# The Elephants
# of
# Northern Botswana

# TROPHY HUNTING,
# POPULATION DYNAMICS
# and
# FUTURE MANAGEMENT

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# The Elephants of Northern Botswana

## TROPHY HUNTING, POPULATION DYNAMICS AND FUTURE MANAGEMENT

CONTENTS

APPENDICES

## List of Figures

MAIN REPORT

## **List of Figures** *continued*

APPENDICES

## List of Tables

MAIN REPORT

APPENDICES

## ACRONYMS

| | |
|---|---|
| AfESG | African Elephant Specialist Group |
| CHA | Controlled Hunting Area (Botswana) |
| DWNP | Department of Wildlife and National Parks, Botswana |
| ICI | Intercalving interval |
| MEWT | Ministry of Environment, Wildlife and Tourism, Botswana |
| PAC | Problem Animal Control |

## ACKNOWLEDGEMENTS

We thank the committee and administrators of the DWNP's Conservation Trust Fund for supporting this project and are grateful for their forbearance in tolerating the long delay before this final report.

We thank Debbie Gibson for her strategic inputs into the study not least of which were keeping Colin's nose to the grindstone.

We thank David Cumming for the interest he has shown in the project from its inception and for valuable advice in the course of it.

# Foreword

The original proposal for this study was written in May 2007. The authors envisaged it would take a month or two to carry out the work.

The project was funded by the Conservation Trust Fund (CTF) of the Ministry of Environment, Wildlife and Tourism early in 2010 and we began work on it in May 2010. It is now March 2011. Why did it take so long?

A month after we had started work on it, we still believed it would be completed within another month. The basic population simulation model was developed and we thought it be a simple matter to run it and start producing results which matched the data contained in Debbie Peake's hunting record. How wrong we were.

The major problem lay in finding a selectivity function which would take tusks from the model population in the proportions which occur year-by-year in the hunting data base. We tested many different types of functions of increasing complexity and none of them worked. We soon realised that the selection function could not be a static formula but would have to change over the years. We attempted to develop a GLIM (Generalised Linear Model) which would achieve this. Months passed.

Finally the penny dropped late in 2010 when we realised that the proportions of different-sized tusks in the data had nothing to do with the variables one might expect to control tusk weight selection, e.g. quota size, population growth, the degree of initial adult male depletion in 1986 and the state of recovery from that depletion, the level of background hunting, the age-tusk weight formula and the age-specific natural mortality for elephants in the last 20 years of their life.

Our last resort was to force the simulation model to make the correct selection of proportions of tusks by telling it what the answers were. Needless to say, this worked. Whilst it was disappointing not to be able to create a selectivity function from independent variables, it does not necessarily detract from the value of the simulation model in making predictions for the future.

Despite the time that this study has taken, we still believe there is more that might be learnt from the hunting data. It has been a fascinating project and it would have been very easy to allow it to continue for another six months. However, by that time at least one of us would have been bankrupt!

In due course, we hope to prepare a powerpoint presentation which shows the interesting features of the data, the intricacies in simulating it and the implications for future management. However, that may have to be done as a new project.

# The Elephants of Northern Botswana:
# Trophy Hunting, Population Dynamics and Future Management

## ABSTRACT

The incentive for this study was a remarkable database assembled by Debbie Peake containing the full details of all elephant trophies hunted in Botswana since 1996 when formal trophy hunting was initiated. We set out to develop a population simulation model which would replicate the results of the actual hunting and to use it to predict the outcome of future hunting.

At some 155,000 elephants, the population in northern Botswana is the largest in Africa. The population appears to have increased at a rate exceeding 6% since 1987. To sustain such a rate of increase over 25 years requires values for fecundity and mortality which fall outside the range of recorded values from other elephant populations in southern Africa. Using the maximum values for fecundity and the minimum values for mortality from published data, we conclude that the growth rate is best explained by a highly skewed age structure in 1986. A depletion in the numbers of males over 20 years old would result in the observed population performance.

Dispersal has been taking place from the population for at least the past 6 years: the elephant range in Botswana is expanding and animals are emigrating into neighbouring countries. In providing for emigration in the population model, we found that any sustained emigration, even a very small proportion of the surplus above some density threshold, ultimately regulates the population. We have used the asymptote which results from our assumed emigration parameters to establish the long term outcome of various levels of hunting intensity.

The quotas set for trophy hunting from 1996-2010 reached a maximum of 0.2% of the total population in 2009. This is low by any regional standards where, for years, elephant managers have typically set quotas around 0.5% of the total population. It accounts for the very large trophies which have been taken over the past 15 years. Apart from the number of very large trophies, there are two remarkable features in the data: firstly, the mean tusk weight of the trophies taken over 15 years has remained virtually constant at 25kg (55lbs). Secondly, the proportions of tusk weights has remained constant over the same period. In the number of animals hunted in every year roughly 30% lie between 40-50lbs, 40% lie between 50-60lbs and 20% lie between 60-70lbs. These proportions bear little resemblance to the proportions of tusks occurring in the same weight classes within the population.

