RAPPORT DE STAGE

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À : Institut de Zoologie de Londres, ZSL (*Zoological Society of London*)

Sur le thème : Blue Crane population viability analyses using ULM.

Pour l'obtention du :

DIPLOME D'AGRONOMIE GENERALE

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Acknowledgements.

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I am very grateful to Richard Pettifor too, my supervisor at the Institute of Zoology at ZSL who gave me the opportunity to work on such wonderful birds, not only virtually but also on the field in South Africa. He was very enthusiastic to communicate me his knowledge about Blue Cranes, South African birds and…driving on the left!!!

Very big thanks go to all South African people of SACWG who were very welcoming, especially during the brays! You are doing wonderful work in the field and I understand well now why it is so difficult to collect data on those crazy Cranes!

The final thank you goes to my boyfriend Ben and my family who have really supported me during this practice period.

Introduction.

Cranes are fascinating large, long necked and long legged birds, known for their elaborated and impressive mating dances. This is maybe why they are so revered in many cultures: for instance in Asia, they are considered as auspicious and as a symbol of longevity. They have always been a source of inspiration for artists such as Hokusaï. But despite their attractive power, they are still mysterious. Their biology is not well known and 10 of their 15 species are currently even threatened or critically endangered.
Blue Crane is one of the smaller crane species and has the most range restricted of all the cranes in the world. They can be distinguished by their body plumage silvery bluish grey becoming darker on the upper neck and the lower half of the head and nape. They are with the Demoiselle Crane *Anthropoides virgo* the two species of cranes that do not have bare, red skin on their heads. Blue Cranes are endemic to southern Africa and are the national bird of South Africa. The Blue Crane population comes currently to around 20,000 individuals. The main threats of the population are collision with power lines, trap of fences, accidental and deliberate poisoning and for some areas loss of habitat.

Figure 1 : *Pine, Plum and Cranes,* 1759 AD, by Shen Quan, the Palace Museum, Beijing.

The main aim of this study was to model the Blue Crane population in order to get a better understanding of the population dynamics. We used the free software called ULM (which stands for **U**nified **L**ife **M**odels) with a small black box which allows more freedom in the modelling then other software like Vortex for instance. It was created by Stéphane Legendre in 1995 for ecology management and conservation biology purposes. It is designed for discrete models and particularly matrix population models.
We first study bibliographically the Blue Crane biology in order to know which phenomenon we have to model (for example, the monogamy or the senescence). Then, we translated those biological phenomenons in mathematical equations, using the theory of matrix population models. We have proceeded by beginning with simple model and then by making it more complex and more realistic. We first attached value to characterize key traits, vulnerability and main threats of each sub population in a management goal. In a second approach, we took into account the metapopulation structure to get a more realist modelling.

As conservation costs are high and the funding not always sufficient, population management must be concentrated on main threats. The results of this modelling work will be used to determine to which parameter the population is the most sensitive in order to focus the conservation on those and try to make it more efficient.

I- Blue Crane ecology.

1- Classification and description.

Order = Gruiformes
Family = Gruidae
Subfamily = Gruinae
Species = *Anthropoides paradiseus*

Figure 2 : Blue Crane couple, *Wicus Leeuwner*.

Blue Cranes are more than one meter tall and weight about 4 kg. Their body plumage is pale blue-gray in colour, becoming darker at the extremities. Their crown is a grayish white, the bill is pink and the legs are short bills and black. The primary, secondary and tail feathers are black. The wingtip feathers or tertial feathers are long, dark and trail to the ground. Like the Demoiselle Crane *Anthropoides virgo*, Blue Cranes do not have bare red skin on their heads. This last specie seems to have the closest biology to Blue Crane's.
Blue Cranes seem to moult both partially and completely when they can not fly any more for circa two months. When they become flightless, Blue Cranes form large flocks and stay in calm areas without disturbance which could be very specific. Birds that can fly play the role of alarm birds: they begin to fly to alert the flightless ones they should run and make believe the predator by the same way that the whole flock can escape by flying.

There is no sexual dimorphism: male and female can not be distinguished, except during the 'unison call' or by chemical analyses. Males and females are virtually indistinguishable (Males are a little bit bigger than females but it is very difficult to notice through binoculars.). Juveniles are slightly lighter blue grey than adults, and lack the long tertial wings.

Blue Cranes have a life expectancy around 25 years which is quite long for a bird.

2- Habitat and distribution.

99 % of the Blue Crane population is found in South Africa. There are a few isolated birds in Botswana and Swaziland and a sub population in northern Namibia, in Etosha National Park but this small population (circa 60-80 individuals) is isolated and rapidly declining.

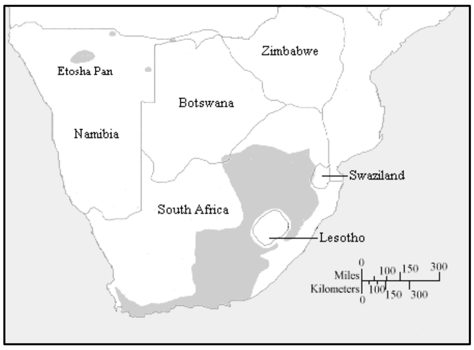


Figure 3 : Repartition of Blue Crane in southern Africa.

Blue Cranes used to occur historically mainly in the grassland biome and more precisely in short dry grasslands. The loss of grassland and the disappearance of natural vegetation for crops and pastures have not only reduced the number of Blue Cranes, but also the repartition and the habitat of them. For instance, Blue Cranes are now really frequent in the province of Western Cape in cereal crops fields and dryland pastures. Blue Cranes are mostly independent of wetlands for breeding, like the Demoiselle Crane. This is a good potential for being more widespread than other cranes species.

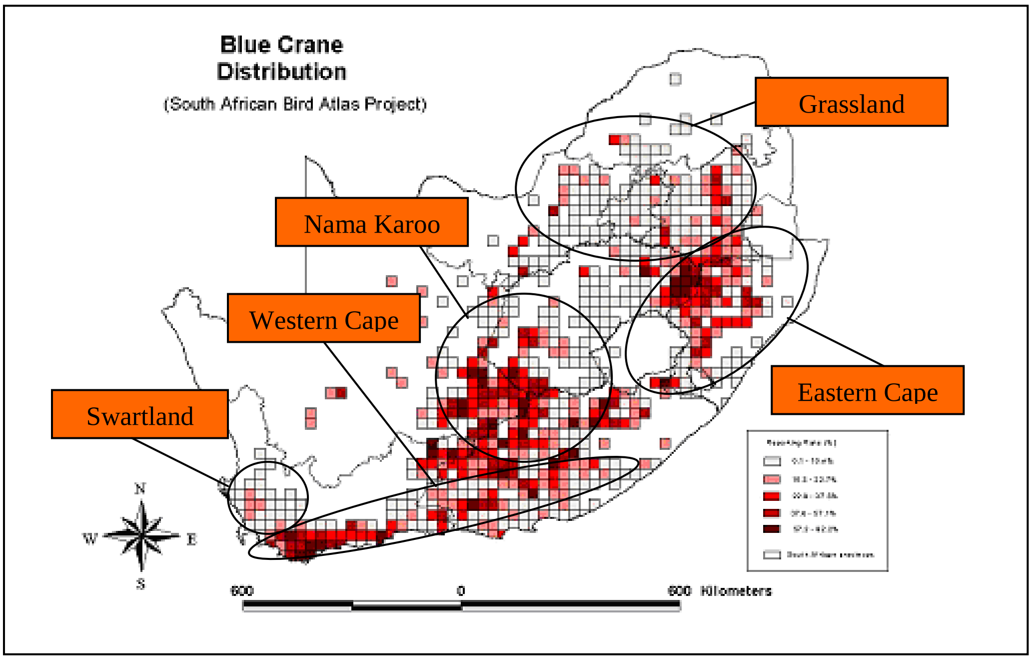


Figure 4 : The distribution of the Blue Crane according to the South African Bird Atlas Project.

Blue Crane population in South Africa can be subdivided in 5 sub-populations: the Overberg population, the Swartland population, the Nama Karoo population, the Eastern Cape population and the Grassland population which corresponds to individuals found in the south of Limpopo and the Gauteng provinces. In the area of the Karoo, the habitat is made up of grassy and dwarf shrubland. In the Overberg and the Swartland which are the areas of the biome Fynbos, Blue Crane do not like natural vegetation, they prefer artificial environment represented by agricultural lands. The Eastern Cape like the south of Limpopo and the Gauteng are open grasslands areas.

The current estimations for numbers are the following: ± 12 000 birds in the Western Cape, ± 5 000 birds in the Eastern Cape and the northern grasslands and ± 5 000 birds in the Karoo.

3- Nutrition.

All Cranes are omnivorous. Blue Cranes mainly eat the seeds of sedges and grasses, waste grains, insects, frogs, reptiles and small mammals. They forage mostly by pecking on the ground but sometimes dig with their beak. In some areas, there take advantage of breeding environment eating the stock food in the feedlots, especially during the winter and this is often a conflict source with farmers.

Figure 5 : Blue Crane pecking on the ground, *Wicus Leeunwer.*

4- Reproduction.

Blue Cranes are long term monogamous that is to say they mate for life. They may meet during pairing displays in flocks. Those displays consist in running, leaping into air with flapping the wings (behaviour called 'dance'), calling and tossing vegetation and mammal dung into air. The birds are sexually mature when about 3 to 5 years old.

There are also courtship displays within mated pairs of Blue Cranes. The male initiates the display and calls after each female call. This call is named 'unison call'. This is a complex series of calls, while the birds are standing with the head thrown back and the beak towards the sky. The male has got his wings opened but not the female: this is almost the only moment when one can distinguish male from female. Pair bond of Blue Crane also 'dance' during those displays: they jump, bow, run in circles, toss grass and flap wings from 28 minutes to 4 hours. Those displays are repeated frequently two weeks before copulation.

Blue Cranes breed in summer, from late September through to February. They choose secluded open grasslands for nesting sites, with a cleared view to be on the lookout for predators and to be able to escape in the case of an alert. In agricultural areas, they prefer pastures or crops fields that have been harvested. The couple nest generally in the same area year after year; the nest is a few meters further than the previous year's.

Blue Cranes lay generally a clutch of two eggs (sometimes 3), coloured in light-pinkish with brown blotches. The nest is not very complex; this is only a shallow grassy depression or simply on the ground. Female and male both incubate during 30-33 days. The chicks are fed by the mother who uses the tips of her beak on an initial diet of insect larvae and worms.

The male is in charge to defend the nest and the eggs. Generally the tactics consists of diverting the predator while the chicks are hiding. Blue Cranes are territorial breeders; they drive other birds away from the nest. When the chicks can fly, that is to say between 3 and 5 months, the chicks fledge. Juveniles are seldom let alone: either they have been observed with their parents; either they have been found in flocks.

Figure 6 : New born chick and hatching of the other egg, *Wicus Leeuwner*.

Some cases of hybridisations have been recorded in wild with Wattled Cranes.

5- Behaviour.

Blue Cranes are usually found in big flocks (up to 1000 individuals circa), especially during the winter season and smaller flocks in the summer. The composition of flocks is not stable, new birds often join the flock and sometimes big flocks split into two different others.

Figure 7 : Part of a 188 birds summer flock in the Overberg, *Cecile Leclere Begueria*.

The summer flocks do not generally include mated pair but only non-breeders individuals. That is why those flocks are believed to be made up of immature birds and to be the structure where pairs are formed but there is no evidence yet of that phenomenon.

Blue Cranes are known to be partial migrants only within South Africa and only within some areas. This assumption lays on the fact that the flocks are not always found in the same areas than the breeding couples and also because winter densities are quite higher than summer densities. But this last observation is biased because of the statistical artefact created by the fact that flocks are more easily observed than breeding pairs.
However, some records seem to show that the seasonal movements would be determined by altitude: Blue Cranes may spend the summer breeding season in higher area and then move with their chicks to lower fields during the fall and the winter.

Regarding the possible migrations of Blue Cranes as for their general habit of forming flocks, research is not sufficient yet to understand movement patterns or even the composition of flocks. This lack of information is currently fulfilled with colour ringing and satellite telemetry assessed by the SACWG (South African Crane Working Group) of EWT (Endangered Wildlife Trust). The first results are showing more local migrations, within subpopulation. At the moment, migrations throughout South Africa are less obvious.

6- Threats, status and conservation actions.

The Blue Crane population is currently listed as vulnerable in the Eskom Red Data Book of South Africa, Lesotho and Swaziland and in 2006 by the International Union for the Conservation of Nature and Natural Resources (IUCN) Red List. This reflects only the situation of last years: Blue Cranes were abundant before the 80s and their population was considered as ‘healthy throughout South and Southwest Africa” and “nowhere endangered”. Although the specie is still found frequently in some areas (particularly in the Overberg), there was significant and rapid local declines over the last thirty years (some subpopulations may have declined by 90%). The main consequence of this decline is the division of the population in three or even five subpopulations. It may have affected the population since the growing of a meta-population is more difficult. However, some of the subpopulations seem to appear stable: in the Karoo area and also in the Fynbos biome where Blue Cranes have become colonizer of agricultural zones.

Blue Cranes are facing many threats: collision with power lines or fences, accidental and deliberate poisoning, predation, and for some areas loss of habitat. Those threats are more or less intense depending on the area considered, the period of the year and also the age of birds. However, the threats that were responsible for the drastic decline of the 80s were widespread poisoning on agricultural land (both intentional and accidental) and loss of habitat.

Figure 8 : Poisonned Blue Cranes in the Overberg, *Wicus Leeuwner.*

- **Deliberate poisoning** is explained by the bad opinion of farmers on Blue Crane since they can damage crops fields and stock food, especially when there is a large flock of more than 1000 birds. Intentional poisoning of cranes is forbidden by the law in South Africa but it is difficult to find guilty people. The poison can be aimed at killing other species that damage crops and can kill the Blue Cranes by the way. Pesticides applied to crops can be toxic for Cranes. Poisoning can affect birds at any age and occurs to be mostly localised in the south-western Cape Province (Overberg), especially during the end of the winter when large flocks are formed. This localization can be explained by the high concentration of agricultural areas and the period of occurrence because this is also when seeds are planted and sheep receive supplementary feed and so also when large winter flocks are the most likely to cause consequent damage and to be massively touched by poisoning.

