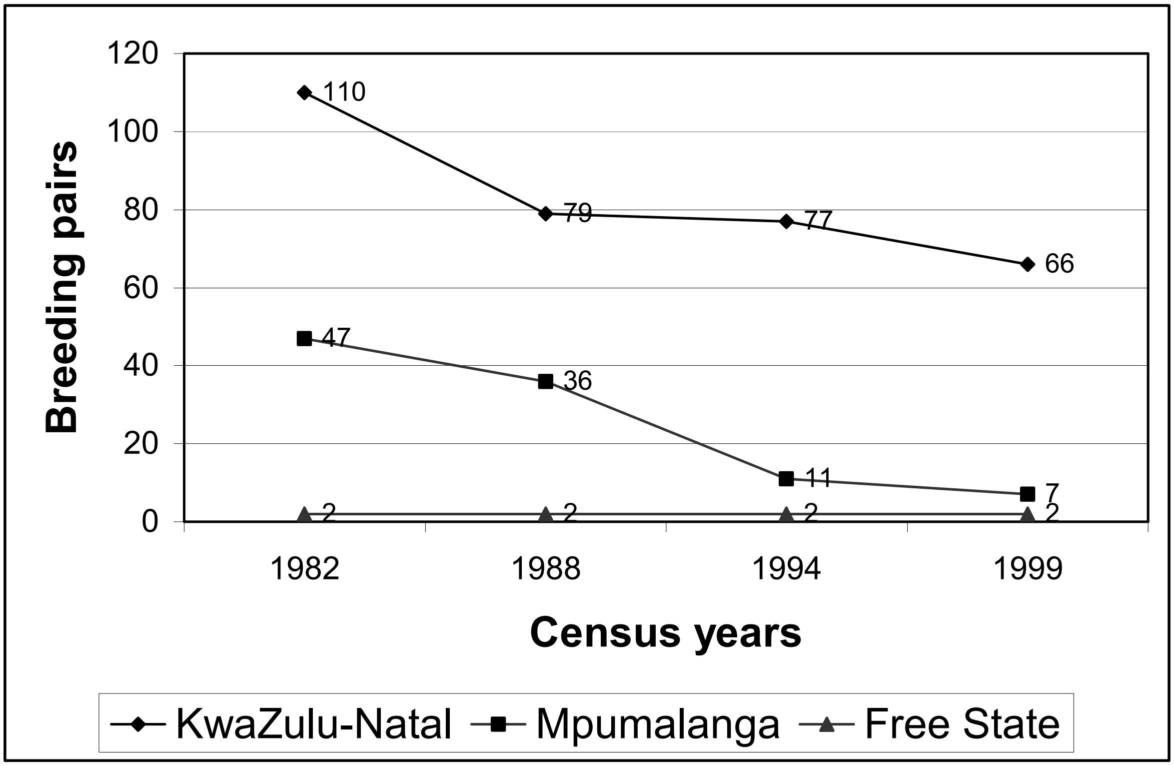

Figure 1: The numbers of breeding pairs of wattled cranes for the KwaZulu-Natal, Mpumalanga and Free State sub-populations.

After reconsideration, it was decided to use figures (section C above) extrapolated from the existing data of mortalities, as it the only data set that closely represents the true situation. The data from Mpumalanga is area specific and as it is such a small sample, it may misrepresent the actual situation. Despite this, the combined mortality rates for the various threats (section C above) does not exceed 2%. The population model shows that with a 2% mortality rate the population remains stable. This proves that the reported incidents of mortalities are in fact far lower than the actual situation.

It is still proposed that the two graphs (Figure 1 and 2) explain a movement of breeding pairs to the non-breeding flock when the breeding site becomes unusable (specifically the trend shown by the KwaZulu-Natal population). This needs to be considered when modelling the population.

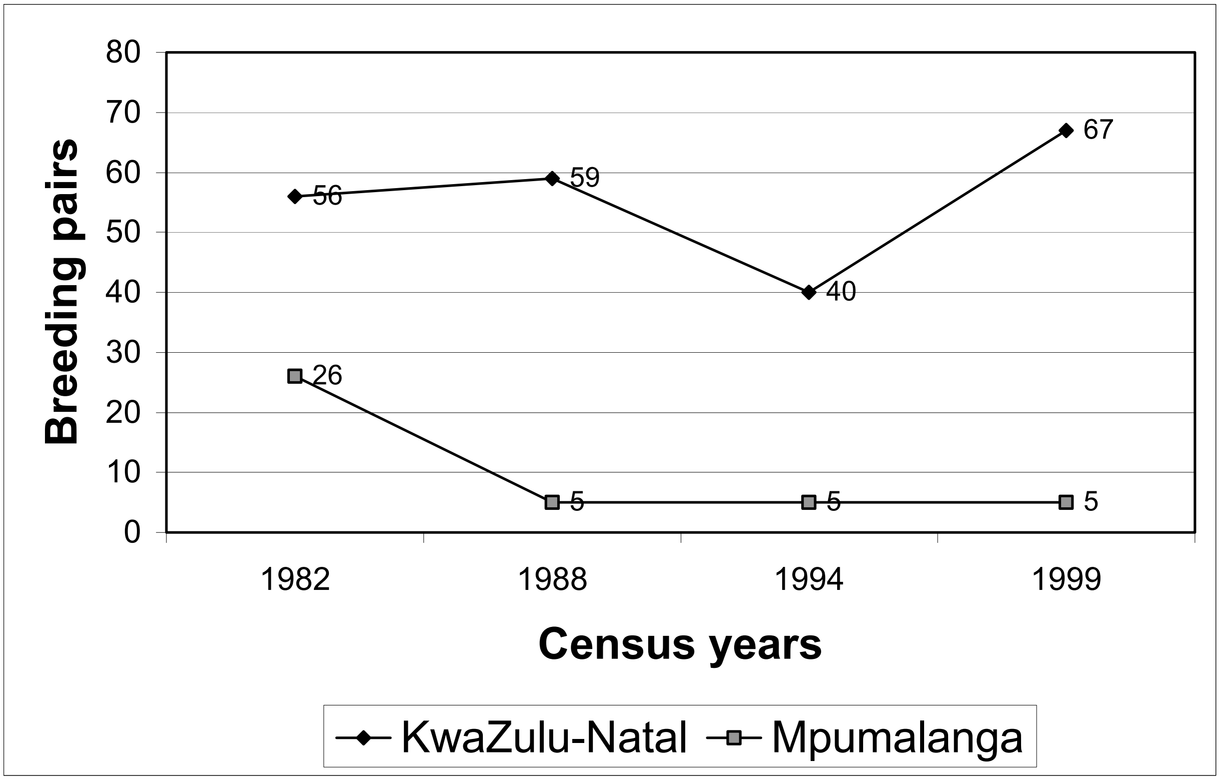

Figure 2: Non-breeding wattled crane numbers for the KwaZulu-Natal and Mpumalanga sub-populations.

Figure 3 Threats Working Group members analyzing the impacts on the South Africa wattled crane population at the PHVA (Wakkerstroom).

GOALS

To reduce the effect that the identified threats have on the wattled crane population, it is proposed that crane conservationists strive to obtain the following goals :

1. Power lines : Reduce collision mortality by 70% over 3 years
2. Fences : Reduce mortality by 50% over 5 years
3. Poisons : Reduce misuse of agrochemicals by the rural communities on farms where wattled cranes are breeding by 90% over the next 5 years
4. Miscellaneous (hunting, chick and egg removal, dogs) : Reduce mortality by 90% in 5 years.
5. Lack of Knowledge : Increase our knowledge on the affects of threats on the crane population.

COURSES OF ACTION

In order to obtain these goals it is recommended that the following actions be implemented.

1. POWER LINE COLLISIONS

a) Courses of Action

- GIS study to identify power lines over home ranges.
- Identify those sections of lines that need to be marked.
- Mark those lines, which have been identified.
- Reroute lines where marking is deemed to be ineffective.

b) Responsibility

- Currently this task is been done by the Eskom / EWT partnership and the group feels that the responsibility of the task remains with the partnership.

c) Time line for completion

- GIS study to identify power lines over home ranges (1 Year).
- Identify those sections of lines that need to be marked (1 Year).
- Mark those lines, which have been identified (2 Years).
- Reroute lines where marking is deemed to be ineffective (3 Years).

d) Resources

- People and their time
  - Eskom, Eskom / EWT partnership, SACWG, crane field officers
- Facilities
  - Computer and applicable software
  - Vehicle
  - Salary
  - Global Positioning equipment
  - Telephone
- Financial – costs, budgets
  - R100 000 per year

e) Measurable Outcome

- Decrease in mortality
- Percentage of those identified lines that are marked.

f) Collaborators

- Eskom, Eskom / EWT partnership, SACWG, crane field officers

2. FENCES

a) Courses of Action

- Identify problem areas around nest sites, as mortalities are restricted to juvenile birds.
- Identify mitigation measures to solve problem.
- Make landowners aware of the problem through the media and crane field officers.
- Reduce disturbances to the wattled crane family.

b) Responsibility

- SACWG, crane field officers

c) Time line for completion

- Identify problem areas around nest sites, as mortalities are restricted to juvenile birds (1 year).
- Identify mitigation measures to solve problem (2 year).
- Make landowner aware of the problem through the media and crane field officers (immediate to ongoing).
- Reduce disturbances to the wattled crane family (immediate to ongoing).

d) Resources

- People and their time
  - Landowners, crane field officers

- Facilities
  - Vehicle
  - Salary
  - Global Positioning equipment
  - Telephone

- Financial – costs, budgets
  - R24 000 per year

- Measurable Outcome
  - Decrease in mortality
  - Percentage of those identified fences that are marked.

- Collaborators
  - Landowners, crane field officers, SACWG

3. POISONS

a) Course of Action

- Incentive induced education and awareness programmes directed at the farm workers and their families on farms where cranes occur.
- Institute prosecution measures where necessary .

b) Responsibility

- Poison Working Group, crane field officers

c) Time line for completion

- Incentive induced education and awareness programmes directed at the farm workers and their families on farms where cranes occur (immediate to ongoing).
- Institute prosecution measures where necessary (immediate to ongoing).

d) Resources

- People and their time
  - Poison Working Group, crane field officers, SA human population

- Facilities
  - Vehicle

- Salary
- Global Positioning equipment
- Telephone
- Poison first aid kit

- Financial – costs, budgets
  - R60 000 per year

e) Measurable Outcome

- Reduction in mortalities by agrochemicals

f) Collaborators

- Poison Working Group, crane field officers, South African human population

4. MISCELLANEOUS (hunting, illegal chick and egg removal, dogs)

a) Course of Action

- Incentive-induced education and awareness programmes directed at the farm workers and their families on farms where cranes occur.
- Institute prosecution measures where necessary .

b) Responsibility
- Responsible provincial authorities, crane field officers

c) Time line for completion
- Incentive induced education and awareness programmes directed at the farm workers and their families on farms where cranes occur (immediate to ongoing).
- Institute prosecution measures where necessary (immediate to ongoing).

d) Resources
- People and their time
  - Responsible provincial authorities, crane field officers, landowners

- Facilities
  - Vehicle
  - Salary
  - Global Positioning equipment
  - Telephone

- Financial – costs, budgets
  - R24 000

e) Measurable Outcome: Reduction of the incidents of hunting, illegal chick and egg removal, killing by dogs.

f) Collaborators

- Responsible provincial authorities, Crane field officers, Landowners, Hunting Associations

5. LACK OF KNOWLEDGE

a) Course of Action

- Determine the effects of threats on the population in terms of mortality (natural anthropogenic) rates by establishing an extensive network of informants and an efficient reporting procedure.
- Look at the marking of birds as a means of increasing the rate of reporting and the cause of mortality.
- Look at the affects of natural mortalities.

b) Responsibility

- SACWG, crane field officers

c) Time line for completion

- Establish an extensive network of informants and an efficient reporting procedure (1 Year).
- Determine the effects of threats on the population in terms of mortality rates (immediate to ongoing, and reviewed every 3 years).
- Look at the marking of birds as a means of increasing the rate of reporting and the cause of mortality (1 Year).

c) Resources

- People and their time
  - SACWG, crane field officers, landowners, farm workers

- Facilities
  - Computer with relevant database software and email
  - Telephone / fax
  - Marking (rings, radio and satellite telemetry, etc.) supplies
  - Salary
  - Vehicle
  - Freezer
  - Media resources

- Financial – costs, budgets
- R 150 000 per year. The group decided that the priority would be to monitor the non -breeding flock.

e) Measurable Outcome

- Increased rate of reporting.
- More accurate idea of the effects of threats on the mortality of the population.

f) Collaborators

- SACWG, crane field officers, landowners, farm workers

CAPTIVE POPULATION AND MODELING WORKING GROUP REPORT

Participants: Lindy Rodwell, Ann Burke, Helena Mattison, Brent Coverdale, Mark Penning, John Spence and Ken Reininger.

WATTLED CRANE CAPTIVE POPULATION DYNAMICS AND MODELLING

The brief of the Captive Population Group was to assess the validity, necessity and contribution of the existing captive breeding and supplementation programme to wattled crane conservation in South Africa. Four major focus areas were identified:
1. The wattled crane supplementation programme
2. The wattled crane captive breeding programme
3. Genetic differentiation of the South African population of wattled cranes relative to populations within the other range states
4. Alternatives to captive breeding

1. WATTLED CRANE SUPPLEMENTATION PROGRAMME.

Status of Supplementation Programme

From 1995 through 2000, 13 birds have been released. One bird was released in 1995, 5 as a cohort in 1997, 4 as a cohort in 1998 and 3 using the one-by-one release technique in 2000. There have been 7 mortalities, 2 through predators, 3 from poisoning, and 2 from powerline collisions. Six birds have survived to date. No chicks have been produced by the captive flock since 1997. Release stock comes from second eggs collected from wild nests. Wild egg collections yield approximately 4 chicks per year (range 1-6) that are suitable for release.

Key Question: Is a release programme necessary?

Concerns (listed in order of highest to lowest priority)

1. Will a release program contribute to the long-term survival of the species in the wild and if so, how?
2. How many chicks need to be released per year to make a significant impact on the wild population? The maximum number of chicks obtained from second, wild egg collections is approximately 4 per year (range 1-6).
3. Is a release program worthwhile based on the amount of public awareness, educational value and public relation opportunities that it generates?

4. Based on the fact that most captive female Wattled cranes initiate egg laying at age 8 or older, can we afford to delay a supplementation program until birds in the captive SA flock mature and come into production?
5. Can a supplementation program be used to generate funds?

Recommendations – Data Collection

Current gaps in our knowledge about Wattled crane biology impacts on the numbers of birds that are released, the specific methodologies used and the release site location.
The following is a list of biological data that is needed to improve the supplementation programme:

1. Identify what constitutes suitable Wattled crane habitat and determine how it can best be managed.
2. Identify an acceptable mortality rate for birds after release.
3. Establish hatching rates of wild eggs.
4. Establish fledge rates of wild birds.
5. Investigate if density (e.g. the number of non-breeding birds within the flock), promotes dispersal and/or colonization of new habitat. Does density influence range expansion?
6. Investigate if age class structure of the non-breeding flock affects the rate of pair formation.
7. Investigate the factors, which influence the size of the non-breeding flock (e.g. recruitment, decrease in the number of breeding pairs, age of breeding pairs (old age), lack of suitable habitat, other factors?)
8. Ensure the movement patterns of the non-breeding flock are fully understood.

Issues to Address

1. Is it necessary to follow the IUCN guidelines for release that state a self-sustaining captive population is an absolute prerequisite for release?
2. A self-sustaining captive population of Wattled cranes exists in the US. In the case of a catastrophic event in the wild, would we use those birds to re-populate SA regardless of the genetics issue? Is it necessary to duplicate resources and maintain a second captive population in SA?
3. The methods currently used to collect second eggs from wild nests do not negatively impact the productivity of the wild population. These second eggs are a source of birds for the release programme. Is it also necessary to maintain a captive flock?
4. Limited resources exist for the supplementation programme:
    - Funding for the supplementation program is limited.
    - The facility used to rear the birds for release is expensive to maintain.
    - There are inadequate personnel for all aspects of the release program (e.g. rearing, post release monitoring) and all associated costs such as salary, lodging etc. are high.
    - Training is required for all personnel involved with the release programme (from chick rearing to post release monitoring) and this is expensive.

- Additional expenses related to the programme include: support vehicles (ATV, truck), colour rings, radio tracking equipment, transponders, portable release pens, and health screening costs.

Recommendations – Release Criteria

1. Investigate release site selection criteria to better identify the optimal physical location of the release site(s).
2. Investigate optimal time of year for release.
3. Investigate specific techniques / methods that can be used to improve post-release survival need.
4. Investigate the age of release that optimizes survival.
5. Review / revise medical screening protocols on a regular basis per expert opinion.

Pros and Cons of Wattled Crane Supplementation Programme

Pros -

- Good public relations and awareness value
- Increases knowledge of the wild flock due to increased monitoring and observation
- Has public appeal and the potential to generate funds
- Project may make a significant contribution to the wild flock
- Provides a model/mentoring to other African crane programmes
- Attention is focused on the issues surrounding Wattled crane conservation such as land use, use of poisons, value of wetlands to people, etc.
- Contains a valuable educational component with an increased focus on protecting habitat for released birds
- Allows for the development of viable release technique(s). It takes time to develop these techniques and in the case of a catastrophic event and very low numbers we want to have a proven methodologies available.

Cons -

- Significant cost implications
- Resources may be better spent in other areas of crane conservation
- Programme may deflect funding away from research and field conservation
- May not make a significant contribution to the wild population
- May deflect focus away from research/urgent need for protection. A project of this nature may create a false sense of security that the supplementation program is solving the problems of Wattled crane decline
- Decreases the number of birds available to the captive breeding programme.

VORTEX Modeling of the Effects the Supplementation Programme has on the Wild Population

The goal of the supplementation programme is to significantly increase the number of Wattled cranes in the wild in South Africa and to develop supplementation techniques in case of catastrophic events. The following was modeled with assistance from the Life History, Populations Dynamics and Modeling Group using VORTEX.

See the Life History, Population Dynamics and Modeling Working Group report for details of this modeling exercise.

Recommendations Based on Model Results

- Discontinue the supplementation program for the next 5-8 years and focus current efforts into developing the captive flock as a genetic reservoir.
- After 5 years, the status of the bird in the wild should be reviewed and the contribution a supplementation programme would make should be re-evaluated.
- If modeling indicates supplementation would significantly contribute to the wild flock, then 3 years prior to a full-scale release effort, resources could be directed into the refinement of release methodologies and techniques.
- Length of time needed to continue supplementation should be examined.

2. WATTLED CRANE CAPTIVE BREEDING PROGRAMME.

Current Flock Status

Presently, there are 19 birds of South African origin held in captivity. Five of these are known founders, while 9 are from unknown wild nesting territories. Three exhibit inappropriate sexual behavior and are therefore of limited reproductive value. This effectively leaves a founder population of 16 potential breeding birds. There have been no chicks produced by the flock at this stage, however it is anticipated that a number of pairs will breed during the 2001 season. All additional birds are obtained from wild second egg collection

Key Question: Is a South African captive breeding program necessary?

Issues to be Addressed (listed in order of highest to lowest priority)

1. Is a South African captive breeding program necessary to ensure the long-term survival of the species in the wild?
2. Does a captive breeding programme have high educational value?
3. Can a captive breeding programme serve as a vehicle to generate much needed conservation funds?
4. Limited resources currently exist for the captive breeding programme:

- There is limited pen space in South Africa. Currently, 7 facilities hold a total of 10 breeding pens. There is the potential to increase the number of breeding pens to 20 through the addition of new programme participants (e.g. private breeders) and expansion within existing facilities.
- Cost is a consideration in the creation of additional breeding pens. Preferably pens should be off-exhibit and designed to promote the retention of species typical behavior. Cost is estimated at R20 000 ($2 800 USD) per new enclosure.
- The cost of rearing chicks to ensure proper imprinting (includes costume rearing and dedicated facilities) is a factor to be considered.
- Captive breeding requires expensive equipment such as incubators, sanitary supplies, etc.
- Routine health care and quarantine testing is essential for all facilities and is costly.
- Staff at all facilities is limited and resources to employ additional staff are difficult to obtain.
- Staff training is required for all aspects of crane husbandry in each facility. This is costly and requires high time input from experts.

5. There are 14 founders of South African origin but 9 of them are of unspecified origin (they were collected as eggs from breeding territories in KwaZulu-Natal but no records were kept). Genetic testing to determine relationships between founders of unknown origin is possible but expensive and may be unwarranted due to such low numbers.
6. There are 16 birds currently held in captivity in South Africa that have the potential to become productive, breeding stock. Is this a large enough number for a viable captive breeding programme?
7. Historically, the flock's reproductive rate has been low and only 2 females of South African origin are currently producing eggs. Given that the flock is small and not self-sustaining, it cannot, at the present time contribute to a supplementation programme.
8. The possibility that the South African birds may be genetically distinct (See Genetics section below), has led to a current moratorium on the import of birds / eggs from the US by the South African CITES authorities. There is a need to determine how many founders / pairs are needed for the establishment of a viable captive population (based on the goals of the North American Wattled crane Species Survival Plan, which targeted maintaining 90% heterozygosity over 150 years, a total of 20 founder birds are required) (Beall 1994).
9. There is a need to standardized record keeping across all the South African facilities holding Wattled cranes.
10. If the captive population of Wattled cranes in South Africa is to be managed as one flock, standardised record keeping will be required for all aspects of the captive breeding process from egg collection to postmortem. A regional Wattled crane studbook has been developed in South Africa and the computer programmes of SPARKS and ARKS are being used by several participating facilities.
11. All captive birds need to be marked with rings and possibly, transponders.