- **The loss of habitat** is the disappearance of grasslands for the benefit of agriculture, urbanization and commercial afforestation with the conversion of grasslands to pine and eucalyptus plantations for pulp and timber production. Such plantings are environmentally enemies since they alter the ecosystem of grassland, but also the wetlands and the groundwater flows which are desiccated.

Figure 9 : Dead Blue Crane caught in a fence with broken legs in the Overberg, *Wicus Leeuwner*.

- **The fences** of livestock fields represent a trap, especially for chicks that have not fledged yet. They break their legs when they try to go through the fence to join the other field to escape a danger for instance.
- **The collisions with power lines** mainly affect adults that can fly and near water points and roosting and breeding sites from where they often come and leave. This source of mortality is quite frequent in the Overberg.
- **The predation** has been increased with the spread of domestic dogs. This affects mainly eggs and chicks.
- **Illegal trade** is also occurring. People capture mainly chicks that can not fly in order either to eat them (magic reputation), either to tame them as pets. Some people like rehabilitation centres can get a permit which allows keeping Blue Cranes in captivity.

Figure 10 : Captive Blue Crane, *Wicus Leeuwner.*

A serial of conservation measures have been taken since the mid-1980s. Concerning the reduction of power lines collisions, Eskom (the South African electricity company) has signed an agreement with NGOs to install some signalisations making lines more visible for the birds. The legislation is now stricter with Blue Crane trade. Management programmes and habitat protection were increased like environmental education and awareness.

However, the Blue Crane metapopulation needs more protection to increase. This modelling study aims to guide conservation programs and fieldworkers in order they are more efficient in terms of the growth of the Blue Crane population thanks to focalisation on the fight against mortality factors to which the population is the most sensitive.

Figure 11 : Signalisation on power lines, *Cecile Leclere Begueria*.

II- Modelling the Blue Crane life cycle.

We have always modelled the Blue Crane population in a case of pre-breeding census. First, we created the simplest model based on stages (the 4 first for the 4 first years of living and the last one for the adult individuals aged of 5 years and more) and also female based. Individuals take part in reproduction only after 5 years of living. The survival rate is the same after 4 years and is called survival rate of adults.
Then we decomposed the survival of youngs in different survival rates in order to model the 3 different steps in the first year of living: egg (se), hatchling (sh) and fledgling (s0). This do not change at all the basis of our first model with only one global survival rate for the first year, but it allows to do sensitivities/elasticities analyse on this 3 new parameters.

Parameters	Meaning
Se	survival rate of eggs
Sh	survival rate of hatch
s0	survival rate of fledge
s1	survival rate between 1st & 2nd year
s2	survival rate between 2nd & 3rd year
s3	survival rate between 3rd & 4th year
sA	survival rate between 4th & next years
P1	probability of clutch size of 1 egg
P2	probability of clutch size of 2 egg
Γ	Clutch size, mean = p1*1 + p2*2
Σ	sex ratio
P	proportion of breeders
K	carrying capacity

Figure 12 : Range of parameters used in the models.

To determine which way of modelling choosing we used a range of mean parameters calculated thanks to the three ranges of parameters we got on the three sub-populations considered later (Grassland, Western Cape and Nama Karoo cf § 'Metapopulation analyze').

Parameters	New value	Confidence Interval	SE
proportion of breeders = p	0,45 [a]		
Survival rate of eggs = se	1,43/1,9=0,75 [b]		
survival rate of hatch = sh	1/1,43=0,69 [b]		
survival rate of fledge = s0	0,63 [c]	0,39-0,82 [c]	0,117 [c]
survival rate between 1st & 2nd yr = s1	0,81 [c]	0,56-0,93 [c]	0,093 [c]
survival rate between 2nd & 3rd yr = s2	0,81 [c]	0,55-0,94 [c]	0,099 [c]
survival rate between 3rd & 4th yr = s3	0,97 [c]	0,89-0,99 [c]	0,021 [c]
survival rate between 4th & next yrs = sA	0,97 [c]	0,89-0,99 [c]	0,021 [c]
Number hatched per pair = Nbh	1,43 [b]		
Number fledged per pair = Nbf	1 [b]		
Clutch size = γ	1,90 [b]		
Sex ratio = σ	0,5 [d]		
Carrying capacity = K	10000 [d]		
Parameter to multiply to maturity factor (polynomial function)	1,64 [e]		

Figure 13 : Range of values used when modelling the Blue Crane life cycle

[a] From Leon Theron (Richard)
[b] Calculated cf fecundity[2].xls file = mean on the values of the 3 sub populations thanks to the data collected by fieldworkers on the 2007 breeding season.
[c]From the publication of Mark Anderson
[d] From old vortex model
[e] Calculated (cf parameters.xls)

1- Generic matricial models: deterministic models without density dependence

a) Baseline model: model with 5 stages, female based, one patch

This first model is the simplest one. It takes into account only 5 stages (the 4 first for the 4 first years of living and the last one for the adult individuals aged of 5 years and more) and is female based. Only individuals over 5 years are taking part in the reproduction.

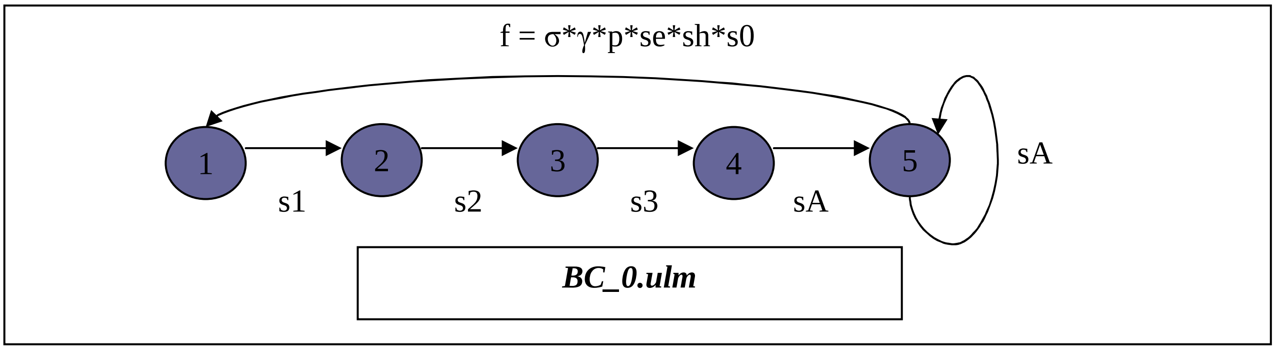


Figure 14 : Blue Crane life cycle with a deterministic model with 5 stages, female based, without density dependence.

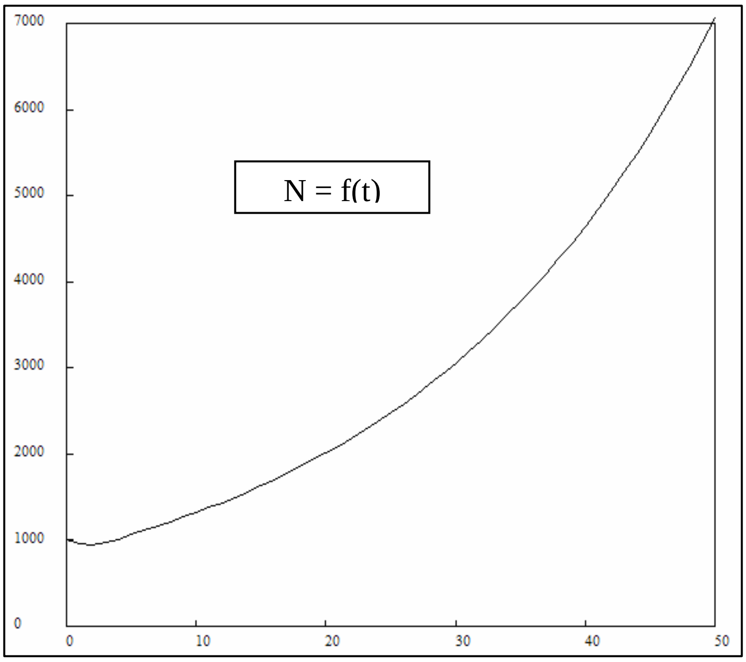


Figure 15 : Total population size evolution between 0 and 50 years for the BC_0.ulm model.

Lambda	1.04277
Generation time	25.16

Figure 16 : Growth rate and generation time obtained thanks to the BC_0.ulm model.

We get a growing population which increases its size of 4,1 % per year (intrinsic rate of increase = 0,04188).

	Reproductive value	**Stable distribution**
1	0,1309	0,0959
2	0,1685	0,0745
3	0,2169	0,0579
4	0,2332	0,0538
5	0,2506	0,7178

Figure 17 : Reproductive value and stable distribution for the BC_0.ulm model.

The reproductive values are nearly equally distributed: even the stage for the first year is important for the reproductive success since those individuals will become reproducers in the future. Adults are the class the most present in the stable distribution: they represent around 71 % of this distribution.

Elasticities to :	**BC_0.ulm**
proport° of breeders	0.05456
Se	0.05456
Sh	0.05456
s0	0.05456
s1	0.05456
s2	0.05456
s3	0.05456
sA	0.7818
γ	0.05456
σ	0.05456

Figure 18: Elasticities obtained with the BC_0.ulm model.

The population is more sensitive to the adult survival sA than to the other parameters since sA explains around 78 % of the growing rate whereas the other parameters account around 5 % of the growing rate.
Another way of estimate the sensitivities to the different parameters of our model is to draw the fitness landscape with ULM. It will not give us figures of sensitivities or elasticities but we will be able to compare sensitivities of the chosen parameters.

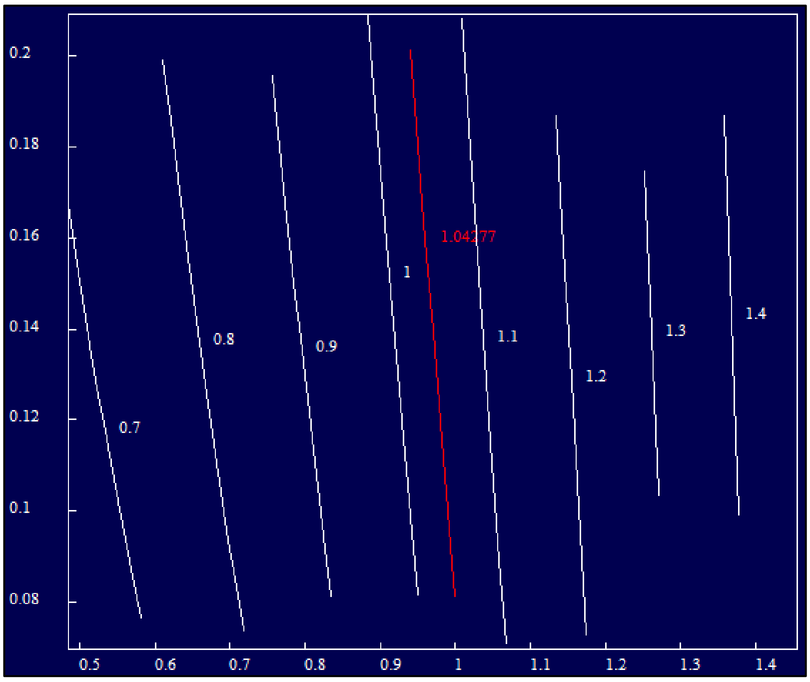


Figure 19 : Fitness landscape for the BC_0.ulm model with adult survival rate in X and fertility f in Y. The red isocline corresponds to the set of (*f*, *sA*) values giving the actual growth rate λ = 1.04277.

The steepness of the isoclines reflects the large sensitivity of sA as compared to f. A small change in sA must be compensated by a large change in f to maintain the growth rate.
Those isoclines show that for a given fertility, a little variation in the adult survival rate affects a lot the growth rate lambda since the slope is high. On the contrary, for a given adult survival rate, a little change in the fertility induces little variations in the growth rate. That is to say population growth is more sensible to the adult survival rate than to the fertility.

A third way of getting an idea of the main factors to which the population is sensitive is to make a batch analyse, that is to say make a parameter variate while the other are not changed and observed whether the population is growing or not. This is how we can obtain the Fig.20.

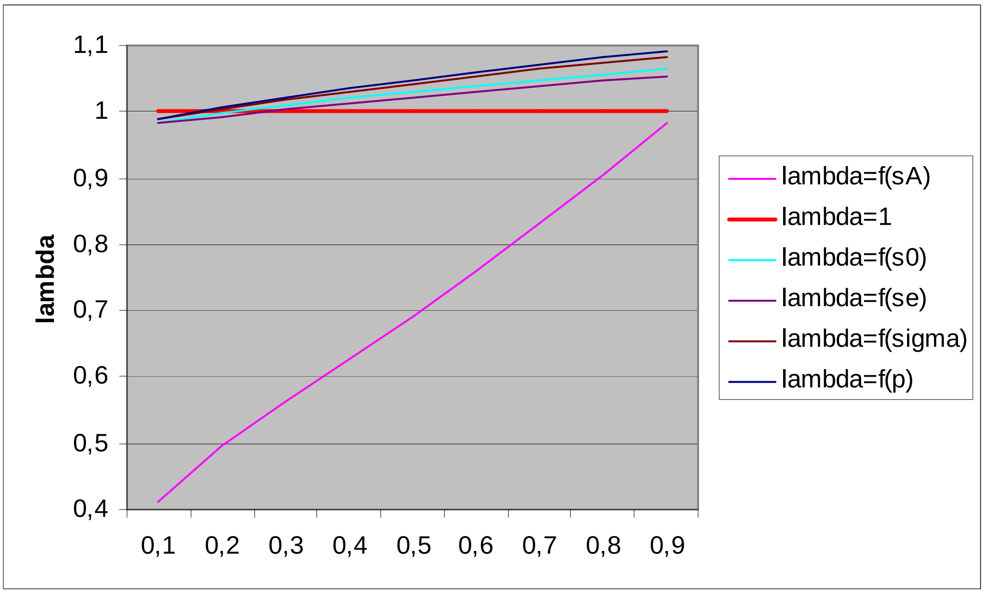


Figure 20 : Batch analyse where all the parameters were successively and independently made variate between 0,1 and 0,9 while the others were constant with the BC_0.ulm model.

Two main facts should be noticed on this graph:

- *the slopes of the different curbs*

The slope for the survival rate sA is higher than for the other parameters. That is another way of seeing that the population is very sensitive ot sA. Indeed, a little variation in the value of sA will induce a wider variation in the growth rate lambda than the same little variation in the value of the other parameters (s0, se, σ, p).

- *the intersection with the red straight line*

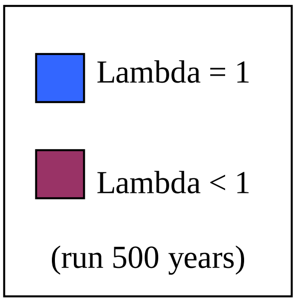
Those intersections are thresholds bellow which population is declining. All the points under the red straight line are figures which lead to a declining population. So, for example, for sA, the intersection is reached for a sA value of 0,93. This means that if the adult survival rate sA decrease under 0,93 –all other parameters staying the same-, the population will decline.

Parameter	Threshold
sA	0,93
s0	0,24
se	0,29
σ	0,2
p	0,18

Figure 21 : Thresholds under which the population will decline.

There again, we can notice that the threshold for the adult survival rate is very high in comparison with those of other parameters. This means that the range of value for keeping a growing population is not very large for the adult survival whereas this amplitude is quite more important for other parameters.

In the reality, one parameter does not variate alone; there is some dependence between the variations of parameters. To make a better simulation, it is possible to make a batch analyse where two parameters variate at the same time while the other are constant. (it is not possible to make more than 2 parameters variate at the same time because there is only 3 dimensions: two for the 2 parameters and one for the growth rate).



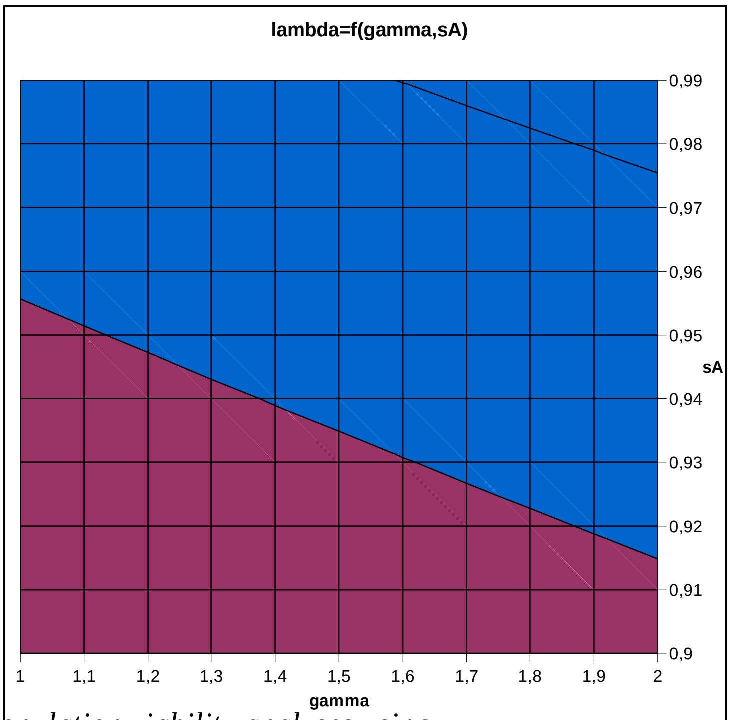


Figure 22 : Batch analyse with the BC_0.ulm model where the adult survival rate sA was made variate between 0,9 and 0,99 and the mean clutch size γ between 1 and 2. In purple the combinations of (sA; γ) which lead to a declining population

and in blue those which lead to a growing one.

We can say after a batch analyse where sA and γ variate that there is some chance (around 39,4%) to find a combination between this 2 variables that will make the population decrease (cf the surface with a lambda under 1 on the graph besides is not so small). In this range of high adult survival rates, even a clutch size γ of 2 does not allow a growing population (for the lowest figures of sA).

b) Addition of males: model with 5 stages, 2 sex, monogamy and one patch

We add to the first model the male population and an equation to represent the monogamy to long term that is usual in Blue Cranes populations (this was thanks to the calculation of a mating probability, knowing that the number of matings according to monogamy will be determined by the minimum between number of males and females).

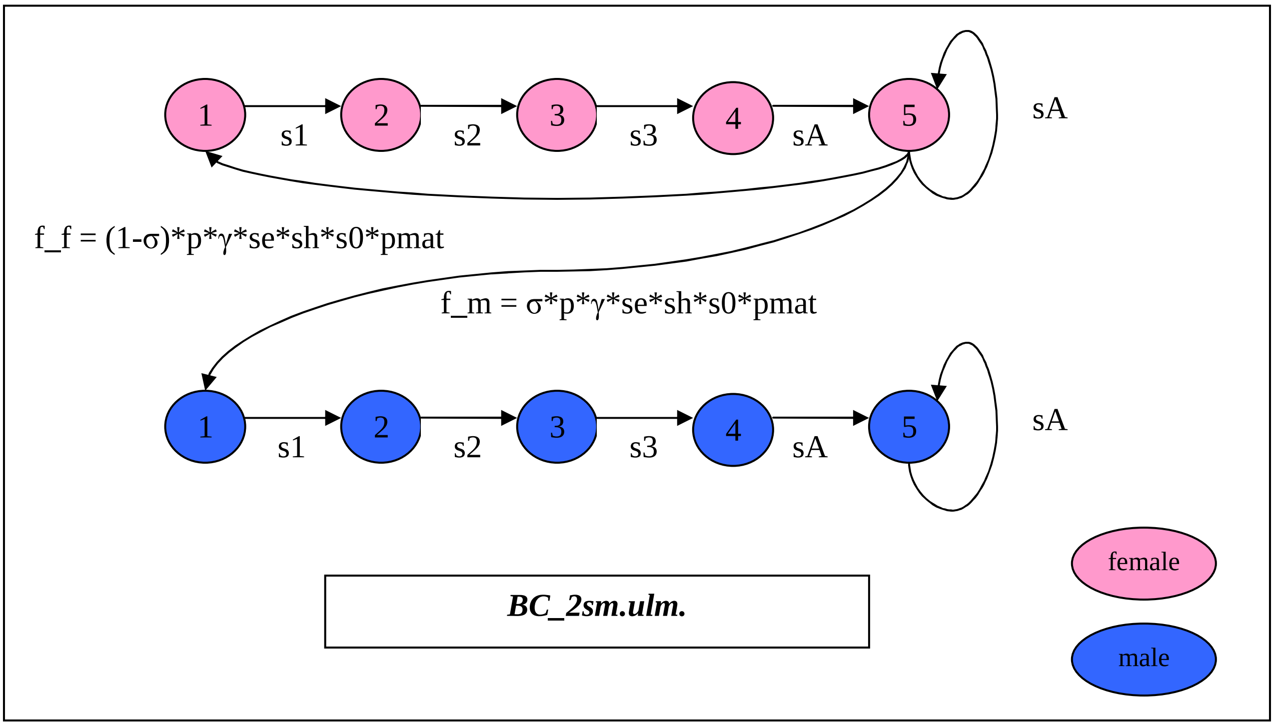


Figure 23 : Blue Crane life cycle with a deterministic model with 5 stages, two sex and monogamy, without density dependence.

The addition of 2 sex and monogamy does not seem to affect the results since we obtain the same growth rate as the previous with the simplest model (lambda=1.04277). We can conclude that the addition of males and monogamy do not bring more precision to our model since females and males have the same values for survival rates. We do not need to take into account the two sex and the monogamy in further models. We can notice the importance of sA and especially the female sA since 72.7 % of the population growth is explained by this parameter (cf elasticities).

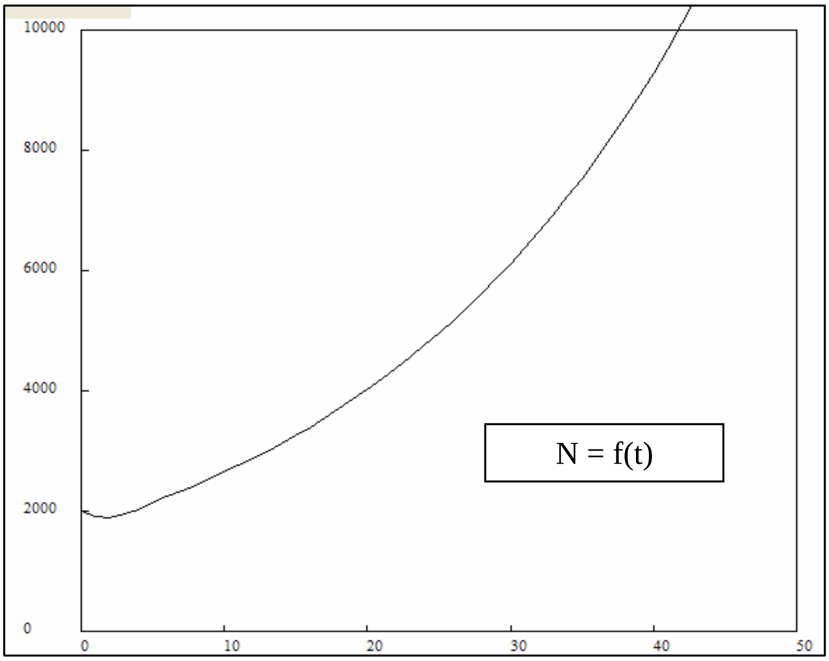


Figure 24 : Total population size evolution between 0 and 50 years for the BC_2sm.ulm model.

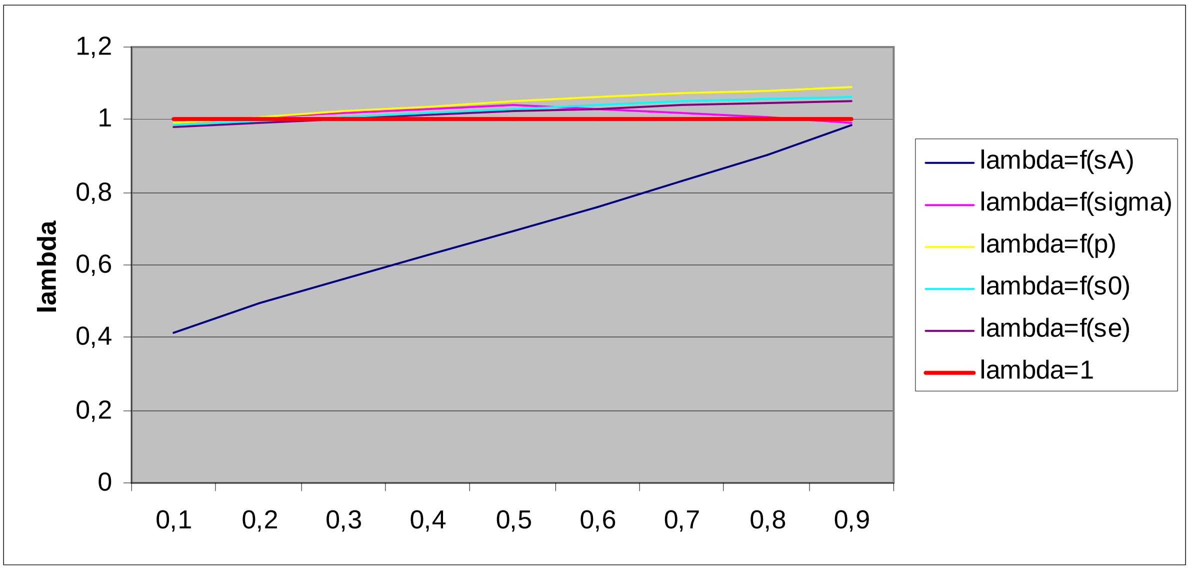


Figure 25 : Batch analyse where all the parameters were successively and independently made variate between 0,1 and 0,9 while the others were constant with the BC_2sm.ulm model.

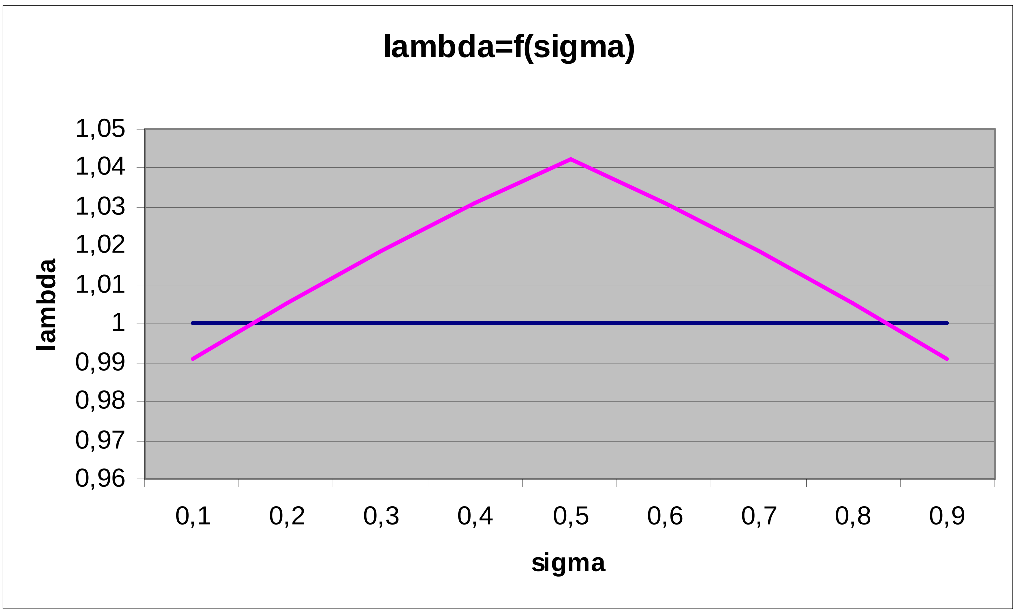


Figure 26 : Batch analyse where the sex ratio σ was made variate between 0,1 and 0,9 while the others were constant with the BC_2sm.ulm model.

We can check with a batch on σ that the growth rate is maximum with a sex ratio of 0,5. Indeed, if there are more males or females, the population will grow more slowly than with a balanced sex-ratio since the mating function is monogamy hence an equal number of males and females are optimal for the population growth.
We can choose not to take into account the two sexes in our models but there is some bias on the measure of the sex ratio that will justify using a two sex model. However, we do not have any figures on such data at our disposal so this is not very discerning.