12. Improperly imprinted captive stock is a major problem facing current captive breeding efforts in South Africa. Three females of the 19 birds in the captive population exhibit inappropriate sexual behavior and are therefore of limited reproductive value. However, these birds may have educational value.
13. Disposition of improperly imprinted birds are currently taking up pen space that is needed for breeding stock.
14. Artificial insemination is required for imprinted birds. This technique requires expertise and resources that currently do not exist at each facility and would need to be developed.
15. Imprinted females may require a full-time human male partner to bring them into egg production. This is not a viable proposition given limited resources.

Pros and cons of a South African wattled crane captive breeding programme as a genetic reservoir to guard against catastrophic loss:

It was discussed that the need for a captive breeding programme, in part, is based on the need to preserve the genetic uniqueness of a particular species. If the South African wattled crane population is unique, then a captive programme is justified and the use of stock from a dissimilar population (e.g. the US) is not appropriate.

Pros -

- There is an educational and awareness value to maintaining birds in captivity.
- Close observation in captivity allows for a greater understanding of species biology.
- A captive programme is a vehicle to potentially generate funds and support for a supplementation program.
- There is the potential to generate funds by exchanging captive produced wattled cranes for support of field conservation activities.
- A self-sustaining captive population reduces dependence on erratic wild egg collections.
- Captive produced breeding stock could be used to supplement other breeding populations outside of South Africa.
- There is the potential to defuse illegal trade in wild caught birds through the legal provision of captive produced birds.

Cons -

- There are substantial costs associated with the programme.
- The captive breeding programme is a long-term endeavour, requiring extended continuity, which may be difficult to achieve in South Africa due to limited funding and skill capacity.
- There is a limited availability of resources within South Africa to support a large number of captive breeding pairs (if that is a requirement for the establishment of a self-sustaining population).
- There is the potential to actually increase the illegal trade by collectors selling the birds as "captive reared" when in fact they were obtained through illegal wild collections.
- A captive breeding program creates the false public perception that the program is ensuring the survival of the species.
- The captive program has the ability to divert funds from other conservation efforts. It was discussed that the potential diversion of funds and the potential incorrect public perception that captive breeding is the solution to wattled crane conservation can be managed, and that these are not strong enough reasons to discontinue the captive breeding programme.

VORTEX Modeling Results of South African Wattled Crane Captive Population

It should be noted that VORTEX models are based upon key input parameters. The base scenario parameter values selected for this portion of the captive chapter are based upon the most current and available information about captive wattled cranes (Table 1). These parameters are subject to change based on revised assumptions or new information.

Table 1: Base scenario parameter values and their sources.

Parameter	Value
First age of reproduction for females	8 years[A]
First age of reproduction for males	8 years[A]
Maximum breeding age (senescence)	40[B]
Sex ratio at birth (percent males)	50[C]
Inbreeding depression	None[C]
Long term monogamous	L [B]
Percent of adult females producing chicks	33%[D]
Of the females producing chicks:	47% of females produce 1 living chick per year[E] 20% " 2 living chicks 16% " 3 living chicks 10% " 4 living chicks 5% " 5 living chicks 2% " 6 living chicks
Percent mortality of females between the ages of 1-8 years	0-1 year (32%), 1-2 years (7%), 2-3 years (2%), 3-4 years (6%), 4-5 years (2%), 5-6 years (5%), 6-7 years (7%), 7-8 years (11%) [F]
Percent mortality in females in adult classes, 9-40	3.0%[F]
Percent mortality of males between the ages of 1-8 year	0-1 year (29%), 1-2 years (11%), 2-3 years (10%), 3-4 years (4%), 4-5 years (5%), 5-6 years (2%), 6-7 years (4%), 7-8 years (3%) [F]
Percent mortality in males in adult age classes, 9-40	3.2%[F]
Frequency of Type 1 catastrophes	10%, r = 0.5, s = 1.0*
Frequency of Type 2 catastrophes	10%, r = 1.0, s = 0.8*
Initial age structure of population (males) (n = 6)	1, 4 year old, 1, 5 year old, 2, 6 year old, 1, 9 year old, 1, 13 year old[C]
Initial age structure of population (females) (n = 10)	4, 1 year old, 1, 2 year old, 1, 5 year old, 3, 8 year olds, 1, 12 year old[C]
Carrying capacity	50[G]
No. of chicks (initially collected as wild eggs) available annually to supplement the captive flock	2-4[C]
No. of birds harvested from the captive flock at different intervals. One year old birds used for supplementation	4-6[H]

A = International Wattled Crane Studbook – Fecundity and Mortality Report
B = Johnsgard – Cranes of the World
C = South African studbook, 1912-1999 (includes all individuals captured out of the wild and second eggs collected, n=40)
D = International Wattled Crane Studbook. Percentage of females targeted to breed over the age of 8 that produced at least one chick
E = International Wattled Crane Studbook. Females (n=23) that have produced at least one chick
F = North American Wattled Crane Studbook – Fecundity and Mortality Report through 31 Dec. 1999
* = Captive facilities may encounter conditions that result in catastrophic loss. This could include disease outbreak, fire, theft, contaminated feed supply, construction / facility maintenance that disrupts breeding single year, unfavorable weather conditions, etc.
G = Carrying capacity (K) within South African institutions was estimated to be 40 by wattled crane PHVA Captive Group. However, the Vortex programme truncates the simulations below the set K (does not allow the population to ever reach K). To achieve an actual population of 40, K had to be set at 50. Managers will be able to adjust the number of birds in captivity, based on the availability of holding spaces.
H = Numbers obtained through sensitivity analysis using base scenario parameters.

Table 2: Second egg collections in South Africa[C] from 1986 to 1999.

Total number of eggs collected	47
Total number of eggs hatched	42 (89% hatch rate)
Total number of chicks that survive to fledge	37 (88% survival rate)
Percentage of collected eggs that survive to fledge	78% (0.89 x 0.88)

Table 3: Number of wild collected eggs needed to produce fledglings for the South African wattled crane captive breeding programme.

Number of eggs collected	**Survival rate – 78%**	Number of fledged chicks produced
1	0.78	0.78
2	0.78	1.6
3	0.78	2.3
4	0.78	3.0
5	0.78	3.9
6	0.78	4.7
7	0.78	5.5
8	0.78	6.2

Introduction to VORTEX Modeling Scenarios

It is suggested that the base scenario parameters be fully reviewed prior to reading the following section. Each modeling scenario begins with a table listing the specific values used to produce each set of figures (graphs) below each table. For Tables 4 – 8 and Figures 1- 8, note that the first scenario on each table and figure is a model of the current captive flock with no supplementation of fledged chicks obtained from the collection of wild second eggs and no birds harvested from the captive flock for a release programme.

The second scenario on each table and figure is a model of the current captive flock with the supplementation of 4 fledged chicks / year obtained from the collection of wild second eggs in years 1-10, and no harvest of birds from the captive flock for a release programme.

The third scenario on each table and figure is a model of the current captive flock with the supplementation of 4 fledged chicks / year obtained from the collection of wild second eggs in years 1-10, and a harvest of 4 birds from the captive flock, beginning in year 9 for a release programme. Note that the timing of harvest has been manipulated throughout the entire modeling process. (See the description in bold type in each table heading for exact numbers used for each specific model. In addition, the number of females 8 years of age and older that produce eggs each season will be manipulated throughout the modeling as will the number of chicks produced by each female per season).

The fourth scenario on each table and figure is a model of the current captive flock with the supplementation of 4 fledged chicks / year obtained from the collection of wild second eggs in years 1-10, and a harvest of 6 birds from the captive flock, beginning in year 9 for a release programme.

The fifth scenario on each table and figure is a model of the current captive flock with the supplementation of 2 fledged chicks / year obtained from the collection of wild second eggs in years 1-10, and a harvest of 6 birds from the captive flock beginning in year 9 for a release programme.

Table 4: Input includes base scenario parameter values, **annual supplementation** of the captive flock with wild chicks (2-4) collected as wild eggs in years 1-10, and an **annual harvest** of birds (4-6) from the captive flock for a release programme, beginning in year 9. The stochastic growth rate (r) of the captive population is an average rate over 100 years.

Scenario No.	Graph Line No.	No. of females reproducing	No. of fledged chicks obtained from the collection of wild second eggs in years 1-10	No. of birds harvested annually from captive population beginning in year 9	Mean stochastic growth rate (r) across all years	Mean surviving population size (N) at 100 years	Probability of extinction (Pe) at 100 years
224	1	33%	0	0	0.029	43	0.034
225	2	33%	2 males, 2 females	0	0.031	44	0.002
226	3	33%	2 males, 2 females	2 males, 2 females	-0.009	16	0.666
227	4	33%	2 males, 2 females	3 males, 3 females	-0.023	11	0.960
228	5	33%	1 male, 1 female	3 males, 3 females	-0.030	7	0.988

Scenario 224 (no supplementation and no harvest) and 225 (supplementation only, no harvest) give a low probability of extinction and a positive growth rate for the captive flock. Scenarios 226, 227, and 228 (each with varying degrees of supplementation and harvest) produce a high probability of extinction and negative growth rates (-r).

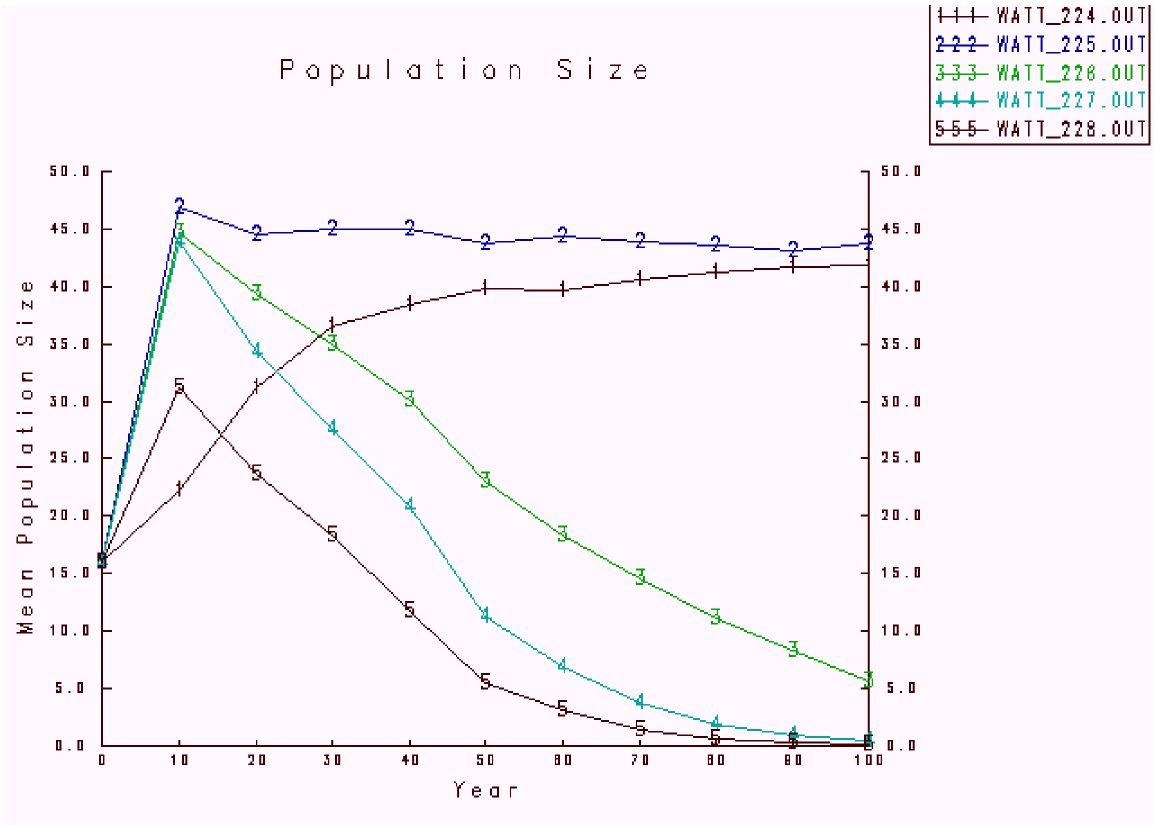

Figure 1: Under scenario 224, (no supplementation and no harvest) a carrying capacity (K) of 40 is reached after 40-50 years and the population is maintained above K(40) for the remainder of the 100 years. Scenario 225 (supplementation of 4 birds per year for the first 1-10 years, and no harvest), shows K(40) is reached after 8-10 years and remains at K for the remainder of the 100 years. Scenario 226 and 227 show that K(40) is reached after 8-10 years, but the population is not self-sustaining because as birds are harvested annually for release, the population declines. Scenario 228 illustrates that the population never reaches K(40) due to the lower rate of supplementation and annual harvest and the population declines.

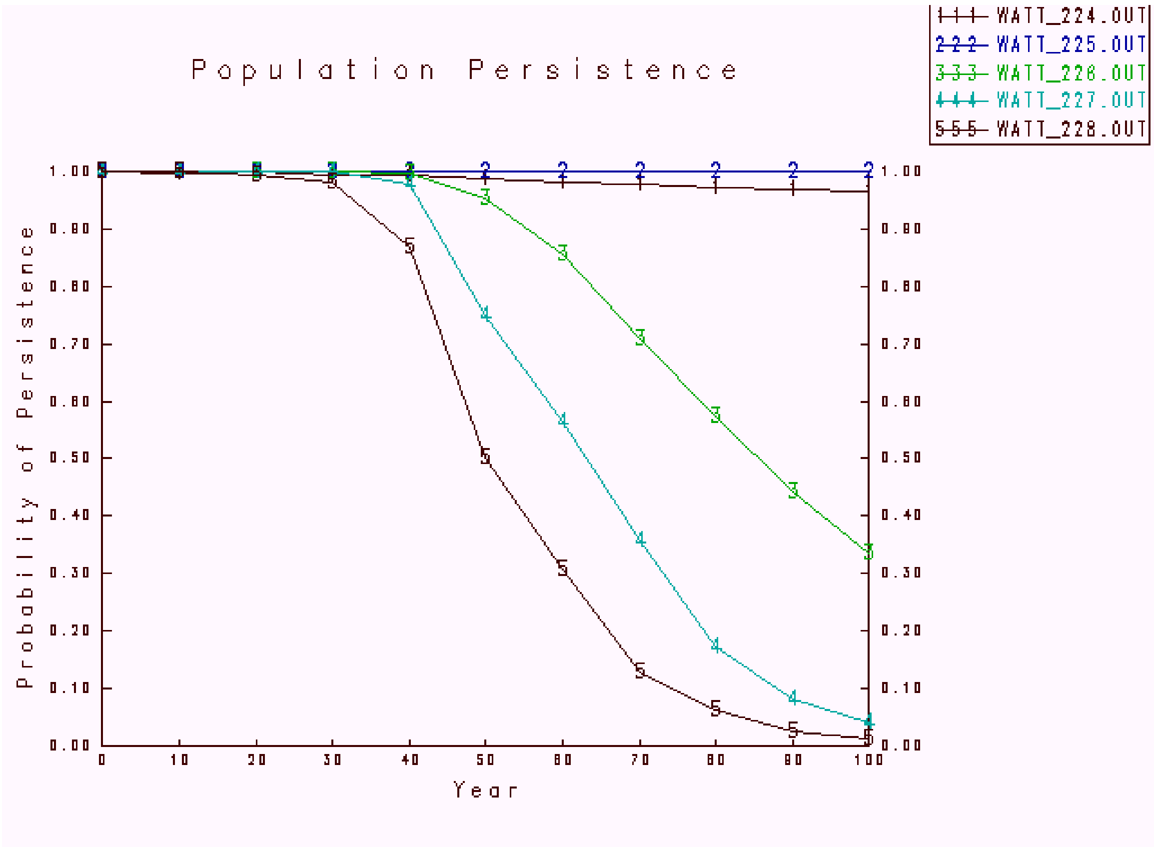

Figure 2: Under scenario 224, the captive flock (no supplementation or harvest) has a high probability of persisting over 100 years (probability of extinction, 'Pe' = 0.034). Scenario 225 (supplementation of 4 birds / year for the first 1-10 years, and no harvest) also shows that the captive flock has a high probability of persisting over 100 years. Under scenario 226, the population (with both supplementation of 4 birds / year for the first 1-10 years, and annual harvest of 4 birds beginning in year 9) persists for approximately 40 years and has a lower probability of persistence (30%). Scenario 227 and 228 have appreciably lower persistence probabilities after 15 and 35 years respectively, due to the higher annual harvest of 6 birds (Pe = 0.96 and 0.988 respectively).

Table 5: Input includes base scenario parameter values, **annual supplementation** of the captive flock with wild chicks (2-4) collected as wild eggs in years 1-10, and a **harvest every 3 years** of birds (4-6) from the captive flock for a release programme, beginning in year 9.

Scenario No.	Graph Line No.	No. of females reproducing	No. of fledged chicks obtained from the collection of wild second eggs in years 1-10	No. of birds harvested at 3 year intervals from captive population beginning in year 9	Mean stochastic growth rate (r) across all years	Mean surviving population size (N) at 100 years	Probability of extinction (Pe) at 100 years
234	1	33%	0	0	0.028	42	0.038
235	2	33%	2 males, 2 females	0	0.031	44	0.004
236	3	33%	2 males, 2 females	2 males, 2 females	0.039	39	0.020
237	4	33%	2 males, 2 females	3 males, 3 females	0.042	38	0.022
238	5	33%	1 male, 1 female	3 males, 3 females	0.042	37	0.066

All scenarios have a relatively low probability of extinction and positive average growth rates. Scenario 234, without supplementation has an average growth rate (r = 0.028) which is slightly lower than scenario 235 with a supplementation of 4 fledged chicks per year for the first 1-10 years. The 2 scenarios, 236 and 237 are not significantly different. Scenario 237 (with a supplementation rate of 4 chicks per year and a harvest of 6 birds every 3 years), yields an average growth rate (r = 0.024) and a low probability of extinction.

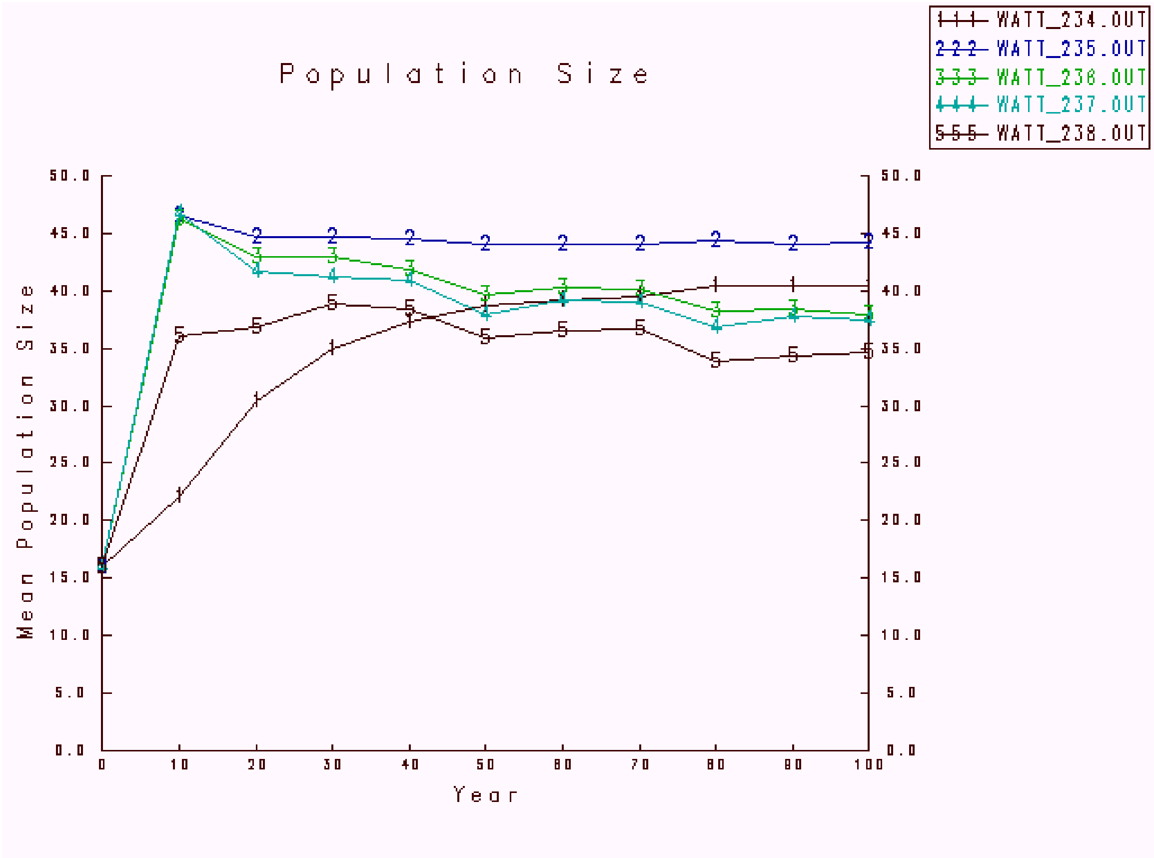

Figure 3: Under scenario 234 (no harvest or supplementation) the current captive flock will reach K(40) in 40-50 years. Scenario 235 (supplementation of 4 birds per year for the first 1-10 years, and no harvest), shows K(40) is reached in 6-8 years and then stabilizes above K for the remainder of the 100 years. Scenario 236 (supplementation of 4 birds / year in the first 10 years, and a harvest of 4 birds every 3 years, beginning in year 9) shows that K(40) is reached after 6-8 years and then the population maintains itself at or just slightly under K for the remainder of the 100 years. Scenario 237 (supplementation of 4 birds / year in the first 10 years, and a harvest of 6 birds every 3 years beginning in year 9) shows that K(40) is reached after 6-8 years, and the population can sustain its numbers just under K for the remainder of the 100 years. Scenario 238 (supplementation of only 2 birds / year in the first 10 years, and a harvest of 6 birds every 3 years beginning in year 9), that the population never quite reaches K, but its numbers are maintained (approximately 35-37 individuals) over the remaining years.