➔ Modelling only one sex is sufficient.

c) <u>Addition of simple senescence: model age structured, female based and one patch</u>

We finally wanted to take into account the senescence in our model. This is only possible by using an age structure that is to say one stage represents one year of living. Blue cranes seem to live 25 years in average. Parameters like survival rate and fertility depend on the age of individuals. First, we chose a simple model of senescence where only individuals between 5 and 24 years can participate in the reproduction (individuals under 5 or over 24 have a fertility of 0). Here, the decline of survival rate after 20 years is not modelled yet, nor the variations in fertility between 5 and 24 years.

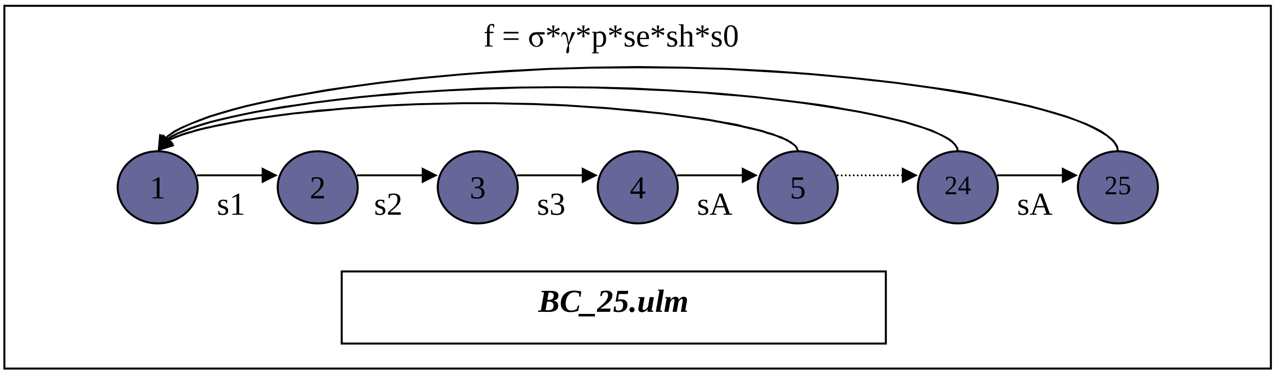


Figure 27 : Blue Crane life cycle with a deterministic age structured model (25 classes), female based, without density dependence.

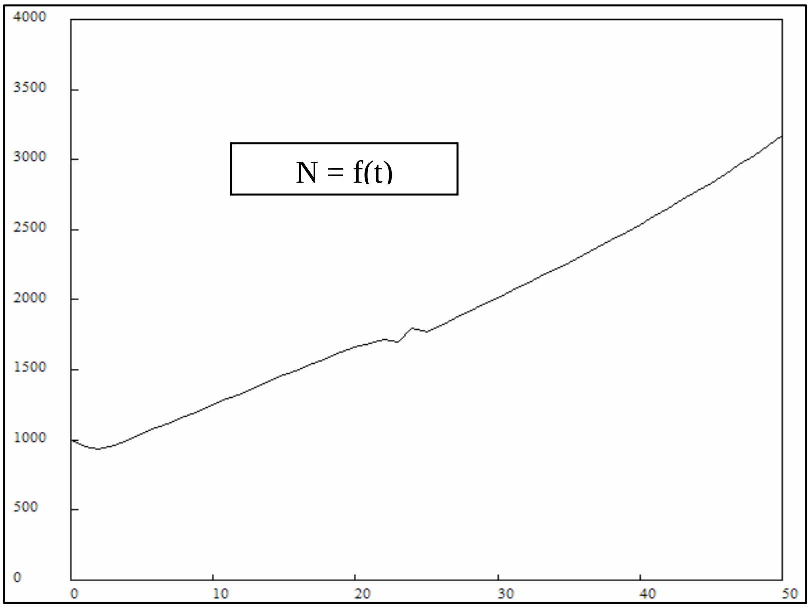


Figure 28 : Total population size evolution between 0 and 50 years for the BC_25.ulm model.

	BC_0.ulm	BC_25.ulm
Lambda	1.04277	1.02279
Generation time	25.16	13.49

Figure 29 : Comparative table between growth rates and generation times obtained thanks to the BC_0.ulm model and the BC_25.ulm model.

We get a growing population with a growth rate a little bit weaker than with the simplest model with 5 stages.

	BC_0.ulm		BC_25.ulm	
	Reproductive value	**Stable distribution**	**Reproductive value**	**Stable distribution**
1	0,1309	0,0959	0,0352	0,0966
2	0,1685	0,0745	0,0444	0,0765
3	0,2169	0,0579	0,0561	0,0606
4	0,2332	0,0538	0,0592	0,0575
5 and +	0,2506	0,7178	0,8049	0,709

Figure 30: Comparative table between reproductive values and stable distributions for the BC_0.ulm model and for the BC_25.ulm model.

Elasticities to :	BC_0.ulm	BC_25.ulm
proport° of breeders	0.05456	0.07636
Se	0.05456	0.07636
Sh	0.05456	0.07636
s0	0.05456	0.07636
s1	0.05456	0.07636
s2	0.05456	0.07636
s3	0.05456	0.07636

sA	0.7818	0.6946
γ	0.05456	0.07636
σ	0.05456	0.07636

Figure 31: Comparative table between elasticities obtained with the BC_0.ulm model and the BC_25.ulm model.

The lower growth rate obtained with this model in comparison to the 5 stages one can be explained by the fact that with only 5 stages, the adult class can live more than 25 years and can take part in reproduction longer than with 25 stages. In this model, most of the reproductive value is concentrated by the '5 and more' class whereas in the BC_0.ulm model, all the stages participate almost at the same rate to reproduction. The stable distribution in BC_25.ulm let less individuals in the stage '5 and more' since individuals can not be stored in this stage as in BC_0.ulm where individuals can live longer than 25 years.
The population growth is less explained by the sA of aged class than the sA of younger class. Globally it is still the sA that explained the growth. Elasticities are higher with BC_25.ulm than with BC_0.ulm except for sA.
The stage model groups all individuals over 5 years together in the same stage. They are going to reproduce every year and will stay long in this stage. They can live and reproduce themselves for a long time which affects elasticities because for this model, the lifetime of a reproducer depends only on sA. So the more sA is high, the longer they live and reproduce.
For the age structured model the reproductive life is limited by the age. They can not reproduce themselves over the limit given by their age: they reproduce themselves a last time at 25 and then it is over. It decreases elasticity to sA and as ∑elasticities = 1, when elasticity to sA decreases, other elasticities increases.

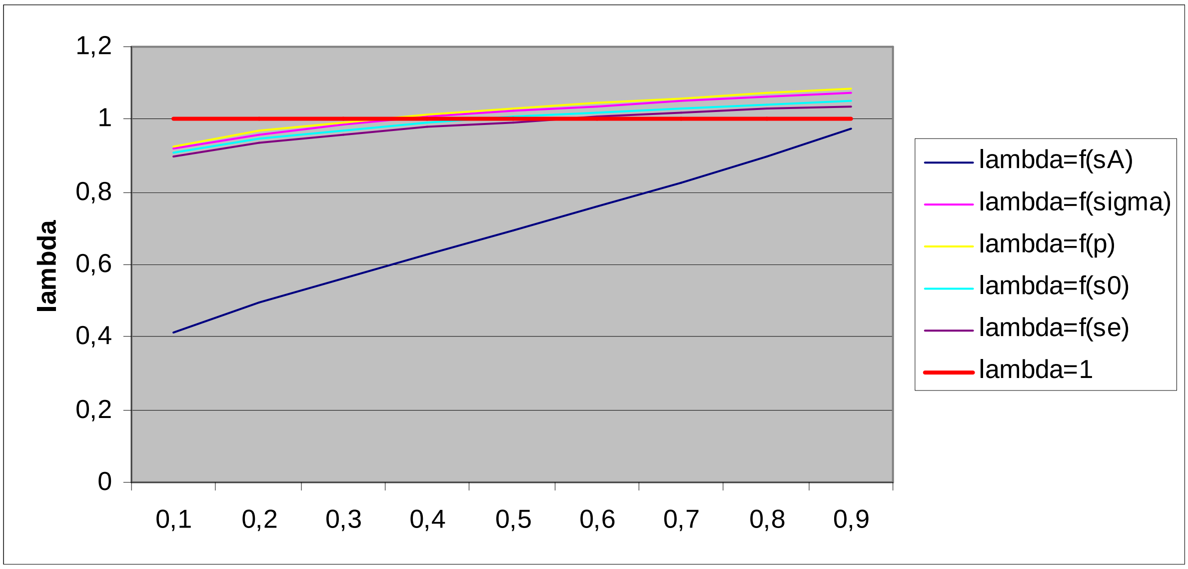


Figure 32 : Batch analyse where all the parameters were successively and independently made variate between 0,1 and 0,9 while the others were constant with the BC_25.ulm model.

➔ The model in stage overvalues the reproductive value => the age structured model is kept.

d) Addition of senescence on fertility: model age structured with polynomial fertility, female based and one patch.

This model is also with 25 stages and female based. We wanted to model variations in the fertility, increasing with the age at the beginning and then declining when approaching the sexual senescence. The only difference between this one and the previous one is that we used a polynomial function (degree 4) for modelling the fertility:

$$\begin{cases} \mathbf{f_i = f * SenMat_i} \\ \mathbf{SenMat_i = 1.0085725 - 0.000765 * i + 0.0009628 * (i - 13.4545)^2 + 0.0001654 * (i - 13.4545)^3 - 0.0000772*(i - 13.4545)^4} \end{cases}$$

f = fertility
f_i = fertility at age i
SenMat = Senescence Maturity
i = age = 0…n with n = 25 years (life expectancy)

Thus, we modelled the fact that there is no reproduction before 5 years, an increasing fertility until 11 years, a stable fertility between 11 and 18 and a decreasing fertility after 18 years.

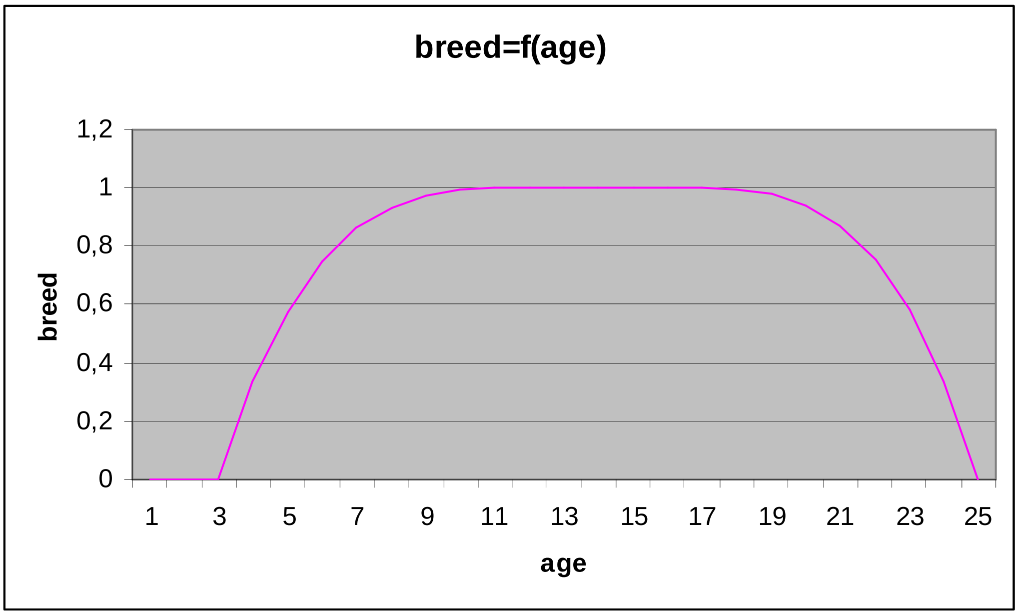


Figure 33 : Polynomial senescence on fertility: the reproductive success depends on the age of individuals.

We had to correct this polynomial function in order the mean of this senescent fertility is the same as the original one, corresponding to the calculation of fertility with data given in the Fig. 13 thanks to the following equation:

$$\mathbf{f = \sigma*\gamma*p*se*sh*s0}$$

This fertility should be equal to the mean of the 'polynomial' fertility; it is possible with c, a correction factor:

$$f = \sum f_i*c/n$$
$$\Leftrightarrow f = \sum f*SenMat_i*c/n$$
$$\Leftrightarrow f = (f*c/n)*\sum SenMat_i$$

(as f,c and n are constants)

$$\Leftrightarrow \mathbf{c = n / \sum SenMat_i}$$

c = correction factor

This equation allows us to calculate this correction factor with the range of parameters given in the Fig. 13. We obtain c = 1,64.

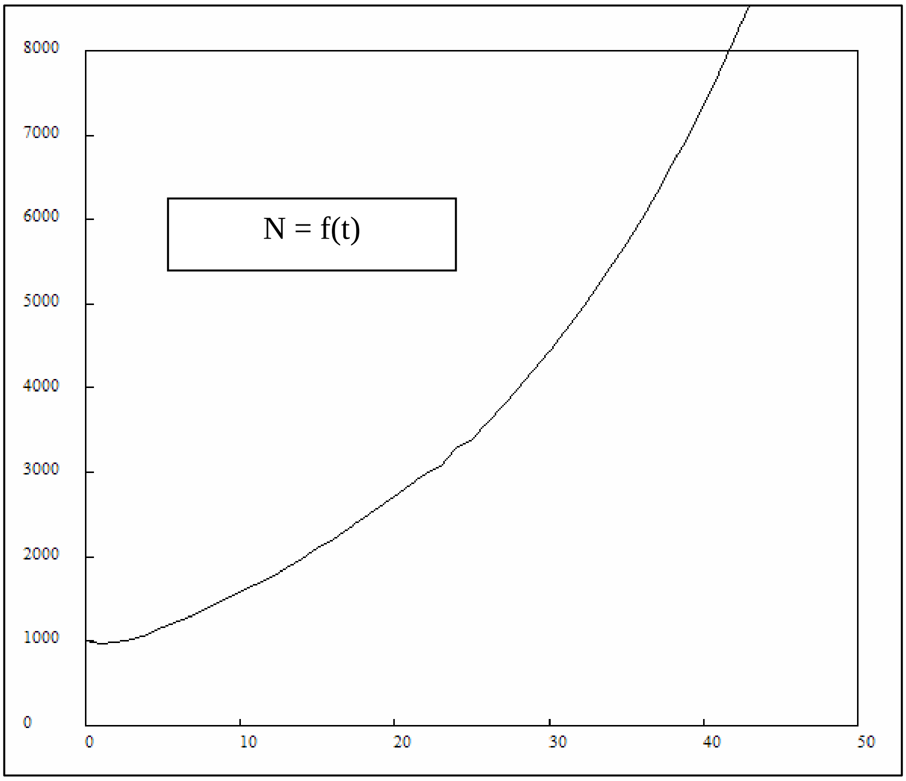


Figure 34 : Total population size evolution between 0 and 50 years for the BC_25poly.ulm model.