The following graph shows the same modeling scenarios as in Figure 3 (**harvest every 3 years**) but iterations have been allowed to run for 20 years and graphed at 2 year time intervals. Only years 0 - 20 are shown on the x-axis.

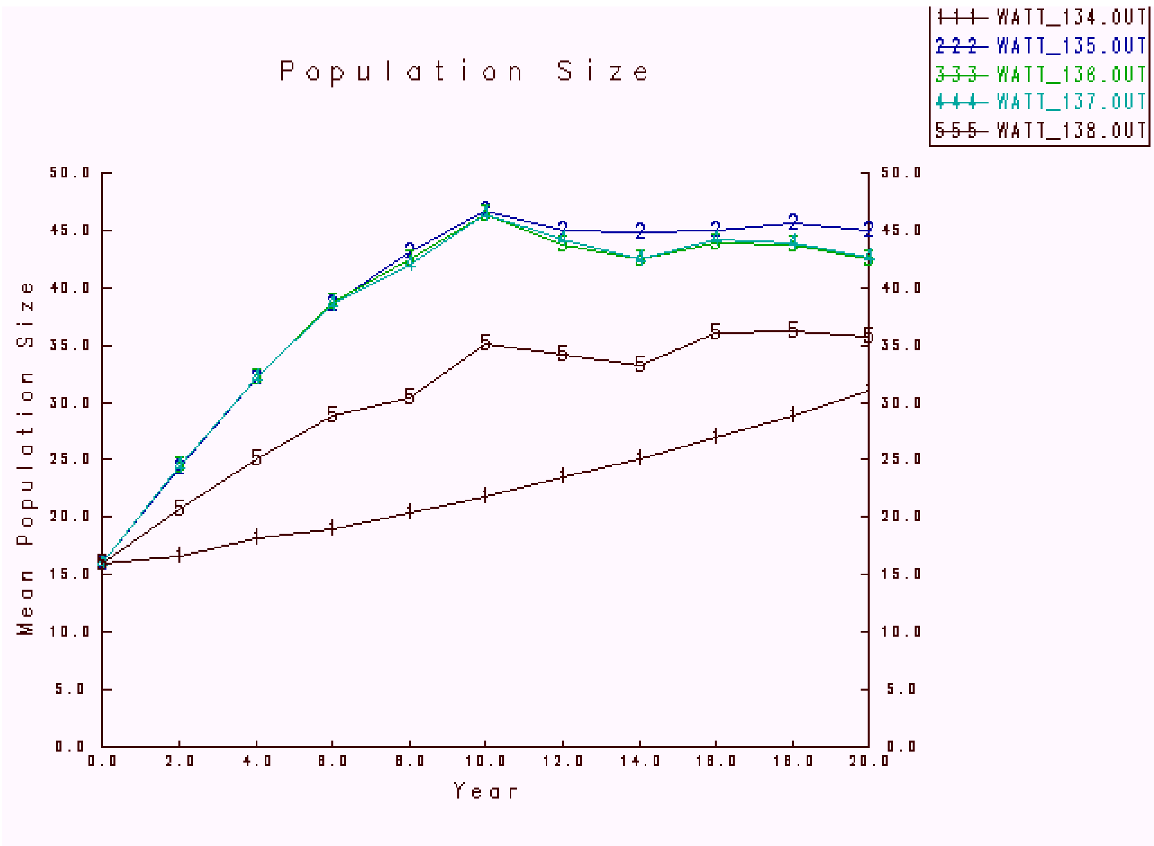

Figure 4: Under Scenario 134 (no harvest or supplementation), K(40) is not reached within 20 years. In Scenario 135, (supplementation of 4 birds per year for the first 1-10 years, and no harvest) the population reaches K within 6 - 8 years, stabilizes, and maintains itself above K for the remainder of the 20 years. Scenarios 136 (supplementation of 4 birds per year for the first 1-10 years, and a harvest of 4 birds every 3 years) and 137 (supplementation of 4 birds per year for the first 1-10 years, and a harvest of 6 birds every 3 years) also reach K within 6 – 8 years, and then fall slightly. These 2 scenarios show slight fluctuations in population size. Under Scenario 138 (supplementation of only 2 birds / year in the first 10 years, and a harvest of 6 birds every 3 years beginning in year 9), the population never reaches K(40) but after 10 – 12 years reaches a mean final population size of 35. The population then maintains itself between 34-37 individuals.

Table 6: Input includes **annual supplementation** of the captive flock with wild chicks (2-4) collected as wild eggs in years 1-10, and an **annual harvest** of birds (4-6) from the captive flock for a release programme, beginning in year 9. Base scenario parameter values were also used except that **40% of adult females over the age of 8 produce eggs**. This number may realistically be achieved through intensive management of the captive flock.

Scenario No.	Graph Line No.	No. of females reproducing	No. of fledged chicks obtained from the collection of wild second eggs in years 1-10	No. of birds harvested annually from captive population beginning in year 9	Mean stochastic growth rate (r) across all years	Mean surviving population size (N) at 100 years	Probability of extinction (Pe) at 100 years
244	1	40%	0	0	0.040	45	0.018
245	2	40%	2 males, 2 females	0	0.041	46	0.002
246	3	40%	2 males, 2 females	2 males, 2 females	0.001	23	0.448
247	4	40%	2 males, 2 females	3 males, 3 females	-0.016	13	0.856
248	5	40%	1 male, 1 female	3 males, 3 females	-0.023	10	0.924

Scenario 244 (no supplementation or harvest) shows a positive growth rate and low extinction probability for the captive flock. In scenario 245, (supplementation of 4 fledged chicks / year in years 1-10, and no harvest), the average growth rate of the captive flock is the same but has a lower probability of extinction. Scenario 246 (supplementation of 4 fledged chicks / year in years 1-10 and an annual harvest of 4 individuals beginning in year 9) shows a near zero average growth rate coupled with a greatly increased probability of extinction (44.8%). Scenarios 247 and 248 illustrate that the population has a negative growth rate (-r) and high extinction probabilities even though a higher percentage of adult females are producing eggs. These populations are unable to sustain an annual harvest of 6 individuals.

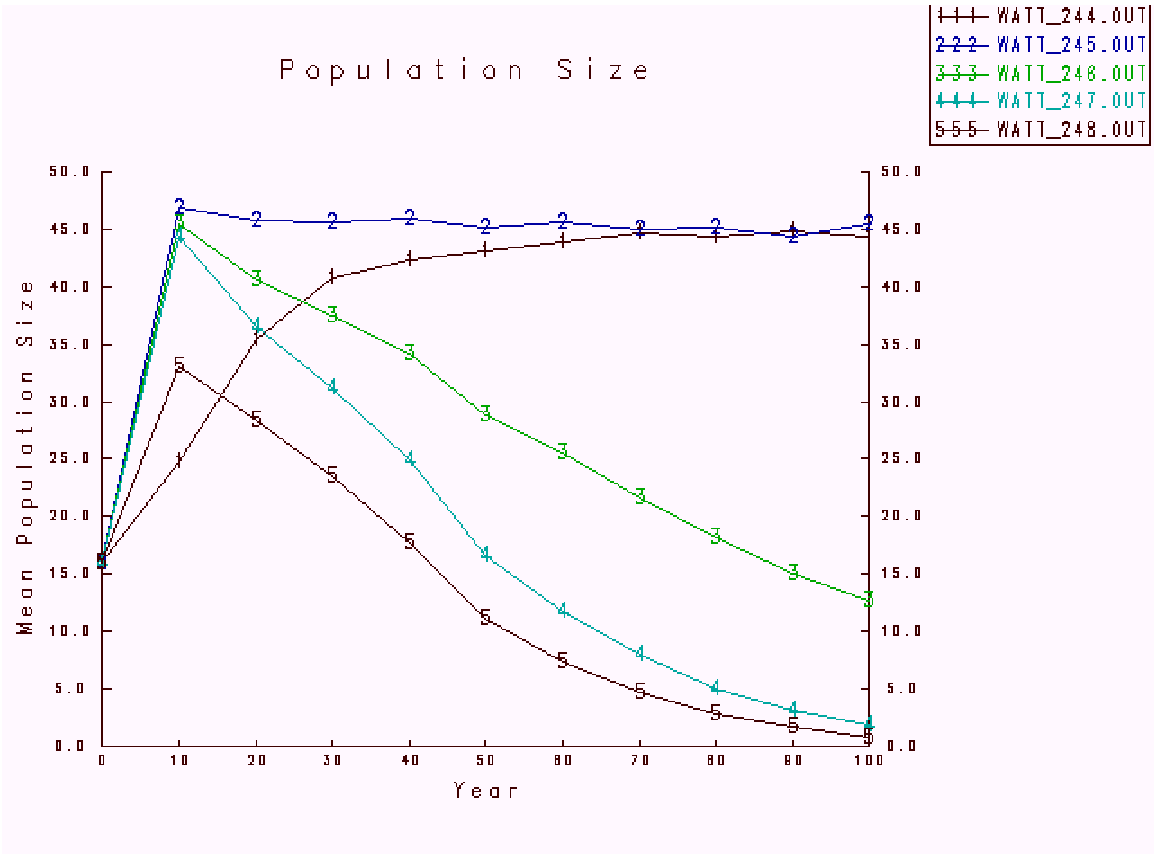

Figure 5: This graph shows scenarios with an annual harvest and 40% of adult females over the age of 8 produce chicks. Scenario 244 (no supplementation or harvest) reaches K(40) after approximately 30 years. The population increases slightly above K (41-45 individuals) and maintains itself over the remainder of the 100 years. Scenario 245 (supplementation of 4 fledged chicks / year in years 1-10, and no harvest) reaches K(40) after 6-10 years and then stabilizes around a total population of 46 individuals. Mean population sizes in scenarios 246 and 247 also reach K(40) after 6-10 years, but after 20-25 years, and 15-20 years respectively, fall below K and continue to decline with a high risk of extinction. Scenario 248 never reaches K(40) and the population progressively declines.

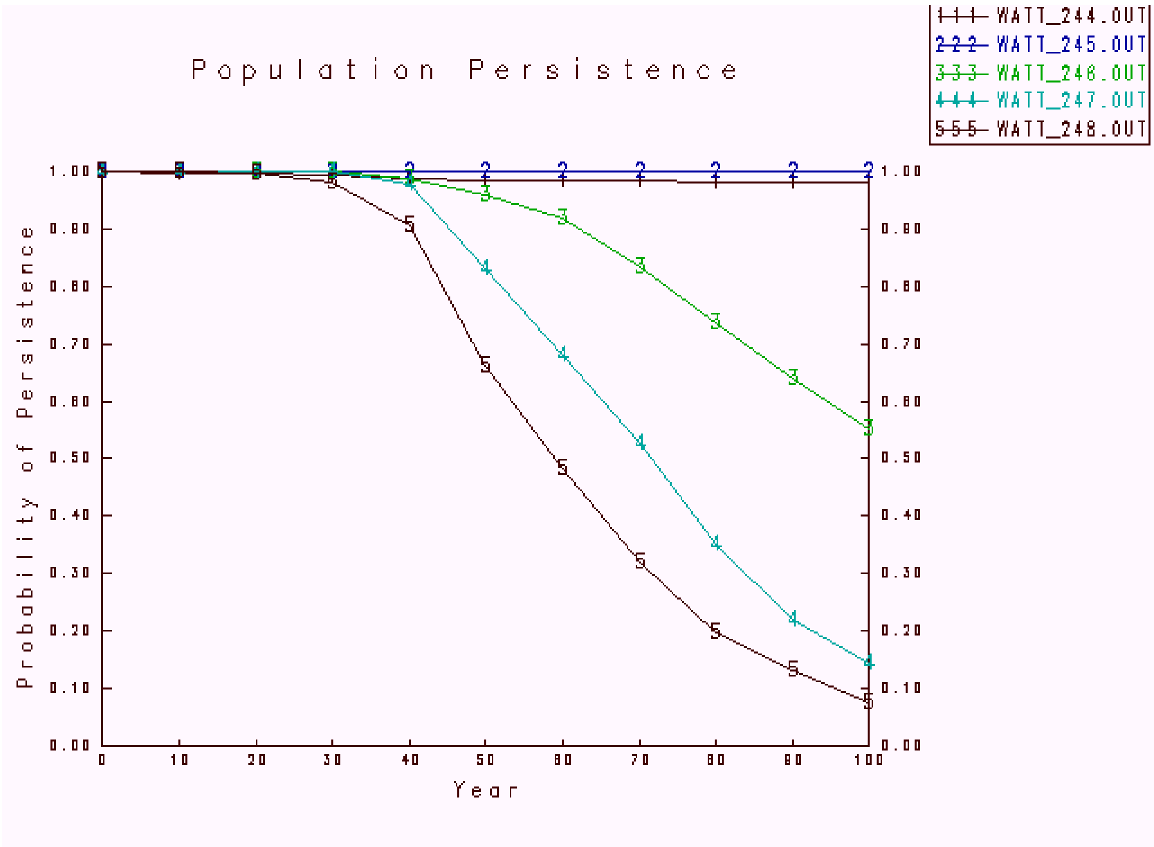

Figure 6: This graph shows scenarios with an annual harvest and 40% of adult females over the age of 8 produce chicks. Under scenario 244 and 245 (with or without supplementation, and no harvest) show the captive flock has a high probability of persisting over 100 years. Scenarios 246, 247, and 248 show that in spite of supplementation during the first 10 years, and an increased number of females producing eggs, the population has a decreased probability of persistence. The population cannot sustain an annual harvest of 4 to 6 individuals.

Table 7: Input includes **varying levels of annual supplementation** to the captive flock with wild chicks (2-4) collected as wild eggs in years 1 – 10, and **no harvest for release**. Iterations have been allowed to run for 20 years and graphed at 2 year time intervals. Base scenario parameter values have been used except **increased number of living chicks** per female has been used:

Scenario 107-100				Baseline parameter		
20% of females produce 1 living chick / year				47% of females produce 1 living chick / year		
30%	"	2	"	20%	"	2 "
30%	"	3.	"	16%	"	3 "
15%	"	4	"	10%	"	4 "
5%	"	5	"	5%	"	5 "
0%	"	6	"	2%	"	6 "

Also in scenarios 109 and 110, that the **number of females (over the age of 8) producing eggs per year has been increased** from 33% to **50%.**

Scenario No.	Graph Line No.	No. of females reproducing	No. of fledged chicks obtained from the collection of wild second eggs in years 1-10	No. of birds harvested from captive population beginning in year 9	Mean stochastic growth rate (r) during years after supplementation completed	Mean population size (N) at 20 years	Probability of extinction (Pe) at 20 years
107	1	33%	2 males, 2 females	0	0.038	45	0
108	2	33%	1 male, 1 female	0	0.041	43	0
109	3	50%	1 male, 1 female	0	0.065	47	0
110	4	50%	2 males, 2 females	0	0.063	47	0

All scenarios have low extinction probabilities. Scenario 107 (supplementation of 4 birds for the first 10 years) shows that the current captive flock would have a positive average growth rate and would sustain itself above K(40) over 20 years. Scenario 108 (supplementation of the captive flock reduced to 2 birds / year for the first 10 years) shows a slightly larger average growth rate and a similar population size after 20 years as compared to scenario 107. Scenario 109 (supplementation of 2 birds / year to the captive flock, and the number of females producing eggs per year has been increased from 33% to 50%) shows the largest average growth rate (0.065) of all scenarios. Scenario 109 has a population size of 47 individuals after 20 years because a greater number of females are producing eggs each year. Scenario 110 (supplementation of 4 birds per year for the first 10 years, and the number of females producing eggs each year set at 50%) shows essentially the same average growth rate (0.063) as Scenario 109, and has the same mean sized population (47 individuals) as scenario 109 at 20 years.

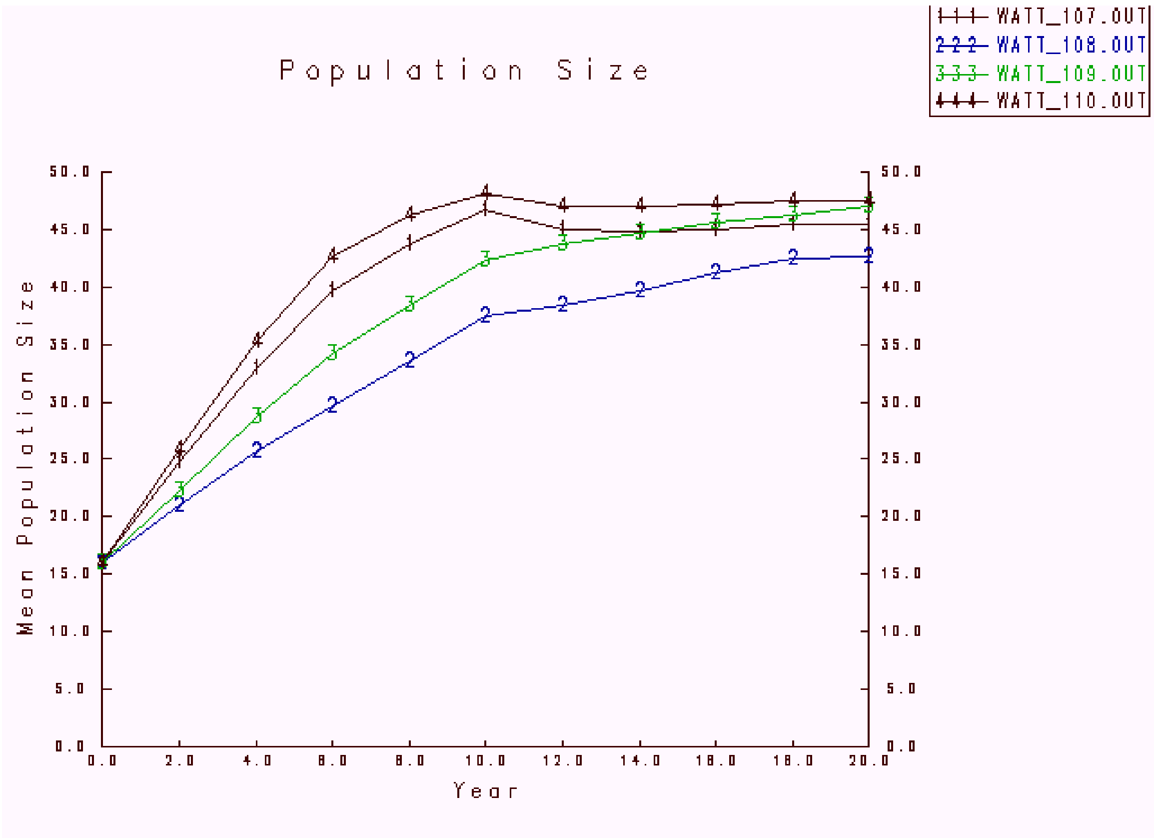

Figure 7: No harvest; iterations have been allowed to run for 20 years and graphed at 2 year time intervals. Only years 0 - 20 are shown on the x-axis. **Number of living chicks per female has been increased**; and in scenarios 109 and 110 the number of females (over the age of 8) producing eggs per year has been increased to **50%**.

Under scenario 107 (33% females producing eggs and 4 birds supplemented per year for the first ten years) reaches K(40) after approximately 8 years. Scenario 108 (33% of females producing eggs and a lower supplementation rate of 2 birds / year for the first 10 years) reaches K(40) after approximately 14 years. Scenario 109 (50% females producing eggs and 2 birds supplemented per year for the first 10 years) reaches K(40) after approximately 9 years. Scenario 110 (50% females producing eggs and 4 birds supplemented per year for the first 10 years) reaches K(40) after 6-8 years.
Table 8 : Input includes **annual supplementation** of 4 birds to the captive flock during years 1 – 10. Iterations have been allowed to run for 20 years and graphed at 2 year time intervals. Baseline parameter values have been used

except **the number of females (over the age of 8) producing eggs per year** has been increased to **50%. Annual harvest begins in year 11** and **harvest level (2-4) has been varied** in scenarios 112 and 113.

Scenario No.	Graph Line No.	No. of females reproducing	No. of fledged chicks obtained from the collection of wild second eggs in years 1-10	No. of birds harvested from captive population beginning in year 11 -20	Mean stochastic growth rate (r) across all years	Mean population size (N) at 20 years	Probability of extinction (Pe) at 20 years
111	1	50%	2 males, 2 females	0	0.087	47	0
112	2	50%	2 males, 2 females	1 male, 1 female	0.077	45	0
113	3	50%	2 males, 2 females	2 males, 2 females	0.066	42	0

All 3 scenarios show positive average growth rates over 20 years with low probabilities of extinction.

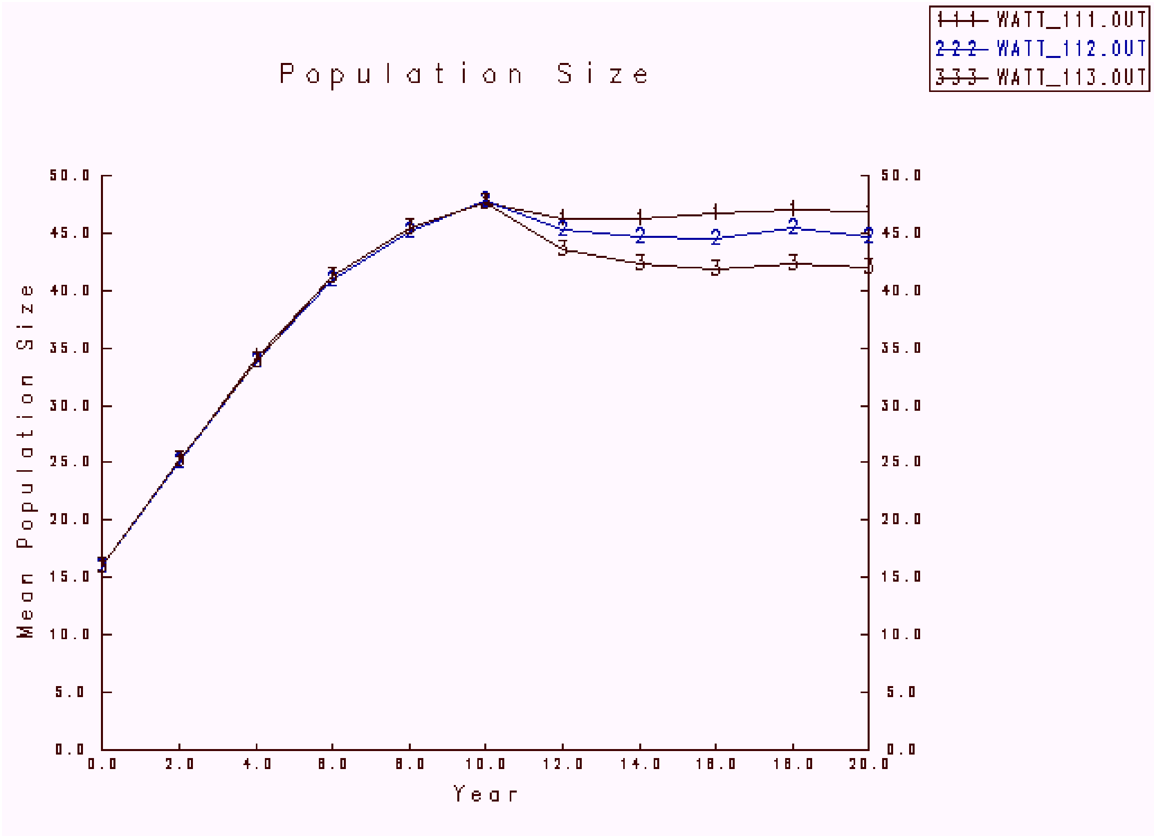

Figure 8: Iterations have been allowed to run for 20 years and graphed at 2 year time intervals. Base scenario parameter values have been used except the **number of females (over the age of 8) producing eggs per year** has been increased to 50%. **Annual harvest begins in year 11** and harvest level (2-4) has been varied in scenarios 112 and 113.

Under all 3 scenarios the captive populations reach K(40) after 6-8 years, and total population sizes are all above K (range between 42 and 47 individuals) after 20 years.

Summary of VORTEX Modeling of the Captive Flock in South Africa

If management of the captive flock obtains the base scenario parameter values of production (see Table 1) and if it undergoes no harvest of any kind for a release programme, modeling shows the flock could reach a K(40) after approximately 40 – 50 years and then maintain itself (be self-sustaining) for the remainder of 100 years.

The supplementation of 4 fledged chicks obtained from the collection of wild second eggs in years 1-10, greatly reduces the time it takes for the captive population to reach K(40). With this level of supplementation, the captive population reaches K(40) after 8 to 10 years (see Figure 1, scenario 224 and 225). In addition, if the number of females producing eggs increases to 40 or 50%, the time to reach K(40) is reduced slightly to 6 to 8 years (see Figure 7, scenarios 108, 109, and 110, and Figure 8). It is also logical to assume that an increase in living offspring per female will also assist the population in reaching K(40) more quickly (see Figure 7).

The size of the captive population is affected by the number of birds harvested and the timing of harvests. The length of time the captive population stays at or above K is also affected by the number of birds harvested and the timing of harvests. In all scenarios when annual harvest was modeled, the captive population could not sustain itself over a 100 year time period (see Figure 1, scenarios 227 and 228, and Figure 5, scenarios 247 and 248).

When 4 birds are harvested every 3 years beginning in year 9, the total captive population falls just slightly below K after 60-70 years and maintains itself around 40 individuals for the remainder of the 100 years (see Figure 3, scenario 236). When the number of birds harvested every 3 years is increased to 6, the total captive population falls below K(40) earlier (after 40-50 years) and maintains itself for a longer period of time under K (approximately 35 individuals) (see Figure 3, scenario 237). With the supplementation of only 2 fledged chicks to the captive flock in years 1-10, K(40) is never obtained, but the population is able to maintain itself just below 40 individuals even with a harvest of 6 birds every 3 years (see Figure 3., scenario 238).

Management Recommendations

The following management recommendations are based upon the outcome of the VORTEX modeling. It has been demonstrated that a supplementation programme can play a significant role in the long-term survival of the wild South African population of wattled cranes. The current goal is to build the present captive flock so that in the future, it can be used to provide birds for a supplementation programme.

To achieve this goal, over the next 1-10 years, effort should be made to add as many chicks as possible to the captive flock to allow it to reach a carrying capacity of 40 as quickly as possible. This will improve the age pyramid of the population by increasing the number of mature birds (8+ years old) within the flock. After carrying capacity is reached, then supplementing the captive flock with 2 birds every 10 years will be necessary to reduce inbreeding effects, which should reduce the loss of heterozygosity to approximately 1% per generation. Inbreeding levels should be closely monitored in the future. Maximum inbreeding coefficient of 0.0625 in any offspring is targeted for the management of captive whooping cranes (*Grus americanus*) and Japanese red-crowned cranes (*Grus japonensis*). Supplementation of the captive flock from the wild population also has the added benefit of almost eliminating the probability of extinction for the captive flock.

VORTEX modeling also shows that every effort must be made to improve the husbandry and egg production potential of the birds in captivity:

- Chick survivorship should be maximized for both captive and wild produced eggs. First year mortality needs to be 30% or less.
- All chicks need to be properly reared and optimally managed from hatch through fledging and adulthood (e.g. socialized at an early age, given good environmental conditions) to ensure they will breed at age 8 or earlier.
- All breeding pairs need to be monitored and managed closely. Attention should be given to optimizing the physical environment pairs are housed in (i.e. secure territory with minimal human disturbance). The International Wattled Crane Studbook shows that only 33% of mature birds (8+ year of age) in any given year produce eggs. Every effort should be made to improve this number to 50% or greater. Increasing the rate from 33 to 50% also has the added benefit of increasing the growth rate of the captive flock and reducing the probability of extinction.
- Fertility must be optimized in all captive pairs and females must be managed for increased egg production/year.
- A viable technique for improving the current flock's age pyramid and reaching carrying capacity quickly would be to supplement the flock with eggs / live birds from another sources such as captive breeding facilities in the U.S. However, at this point in time, preliminary genetic research suggests that the birds in South Africa are genetically distinct from the birds in the US. Based on the potential contribution U.S. birds could contribute to South African captive breeding efforts, we recommend further investigation of the genetics issue (also see genetics section of this chapter).

Once carrying capacity is reached after approximately. 6-10 years, there is a high probability that chicks will be available from the captive flock for a release programme. The captive population, as modeled, will allow a sustained harvest of 4-6 birds every 3 years and will be self-sustaining at or just below a carrying capacity of 40.

As South African facilities gain additional experience with breeding wattled cranes in captivity, the baseline parameters used for modeling will need to be altered. It is recommended that all base scenario parameter values are reviewed annually based on the outcome of breeding efforts specifically in South Africa and that VORTEX modeling be updated on an annual basis.

3. SOUTH AFRICAN WATTLED CRANE GENETICS ISSUE.

In 1996 and 1999, several U.S. institutions donated adult cranes and eggs to the South African Wattled Crane Captive Breeding and Supplementation Programme. In 1995 South Africa signed the Convention of Biodiversity that attempts to ensure that the genetic integrity of South African species is maintained. As a result, in 1999, the South African CITES authority imposed a moratorium on imports of wattled crane adults and eggs from any other population, including the U.S. captive population. This moratorium will remain in force until the genetic relationships between the various sub-populations of wattled cranes in southern Africa have been established.

Genetic differences exist between those populations inhabiting large floodplain wetland systems (such as the Kafue Flats, Marromeu delta and the Okavango delta) and those of the small isolated wetlands of South Africa and Ethiopia. It is unclear whether there is movement between the various sub-populations (i.e. mixing of genetic material).

Genetics Study and Results

In 1999 and 2000, the South African Crane Working Group sent blood samples from South African, Zimbabwean and Botswanan wattled cranes to Ken Jones at the University of Illinois at Chicago. Ken used both microsatellite and mitochondrial DNA techniques to analyze the samples.

Samples sizes were too small to make any definitive conclusions but preliminary investigation supports the following:

- South African samples show no loss of nuclear or mitochondrial genetics diversity, as compared to Zimbabwean samples.
- Although they share many microsatellite alleles and one mitochondrial haplotype, the South African and Zimbabwean populations show significant divergence and should be for the moment considered different populations.
- Botswana and Zimbabwean samples showed very little divergence. However much larger sample sizes are necessary to make any strong conclusions. The assumption that they are in the same population was not refuted by this study.
- The Kalahari / Limpopo River Basin seems to be a barrier to gene flow between the South African and Zimbabwean / Botswanan populations.

However, the addition of samples from Mozambique will be necessary to explore the possibility of gene flow across the historic coastal populations

- A complete species wide study encompassing samples from all geographic areas is necessary to resolve issues of taxonomic management units (e.g. subspecies, evolutionary significant unit's, management units, etc.) (Jones and Ashley, unpublished report to South African Crane Working Group)

A special session was convened to discuss the genetics study results at the PHVA. It was agreed that it is important to resolve the genetics question. However VORTEX modeling of the captive population in South Africa showed that our current flock of South African origin is large enough, if correctly managed, to reach a target capacity of 40 birds within 8 – 10 years time. Imports of birds or eggs from the U.S. are therefore, not necessary at this time.

In conclusion it was agreed that there must be continued research to address the origins of the South African population. Two valid hypotheses with vastly differing consequences were discussed:

1. Range expansion of the species has left South Africa its own unique population with no gene flow to the core population.
2. Range expansion was via coastal colonization with recent (1930's) gene flow via Mozambique. If gene flow existed from Zimbabwe to Mozambique and Mozambique to South Africa, a clinal gene flow could explain the genetics differentiation seen in the study (Jones and Ashley 2000 - Unpublished report to the South African Crane Working Group).

Hypothesis 1 implies no further importation of birds from the U.S. or other range states. Hypothesis 2 allows the possibility of the CITES authorities to permit importation from the U.S. or other range states and this may negate the need for a captive breeding programme in South Africa.

To further test these 2 hypotheses the following were suggested:

- Conduct research on the Mozambique population through the collection of samples – from museum specimens located in Maputo, Lisbon and other international museum collections.
- Continue the collection of additional blood samples from South African birds.
- Liaison with Zimbabwe, Botswana and Zambia to obtain more samples (50 is the suggested minimum number of blood samples needed from each population).

Timing and Potential Costs of Further Investigation

The process of sample collection through the analysis stage is estimated to take one year. Estimated cost per sample is $86.00 USD (includes mitochondrial and micro-satellite analysis). Salary for one year is $14,000 USD. Total cost of the analysis for one year is $25,000 USD. These costs may be negotiable. To reach consensus on the genetics issue that will satisfy the South African CITES authorities, it is recommended that at least 5 geneticists review the initial survey and comment on the validity of the above hypothesis and the future direction of research.

Other Issues

It was agree that we need to identify all the relevant authorities that require this information in the formulation of their importation policies, (i.e. South African CITES, U.S. CITES, KwaZulu-Natal Nature Conservation Services, Mpumalanga Parks Board). Governmental authorities are traditionally very conservative and it may take a number of years to conduct the study and reach consensus on the results. It was decided that we would not wait for this issue to be resolved before employing resources to build a captive flock.

4. ALTERNATIVES TO CAPTIVE BREEDING.

Translocation

There was brief discussion on the possibility of capturing non-breeding birds from the floating flock and translocating them to areas of suitable habitat. These techniques could be used to re-colonize vacant, previously used areas or areas of unoccupied, suitable habitat. Translocation was not considered a viable option as the characteristics of suitable wattled crane habitat have not been clearly delineated and not enough is known about wattled crane social structure to recommend such an action at this time.

Cryopreservation

Cryopreservation of crane sperm is being successfully used at several facilities in the U.S. Currently, there is no technology available to preserving female crane ovum. Cloning may be applicable in the future. It was agreed that further investigation of cryopreservation is warranted.

Specific Courses of Action Recommended by the Captive Group

Based on the outcome of the VORTEX modeling and the PHVA process, the Captive Group recommends that the supplementation programme be discontinued for the next 6-8 years. During this time, emphasis will be placed on increasing production in the captive stock. Once the captive population reaches the targeted K of 40 individuals, young chicks need only be retained to replace birds that die. All other chicks would be available for release.

The following actions were identified as priorities. Groups or persons were charged with the responsibility for completing the tasks, and time lines for completion were established.

a) Encourage and support research to improve knowledge of the floating flock. This includes research to:

- **Identify characteristics of suitable wattled crane habitat**
- **Identify mortality factors affecting all age classes**
- **Identify factors that influence the size of the non-breeding flock**
- **Determine if age class structure affects rate of pair formation**
- **Determine the movement patterns of the non-breeding flock and birds fledged from individual nesting territories.**

Responsibility :	SACWG and KwaZulu-Natal Crane Foundation
Time line for completion :	2 years (August 2002)
Resources :	National Crane Research Co-coordinator and Field officers
Collaborators :	KwaZulu-Natal Nature Conservation Services, SA research institutions, Fitzpatrick Institute, other universities
Measurable outcomes:	Release site selection and management will be improved when the characteristics of suitable Wattled Crane habitat are determined. The effects of directly supplementing birds into the wild flock will be better understood. This information can be used to measure release success and improve release techniques.

b) Review the current participants and structure of the Wattled Crane Recovery Team

Responsibility :	Wattled Crane Recovery Team (WCRT) / Lindy Rodwell
Time line for completion :	First revision August 4th 2000, 2nd revision, November 2000
Resources :	SACWG, outside crane experts
Collaborators :	Pan African Association of Zoological Parks, Aquarium and Botanical Gardens (PAAZAB)
Measurable outcomes :	Recommendations for a new structure and function of WCRT based on priority action steps identified by the PHVA.

c) Review annually the infrastructure and capacity of the captive program in South Africa and develop a plan for the expansion of number of facilities involved with the Wattled Crane captive breeding programme.

Responsibility:	WCRT
Time line for completion:	November 2000 in tandem with South African Crane Working Group's bi-annual workshop

Resources:	All facilities currently involved with the captive breeding programme, potential facilities, SACWG participants, and PAAZAB
Measurable outcomes:	Identify all facilities that will be involved with housing the target captive population. Identify specific gaps in training needs and capacity per each facility. Finalize a plan of action.
Collaborators:	PAAZAB/other potential facilities
Measurable outcomes:	Increase in the number of facilities involved with the captive breeding programme

d) Investigate options for chicks to be reared at alternative facilities, review rearing protocols, ownership/directorship of the National Wattled Crane Captive Breeding Programme, Memorandum of Participation for all facilities, logistics and strategy of maintaining of captive flock, and the housing of the birds imported from the US.

Responsibility:	SACWG
Time Line for completion:	November 2000 and again May 2001
Resources:	SACWG
Collaborators:	PAAZAB, Treehaven Waterfowl Trust, Umgeni River Bird Park, KwaZulu-Natal Crane Foundation.
Measurable outcomes:	Gain long-term facility support for the captive breeding programme.

e) Resolve the issue of chicks continuing be reared on Verloren Valei Nature Reserve given that no wild releases will occur there for at least the next 5 years and that birds will only be reared as captive stock.

Responsibility:	SACWG
Time Line for completion:	Prior to November 2000
Resources:	SACWG
Collaborators:	Mpumalanga Parks Board
Measurable outcomes:	Determine how VVNR rearing facility will be utilized over the next 5-8 years

f) Review captive breeding and supplementation program based on the future results of genetic testing.

Responsibility:	WCRT
Time line for completion:	Post genetics results (most likely in 2- 5 years).
Resources:	SACWG
Collaborators:	Geneticists (US and SA), South African CITES
Measurable outcomes:	Potentially develop a new strategy for captive program based on outcome of genetic study.

If further investigation demonstrates a range-wide genetics study is warranted, the group will review its ability to lend additional assistance to sample acquisition.

Responsibility:	WCRT
Time line for completion:	Post genetics study – in 2- 5 years
Resources Involved with Sample Acquisition:	Field Officers (SA), Carlos Bento (Mozambique), Ben Kamwaneshe (Zambia)
Collaborators:	Geneticists (USA and SA), South African CITES
Measurable outcomes:	Resolution / agreement on genetics issue

g) Explore the supportive technologies of nuclear transfer and cryopreservation

Responsibility:	Dr. Mark Penning
Time line for completion:	1 year (completed by August 2001)
Resources:	Umgeni River Bird Park
Collaborators:	Julie Langenberg, Yolan Friedman, Naida Loskutoff, other experts
Measurable outcomes:	Recommendations on feasibility to WCRT

LIFE HISTORY, POPULATION DYNAMICS AND MODELLING WORKING GROUP REPORT

Participants: Kevin McCann, Ken Jones, Ian Rushworth, Neil Langley, Muchai Muchane, Yolan Friedman.

MODELLING OF WILD SOUTH AFRICAN WATTLED CRANE POPULATION

INTRODUCTION

Species: *Bugeranus carunculatus* Gmelin 1789

Study population location: Entire range in the Republic of South Africa (including the provinces of Mpumalanga, Free State, KwaZulu-Natal and the Eastern Cape).

WORKING GROUP TASK

The Modelling Working Group was tasked with developing a baseline model which best approximates the current population dynamics of the wattled crane population in South Africa, taking into account knowledge of the current population parameters, genetic structure and carrying capacity. The model was then used to predict the outcome of different scenarios on the population so as to improve decision-making in respect of management / objectives needed to maintain a viable wattled crane population.

The wattled crane population in South Africa has been reduced over the past decades to very low numbers (1982 = 379 individuals, 1999 / 2000 = 234 individuals), and is therefore being impacted upon by small population dynamics (see accompanying article on small population biology). It is for this reason that a modelling working group forms an important component of the PHVA process. The wattled crane population parameters allow the use of the VORTEX simulation model (REF), a simulation programme designed to aid the understanding of the effects of deterministic, demographic, environmental, and genetic stochastic events on the dynamics of a wild population.

CONCEPTUAL MODEL

Figure 1 indicates conceptually the best understanding of the wattled crane's population dynamics and parameters. Chicks are produced at a rate determined by the nesting and fledging success rates. Successfully fledged chicks move into the floater population deterministically at one year of age, and then at 8 years (age at which maturity is achieved) deterministically attempt to move into the adult breeding population. If habitat is available, then this move is successful; if not then they remain in the floater population. Adult breeding birds can move back into the floater population if breeding habitat is reduced (i.e. carrying capacity is reduced below adult population size). These birds attempt to re-enter the adult breeding population every year. Mortality factors impact on the floaters and breeders independently as a result of different behaviour and response to environmental stochasticity.

However, VORTEX did not allow such complex modelling, and a simpler model was used that grouped floaters and breeding adults into a single population, with provision being made for age-specific mortality rates. As carrying capacity of breeding adults is determined directly by the availability of suitable wetlands, and that of floaters is independent, or only indirectly dependent, on wetlands, this simple model does not adequately account for population responses to wetland loss or differential response to mortality factors.