	BC_25.ulm	**BC_25poly.ulm**
Lambda	1.02279	1.05169
Generation time	13.49	12.7

Figure 35 : Comparative table between growth rates and generation times obtained thanks to the BC_25.ulm model and the BC_25poly.ulm model.

	BC_25.ulm		**BC_25poly.ulm**	
	Reproductive value	**Stable distribution**	**Reproductive value**	**Stable distribution**
1	0,0352	0,0966	0.0318	0.1217
2	0,0444	0,0765	0.0413	0.0937
3	0,0561	0,0606	0.0537	0.0722
4	0,0592	0,0575	0.0582	0.0666
5 and +	0,8049	0,709	0,8151	0,6459

Figure 36 : Comparative table between reproductive values and stable distributions for the BC_25.ulm model and for the BC_25poly.ulm model.

Elasticities to :	BC_25.ulm	BC_25poly.ulm
Proport° of breeders	0.07636	0.08301
Se	0.07636	0.08301
Sh	0.07636	0.08301
s0	0.07636	0.08301
s1	0.07636	0.08301
s2	0.07636	0.08301
s3	0.07636	0.08301
sA	0.6946	0.668
Γ	0.07636	0.08301
Σ	0.07636	0.08301

Figure 37 : Comparative table between elasticities obtained with the BC_25.ulm model and the BC_25poly.ulm model.

We get here a higher growth rate than previously because of higher reproductive values for classes over 5 years. We could assume that with senescence only individuals with a great reproductive potential take part in reproduction which facilitates a little the population growth.
This explanation makes biological sense but not 'modelling sense' since we have specially included the correction factor c to ensure that the reproductive success does not change. Here the fact that the growth rate is higher seems to implicate the correction factor.

➔ We prefer to keep simple senescence since polynomial senescence gives contradictory results to interpret.

2- Inclusion of competition for resources: deterministic models with density dependence

More realistic models take into account the fact that access to reproduction depends on density of the population: it decreases when population is close to saturation of carrying capacity. We have chosen to model those variations thanks to a proportion of breeders depending on the size of population.

a) Baseline model with addition of density dependence: model with 5 stages, female based, one patch and density dependence

We had the choice between 2 equations of density dependence.

- First we used the **Ricker**'s equation which is defined as following:

$$\begin{cases} g(N_t)=p*e^{(-\alpha*Nt)} \\ N_{t+1}=g(N_t)*N_t \end{cases}$$

In our model: $g(N_t)=pbis$
proportion of breeders = $\alpha = 0{,}000023$
$p = 0{,}45$

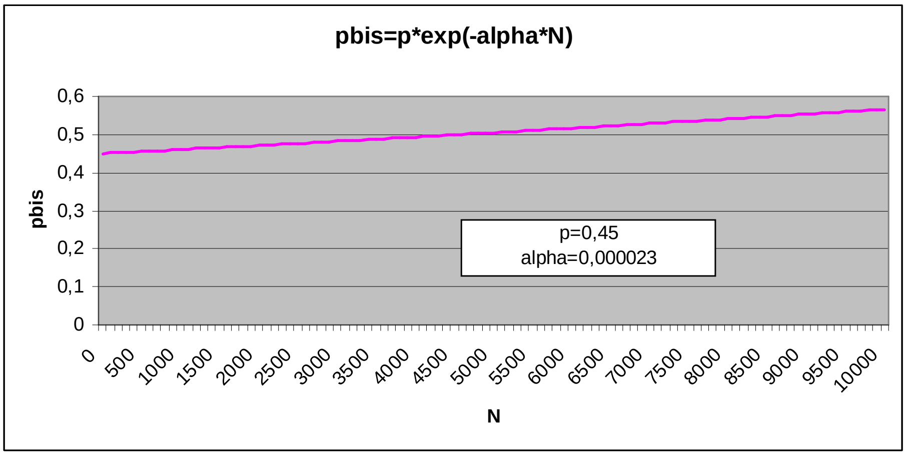


Figure 38 : Addition of density dependence: the proportion of breeders depends on the population size N.

We can notice that for a population which has reached the carrying capacity of 10,000 individuals, we get a proportion of breeders over 0,55 while p = 0,45 is the maximum really observed.

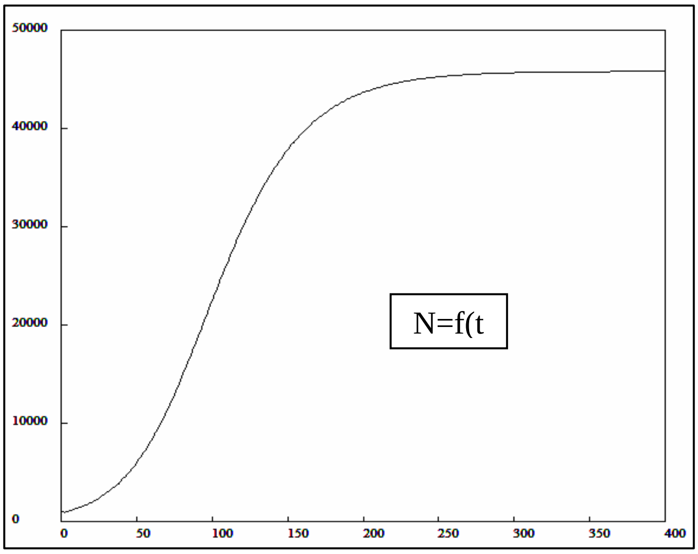


Figure 39 : Total population size evolution between 0 and 50 years for the BC_0ddRicker.ulm model.

With the addition of density dependence, the graph of the population growth is no more exponential as previously but presents a saturation plateau. The balanced population size is around 45,000 individuals for a carrying capacity of 10,000. It is due to the fact we can not really fix the carrying capacity K at 10,000. In fact, the carrying capacity depends on the transition affected.

This is not a very satisfying modelling: that is why we tried another modelling of density dependence.

- Second we add to BC_0.ulm the equation of density dependence used for the first Vortex model where an Allee effect is also considered, in order to account for the monogamous mating system. The proportion of breeders is defined by:

$$\mathbf{p = ((0.5*(1-((N/K)\hat{}2)))+(0.25*((N/K)\hat{}2)))*(N/(1+N))}$$

N = population size
K = carrying capacity = 10,000

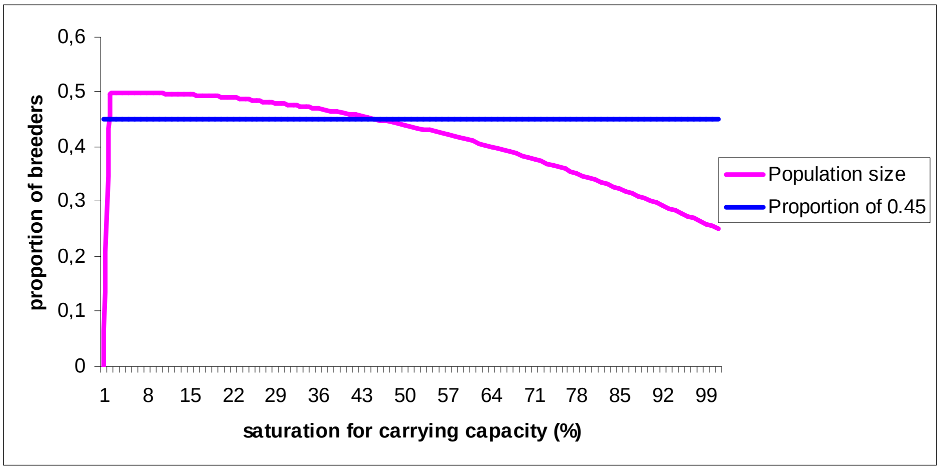


Figure 40 : Addition of density dependence: the proportion of breeders is no more constant as previously (value of 0,45) but depends on the saturation for the carrying capacity/the population size.

At the beginning the proportion of breeders is weak but increases with the size of the population: an Allee effet is thus modelled. Then, the proportion of breeders declines with the size of the population as the access to reproduction depends on the density of the population.

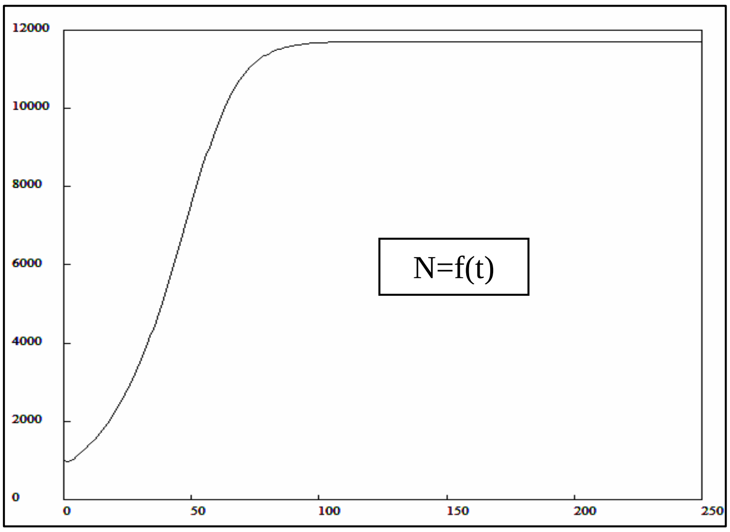


Figure 41 : Total population size evolution between 0 and 50 years for the BC_0dd.ulm model.

After 150 years the population reaches the real carrying capacity which is around 12,000 individuals and not 10,000 as we could have believed. Here again the density dependence equation does not define a threshold for the carrying capacity, as with the Ricker's equation. But here, we get a value for the carrying capacity which is close to the estimate value. As we are not sure of the real figure, we could consider that the current population has not reached the saturation yet (it would be in that case around 12,000 birds) but only circa 80% of the carrying capacity (10,000 birds regarding this hypothesis). That is why we considered this modelling as satisfying and that we made sensitivities analyses on that model.

➔ We keep the equation of the old Vortex model for our modelling of Blue Crane populations and further sensitivity analyses.

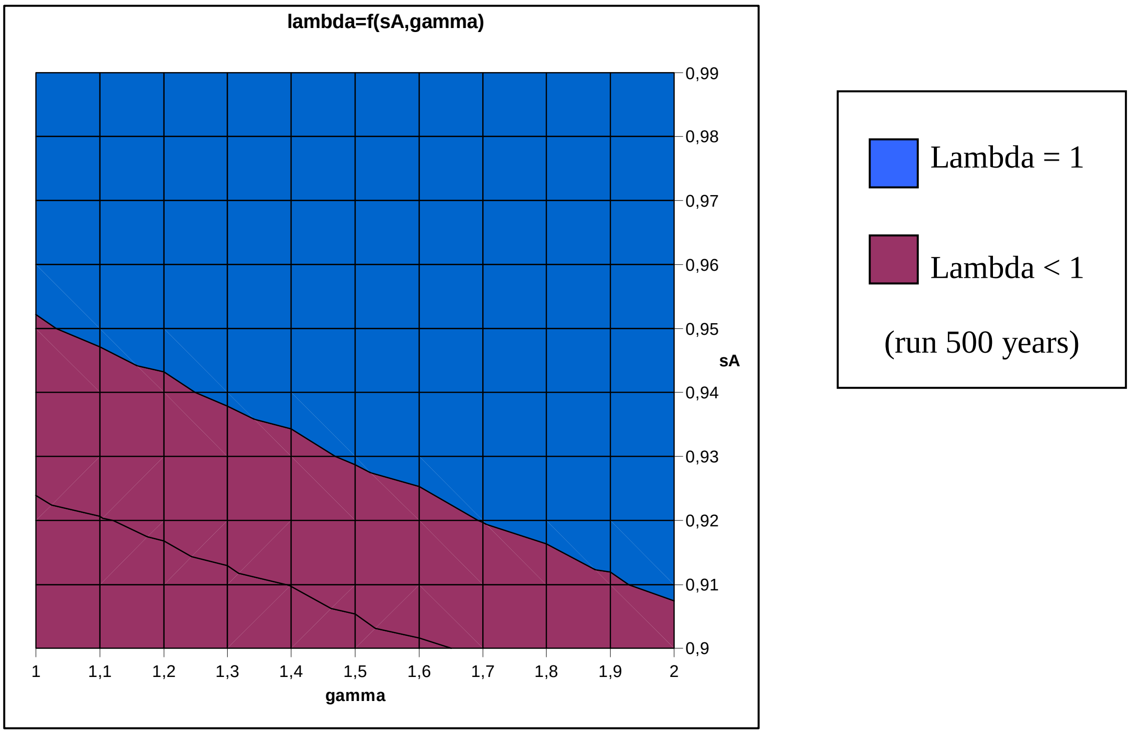


Figure 42 : Batch analyse with the BC_0dd.ulm model where the adult survival rate sA was made variate between 0,9 and 0,99 and the mean clutch size γ between 1 and 2. In purple the combinations of (sA; γ) which lead to a declining population and in blue those which lead to a growing one.

The batch analyses on sA and γ reveals that with a model with density dependence there are more chances to get a growing population than with the model without density dependence. It is possible because when the population size N declines, the carrying capacity K will surpass the proportion of breeders of 0.45.

The probability of having a couple (sA;γ) which implies a decreasing population is now about 0,322 (against 0,394 % for BC_0.ulm). Even with a range of high adult survival rates, a clutch size higher than 2 is needed to get a growing population which happens rarely in the nature.

b) <u>Addition of simple senescence: model age structured, female based, with one patch and density dependence</u>

We do the same way with the previous BC_25.ulm model: we add to this model the equation of density dependence of the old Vortex model.

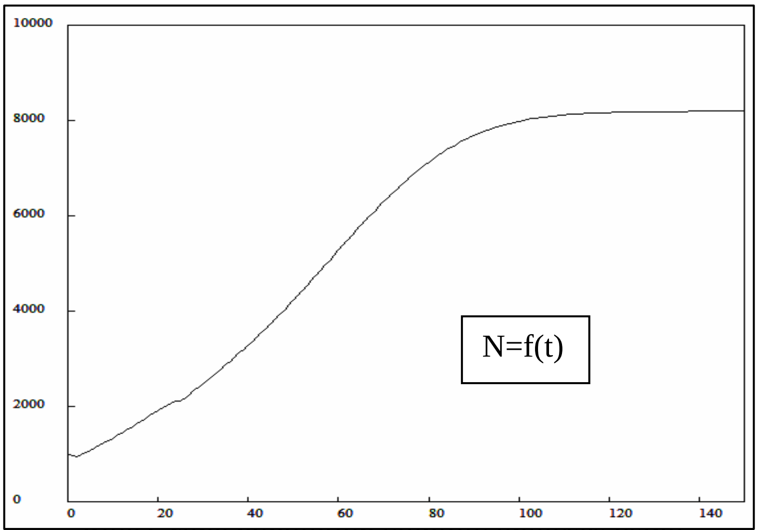


Figure 43 : Total population size evolution between 0 and 50 years for the BC_25dd.ulm model.

After 100 years the population reaches the real carrying capacity which is around 8000 individuals and not 10,000 as we could have believed. As previously, the carrying capacity is not limited by the density dependence equation. It may mean that the model allow only to reach a certain threshold for the saturation of the real carrying capacity.

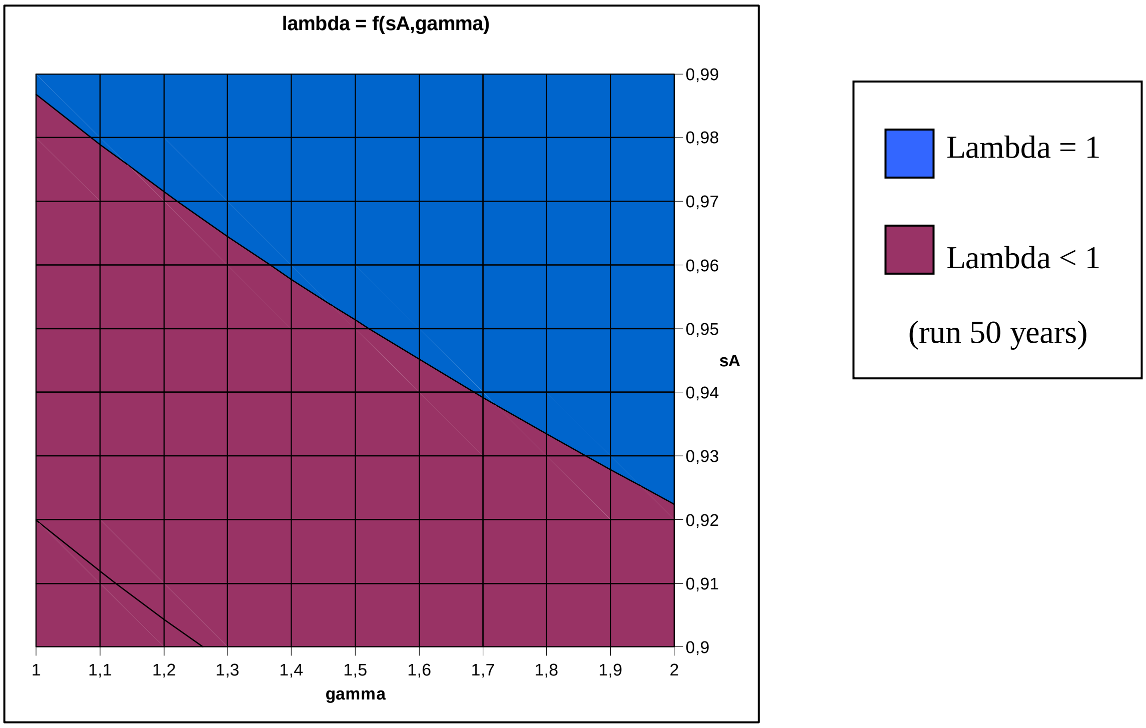


Figure 44 : Batch analyse with the BC_25dd.ulm model where the adult survival rate sA was made variate between 0,9 and 0,99 and the mean clutch size γ between 1 and 2. In purple the combinations of (sA; γ) which lead to a declining population and in blue those which lead to a growing one.

There are lots of cases where the population can be a growing one. With (γ,sA) couples in the blue area of the graph above we get a growing population. In this range of high adult survival rates, even a clutch size γ of 2 does not allow a growing population (for the lowest figures of sA).

c) Addition of senescence on fertility: model age structured with polynomial fertility and density dependence, female based and with one patch

This model is also with 25 stages and female based. The difference between this one and the previous one is that we used a polynomial function (degree 4) for modelling senescence fertility as previously:

$$\begin{cases} \mathbf{f_i = f * SenMat_i} \\ \mathbf{SenMat_i = 1.0085725 - 0.000765 * i + 0.0009628 * (i - 13.4545)^\wedge 2 + 0.0001654 * (i - 13.4545)^\wedge 3 - 0.0000772*(i - 13.4545)^\wedge 4} \end{cases}$$

f = fertility
f_i = fertility at age i
SenMat = Senescence Maturity
i = age = 0…n with n = 25 years (life expectancy)

Thus, we modelled the fact that there is no reproduction before 5 years, an increasing fertility until 11 years, a stable fertility between 11 and 18 and a decreasing fertility after 18 years. The density dependence is still modelled by the equation used in the old Vortex model. The population reaches the carrying capacity after around 70 years.

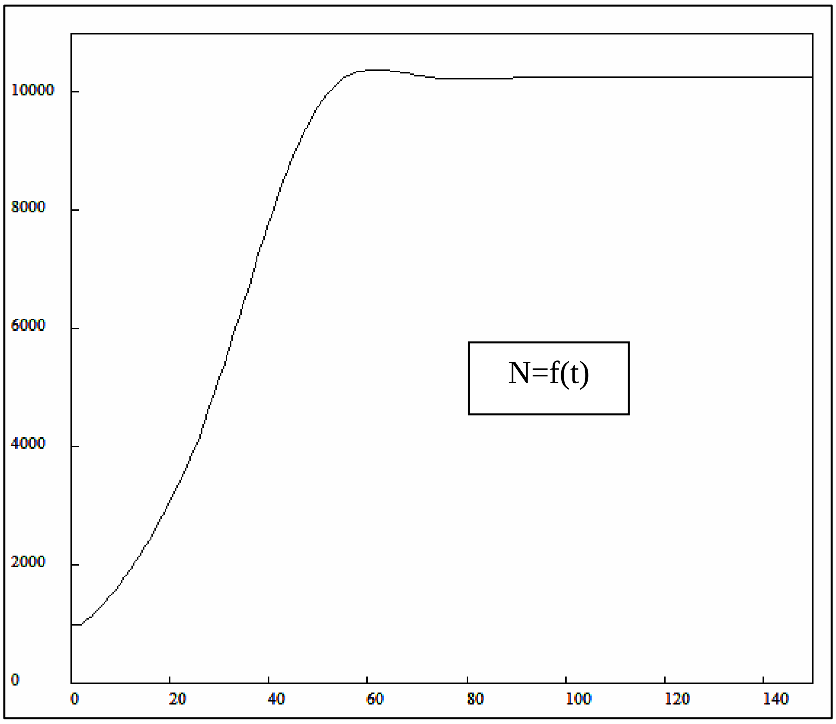


Figure 45 : Total population size evolution between 0 and 50 years for the BC_25polydd.ulm model.

The population reaches the real carrying capacity after 80 years, which is around 10,000 individuals which corresponds well to our input value for this parameter.

3- Stochastic models

There are some spatial and temporal variations. Furthermore, survival rates and reproductive success variate from one season to the next in response to weather, disease, competition, predation, or other factors external to the population. All those variations in parameters due to environmental hazards should be included to improve the realism of our models.
Another kind of stochasticity should be taken into account: the demographic stochasticity which relies on the fact that reproduction and survival are randomly.

a) Global modelling of stochasticity: model age structured, female based, one patch and with environmental stochasticity on survival rates.

We define now the parameters as not constant but as variables around the basic value (cf deterministic models) with a certain standard error. In order to get this, we use in the previous models a new variable, param_obs (and no more param only).

$$\begin{cases} \textbf{param\_aux = param + gauss(SE\_param)} \\ \textbf{param\_obs = min(max(param\_aux,min\_CI),max\_CI)} \end{cases}$$

param = basic parameter that is to say value of se, or sh,or s0, or s1, etc...for deterministic models
SE_param = Standard Error of parameter
Gauss = Gaussian function
Min_CI = minimal value of the confidence interval
Max_CI = maximal value of the confidence interval

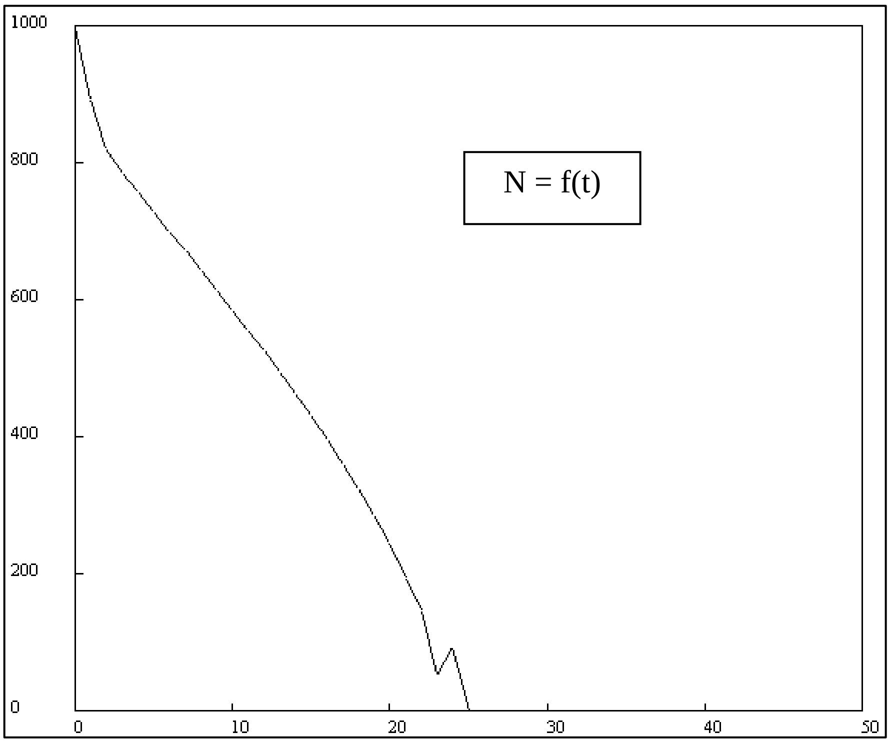


Figure 46 : Total population size average trajectory between 0 and 50 years get thanks to a Montecarlo procedure (m 100 50) for the BC_25stoch.ulm model.

	BC_25stoch.ulm		BC_25.ulm
Mean growth rate	0.87	**Lambda**	1.02279
Expected extinction time	25 years	**Generation time**	13.49
Pe (probability of extinction)	1		-

Figure 47 : Comparative properties table obtained thanks to the BC_25stoch.ulm and the BC_25.ulm models.

The addition of stochasticity affects a lot the population in comparison to the corresponding deterministic model. The population is now declining and extinct in 25 years.

b) Another modelling: model with dependence between environmental stochasticities on survival rates

The environmental stochasticity of one parameter is not independent from other stochasticities. Indeed, if environmental conditions are good during one year, it will influence not only one parameter but also other parameters. For instance, for one good year, all the survival rates will be higher than the mean values (and the inverse for bad years).
Survival parameters are now no more constant as in deterministic models. They are equal to the previous value (cf deterministic models) plus some variations. The first variation is the same as in the previous stochastic model but only in a proportion (1-q). The second variation is a Gaussian in a proportion q.

$$\left\{\begin{array}{c} \mathbf{q=0.5} \\ \mathbf{stoch\_env = gauss(1)} \\ \mathbf{stoch\_env\_param = gauss(SE\_param)} \\ \mathbf{param\_aux = param + (1\text{-}q)*stoch\_env\_param + q*stoch\_env*SE\_param} \\ \mathbf{param\_obs = min(max(param\_aux,min\_CI),max\_CI)} \end{array}\right.$$

q = proportion of dependence between the environmental stochasticity on survival rates
param = basic parameter that is to say value of se, or sh,or s0, or s1, etc...for deterministic models
SE_param = Standard Error of parameter
Gauss = Gaussian function
Min_CI = minimal value of the confidence interval
Max_CI = maximal value of the confidence interval

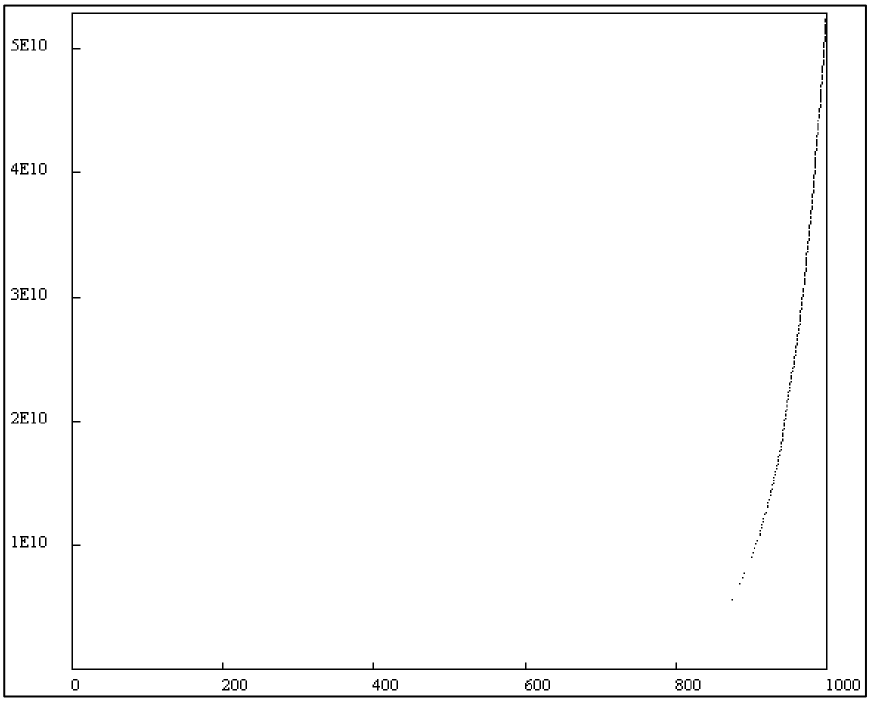


Figure 48 : Total population size average trajectory between 0 and 50 years get thanks to a Montecarlo procedure (m 50 1000) for the BC_25stoch_dpce.ulm model.