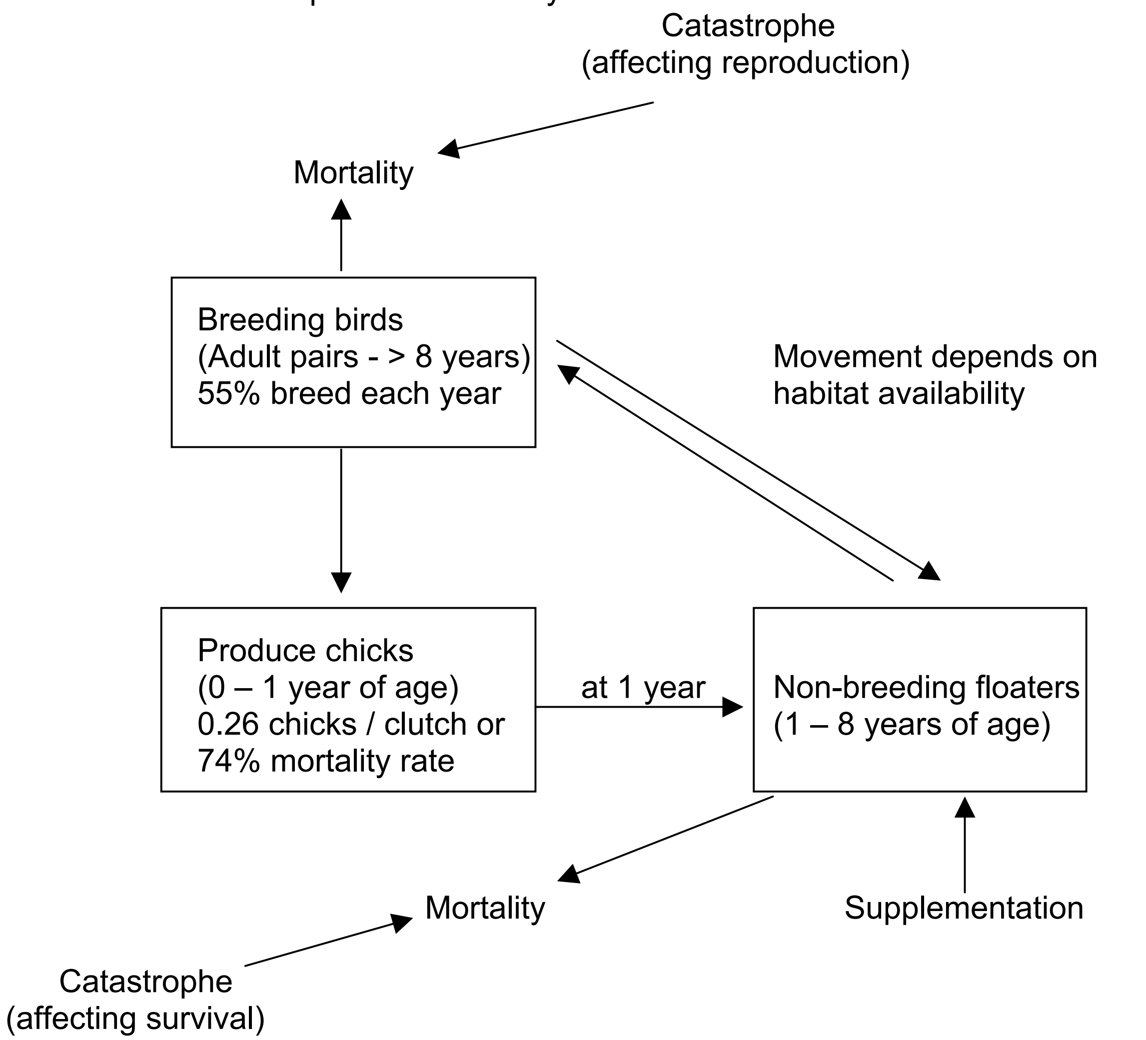

Figure 1: Conceptual model of the population dynamics of the wild wattled crane population in South Africa.

BASELINE MODEL

Input parameters for baseline model were as follows -

- Definition of Extinction :
  Extinction was defined as the complete absence of one or the other sex.

- Number of Populations :
  Due to the mixing of the breeding subpopulations in South Africa (determined through unpublished colour ringing return data), the South Africa population is assumed to be a single population.

- Inbreeding Depression :
  Preliminary genetic investigation (Ken Jones – unpublished report) suggests that the population shows no signs of inbreeding depression (depressed survival due to mating between close relatives) and hence no depression was assumed.

- EV (reproduction) to be concordant with EV (survival) :
  In the absence of data to the contrary, it was assumed that environmental variation (EV) would affect reproduction and survival equally.

- Types of Catastrophes :
  A single catastrophe event was modelled. This event was the well documented 10-year cyclical rainfall pattern in South Africa. Long-term rainfall figures shows a 10-year wet period followed by a 10-year dry period. The catastrophe modelled the negative affect on breeding during the dry period. This was modelled as depressing reproduction by 10% and survival by 5%, with a 20% probability of the event occurring each year.

- Monogamous, Polygynous or Hermaphroditic population :
  Wattled cranes are assumed to mate for life and are therefore classed as long-term monogamous breeders.

- Age at First Reproduction (males and females) :
  Although sexually mature at age 4 (laproscopic investigations), captive birds do not breed until age 7 (Abrey 1992), and wild birds were found to pair and breed for the first time at age 8 (unpublished colour ringing data). Males and females were therefore assumed to breed at age 8.

- Maximum Breeding Age :
  The maximum breeding age was assumed to be 45 years of age. Discussion was held in plenary on the maximum breeding age, with opinions ranging from 30 years to 60 years. Consensus was reached to use 45 years as the best estimate of maximum breeding age.

- Sex Ratio :
  Data taken from the South African studbook dating from 1912 to 1999 (Wilkins 2000, in press), including all individuals taken from the wild as well as second eggs collected, shows a hatching sex ratio of : Male : Female : Unknown, 20 : 20 : 25). An even sex ratio was chosen, 50 : 50 sex ratio.

- Maximum Litter Size :
  A litter size of 1 was used as the second egg is abandoned as soon as the first hatches.

- Density Dependent Breeding :
  No data exists to disprove the use of density dependence.

- Percentage of Adult Females Breeding:
  The percentage of adults breeding was determined by analysing the Mpumalanga population between 1986 and 1992 (for which there is detailed raw data on breeding biology) and for aerial counts of the KwaZulu-Natal population between 1993 and 2000 (Kevin McCann – unpublished report). In Mpumalanga 54.63% (SD = 31.47) of breeding pairs bred in any one year, while in KwaZulu-Natal 55.49% (SD = 6.84) of pairs bred. Combining data for both regions, 54.82% (SD = 27.94) of pairs bred in any one year.

- Mortality Rates :
  Juvenile –
  The juvenile mortality rate was determined from Tarboton *et al* (1984). In the KwaZulu-Natal population in the early 1980's the success rate was 0.26 chicks per clutch (0.55 hatching success X 0.49 fledging success). Therefore, the juvenile mortality rate was set at 74%, i.e. 0.74 of all clutches laid do not successfully raise a chick (maximum litter size of 1).
  Immature / Adult Mortality Rates –
  The first accurate population estimate of 379 individuals was made in 1980 and the immature / adult mortality rate which best approximates the decline to the current (1999 / 2000) population of 234 individuals is 6%. This rate was used for all age groups from 1 year of age to reproductive senescence.

- Population Age Distribution :
  The population is assumed to have a stable age distribution.

- Initial Population Size :
  The initial population size was set at 379 individuals (1980 data - Wattled crane PHVA Briefing Document).

- Carrying Capacity :
  The carrying capacity was arbitrarily set at 500, due to the lack of adequate information on the availability of wetland breeding habitat.

- Trend in Carrying Capacity :
  No trend was set for the carrying capacity.

- Harvest / Supplementation :
  None

Output data:

The model was run producing the following population response:

Table 1: Vortex output data from the baseline model of the wattled crane population.

Deterministic Growth rate R	Stochastic Growth rate r	Standard Deviation	Probability of Extinction (%)	Population Size (N)	Standard Deviation	Time to Extinction (years)	Standard Deviation	Observed Heterozygocity (%)
-0.028	-0.0357	0.062	7.00	14.55	9.71	93.43	7.70	95.85

Notes on the Output Baseline Model:

Year 0 in Figure 2 represents the year 1982 while year 18 approximates the current time of year 2000. This population has a negative growth rate (Table 1 - r = -0.028), indicating that the population is in deterministic decline (the numbers of deaths outpace the numbers of births), and will become extinct even in the absence of any stochastic fluctuations. Following the model simulation, the stochastic growth rate becomes more negative (-0.0347) indicating that stochastic fluctuations further affect the population negatively. In summary, this baseline model indicates that the South African wattled crane population (without any management intervention) has a 7% chance of becoming extinct within approximately 93 years from 1980 (Figure 2).

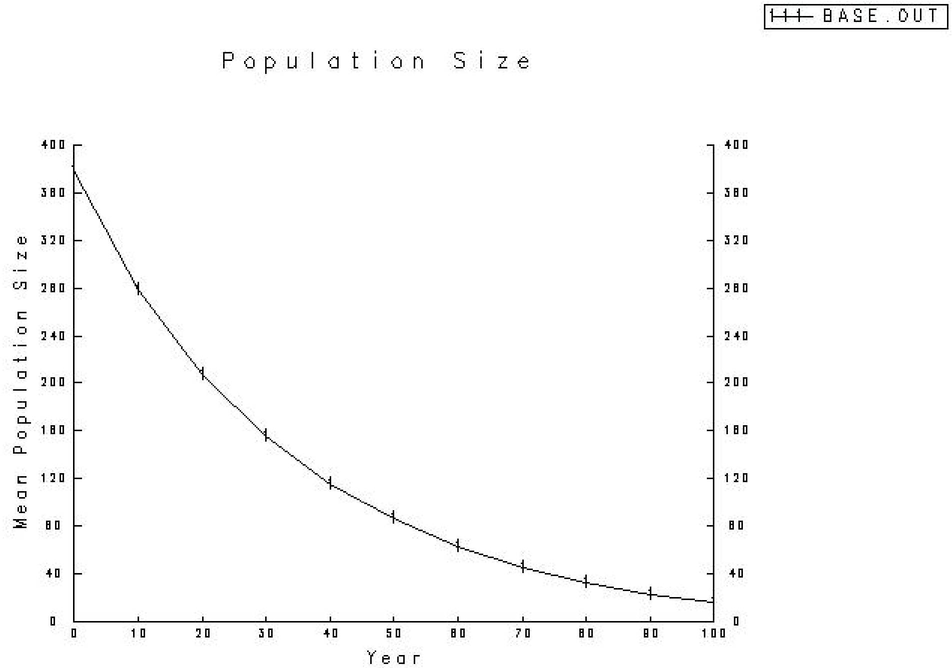

Figure 2: The output of the baseline model (100 iterations) of the wild wattled crane population showing the decline in population size over the next 100 years (1980 represented at year 0).

MODELLING RESULTS

The baseline model was then used to model different scenarios, including:

- the effect of different mortality rates, and
- the effect of different supplementation strategies

For these scenarios, the sensitivity of the model to the age at first reproduction and age at last reproduction (reproductive senescence) was tested using the following values for these parameters :

Age at first breeding – 7, 8 and 9 years old
Reproductive senescence – 30, 45 and 60 years old

The different scenarios were modelled using VORTEX for 100 iterations for 100 years giving the results shown in Table 2 to 4.

The aim of the modelling was to determine the characteristics of the population which could be manipulated (through management) that would result in the reduction of the decline in the wattled crane population and the ensured survival of the population into the long-term. Therefore, the conservation objectives were as follows :

- Reverse the current negative growth rate, to result in a positive growth rate for the population,
- Have a population that has a greater than 50% chance of survival over the next 100 years,
- Maintain a population with 95% genetic heterozygosity.

Notes on the following tables -

The text format in the following tables represent outcomes based on the conservation objectives.
Bold text = a positive growth rate
Normal text = % of extinction up to 50% and if 0% then if it still has a negative growth rate
Italics text = negative growth rate with a % extinction greater than 50 % or less than 95% genetic heterozygosity

Table 2: The output table of scenarios with a mortality of 6%, modelling the sensitivity of the age at first reproduction and maximum age of reproduction.

	Input Values					Output for 100 iterations over 100 yrs						
File	Mortality %	Breeding Age	Max. Breed Age	Supplementation	Carrying Capacity K	Deterministic growth rate - r	Stochastic growth Rate - r	Standard Deviation	Probability Extinction	N (Population size)	Time to Extinction	Observed Heterozygosity
Base	6	8	45	0	500	-0.028	-0.0357	0.062	7%	14.6	93.43	95.85
1.01	*6*	*7*	*30*	*0*	*500*	*-0.039*	*-0.0504*	*0.0907*	*83%*	*1.4*	*81.92*	*90.62*
1.02	6	7	30	4	500	-0.039	-0.0085	0.0432	0%	101.5	N/A	99.79
1.03	6	7	30	6	500	-0.039	-0.0042	0.0418	0%	155.6	N/A	99.93
1.04	6	7	45	0	500	-0.026	-0.0334	0.0693	17%	10.7	87.59	95.79
1.05	6	7	45	4	500	-0.026	-0.0056	0.0409	0%	135.8	N/A	99.80
1.06	6	7	45	6	500	-0.026	-0.002	0.0395	0%	194.3	N/A	99.82
1.07	6	7	60	0	500	-0.022	-0.0277	0.0601	4%	18.1	91.75	95.48
1.08	6	7	60	4	500	-0.022	-0.0045	0.04	0%	152.0	N/A	99.72
1.09	6	7	60	6	500	-0.022	-0.0012	0.0391	0%	211.2	N/A	99.84
1.10	*6*	*8*	*30*	*0*	*500*	*-0.043*	*-0.535*	*0.0939*	*87%*	*0.9*	*78.09*	*92.45*
1.11	6	8	30	4	500	-0.043	-0.0092	0.0434	0%	94.6	N/A	99.92
1.12	6	8	30	6	500	-0.043	-0.0052	0.041	0%	141.5	N/A	99.87
1.13	6	8	45	0	500	-0.028	-0.0379	0.0757	30%	6.5	90.1	97.10
1.14	6	8	45	4	500	-0.028	-0.0063	0.0398	0%	126.5	N/A	99.83
1.15	6	8	45	6	500	-0.028	-0.0027	0.0391	0%	180.9	N/A	99.88
1.16	6	8	60	0	500	-0.024	-0.0311	0.0655	9%	13.4	90.67	97.03
1.17	6	8	60	4	500	-0.024	-0.0059	0.0396	0%	131.6	N/A	99.68
1.18	6	8	60	6	500	-0.024	-0.0023	0.0388	0%	188.4	N/A	99.87
1.19	*6*	*9*	*30*	*0*	*500*	*-0.046*	*-0.0569*	*0.0933*	*97%*	*0.2*	*75.11*	*93.33*
1.20	6	9	30	4	500	-0.046	-0.0097	0.0433	0%	89.3	N/A	99.90
1.21	6	9	30	6	500	-0.046	-0.0056	0.0405	0%	134.7	N/A	99.93
1.22	*6*	*9*	*45*	*0*	*500*	*-0.031*	*-0.0415*	*0.0807*	*45%*	*4.1*	*87.11*	*91.59*
1.23	6	9	45	4	500	-0.031	-0.0074	0.0404	0%	113.4	N/A	99.80
1.24	6	9	45	6	500	-0.031	-0.0034	0.0386	0%	168.4	N/A	99.87
1.25	6	9	60	0	500	-0.026	-0.0332	0.067	9%	10.1	93.89	96.23
1.26	6	9	60	4	500	-0.026	-0.0066	0.0394	0%	123.6	N/A	99.81
1.27	6	9	60	6	500	-0.026	-0.0028	0.0385	0%	179.3	N/A	99.87

Table 3: The output table of scenarios with a mortality of 5%, modelling the sensitivity of the age at first reproduction and maximum age of reproduction.

	Input Values					Output for 100 iterations over 100 yrs						
File	Mortality	Breeding Age	Max. Breed Age	Supplementation	Carrying Capacity K	Deterministic growth rate - r	Stochastic growth Rate – r	Standard Deviation	Probability Extinction	N (Population size)	Time to Extinction	Observed Heterozygosity
2.01	*5*	*7*	*30*	*0*	*500*	*-0.029*	*-0.0419*	*0.0828*	*46%*	*4.5*	*88.78*	*93.93*
2.02	5	7	30	4	500	-0.029	-0.0051	0.0405	0%	142.2	N/A	99.82
2.03	5	7	30	6	500	-0.029	-0.0013	0.0394	0%	207.2	N/A	99.87
2.04	5	7	45	0	500	-0.016	-0.0227	0.0554	0%	30.4	N/A	96.76
2.05	5	7	45	4	500	-0.016	-0.0011	0.039	0%	212.9	N/A	99.72
2.06	**5**	**7**	**45**	**6**	**500**	**-0.016**	**0.0022**	**0.0375**	**0%**	**294.1**	**N/A**	**99.79**
2.07	5	7	60	0	500	-0.012	-0.0164	0.0481	0%	51.5	N/A	97.78
2.08	**5**	**7**	**60**	**4**	**500**	**-0.012**	**0.0004**	**0.0383**	**0%**	**248.3**	**N/A**	**99.67**
2.09	**5**	**7**	**60**	**6**	**500**	**-0.012**	**0.0033**	**0.0375**	**0%**	**329.6**	**N/A**	**99.77**
2.10	*5*	*8*	*30*	*0*	*500*	*-0.033*	*-0.0435*	*0.0824*	*55%*	*3.6*	*87.22*	*92.15*
2.11	5	8	30	4	500	-0.033	-0.0061	0.0402	0%	128.5	N/A	99.77
2.12	5	8	30	6	500	-0.033	-0.0025	0.0388	0%	184.5	N/A	99.85
2.13	5	8	45	0	500	-0.018	-0.0249	0.0546	4%	22.7	96.25	96.90
2.14	5	8	45	4	500	-0.018	-0.0025	0.038	0%	186.2	N/A	99.77
2.15	**5**	**8**	**45**	**6**	**500**	**-0.018**	**0.0012**	**0.0372**	**0%**	**267.3**	**N/A**	**99.82**
2.16	5	8	60	0	500	-0.014	-0.0188	0.0486	0%	41.0	N/A	98.11
2.17	5	8	60	4	500	-0.014	-0.0009	0.0376	0%	216.6	N/A	99.76
2.18	**5**	**8**	**60**	**6**	**500**	**-0.014**	**0.002**	**0.0374**	**0%**	**290.3**	**N/A**	**99.79**
2.19	*5*	*9*	*30*	*0*	*500*	*-0.036*	*-0.0475*	*0.085*	*74%*	*1.9*	*85.08*	*94.13*
2.20	5	9	30	4	500	-0.036	-0.0073	0.04	0%	114.8	N/A	99.77
2.21	5	9	30	6	500	-0.036	-0.0033	0.0385	0%	169.9	N/A	99.85
2.22	5	9	45	0	500	-0.021	-0.0281	0.0596	4%	17.2	95.25	94.96
2.23	5	9	45	4	500	-0.021	-0.0033	0.0376	0%	170.9	N/A	99.74
2.24	**5**	**9**	**45**	**6**	**500**	**-0.021**	**0.0003**	**0.036**	**0%**	**243.8**	**N/A**	**99.90**
2.25	5	9	60	0	500	-0.016	-0.0204	0.0506	1%	34.8	99	97.92
2.26	5	9	60	4	500	-0.016	-0.0021	0.0373	0%	193.6	N/A	99.73
2.27	**5**	**9**	**60**	**6**	**500**	**-0.016**	**0.0011**	**0.036**	**0%**	**264.5**	**N/A**	**99.86**

Table 4: The output table of scenarios with a mortality 4%, modelling the sensitivity of the age at first reproduction and maximum age of reproduction.

	Input Values					Output for 100 iterations over 100 yrs						
File	Mortality	Breeding Age	Max. Breed Age	Supplementation	Carrying Capacity K	Deterministic growth rate - r	Stochastic growth Rate – r	Standard Deviation	Probability Extinction	N (Population size)	Time to Extinction	Observed Heterozygosity
3.01	4	7	30	0	500	-0.019	-0.0253	0.058	7%	23.9	94.43	95.57
3.02	4	7	30	4	500	-0.019	-0.0013	0.0389	0%	209.6	N/A	99.71
3.03	**4**	**7**	**30**	**6**	**500**	**-0.019**	**0.0024**	**0.038**	**0%**	**301.9**	**N/A**	**99.81**
3.04	4	7	45	0	500	-0.006	-0.0084	0.0423	0%	110.5	N/A	98.23
3.05	**4**	**7**	**45**	**4**	**500**	**-0.006**	**0.0036**	**0.0378**	**0%**	**339.6**	**N/A**	**99.65**
3.06	**4**	**7**	**45**	**6**	**500**	**-0.006**	**0.006**	**0.0372**	**0%**	**423.2**	**N/A**	**99.77**
3.07	4	7	60	0	500	-0.002	-0.0049	0.0409	0%	155.5	N/A	98.76
3.08	**4**	**7**	**60**	**4**	**500**	**-0.002**	**0.0058**	**0.0368**	**0%**	**413.6**	**N/A**	**99.66**
3.09	**4**	**7**	**60**	**6**	**500**	**-0.002**	**0.0072**	**0.0373**	**0%**	**446.8**	**N/A**	**99.83**
3.10	4	8	30	0	500	-0.023	-0.0313	0.0642	13%	13.6	92.46	95.41
3.11	4	8	30	4	500	-0.023	-0.0026	0.0383	0%	183.7	N/A	99.76
3.12	**4**	**8**	**30**	**6**	**500**	**-0.023**	**0.001**	**0.0373**	**0%**	**261.6**	**N/A**	**99.78**
3.13	4	8	45	0	500	-0.008	-0.0128	0.0446	1%	75.0	96	97.86
3.14	**4**	**8**	**45**	**4**	**500**	**-0.008**	**0.0029**	**0.0366**	**0%**	**319.3**	**N/A**	**99.69**
3.15	**4**	**8**	**45**	**6**	**500**	**-0.008**	**0.0053**	**0.0359**	**0%**	**396.2**	**N/A**	**99.81**
3.16	4	8	60	0	500	-0.004	-0.0062	0.0409	0%	136.0	N/A	98.33
3.17	**4**	**8**	**60**	**4**	**500**	**-0.004**	**0.0044**	**0.0363**	**0%**	**368.8**	**N/A**	**99.69**
3.18	**4**	**8**	**60**	**6**	**500**	**-0.004**	**0.0064**	**0.036**	**0%**	**431.7**	**N/A**	**99.82**
3.19	*4*	*9*	*30*	*0*	*500*	*-0.026*	*-0.0353*	*0.0711*	*21%*	*8.8*	*89.33*	*94.98*
3.20	4	9	30	4	500	-0.026	-0.0039	0.0382	0%	161.3	N/A	99.83
3.21	4	9	30	6	500	-0.026	-0.0002	0.0363	0%	232.4	N/A	99.91
3.22	4	9	45	0	500	-0.011	-0.0155	0.0452	0%	57.5	N/A	97.78
3.23	**4**	**9**	**45**	**4**	**500**	**-0.011**	**0.0017**	**0.0353**	**0%**	**281.3**	**N/A**	**99.70**
3.24	**4**	**9**	**45**	**6**	**500**	**-0.011**	**0.0041**	**0.0353**	**0%**	**355.5**	**N/A**	**99.77**
3.25	4	9	60	0	500	-0.006	-0.0092	0.0417	0%	101.3	N/A	98.60
3.26	**4**	**9**	**60**	**4**	**500**	**-0.006**	**0.0034**	**0.0357**	**0%**	**334.5**	**N/A**	**99.69**
3.27	**4**	**9**	**60**	**6**	**500**	**-0.006**	**0.0056**	**0.0352**	**0%**	**409.6**	**N/A**	**99.78**

SENSITIVITY ANALYSIS

At mortality rate of 6% (current level) :

- Individuals with age of senescence of 30 all lead to extinction, including those at 45 with age at first breeding at 9 years of age (therefore age of senescence is significant).
- At mortality rate of 6% all population iterations maintain a negative growth rate, implying that in all these cases the population will eventually become extinct.