	BC_25stoch.ulm	**BC_25stoch_dpdce.ulm**
Mean growth rate	0.87	1.02
Expected extinction time	25 years	-
Pe (probability of extinction)	1	0

Figure 49 : Comparative properties table obtained thanks to the BC_25stoch.ulm model (m 50 100) and the BC_25stoch_dpdce.ulm model (m 1000 50).

The addition of dependence between environmental stochasticities on survival rates establish a growing population back.

III- Metapopulation analyse

Blue Crane population is subdivided in 5 sub-populations: the Overberg population, the Swart land population, the Nama Karoo population, the Eastern Cape population and the Grassland population. Unfortunately, ULM is not able to run the model with 5 sub-populations since there are too many variables in the program (it could have run the model but only with 4 sub-populations).

Two solutions are possible: either we take into account less sub-populations than the 5 considered, either we come back to a simpler model as the one with five stages (not structured aged) and there will not be so realistic since the senescence phenomenon would not be taken into account.

We choose to model only 3 sub-populations: the Grassland sub-population which includes Eastern Cape and Grassland sub-populations (GR), the Western Cape sub-population which includes Overberg and Swartland sub-populations (WC) and the Nama Karoo (NK) sub-population.

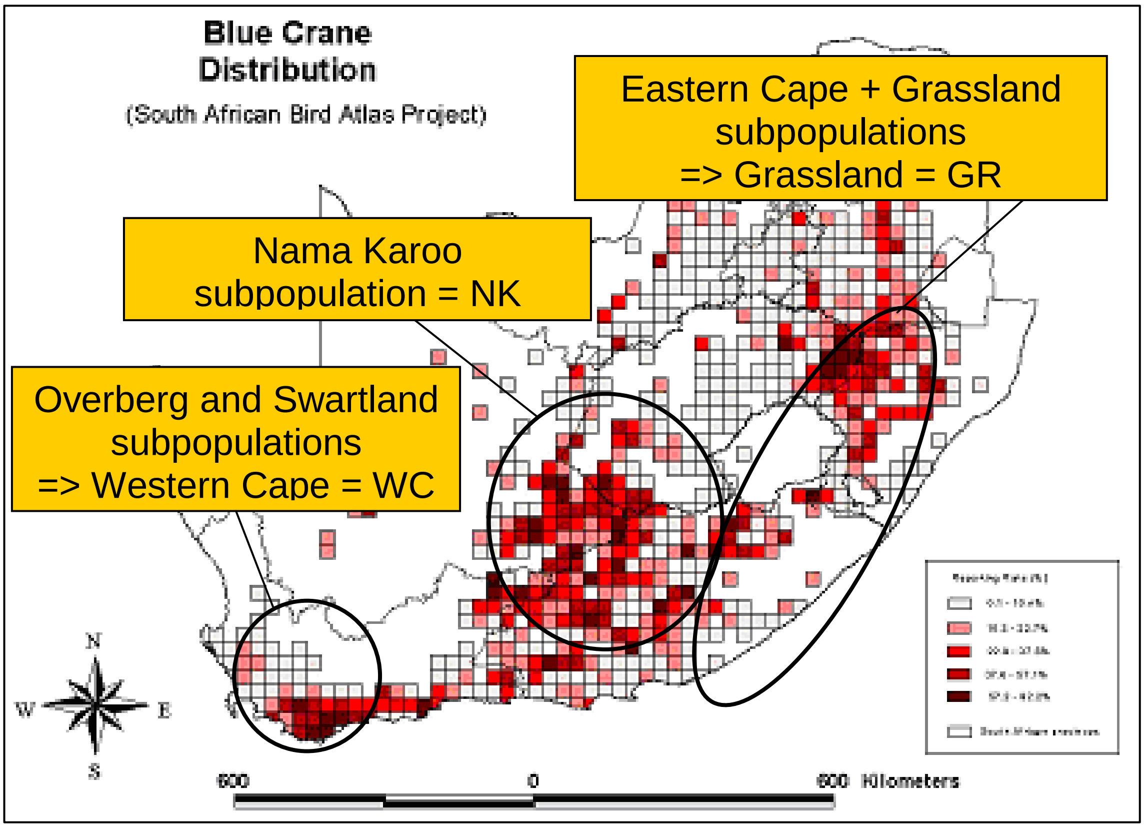


Figure 50 : Sub-populations of Blue Cranes based on the distribution given by the South African Bird Atlas Project.

Parameters	GR			WC (Ov+Sw)			NK		
	New value	Confidence Interval (IC)	SE	New value	IC	SE	New value	IC	SE
Proportion of breeders	0,45 [a]			0,45 [a]			0,45 [a]		
Se	0,796 [b]			0,461 [b]			1 [b]		
Sh	0,911 [b]			0,661 [b]			0,661 [b]		
s0	0,63 [c]	0,39 -0,82 [c]	0,117 [c]	0,63 [c]	0,39 -0,82 [c]	0,117 [c]	0,63 [c]	0,39 -0,82 [c]	0,117 [c]
s1	0,81 [c]	0,56 -0,93 [c]	0,093 [c]	0,81 [c]	0,56 -0,93 [c]	0,093 [c]	0,81 [c]	0,56 -0,93 [c]	0,093 [c]
s2	0,81 [c]	0,55 -0,94 [c]	0,099 [c]	0,81 [c]	0,55 -0,94 [c]	0,099 [c]	0,81 [c]	0,55 -0,94 [c]	0,099 [c]
s3	0,97 [c]	0,89 -0,99 [c]	0,021 [c]	0,97 [c]	0,89 -0,99 [c]	0,021 [c]	0,97 [c]	0,89 -0,99 [c]	0,021 [c]
Sa	0,97 [c]	0,89 [c] -0,99 [c]	0,021 [c]	0,97 [c]	0,89 -0,99 [c]	0,021 [c]	0,97 [c]	0,89 -0,99 [c]	0,021 [c]
Nb hatched per pair	1,512 [b]		0,077 [b]	0,882 [b]		0,077 [b]	1,889 [b]		0,323 [b]
Nb fledged per pair	1,378 [b]		0,081 [b]	0,583 [b]		0,081 [b]	1,25 [b]		0,856 [b]
Γ	1,9 [b]			1,912 [b]		0,049 [b]	1,889 [b]		0,323 [b]
Σ	0,5 [d]			0,5 [d]			0,5 [d]		
K	3000 [a]			10000 [a]			10000 [a]		
Parameter to multiply to maturity factor									
Probability of dispersal to GR	-		0 [e]			0,01 [e]			
Probability of dispersal to WC	0 [e]		-			0,02 [e]			
Probability of dispersal to NK	0,01 [e]		0,01 [e]			-			

Figure 51 : Range of values used.
[a] From Leon Theron (Richard)
[b] Calculated cf fecundity[2].xls file
[c]From the publication of Mark Anderson
[d] From old vortex model
[e] Richard's guestimates

As a first approach, we chose to analyse the 3 populations separately thanks to the BC_25.ulm model (age structured, simple senescence, no density dependence) in order to know their specificities. Then, we modelled a global population composed by those 3 sub-populations to understand how Blue Crane population functions in South Africa.

1- Analyse of the 3 sub-populations: Grassland, Western Cape and Nama Karoo.

	GR	WC	NK
Lambda	1.05044	0.984638	1.04209
Generation time	12.03	14.17	13.17

Figure 52 : Comparative table between growth rates and generation times of the three sub populations obtained thanks to the BC_25.ulm model and figures given in the previous figure.

We have to notice that the Western Cape population is in decline whereas Grassland and Nama Karoo are growing at quite the same rate. This seems logical since the values of se and sh are weaker for this population than for the two others. The expected extinction time for the Western Cape population is 460 years.

	Reproductive value GR	Reproductive value WC	Reproductive value NK	Stable distribution GR	Stable distribution WC	Stable distribution NK
1	0.0303	0.0439	0.0317	0.1206	0.0663	0.1132
2	0.0393	0.0534	0.0407	0.0930	0.0545	0.088
3	0.0510	0.0649	0.0524	0.0717	0.0449	0.0684
4	0.0552	0.0659	0.0563	0.0662	0.0442	0.0637
5 and +	0,8244	0,7719	0,8189	0,635	0,7901	0,6666

Figure 53 : Comparative table between reproductive values and stable distributions of the three subpopulations obtained thanks to the BC_25.ulm model.

The reproductive value is higher for elder classes for Grassland and Nama Karoo populations than for Western Cape.

Elasticities to :	GR	WC	NK
proportion of breeders	0.08192	0.0692	0.08022
Se	0.08192	0.0692	0.08022
Sh	0.08192	0.0692	0.08022
s0	0.08192	0.0692	0.08022
s1	0.08192	0.0692	0.08022
s2	0.08192	0.0692	0.08022
s3	0.08192	0.0692	0.08022
sA	**0.6723**	**0.7232**	**0.6791**
Γ	0.08192	0.0692	0.08022
Σ	0.08192	0.0692	0.08022

Figure 54 : Comparative table between elasticities of the three sub populations obtained with the BC_25.ulm model.

The Western Cape population is more sensitive to sA than the two others populations whereas this is the population the less sensitive to the others parameters.

If we add environmental stochasticity on the three sub-populations, we can make parameters variate for each sub-population and see whether the population is growing or not, in order to determine thresholds under which the population is declining. All the results can be summarized in the graph as below.

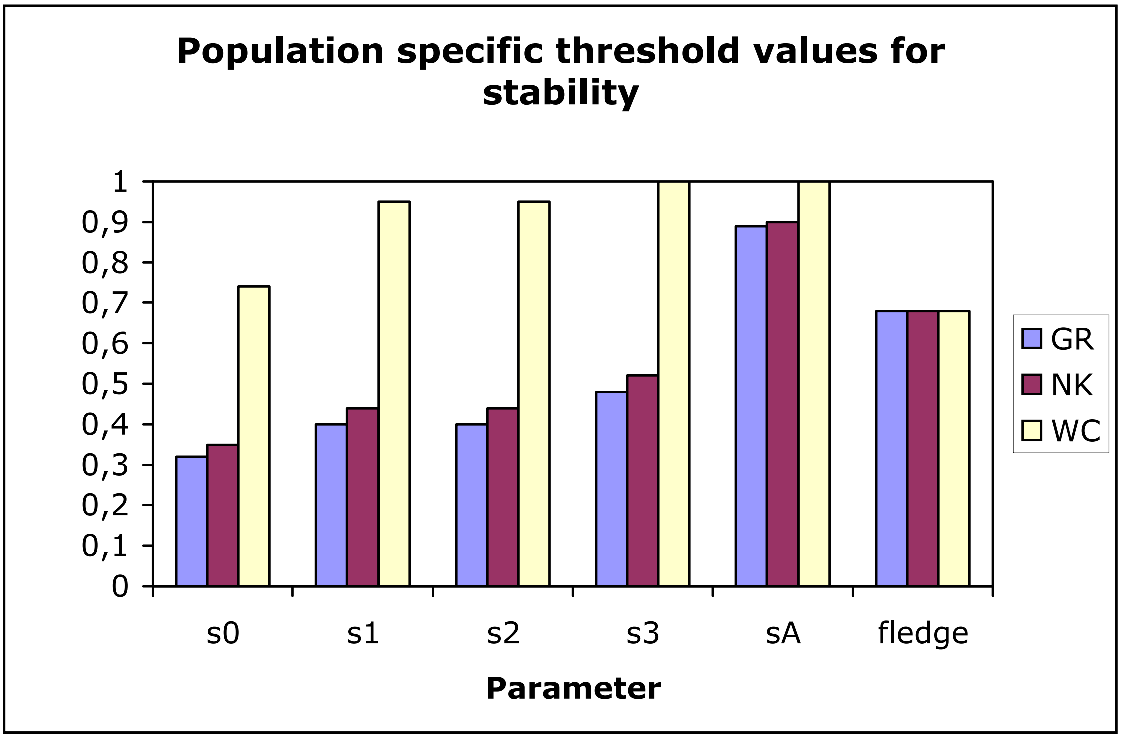
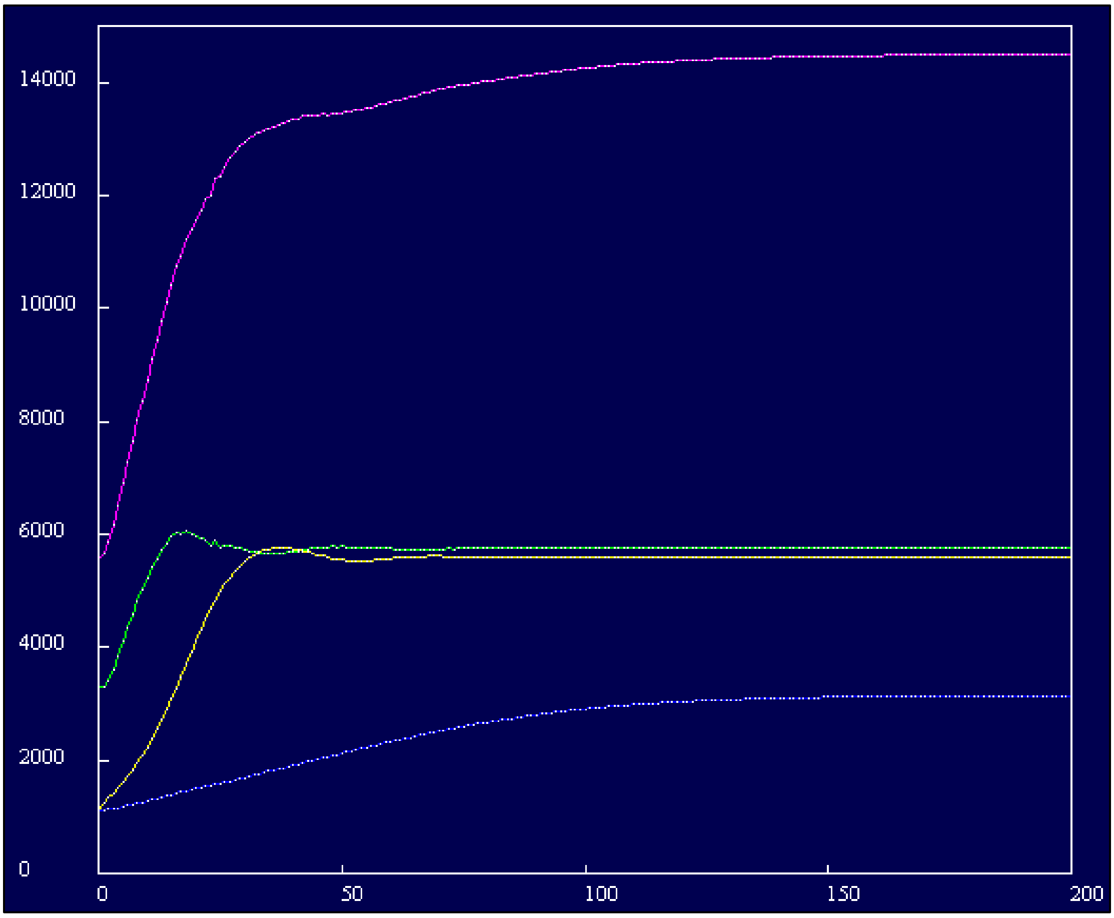


Figure 55 : Sub-population's thresholds for getting growing population, C. Bessa Gomes.