At mortality rate of 5% :

- Irrespective of the age at first breeding, all populations with age of senescence of 30 all become extinct within 100 years.
- At mortality rate of 5%, the only scenarios which generate a positive growth rate is a supplementation of 6 individuals per year after an initial 8 year period.

At mortality rate of 4% :

- Reducing the mortality rate to 4% (with no supplementation) results in a reduced probability of extinction (except for age of first breeding at 9 years of age and age of senescence at 30 years).
- In all cases (except where age of senescence = 30 years) the reduced mortality rate to 4% allows for supplementation of either 4 or 6 to result in a positive growth rate.

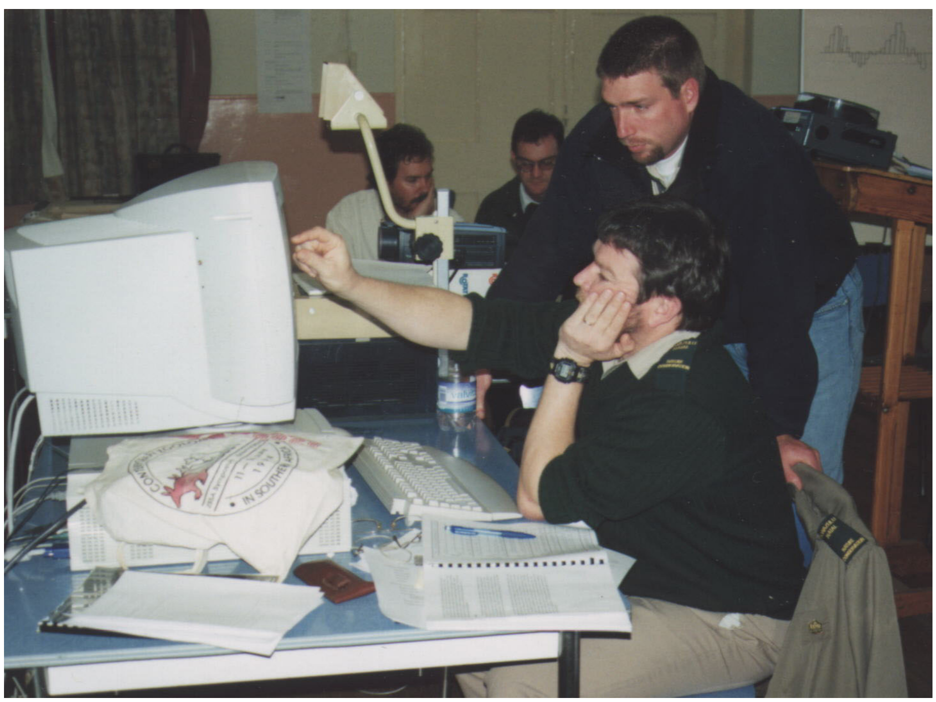

Figure 3 : Modelling Working Group members discussing population modelling parameters during the wattled crane PHVA (Wakkerstroom).

FINDINGS:

Priority 1 Age-Specific Mortality

- Age-specific mortality has an important influence on the population trends.

Model: Age-specific mortality was varied between 4%, 5% and 6%, maintaining all other baseline demographic parameters, and modelled over 100 years.

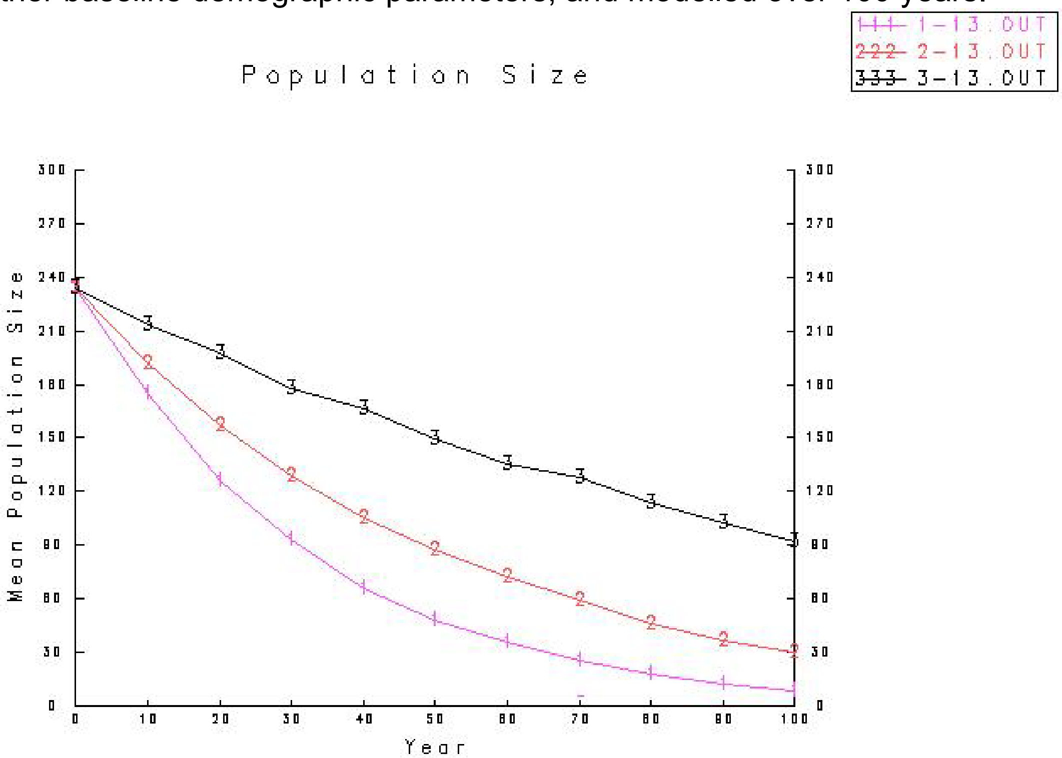

Figure 4: Wattled crane population size over 100 years at different immature / adult mortality rates (1.13 = 6%, 2.13 = 5%, 3.13 = 4%).

Result: The population showed the most significant sensitivity to age-specific mortality rates, with even a 1% difference in the rate resulted in a markedly different final population size.

Interpretation: The model shows that a reduction from a 6% immature / adult mortality rate to a 4% immature / adult mortality rate decreases the probability of extinction from 83% to 7%. This translates to a decrease in mortality each year of 4 individuals in the immature / adult classes. In addition, the population modelled at a lower immature / adult mortality rate has a higher growth rate (both deterministic and stochastic) than those with higher mortality rates. The lower immature / adult mortality rate allows for the maintenance of a higher observed heterozygosity in the final population after 100 years. Current data has been shown to be inadequate, resulting in an average rate being used based on recorded population performance.

The wattled crane population appears to be the most sensitive to this mortality factor, thereby making it important to accurately and precisely determine age-specific mortality rates, and the causes of those mortalities, in order to improve the accuracy and predictive value of the model.

Priority 2 – Age of Reproductive Senescence

- Age of reproductive senescence has not been determined and remains unclear in wattled cranes.

Model: The age of reproductive senescence was varied between 30, 45 and 60 years of age, maintaining all other baseline demographic parameters, and modelled over 100 years.

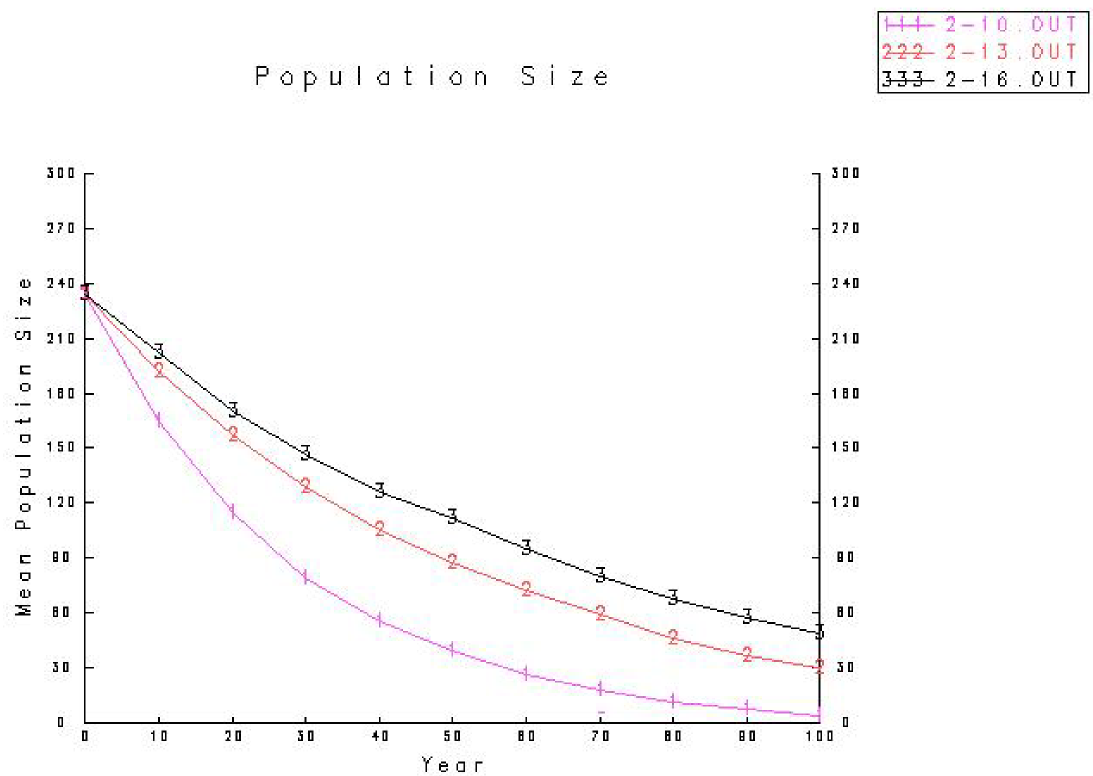

Figure 5: Wattled crane population size over 100 years at different ages of senescence (2.10 = 30 years of age, 2.13 = 45 years of age, 2.16 = 60 years of age).

Result: The final population showed significant differences between the different variables of age of reproductive senescence.

Interpretation : VORTEX modelling has demonstrated that the older the age of reproductive senescence, the more positive the scenario for the population. An increase in age of senescence from 30 to 45 to 60 increases the time to extinction; it decreases the probability of extinction from 83% to 4% at 60 years of age, while increasing the population growth rate (both deterministic and stochastic) marginally. Therefore, <u>it is important to determine the age of reproductive senescence accurately and precisely</u>.

Priority 3 – Age of First Reproduction

- There is a very small data set indicating the age of first reproduction in wattled cranes in the wild, yet it is an important factor in the demographic of a population.

Model: The age of first reproduction was varied between 7, 8 and 9 years of age, maintaining all other baseline demographic parameters, and modelled over 100 years.

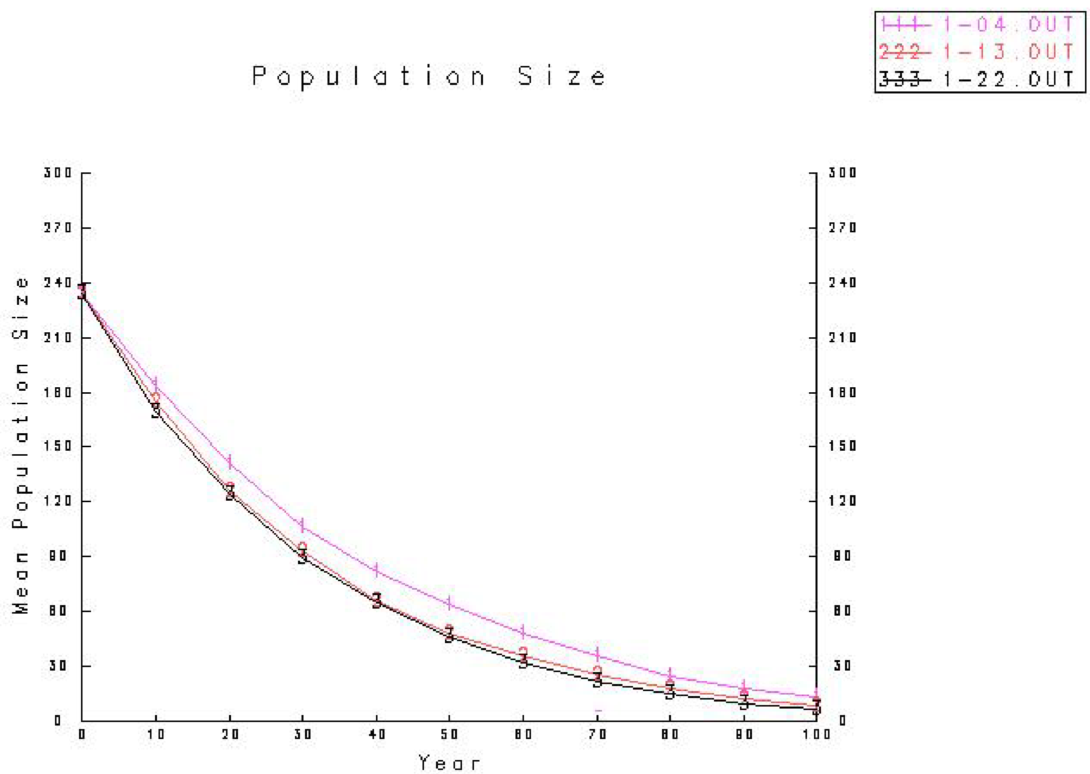

Figure 6: Wattled crane population size over 100 years at different ages of first reproduction (1.04 = 7 years of age, 1.13 = 8 years of age,1.22 = 9 years of age).

Result: The final population showed very little difference between the different variables of age of first reproduction.

Interpretation: VORTEX modelling has demonstrated that the age of first reproduction has an influence on population performance. The older the bird begins breeding, the lower it's population growth rate (both deterministic and stochastic), and the higher the chance of, and the shorter the time to, extinction. The difference is however small between the modelled ages and the need to determine age of first breeding is less than the need to determine age specific mortality and age of senescence.

VORTEX Modelling of Effect Supplementation Programme has on Wild Population

The goal of the supplementation programme is to significantly increase the number of Wattled Cranes in the wild in South Africa and to develop supplementation techniques in case of catastrophic event. The following scenarios were modelled with assistance from the Life History Modelling Group using VORTEX.

- No supplementation
- Supplementing 4 birds (2 males / 2 females) every year from the first year
- Supplementing 6 birds (3 males / 3 females) every year starting at year 9
- Supplementing 12 birds (6 males / 6 females) every alternate year starting at year 9
- Supplementing 4 birds (2 males / 2 females) every year for the first 20 years
- Supplementing 4 birds (2 males / 2 females) every third year from year 9
- Supplementing 5 birds (2 males / 3 females) every third year from year 9
- Supplementing 6 birds (3 males / 3 females) every third year from year 9

Note - In all cases for this analysis, the worst cases have been taken for the wild populations' parameters, i.e. 6% mortality rate from 1 year onwards, 7 years as first age of breeding (this parameter was the least sensitive), and age of senescence of 30 years of age. In all cases the carrying capacity was kept at 500 individuals.

Table 5: Input and output values of the supplementation modelling.

	Input Values					Output for 100 iterations over 100 yrs						
File	Mortality %	Breeding Age	Max. Breed Age	Supplementation	Carrying Capacity K	Deterministic growth rate – r	Stochastic growth Rate – r	Standard Deviation	Probability Extinction	N (Population size)	Time to Extinction	Observed Heterozygosity
1.01	6	7	30	0	500	-0.039	-0.0504	0.0907	83%	1.4	81.92	90.62
1.02	6	7	30	4	500	-0.039	-0.0085	0.0432	0%	101.5	N/A	99.79
1.03	6	7	30	6	500	-0.039	-0.0042	0.0418	0%	155.6	N/A	99.93
12-8	6	7	30	12	500	-0.039	-0.0042	0.0548	0%	155.3	N/A	99.89
Suppl20	6	7	30	4	500	-0.039	-0.0424	0.0841	51%	3.92	90.14	92.09
Capt1	6	7	30	4	500	-0.039	-0.0191	0.0659	0%	36.1	N/A	99.49
Capt2	6	7	30	5	500	-0.039	-0.0162	0.0644	0%	47.5	N/A	99.51
Capt3	6	7	30	6	500	-0.039	-0.0146	0.064	0%	55.5	N/A	99.55

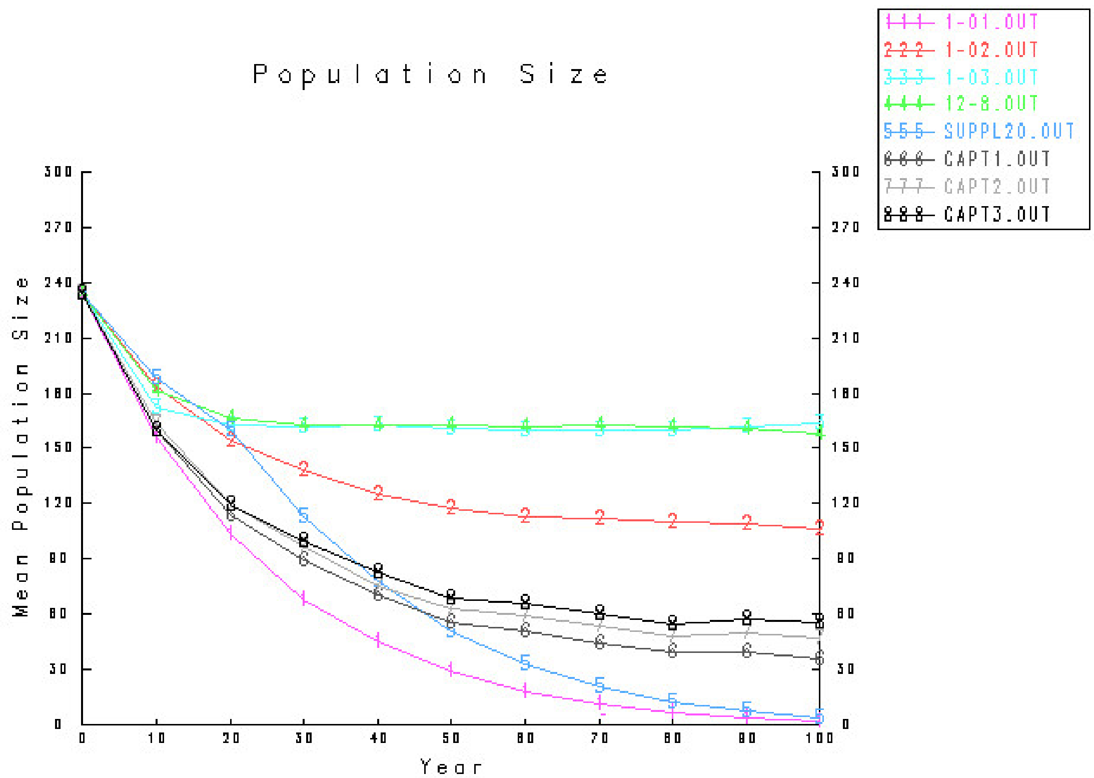

Figure 7: The output of the Vortex modelling comparing the effects of different supplementation rates on the wild wattled crane population in South Africa (1.01 = no supplementation, 1.02 = supplementing 4 individuals for year 1, 1.03 = supplementing 6 individuals each year from year 9, 12-8 = supplementing 12 individuals every alternate year from year 9, supple20 = supplementing 4 individuals every year from year 1 for 20 years).

Model 1: No supplementation.

Result: Population continues to decline.

Model 2: Starting in the year 2000, four birds per year released over 100 years.

The 4 birds would come from second, wild collected eggs.

Result: This scenario shows a population decline but at a slower rate than model 5 (assuming no other factors substantially impacted the wild population) There is still a negative growth rate but we see the population stabilizing out at about 80 birds.

Interpretation: This scenario does not show the supplementation significantly impacting the wild population.

Model 3: Starting in the year 2008, six birds per year released per year for 92 years.

This scenario would provide time for the existing captive flock to increase over the next 8 years and then begin a supplementation of 6 birds per year.

Result: Initially, a similar decline as for model 3 is observed, followed by stabilization of the population.

Interpretation: This scenario allows both for an increase in the number of captive birds and a supplementation programme that significantly contributes to maintaining the wild population.

Model 4: Starting in the year 2008, twelve birds released every other year for 92 years.

Result and recommendation: Same as Model 3.

Model 5: Starting in the year 2000, four birds per year released over 20 years.

The 4 birds would come from second, wild collected eggs. (If one takes into account that currently there are no chicks produced by the captive flock, this strategy does not allow a simultaneous increase in the number of captive birds based on the ability to only collect a limited number of wild collected eggs).

Result: Population continues to decline at a lesser rate than for model 1.

Interpretation: An insignificant impact of supplementation on the birds in the wild.

With the predicted current immature/adult mortality rate of 6% (determined through the base model), the population will have an 83% chance of extinction within 82 years time. An addition of 4 individuals every year significantly improves the situation resulting in a final population of 102 individuals after 100 years, although the population maintains a negative population growth rate. If the supplementation of 4 individuals is only sustained for the next 20 years, then the population mirrors that of the baseline model with no supplementation (Table). Not supplementing for the first eight years results in a decline similar to that of the “no supplementation” scenario, but improves dramatically by supplementing 6 individuals after the initial eight years. The population stabilizes, showing only a small negative population growth rate (-0.0042), resulting in a final population size of 156 individuals after 100 years.

However, modelling of the captive flock shows that the carrying capacity is reached after approximately 6-10 years, when chicks will become available from this captive flock for a supplementation and release programme. The captive population, as modeled, will allow a sustained harvest of 4-6 birds every 3 years and will be self-sustaining at or just below a carrying capacity of 40 individuals (see Captive chapter). Therefore the potential of the captive flock to supply birds for supplementation was also modeled, where varying numbers of individuals, either 4, 5 or 6 individuals (obtained from the Captive chapter), were released into the wild population. In all three of these scenarios the wild population declined dramatically before stabilizing around 50 individuals. Although none of these populations went extinct, the decline to a very low number of individuals would not fit the conservation strategy for the wattled crane. The period between releases appears to be too great (i.e. three years) to have a significant impact on reducing the negative growth rate of the species over the long-term.

Model 6: Starting in the year 2008, four birds per year released every three years for 92 years.

This scenario would provide time for the existing captive flock to increase over the next 8 years and then begin a supplementation of 4 birds every three years, which is obtained from the recommendations from the Captive Population modelling where between 4 – 6 birds will be available every third year for release, which is the quantity of birds available for release that allows the persistence of the captive flock at or close to carrying capacity, i.e. 40 individuals.

Result: Initially, a similar decline as for model 1 is observed, but breaks away from the decline to stablize at a slightly higher final population level, a level significantly lower than models 2, 3 and 4.

Interpretation: This scenario allows both for an increase in the number of captive birds but does not contribute to maintaining the wild population.

Model 7: Starting in the year 2008, five birds per year released every three years for 92 years.

This scenario would provide time for the existing captive flock to increase over the next 8 years and then begin a supplementation of 5 birds every three years, which is obtained from the recommendations from the Captive Population modelling where between 4 – 6 birds will be available every third year for release, which is the quantity of birds available for release that allows the persistence of the captive flock at or close to carrying capacity, i.e. 40 individuals.

Result: Same as model 6.

Interpretation: This scenario allows both for an increase in the number of captive birds but does not contribute to maintaining the wild population.

Model 8: Starting in the year 2008, six birds per year released every three years for 92 years.

This scenario would provide time for the existing captive flock to increase over the next 8 years and then begin a supplementation of 6 birds every three years, which is obtained from the recommendations from the Captive Population modelling where between 4 – 6 birds will be available every third year for release, which is the quantity of birds available for release that allows the persistence of the captive flock at or close to carrying capacity, i.e. 40 individuals.

Result: Same as model 6.

Interpretation: This scenario allows both for an increase in the number of captive birds but does not contribute to maintaining the wild population.

Recommendation based on model results:

- Discontinue the supplementation program for the next 5-8 years and focus current efforts into developing the captive flock as a genetic reservoir.
- After 5 years, the status of the bird in the wild should be reviewed and the contribution a supplementation programme would make should be re-evaluated.
- If modeling indicates supplementation would significantly contribute to the wild flock, then 3 years prior to a full-scale release effort, resources could be directed into the refinement of release methodologies and techniques.
- <u>Length of time needed to continue supplementation should be examined.</u>

OVERALL RECOMMENDATIONS

The use of Vortex to model the wattled crane population allows for the interpretation of the effects of different ranges of factors and different management actions on the population. This allows for the setting of conservation management goals, which are more likely to reverse the population decline.

The baseline model shows the current trend of the wild wattled crane population in South Africa, using the most current information on population demographic parameters. This model shows that the population is in steep decline, a process that needs to be reversed in ensure the long-term survival of this wetland-dependent species.

Therefore, the following model shows the overall result of several management actions, which will result in the long-term conservation of the species, i.e. a positive growth rate in the wild wattled crane population.
The factors, which result in this model, are as follows, and form the basis of work required in the future on the wild wattled crane population :

- The reduction of immature / adult mortality by 4 individuals per year, thereby reducing the mortality rate to 4%.
- Implement long-term habitat management plans to safe-guard breeding sites, thereby allowing breeding pairs to successfully occupy a site for up to 45 years (several pairs in the past may have had the potential to utilize sites for longer periods due to their long life spans, but have been prevented through serious habitat degradation where breeding sites have become unsuitable).
- Supplementing the wild population with 6 captively bred individuals every second year, after an initial 8 years where the focus is placed on establishing a viable captive flock within recognised breeding institutions. The modelling of the captive flock has shown that after the initial 8 year period, between 4 and 6 chicks will become available for supplementation every three years. Therefore, this more intensive release of 6 birds every second year will mean that the individuals available from the captive breeding programme will need to be supplemented with second eggs from the wild to increase the number available for release every second year.

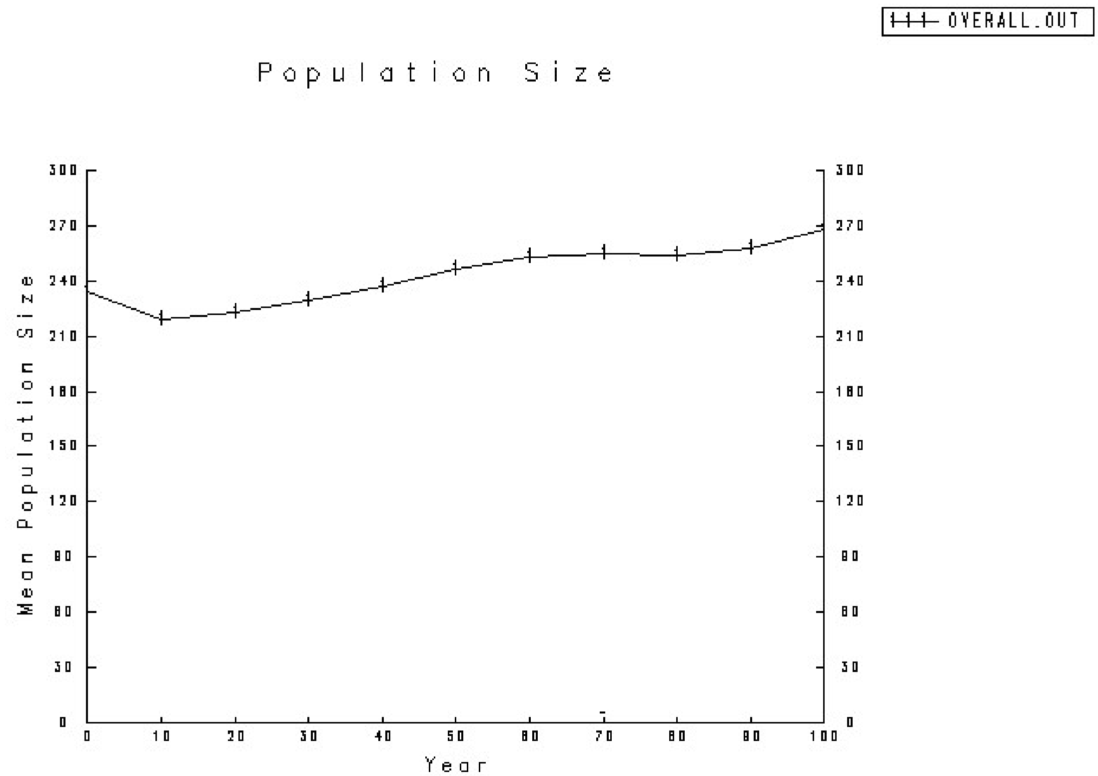

Figure 8: The result of the wild wattled crane population modelling, showing the set of factors / management actions required to ensure the species' long-term survival, i.e. age of first breeding = 8 years of age, age of breeding senescence = 45 years, immature / adult mortality rate = 4% and a supplementation of 6 individuals (3 males / 3 females) every second year from year 9, (all other input value remain the same as that of the baseline model).

Additional research required into the population to refine our understanding of the species includes :

- Determining the age of reproductive senescence.
- Determining the actual age of first reproduction.

CONCLUSION

The long-term survival of the wild population of wattled crane in South Africa relies on the implementation of several research projects, assessment programmes as well as management actions, as indicated by the Vortex modelling.

PRIORITIZATION OF THE OVERALL PROJECTS IDENTIFIED DURING THE PHVA WORKSHOP

Towards the end of the workshop, all projects identified by the different working groups were accumulated and were subjected to a voting system by all workshop participants in order to priority rank each project. The following table lists all projects and their respective voting tally and rank.

Rank	Voting Score	Project/Action
1	462	Develop an accurate description of what constitutes viable wattled crane habitat – must include breeding and foraging habitat with correct nutrition.
2	392	Develop an action plan to reduce the risk at "high risk" sites – thereby ensuring that they are not lost.
3	384	Determine the biophysical characteristics of wattled crane nest sites.
4	373	Survey and classify all wetlands that fall within viable wattled crane distribution according to their suitability and risk.
5	364	Gain a clear understanding of how fast wetlands are lost in total and in terms of wattled crane requirements (deducing the historical rate of change).
6	340	Complete a risk assessment of all breeding sites.
7	329	Age-specific mortality has an important influence on the population trajectory. Current data ahs been shown to be inadequate, resulting in the need for the accurate determination of age-specific mortality rates and the causes of those mortalities.
8	307	Determine the diet and energy requirements of the wattled crane throughout its annual cycle.
9	286	Determine the minimum area requirements of the wattled crane throughout its annual cycle.
10	282	A project has been established within ESKOM to proactively fit mitigating measures to power lines in the vicinity of 36 wattled crane nests. It is recommended that this project be extended to the other nest sites throughout its South Africa breeding range, as well as to those areas utilized by the non-breeding flocks.
11	259	Establish an effective network of informants and an efficient reporting procedure to determine the effects of threats on the population in terms of mortality rates and increase the rate of effective reporting mortalities.
12	259	To heighten the awareness of the plight of the wattled crane using a publicity and awareness program.

13	234	Accepting that there is a need for the use of agrochemicals, there should be definite requirements to reduce their misuse.
14	225	Develop and maintain a central database for all crane related information.
15	218	Develop and build a captive wattled crane population over the next 5 – 8 years and then review the supplementation and release program.
16	197	VORTEX modelling has demonstrated that the age of first reproduction has an influence on population performance. Therefore, it is important to determine the age of first reproduction accurately and precisely
17	187	There is currently major uncertainty as to the age of reproductive senescence. VORTEX modelling has demonstrated that the older the age of senescence, the more positive the scenario for the population. Therefore, it is important to determine the age of reproduction senescence accurately and precisely.
18	164	The reduction of the illegal exploitation of wattled cranes, through education and awareness programs as well as prosecution.
19	157	Reduce the mortality caused by fences, by reducing the disturbance around the nest site and making landowners and farmers aware of the problem.
20	130	Pursue viable and cost effective methods of further investigating the genetics of potential sub-species populations.
21	72	Explore alternative emerging technologies as support for guarding against extinction, e.g. translocation and cryopreservation.

These projects form the basis of the recommendations from the respective working groups and will be implemented according to the priority ranking by the SACWG staff over the forthcoming months.

Population and Habitat Viability Assessment for the Wattled Crane (*Bugeranus carunculatus*) in South Africa

Final Report from the Workshop
Held 31 July – 2 August 2000 in Wakkerstroom, South Africa

February 2001

Edited by

K. McCann, A. Burke, L. Rodwell, U.S. Seal and M. Steinacker

Section 4

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Section 5

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Section 6

Appendices

APPENDIX 1

INVITATION TO :

THE WATTLED CRANE POPULATION AND HABITAT VIABILITY ANALYSIS WORKSHOP (PHVA)

FROM THE SOUTH AFRICAN CRANE WORKING GROUP OF THE ENDANGERED WILDLIFE TRUST

THE WORKSHOP WILL BE RUN BY DR ULYSSES SEAL, CHAIRMAN OF THE CONSERVATION BREEDING SPECIALIST GROUP – USA

DATE	Monday 31st July – Thursday 3nd August 2000 The meeting will end at noon on the 3rd
VENUE	Wakkerstroom
ACCOMMODATION	Generously donated by Wakkerstroom townsfolk! Using the reply form attached please let us know your accommodation requirements so that we can allocate the accommodation accordingly. We will inform you prior to the meeting of the accommodation allocations.
ALTERNATIVE ACCOMMODATION (If you would prefer to book your own accommodation here are the contact details for the hotel and some local B&B')	• Wakkerstroom Inn Tel: (017) 730 0067 • Weavers Nest Tel: (017) 730 0115 • Wetland Lodge Tel: (017) 730 0101 • Di Osborne Tel: (017) 730 0427 • Ingrid Niebuhr Tel: (017) 730 0017 • John McAllister Tel: (017) 730 0269 • Hettie Bornman Tel: (017) 730 0450
BRING	Wakkerstroom can be freezing winter. We will ensure the venue is heated but advise you bring along warm clothing and extra blankets etc.
TIME	The meeting will commence at 08h15 sharp every morning, lunch and dinner will be served on-site - there will be discussion and workshop sessions after dinner.
MEALS	**Lunch and dinner**: lunch and dinner will be served 'on-site' during the meeting. (At the cost price of R45 per day) Due to the intense nature of this meeting, we would appreciate it if participants do not make alternative arrangements for lunch and dinner. **Breakfast**: Due to the varied accommodations we have been offered we are leaving breakfasts up to the participants themselves.

APPENDIX 2

THE SOUTH AFRICAN CRANE WORKING GROUP

Threats facing cranes in South Africa have led to significant declines in the populations of all three species. The Blue Crane, South Africa's national bird, has declined by almost 80% over the eastern parts of its range during the past two decades.

In response to this crisis, a number of crane groups emerged in the late eighties and early nineties, in order to address these problems in 'key' crane areas in South Africa. At the same time the government nature conservation departments started addressing these problems and directed some effort toward crane conservation.

As the focus on our cranes intensified and projects were initiated, a need arose for co-ordination on a national level. Co-ordination would prevent the duplication of work or research, and a central data base would be set up to enable the various groups to tap into the vast amount of expertise available. So in 1995 after conferring with all the 'groups' and role players, the SOUTH AFRICAN CRANE WORKING GROUP (SACWG) was established as a working group of the Endangered Wildlife Trust. The Trust provides the group with access to a working office and infrastructure, a wealth of advice and expertise, and with EWT's influence and credibility in the conservation world, a means to raise funds.

SACWG is a national body whose aim is to co-ordinate and initiate crane conservation efforts in South Africa. A National Crane Habitat and Action Plan has been established and acts as a guideline for crane conservation. The group is made up of a network of regional and national crane conservation projects and working groups and is active in all seven key crane regions in South Africa. A number of scientists or experts in fields, closely aligned with crane conservation have also been co-opted into the group.

Beyond the borders of South Africa, SACWG's aim is to assist with building a network of colleagues across central southern Africa with a view to establishing regional crane conservation programmes. We have the capacity to provide training and skills, technical and management support and effective information exchange. We seek to identify and support organizations and key individuals whose efforts will drive crane conservation into the future.

APPENDIX 3

INTRODUCING: THE CONSERVATION BREEDING SPECIALIST GROUP

Web site at http://www.cbsg.org.

Introduction

There is a lack of generally accepted tools to evaluate and integrate the interaction of biological, physical, and social factors on the population dynamics of the broad range of threatened species. There is a need for tools and processes to characterize the risk of species and habitat extinction, on the possible effects of future events, on the effects of management interventions, and on how to develop and sustain learning-based cross-institutional management programs.

The Conservation Breeding Specialist Group (CBSG) of IUCN's Species Survival Commission (SSC) has 10 years of experience in developing, testing and applying a series of scientifically based tools and processes to assist risk characterization and species management decision making. These tools, based on small population and conservation biology (biological and physical factors), human demography, and the dynamics of social learning are used in intensive, problem-solving workshops to produce realistic and achievable recommendations for both *in situ* and *ex situ* population management.

The mission of the Conservation Breeding Specialist Group is *"to conserve and establish populations of threatened species through conservation breeding programs and through intensive protection and management of these plant and animal populations in the wild."*

Our Workshop processes provide an objective environment, expert knowledge, and a neutral facilitation process that supports sharing of available information across institutions and stakeholder groups, reaching agreement on the issues and available information, and then making useful and practical management recommendations for the taxon and habitat system under consideration. The process has been remarkably successful in unearthing and integrating previously unpublished information for the decision making process. Their proven heuristic value and constant refinement and expansion have made the CBSG CAMP and PHVA processes two of the most imaginative and productive organizing forces for species conservation today (Conway, 1995).

What does the Conservation Breeding Specialist Group do?

Wildlife and governmental officials invite the Conservation Breeding Specialist Group (CBSG) to help with their conservation efforts. CBSG uses numerous processes and tools it has developed to carry out its globally recognized program. (For the purposes of this document only details of the PHVA are given)

Population and Habitat Viability Assessments (PHVAs)

Trying to save the all the world's biodiversity at one time is impossible. A more realistic approach, however, is to save a single threatened species and its corresponding habitat. Population and Habitat Viability Assessment Workshops attempt to bring together biologists and other professionals with relevant expertise in a collaborative effort to assess the extinction risk and develop better management strategies for particular endangered species. Computer modeling tools, using all available data for the species in question, are utilized for this process. These workshops are held in the countries which the plants and animals inhabit. Moreover, decisions are made by the corresponding country's wildlife officials allowing practical and expedient implementation of the resulting management plan.

Integration of Science, Management, and Stakeholders

The CBSG Population and Habitat Viability Assessment (PHVA) Workshop process is based upon biological and sociological science. Effective conservation action is best built upon a synthesis of available biological information, but is dependent on actions of humans living within the range of the threatened species as well as established national and international interests. There are characteristic patterns of human behavior that are cross-disciplinary and cross-cultural which affect the processes of communication, problem-solving, and collaboration: 1) in the acquisition, sharing, and analysis of information; 2) in the perception and characterization of risk; 3) in the development of trust among individuals; and, 4) in 'territoriality' (personal, institutional, local, national). Each of these has strong emotional components that shape our interactions. Recognition of these patterns has been essential in the development of processes to assist people in working groups to reach agreement on needed conservation actions, collaboration needed, and to establish new working relationships.

Frequently, local management agencies, external consultants, and local experts have identified management actions. However, an isolated narrow professional approach which focuses primarily on the perceived biological problems seems to have little effect on the needed political and social changes (social learning) for collaboration, effective management and conservation of habitat fragments or protected areas and their species components. CBSG workshops are organized to bring together the full range of groups with a strong interest in conserving and managing the species in its habitat or the consequences of such management. One goal in all workshops is to reach a common understanding of the state of scientific knowledge available and its possible application to the decision-making process and to needed management actions. We have found the decision-making driven workshop process with risk characterization tools, stochastic simulation modelling, scenario testing, and deliberation among stakeholders are powerful tools for extracting, assembling, and exploring information. This process encourages developing a shared understanding across wide boundaries of training and expertise. These tools also support building of working agreements and instill local ownership of the problems, the decisions required, and their management during the workshop process. As participants appreciate the complexity of the problems as a group, they take more ownership of the process as well as the ultimate recommendations made to achieve workable solutions. This is essential if the management recommendations generated by the workshops are to succeed.

CBSG's interactive and participatory workshop approach produces positive effects on management decision-making and in generating political and social support for conservation actions by local people. Modelling is an important tool as part of the process and provides a continuing test of assumptions, data consistency, and of scenarios. CBSG participants recognize that the present science is imperfect and that management policies and actions need to be designed as part of a biological and social learning process. The Workshop process essentially provides a means for designing management decisions and programs on the basis of sound science while allowing new information and unexpected events to be used for learning and to adjust management practices.

CBSG participants have learned a host of lessons in more than 100 workshop experiences in 40 countries. Traditional approaches to endangered species problems have tended to emphasize our lack of information and the need for additional research. This has been coupled with a hesitancy to make explicit risk assessments of species status and a reluctance to make immediate or non-traditional management recommendations. The result has been long delays in preparing action plans, loss of momentum, dependency on crisis-driven actions or broad recommendations that do not provide useful guidance to the managers.

Workshop Processes and Multiple Stakeholders

Experience: The Chairman and three Program Officers of CBSG have conducted and facilitated more than 100 species and ecosystem Workshops in 40 countries including the USA during the past 6 years. *Reports from these workshops are available from the CBSG Office*. We have worked on a continuing basis with agencies on some taxa (e.g., Florida panther, Sumatran tiger) and have assisted in the development of national conservation strategies for other taxa (e.g., Sumatran elephant, Sumatran tiger, Indonesia). Our *Population Biology Program Officer (Dr. P. Miller)* received his doctoral training with Dr. P. Hedrick and has experience with the genetic and demographic aspects of a range of vertebrate species. He has worked extensively with VORTEX and other population models.