We can first observe that the Western Cape population has more strict thresholds since they are higher (no one under 0.7). Regarding parameters, the adult survival rate sA has the narrowest range of values for a growing population as both the 3 sub-populations' thresholds are over 0.8.

2- Metapopulation structure: model age structured with polynomial senescence on fertility and density dependence, female based and with 3 sub-populations.

Figure 56 : Total population size evolution in pink and sub-populations size evolution between 0 and 150 years



for the BC_25polydd3pop.ulm model: Grassland in green, Nama Karoo in yellow and Western Cape in blue.

Grassland and Nama Karoo sub-populations reach the saturation threshold before the Western Cape population (50 and 70 years against 150 for WC). The modelling carrying capacity of Western Cape sub-population is 3000 individuals. For Grassland and Nama Karoo sub-populations, it is around 5800 birds. After 200 years, the total population is stabilized around 14,000 individuals.

3- Addition of partial migrations between sub-populations.

Migration for Blue Cranes is bad known at the moment. They are supposed to move seasonally within South Africa. We supposed they face an additional mortality around 0.3 due to this partial migration.

	GR	WC	NK
Probability of dispersal to GR	-	0	0,01
Probability of dispersal to WC	0	-	0,02
Probability of dispersal to NK	0,01	0,01	-

Figure 57 : Guestimates from Richard Pettifor on the different dispersal probabilities of Blue Cranes.

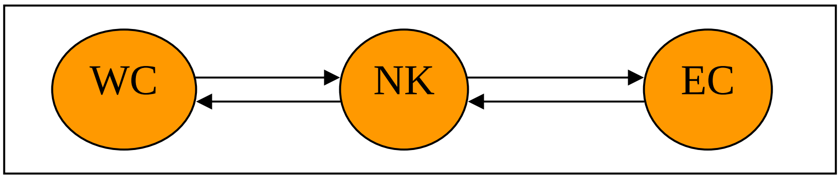


Figure 58 : Graphic representation of Blue Cranes' partial migrations.

There is no migration between Western Cape sub-population and Eastern Cape sub-population because they are believed to be localised too far from each over to migrate.

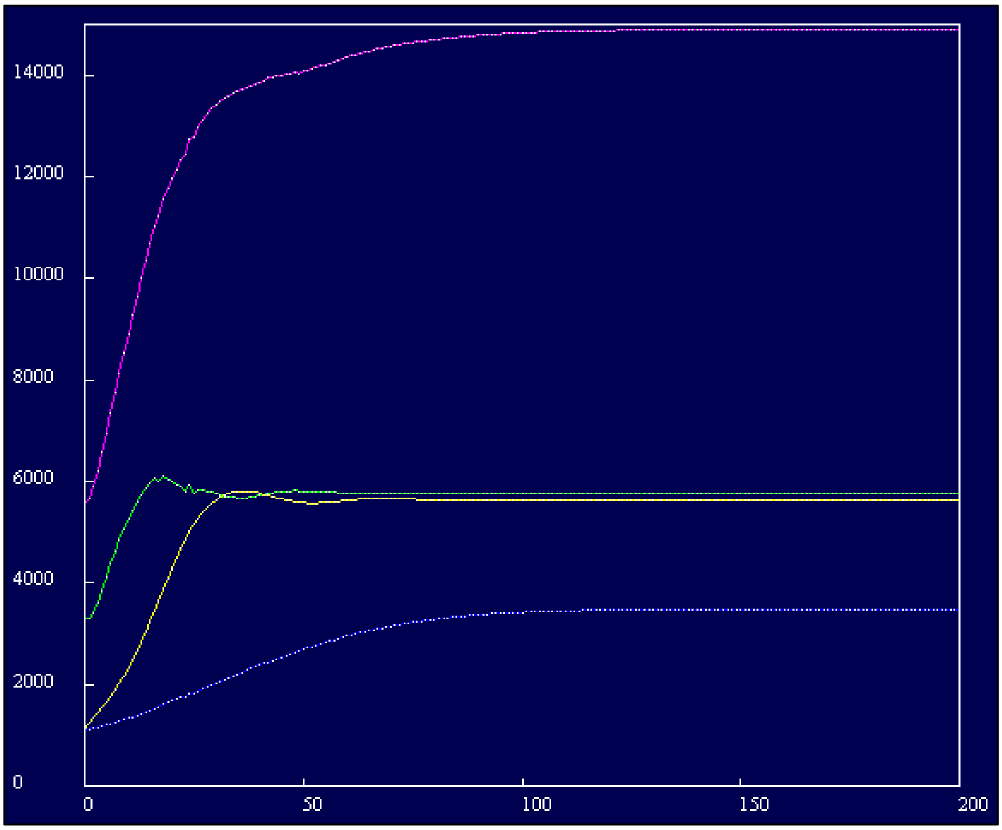


Figure 59 : Total population size evolution in pink and sub-populations size evolution between 0 and 150 years for the BC_25polydd3popmigration.ulm model: Grassland in green, Nama Karoo in yellow and Western Cape in blue.

Grassland and Nama Karoo sub-populations reach the saturation threshold before the Western Cape population (70 years against 100 for WC). The modelling carrying capacity of Western Cape sub-population is 3000 individuals. For Grassland and Nama Karoo sub-populations, it is around 5800 birds. The saturation threshold is reached faster here than in the previous model without migrations. After only 100 years, the total population is stabilized around 15,000 individuals which is faster and more than previously.
Migrations seem to facilitate the population growth since the saturation thresholds are higher and reached faster. This can be explained a little by the fact that birds will better reproduce if they have a larger choice for their breeding place. This could even over-compensate the additive mortality due to the migration.

IV- Critics of our models, projections and recommendations to fieldworkers.

1- Critics of our models.

Modelling is always quite frustrating since the aim is to be the most realistic possible and in the same time be aware a model will never be the reality. We should certainly have modelled the demographic stochasticity and analyse more the results but time and organisational issues were real barriers to this necessary improvement.

We had also to deal with missing figures and guessing some parameters. Standard errors for survival rates were not available for instance. This can be a real problem for our results, especially because of the distance with the reality of the field.

Furthermore, we could have modelled the senescence on survival rates and improve the modelling of fertility senescence and metapopulation structure.

The behaviour of forming flocks could also influence the dynamics of the Blue Crane population. The composition of those flocks should be known before trying to model this phenomenon.

Finally, it could be interesting to take into account future changes in agriculture due to the global warming. Indeed, it could influence the most important sub-population of Blue Crane which is found in certain crops fields of the Western Cape.

2- Results

Although modelling will never be the reality, some of our results can be interpreted and taken into account for advising conservation management. The main result is that all models showed that the Blue Crane population is more sensitive to the adult survival than to other parameters. That shows the most dangerous threat for Blue Cranes populations is all the sources which affect the adult class.

Mortality factors have two different kind of origin:

- **Anthropogenic mortality**

It represents the smallest part of the global mortality (around 20 %) and is the only part which can be decreased by conservation measures. It includes power lines collisions, fences traps, predation due to domestic dogs, poisoning (intentional or accidental), and other causes like shooting.

- **Natural mortality**

It affects mainly chicks and juveniles. It explains circa 80 % of global mortality but can not be really reduce by human actions.

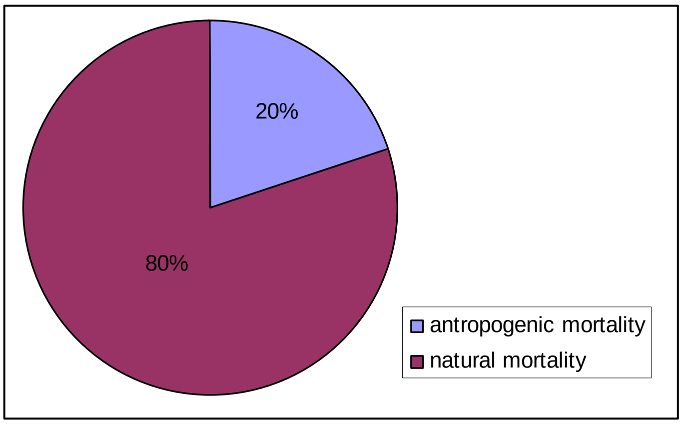


Figure 60 : Origins of global mortality.

3- Orientation of conservation management.

We went to South Africa from January, 21st to February, 10th in order to meet fieldworkers and present them our inputs and results to know if they found them realistic. A power point about main sensitivity analyses results was presented to them during a workshop.

What was enhanced is that our inputs are not really realistic, nor our outputs since for instance we got a declining Western Cape population which is not currently the case. This shows once again the importance of collecting accurate data on Blue Cranes especially through ringing.

Concerning the advice about conservation management, our models showed that efforts should be focused on mortality sources that threat adults. Those mortality sources are mainly the power lines, but also loss of habitat and poisoning. That is why fieldwork should focus on the awareness education and work more with Eskom to signalize power lines.

Last but not least, this trip to South Africa has permitted to become more aware of difficulties to collect data. First, Blue Cranes are very shy and hide from observations. Ringing is a delicate operation: fieldworkers have to spot juveniles to determine if they are tall enough to support rings but not too old so that they can not fly yet to be able to run after them and catch them. The ringing operation is quite dangerous for the well being of birds since they are stressed and they can simply run into fences where they broke their legs. Besides, Blue Cranes are very aggressive birds when you try to catch them. Finally, South Africa is such a big country that 5 fieldworkers to collect data on all over the entire territory are not really enough. Despite all those barriers, efforts regarding data collecting must be sustained in the future to improve the knowledge about Blue Cranes, and by this way the modelling and projections.

Conclusion

Despite the classification of Blue Cranes as endangered, despite the rapid and huge decline Blue Cranes have faced in the last 30 years and despite all the threats that are unfortunately always current, I have the feeling that this fascinating bird has some secret resources. Blue Cranes can live in such different biomes than Grasslands or Nama Karoo. Besides, it was unpredictable that it can so well adapt to human presence and artificial lands like crops in the Western Cape and growing there so well that fieldworkers lose their minds counting their flocks.

The fight is not won yet, and especially because new threats appear and reduce survival rates like bent leg syndrome on juveniles. But good hopes are now allowed if conservation measures go on. And for sure, more research on Blue Crane's biology and ecology must be leaded to understand better Blue Crane's needs and to get more accurate figures to be able to model better.

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Internet sites:

- International Crane Foundation (ICF), Species Field Guide: http://www.savingcranes.org/species/blue.cfm
- IUCN, the Red List of Threatened Species: http://www.birdlife.org/datazone/species/index.html?action=SpcHTMDetails.asp&sid=2792&m=0
- Bird Life International, Species Factsheet: http://www.birdlife.org/datazone/species/index.html?action=SpcHTMDetails.asp&sid=2792&m=0
- Endangered Wildlife Trust (EWT), South African Crane Working Group: http://www.ewt.org.za/workgroups_overview.aspx?group=sacrane&page=activities&morePage=activities_more&activity=5
- Overberg Blue Crane Group : http://www.bluecrane.org.za/index2.php?option=com_content&do_pdf=1&id=1
- University of Cape Town, Department of Statistical Sciences, Avian Demography Unit : http://web.uct.ac.za/depts/stats/adu/bn9_2_10.htm

Annexe : Recapitulation table of ULM models.

Model name	Deterministic	Environmental stochasticity	5 stages	25 stages	Senescence on fecundity	1 sex	2 sex	Density dependence	Nb of patch	Data
BC_0.ulm	×		×			×			1	
BC_2sm.ulm	×		×				×		1	
BC_25.ulm	×			×	simple	×			1	
BC_25poly.ulm	×			×	polynomial	×			1	
BC_0ddRicker.ulm	×		×			×		Ricker equation [a]	1	
BC_0dd.ulm	×		×			×		Old Vortex Model [b]	1	
BC_25dd.ulm	×			×	simple	×		Old Vortex Model [b]	1	
BC_25polydd.ulm	×			×	polynomial	×		Old Vortex Model [b]	1	
BC_25polydd3pop.ulm	×			×	polynomial	×		Old Vortex Model [b]	3	
BC_25polydd5pop.ulm	×			×	polynomial	×		Old Vortex Model [b]	5	
BC_25polydd3popmigration.ulm	×			×	polynomial	×		Old Vortex Model [b]	3	
BC_25_GR.ulm	×			×	simple	×			1	Grassland
BC_25_WC.ulm	×			×	simple	×			1	Western Cape
BC_25_NK.ulm	×			×	simple	×			1	Nama Karoo
BC_0stoch.ulm		×	×			×			1	
BC_0stoch_dpdce.ulm		Dependant stochasticities	×			×			1	
BC_25stoch.ulm		×		×		×			1	
BC_25stoch_dpdce.ulm		Dependant stochasticities		×		×			1	
BC_25poly_stoch.ulm		×		×	polynomial	×			1	
BC_0ddRicker_stoch.ulm		×	×			×		Ricker equation [a]	1	
BC_0dd_stoch.ulm		×	×			×		Old Vortex Model [b]	1	
BC_25dd_stoch.ulm		×		×	simple	×		Old Vortex Model [b]	1	
BC_25polydd_stoch.ulm		×		×	polynomial	×		Old Vortex Model [b]	1	