Facilitator's Training and Manual: A manual has been prepared to assist CBSG workshop conveners, collaborators, and facilitators in the process of organizing, conducting, and completing a CBSG workshop. It was developed with the assistance of two management science professionals and 30 people from 11 countries with experience in CBSG workshops. These facilitator's training workshops have proven very popular with 2 per year planned for 1996 and 1997 in several countries including the USA. *Copies of the Facilitator's Manual are available from the CBSG Office.*

Scientific Studies of Workshop Process: The effectiveness of these workshops as tools for eliciting information, assisting the development of sustained networking among stakeholders, impact on attitudes of participants, and in achieving consensus on needed management actions and research has been extensively debated. We initiated a scientific study of the process and its long term aftermath three years ago in collaboration with an independent team of researchers (Vredenburg and Westley, 1995). A survey questionnaire is administered at the beginning and end of each workshop. They have also conducted extensive interviews with participants in workshops held in five countries. *Three manuscripts on CBSG Workshop processes and their effects are available from the team and the CBSG office.* The study also is undertaking follow up at one and two years after each workshop to assess longer-term effects. To the best of our knowledge there is no comparable systematic scientific study of conservation and management processes. *We will apply the same scientific study tools to the workshops in this program and provide an analysis of the results after each workshop.*

CBSG Workshop Toolkit

Our basic set of tools for workshops include small group dynamic skills, explicit use in small groups of problem restatement, divergent thinking sessions, identification of the history and chronology of the problem, causal flow diagramming (elementary systems analysis), matrix methods for qualitative data and expert judgements, paired and weighted ranking for making comparisons between sites, criteria, and options, utility analysis, stochastic simulation modeling for single populations and metapopulation and deterministic and stochastic modeling of local human populations. Several computer packages are used to assist collection and analysis of information with these tools. We provide training in several of these tools in each workshop as well as intensive special training workshops for people wishing to organize their own workshops.

Stochastic Simulation Modelling

Integration of Biological, Physical and Social Factors: The Workshop process, as developed by CBSG, generates population and habitat viability assessments based upon in-depth analysis of information on the life history, population dynamics, ecology, and history of the populations. Information on demography, genetics, and environmental factors pertinent to assessing population status and risk of extinction under current management scenarios and perceived threats are assembled in preparation for and during the workshops. Modeling and simulations provide a neutral externalization focus for assembly of information, identifying assumptions, projecting possible outcomes (risks), and examining for internal consistency. Timely reports from the workshop are necessary to have impact on stakeholders and decision makers. Draft reports are distributed within 3 weeks of the workshop and final reports within 60 days.

Human Dimension: We have collaborated with human demographers in 4 CBSG workshops on endangered species and habitats. They have utilized computer models incorporating human population characteristics and events at the local level in order to provide projections of the likely course of population growth and the utilization of local resources. This information was then incorporated into projections of the likely viability of the habitat of the threatened species and used as part of the population projections and risk assessments. We have prepared a draft manual on the human dimension of population and habitat viability assessment. It is our intention to further develop these tools and to utilize them as part of the scenario assessment process.

Risk Assessment and Scenario Evaluation: A stochastic population simulation model is a kind of model that attempts to incorporate the uncertainty, randomness or unpredictability of life history and environmental events into the modeling process. Events whose occurrence is uncertain, unpredictable, and random are called stochastic. Most events in an animal's life have some level of uncertainty. Similarly, environmental factors, and their effect on the population process, are stochastic - they are not completely random, but their effects are predictable within certain limits. Simulation solutions are usually needed for complex models including several stochastic parameters.

There are a host of reasons why simulation modeling is valuable for the workshop process and development of management tools. The primary advantage, of course, is to simulate scenarios and the impact of numerous variables on the population dynamics and potential for population extinction. Interestingly, not all advantages are related to generating useful management recommendations. The side-benefits are substantial.

- Population modeling supports consensus and instills ownership and pride during the workshop process. As groups begin to appreciate the complexity of the problems, they have a tendency to take more ownership of the process and the ultimate recommendations to achieve workable solutions.
- Population modeling forces discussion on biological and physical aspects and specification of assumptions, data, and goals. The lack of sufficient data of useable quality rapidly becomes apparent and identifies critical factors for further study (driving research and decision making), management, and monitoring. This not only influences assumptions, but also the group's goals.
- Population modeling generates credibility by using technology that non-biologically oriented groups can use to relate to population biology and the "real" problems. The acceptance of the computer as a tool for performing repetitive tasks has led to a common ground for persons of diverse backgrounds.
- Population modeling explicitly incorporates what we know about dynamics by allowing the simultaneous examination of multiple factors and interactions - more than can be considered in analytical models. The ability to alter these

parameters in a systematic fashion allows testing a multitude of scenarios that can guide adaptive management strategies.

- Population modeling can be a neutral computer "game" that focuses attention while providing persons of diverse agendas the opportunity to reach consensus on difficult issues.
- Population modeling results can be of political value for people in governmental agencies by providing support for perceived population trends and the need for action. It helps managers to justify resource allocation for a program to their superiors and budgetary agencies as well as identify areas for intensifying program efforts.

Modeling Tools: At the present time, our preferred model for use in the population simulation modeling process is called VORTEX. This model, developed by Lacy et al., is designed specifically for use in the stochastic simulation of the small population/extinction process. It has been developed in collaboration and cooperation with the CBSG PHVA process. The model simulates deterministic forces as well as demographic, environmental, and genetic events in relation to their probabilities. It includes modules for catastrophes, density dependence, metapopulation dynamics, and inbreeding effects. The VORTEX model analyzes a population in a stochastic and probabilistic fashion. It also makes predictions that are testable in a scientific manner, lending more credibility to the process of using population-modeling tools.

There are other commercial models, but presently they have some limitations such as failing to measure genetic effects, being difficult to use, or failing to model individuals. VORTEX has been successfully used in more than 90 PHVA workshops in guiding management decisions. VORTEX is general enough for use when dealing with a broad range of species, but specific enough to incorporate most of the important processes. It is continually evolving in conjunction with the PHVA process. VORTEX has, as do all models, its limitations, which may restrict its utility. The VORTEX model analyzes a population in a stochastic and probabilistic fashion. It is now at Version 7.3 through the cooperative contributions of dozens of biologists. It has been the subject of a series of both published and in-press validation studies and comparisons with other modeling tools. More than 2000 copies of VORTEX are in circulation and it is being used as a teaching tool in university courses.

We use this model and the experience we have with it as a central tool for the population dynamic aspects of this project. Additional modules, building on other simulation modeling tools for human population dynamics (which we have used in 3 countries) with potential impacts on water usage, harvesting effects, and physical factors such as hydrology and water diversion will be developed to provide input into the population and habitat models which can then be used to evaluate possible effects of different management scenarios. No such composite models are available.

CBSG Resources as Unique Asset

Expertise and Costs: The problems and threats to endangered species everywhere are complex and interactive with a need for information from diverse specialists. No agency or country encompasses all of the useful expert knowledge. Thus, there is a need to include a wide range of people as resources and analysts. It is important that the invited experts have reputations for expertise, objectivity, initial lack of local stake, and for active transfer of wanted skills. CBSG has a volunteer network of more than 700 experts with about 250 in the USA. More than 3,000 people from 400 organizations have assisted CBSG on projects and participated in workshops on a volunteer basis contributing tens of thousands of hours of time. We will call upon individual experts to assist in all phases of this project.

Indirect cost contributions to support: Use of CBSG resources and the contribution of participating experts provide a matching contribution more than equaling the proposed budget request for projects.

Manuals and Reports: We have manuals available that provide guidance on the goals, objectives, and preparations needed for CBSG workshops. These help to reduce startup time and costs and allow us to begin work on organizing the project immediately with proposed participants and stockholders. We have a process manual for use by local organizers, which goes into detail on all aspects of organizing, conducting, and preparing reports from the workshops. Draft reports are prepared during the workshop so that there is agreement by participants on its content and recommendations. Reports are also prepared on the mini-workshops (working groups) that will be conducted in information gathering exercises with small groups of experts and stakeholders. We can print reports within 24-48 hours of preparation of final copy. We also have CD-ROM preparation facilities, software and experience.

APPENDIX 4

SMALL POPULATION BIOLOGY AND POPULATION AND HABITAT VIABILITY ASSESSMENT

Robert Lacy, Tom Foose, John 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 the 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 in 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 weather 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 one out of every 30 years, forest first hit with some probability. Catastrophes include storms, fires, disease, and The Unexpected.

4. Genetic Drift and 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 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.

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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 and mitigate the probability of loss.

There are several approaches to modeling the variability of population extinction. One approach is to develop 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 model 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 allow 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 select 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 95% probability of survival for 200 years with 95% of the average genetic heterozygosity retained?

The advantage of simulation models like VORTEX is that they 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 and 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.

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 in 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.

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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. 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 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.

Inbreeding and Inbreeding Depression – mating between relatives. When number 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 doe to inbreeding has detrimental effects on population survival.

Extinction Vortex. The genetic and demographic processes 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.

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.

As unequal sex ratio of breeding animals, greater that 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 N_e 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 N_e of 500 to achieve some set of genetic objectives, the MVP might have to be 2000.

<u>Generation Time</u>. 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.

<u>The Number of Founders</u>. 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 o 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.

<u>Growth Rate</u>. 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.

APPENDIX 5

VORTEX : SIMULATION MODEL OF STOCHASTIC POPULATION CHANGE

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21 August 1991

STOCHASTIC SIMULATION OF POPULATION EXTINCTION

Life table analyses yield average long-term projections of the population growth (or decline), but do not reveal the fluctuations in the population size that would result from variability in the demographic processes. When a population is small and isolated from other populations of conspecifics, these random fluctuations can lead to extinction even of the populations that, 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 the 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 the 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 female produces broods of size 0, or 1, or 2, or 3, or 4, or 5 during each year, and which of these 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-productive age class and for reproductive-age animals. The mating system can be specified to be either monogamous or polygamous. 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 males and females of breeding age. Each animal in the initial population is assigned two unique alleles at some hypothetical genetic lous, 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 number of years.

The user also has the option of 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:

Proportion breeding = $A + BN+CN^2 + DN^3 + EN^*$ (*=4)

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 dependent function at increasingly higher population sizes. Any of the value 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 4^{th}-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 the birth and death rates is simulated by sampling binomial distributions, with the standard deviations specifying the annual fluctuations in the 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 the occurrence (i.e., a binomial process is simulated). If a catastrophe occurs, the probability of breeding is multiplied by a severity factor specified 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 number 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 a100 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 sub-population, and also on the meta-population. Because of migration (and, possibly, supplementation), there is 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, the computer program 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 unprecisely known.

VORTEX is, however, a simplified model of the dynamics of real 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 can easily be made to the input parameters before rerunning VORTEX. The file VORTEX.BAT is overwritten each time 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 recommend that VORTEX only be used on a 80386 (or faster) computer with a math co-processor. It can run on slower machines but may be slow.

The program can make use of any extended memory available on the computer (note: only extended, not expanded, memory above 1 MB will be used), and the extra memory will be necessary to run analysis with Heterosis inbreeding depression option on populations 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 reboot and run it again (as often as 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, EX 286 needs to be run (if VORTEX is to be used with extended memory) after each rebooting 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 reboot. 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=50

In order to get the program to run.

VORTEX is not copyrighted nor copy protected. Use it, distribute it, revise it, expand upon it. I would appreciate hearing 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 and could lead to erroneous results. It doesn't model all aspects of population stochasticity, and some of its components are simply and crudely represented. It explores the effects of random variability on population persistence, but it should be used with due caution and an understanding of its limitations.

APPENDIX 6

WILD WATTLED CRANE POPULATION VORTEX MODEL – BASELINE MODEL

VORTEX 8.40 -- simulation of genetic and demographic stochasticity

1-000.OUT
Wed Aug 2 06:12:33 2000

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

Extinction is defined as no animals of one or both sexes.

No inbreeding depression

First age of reproduction for females: 8   for males: 8
Maximum breeding age (senescence): 45
Sex ratio at birth (percent males): 50.000000

Population: South Africa
Long-term Monogamous mating; all adult males in the breeding pool.

Reproduction is assumed to be density dependent, according to:
  % breeding = ((55.00*[1-((N/K)^8.00)])+(40.00*[(N/K)^8.00]))*(N/(1.00+N))
   EV in % adult females breeding = 27.94 SD

Of those females producing litters, ...
   100.00 percent of females produce litters of size 1

   74.00 percent mortality of females between ages 0 and 1
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 1 and 2
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 2 and 3
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 3 and 4
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 4 and 5
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 5 and 6
    EV in % mortality = 0.000000 SD
   6.00 percent mortality of females between ages 6 and 7

EV in % mortality = 0.000000 SD
6.00 percent mortality of females between ages 7 and 8
EV in % mortality = 0.000000 SD
6.00 percent mortality of adult females (8<=age<=45)
EV in % mortality = 0.000000 SD
74.00 percent mortality of males between ages 0 and 1
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 1 and 2
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 2 and 3
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 3 and 4
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 4 and 5
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 5 and 6
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 6 and 7
EV in % mortality = 0.000000 SD
6.00 percent mortality of males between ages 7 and 8
EV in % mortality = 0.000000 SD
6.00 percent mortality of adult males (8<=age<=45)
EV in % mortality = 0.000000 SD

EVs may be adjusted to closest values possible for binomial distribution.
EV in reproduction and mortality will be concordant.

Frequency of type 1 catastrophes: 20.000 percent
multiplicative effect on reproduction = 0.900000
multiplicative effect on survival = 0.950000

Initial size of South Africa: 379
(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 26 27 28 29 30 31 32
33 34 35 36 37 38 39 40 41 42 43 44 45 Total
9 9 9 8 8 8 7 7 6 7 6 6 5 6 5 5 4 5
4 4 4 4 4 3 3 3 3 3 3 3 2 3 2 2 3 2 2
1 2 2 2 1 2 0 2 189 Males
9 9 9 8 8 8 7 7 6 7 6 6 5 6 5 5 4 5
4 4 4 4 4 3 3 3 3 3 3 3 2 3 2 2 3 2 2
1 2 2 2 1 2 1 2 190 Females

Carrying capacity = 500
EV in Carrying capacity = 0.20 SD

Deterministic population growth rate
(based on females, with assumptions of
no limitation of mates, no density dependence, no functional dependencies, and no inbreeding depression)

r = -0.028 lambda = 0.972 R0 = 0.565
Generation time for: females = 20.08 males = 20.08

Stable age distribution: Age class	females	males
0	0.079	0.079
1	0.021	0.021
2	0.020	0.020
3	0.019	0.019
4	0.018	0.018
5	0.018	0.018
6	0.017	0.017
7	0.016	0.016
8	0.015	0.015
9	0.015	0.015
10	0.014	0.014
11	0.014	0.014
12	0.013	0.013
13	0.012	0.012
14	0.012	0.012
15	0.011	0.011
16	0.011	0.011
17	0.010	0.010
18	0.010	0.010
19	0.010	0.010
20	0.009	0.009
21	0.009	0.009
22	0.008	0.008
23	0.008	0.008
24	0.008	0.008
25	0.007	0.007
26	0.007	0.007
27	0.007	0.007
28	0.006	0.006
29	0.006	0.006
30	0.006	0.006
31	0.006	0.006
32	0.005	0.005
33	0.005	0.005
34	0.005	0.005
35	0.005	0.005
36	0.005	0.005
37	0.004	0.004
38	0.004	0.004
39	0.004	0.004
40	0.004	0.004
41	0.004	0.004
42	0.004	0.004
43	0.003	0.003
44	0.003	0.003
45	0.003	0.003

Ratio of adult (>= 8) males to adult (>= 8) females: 1.000

Population 1: South Africa

Year 10
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 288.23 (3.34 SE, 33.39 SD)
Means across extant populations only:
Population size = 288.23 (3.34 SE, 33.39 SD)
Expected heterozygosity = 0.997 (0.000 SE, 0.000 SD)
Observed heterozygosity = 1.000 (0.000 SE, 0.000 SD)
Number of extant alleles = 406.77 (3.18 SE, 31.82 SD)

Year 20
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 208.14 (3.35 SE, 33.45 SD)
Means across extant populations only:
Population size = 208.14 (3.35 SE, 33.45 SD)
Expected heterozygosity = 0.995 (0.000 SE, 0.001 SD)
Observed heterozygosity = 1.000 (0.000 SE, 0.001 SD)
Number of extant alleles = 250.07 (2.89 SE, 28.90 SD)

Year 30
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 156.13 (3.06 SE, 30.64 SD)
Means across extant populations only:
Population size = 156.13 (3.06 SE, 30.64 SD)
Expected heterozygosity = 0.992 (0.000 SE, 0.001 SD)
Observed heterozygosity = 0.999 (0.000 SE, 0.004 SD)
Number of extant alleles = 165.80 (2.38 SE, 23.78 SD)

Year 40
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 115.03 (2.90 SE, 29.04 SD)
Means across extant populations only:
Population size = 115.03 (2.90 SE, 29.04 SD)
Expected heterozygosity = 0.987 (0.000 SE, 0.002 SD)
Observed heterozygosity = 0.997 (0.001 SE, 0.007 SD)
Number of extant alleles = 114.13 (2.07 SE, 20.71 SD)

Year 50
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 85.53 (2.71 SE, 27.13 SD)
Means across extant populations only:
Population size = 85.53 (2.71 SE, 27.13 SD)
Expected heterozygosity = 0.982 (0.000 SE, 0.004 SD)
Observed heterozygosity = 0.996 (0.001 SE, 0.009 SD)
Number of extant alleles = 80.92 (1.81 SE, 18.13 SD)

Year 60
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 63.58 (2.25 SE, 22.49 SD)
Means across extant populations only:
Population size = 63.58 (2.25 SE, 22.49 SD)
Expected heterozygosity = 0.974 (0.001 SE, 0.007 SD)
Observed heterozygosity = 0.993 (0.001 SE, 0.012 SD)
Number of extant alleles = 57.67 (1.45 SE, 14.51 SD)

Year 70
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 45.19 (1.81 SE, 18.14 SD)
Means across extant populations only:
Population size = 45.19 (1.81 SE, 18.14 SD)
Expected heterozygosity = 0.963 (0.001 SE, 0.013 SD)
Observed heterozygosity = 0.987 (0.002 SE, 0.019 SD)
Number of extant alleles = 41.34 (1.25 SE, 12.50 SD)

Year 80
N[Extinct] = 0, P[E] = 0.000
N[Surviving] = 100, P[S] = 1.000
Mean size (all populations) = 31.58 (1.48 SE, 14.77 SD)
Means across extant populations only:
Population size = 31.58 (1.48 SE, 14.77 SD)
Expected heterozygosity = 0.943 (0.003 SE, 0.028 SD)
Observed heterozygosity = 0.987 (0.002 SE, 0.023 SD)
Number of extant alleles = 28.91 (1.03 SE, 10.26 SD)

Year 90
N[Extinct] = 3, P[E] = 0.030
N[Surviving] = 97, P[S] = 0.970
Mean size (all populations) = 21.95 (1.18 SE, 11.84 SD)
Means across extant populations only:
Population size = 22.54 (1.17 SE, 11.53 SD)
Expected heterozygosity = 0.916 (0.006 SE, 0.055 SD)
Observed heterozygosity = 0.981 (0.004 SE, 0.043 SD)
Number of extant alleles = 20.68 (0.87 SE, 8.58 SD)

Year 100
N[Extinct] = 7, P[E] = 0.070
N[Surviving] = 93, P[S] = 0.930
Mean size (all populations) = 14.55 (0.97 SE, 9.71 SD)
Means across extant populations only:
Population size = 15.58 (0.96 SE, 9.28 SD)
Expected heterozygosity = 0.882 (0.008 SE, 0.082 SD)
Observed heterozygosity = 0.959 (0.007 SE, 0.072 SD)
Number of extant alleles = 14.84 (0.66 SE, 6.39 SD)

In 100 simulations of South Africa for 100 years:
7 went extinct and 93 survived.

This gives a probability of extinction of 0.0700 (0.0255 SE),
or a probability of success of 0.9300 (0.0255 SE).

7 simulations went extinct at least once.
Of those going extinct,
mean time to first extinction was 93.43 years (2.91 SE, 7.70 SD).

Means across all populations (extant and extinct) ...
Mean final population was 14.55 (0.97 SE, 9.71 SD)

Age 1	2	3	4	5	6	7	Adults	Total	
0.23	0.41	0.27	0.34	0.26	0.31	0.17	5.35	7.34	Males
0.20	0.30	0.18	0.27	0.23	0.33	0.16	5.54	7.21	Females

Means across extant populations only ...
Mean final population for successful cases was 15.58 (0.96 SE, 9.28 SD)

Age 1	2	3	4	5	6	7	Adults	Total	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.75	7.89	Males
0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.96	7.75	Females

Across all years, prior to carrying capacity truncation,
mean growth rate (r) was -0.0347 (0.0006 SE, 0.0630 SD)

Final expected heterozygosity was 0.8823 (0.0085 SE, 0.0816 SD)
Final observed heterozygosity was 0.9585 (0.0075 SE, 0.0720 SD)
Final number of alleles was 14.84 (0.66 SE, 6.39 SD)
****