This finding appears highly significant. Despite dramatic changes in the population age structure from 1996-2010, the proportions of different-sized trophies remained ‘rock-steady’. At the outset of the study we had the preconception that in any given hunting season the elephants carrying the largest tusks would be shot out first, followed by the elephants carrying medium-sized tusks and, finally, the elephants with less impressive tusks would make up the quota. An entirely different process is in place. We could not find a satisfactory selectivity function based on biological parameters and, in the end, we were forced to base selection on the actual proportions of tusks in the hunting data. We have put forward two hypotheses to account for the observed phenomena.

The simulation model replicates faithfully what happened in the hunting industry from 1996-2010. This is not surprising because it uses the known results to carry out its tusk selection. However, this does not detract from its usefulness in making future projections.

We used two approaches to examine the response of the population to changes in the hunting quota. A 'perfect hunting' regime (where trophies are taken from the population strictly in order of size from the largest tusks to the smallest tusks available to satisfy the quota) sets the upper limits on what trophies can be taken from the population and, ultimately, provides the measure of sustainability of any particular hunting regime. The 'actual hunting' regime attempts to maintain the proportions of tusk weights in the quota as they were found in the data. Ultimately, however, the 'actual hunting' regime cannot produce an outcome which exceeds the limits established by 'perfect hunting'.

Two key results emerge from the simulation runs: (1) hunting quotas cannot be increased much beyond 0.35% of the population without the loss of the highly desirable tusks above 70lbs – the large trophies which have established Botswana as a premier hunting destination; and (2) the population is characterised by a very long time constant (>50 years) in responding to changes in the quota. This is not so much dependent on the magnitude of change as it is on the mere fact of a change. A valuable attribute of a population model such as this is that it allows testing of the long-term effects of quota changes.

The impact of trophy hunting on the elephant population is negligible in biological terms. Trophy hunting has no effect whatsoever on limiting population growth and is not a management tool to replace culling when an elephant population is judged to be overabundant.

Conventional concepts of biological sustainability have little relevance to trophy hunting. Long before the population of adult males becomes totally depleted, the safari industry which caused the depletion would have collapsed. In the lower weight classes (animals carrying tusks less than 50lbs) there are thousands of animals in the population. Quotas exceeding 1% of the population are eminently sustainable in biological terms but totally incompatible with the objective of a high-quality elephant trophy hunting safari industry.

Elephant trophy hunting in Botswana is a large-scale complex system where human factors are interacting with the ecological and economic attributes of the system. We give certain principles which apply generally to such complex systems –

1. **Co-operation amongst stakeholders is the vital ingredient for the industry to prosper**.
2. **The diversity (variability) in concessions** dictates that there is no single approach either to quota setting or to the administration of hunting will result in the best outcomes from hunting across all the CHAs in northern Botswana. The right strategy is to give safari operators the maximum leeway to find solutions in the best and the worst concessions.
3. **There is an ongoing need for experimentation**. Even if existing safari hunting practices seem to be working, it is vital to keep trying alternatives. This is part of the adaptation needed in a changing environment. The rôle of government is to create the opportunities for experimentation.
4. **Policy-makers should position themselves at the laissez-faire end of the management continuum** which extends from Command-and-Control at one end of the spectrum (where all decisions are made by government) to Laissez-Faire at the other (where all decisions are made by local stakeholders). If a workable co-management system is seen as a desirable objective, then it is essential that the major rôle is played by the primary local stakeholders.

# 1. INTRODUCTION

The elephant population in northern Botswana is some 155,000 elephants and it is the largest in Africa (AfRSG 2007, p126). Of the estimated number of elephants in Africa (555,000),[1] southern Africa holds 321,000 (58%) and, of these, Botswana holds 48%. More than a quarter of all the elephants in Africa occur in Botswana.

This study is based on a unique data set assembled by Debbie Peake of all the 2,450 elephant trophies hunted in northern Botswana from 1996-2010.[2] The data include the tusk weights and dimensions, the names of the hunters who took the trophies and the CHAs where the trophies were obtained. **It has to be emphasized that these are the 'hard data' for the study** – unlike aerial survey data, the elephant tusk details are not 'estimates'.[3]

The **objective** of the study was to build a simulation model which would generate a set of tusks over the study period from 1996-2010 which closely resembled those found in the hunting data. This implies that –

(1) the mean tusk weights obtained from the hunting in each year and

(2) the proportions of tusks of different weights making up the quota each year

– should match the 'true' records in the data base. If they do so, the simulation model might reasonably be used to predict the outcomes of future management of trophy hunting.

The study begins by examining the dynamics of the northern Botswana elephant population using the DWNP aerial survey data and the reproductive parameters which might be expected for a typical elephant population in a semi-arid southern African savanna (**Chapter 2**). The apparently high growth rate of the population from 1987-2006 is explained by assuming that the numbers of males older than 20 years was severely depleted in 1986. The rôle of emigration in regulating elephant numbers in northern Botswana is also analysed.

The hunting data which the population model is attempting to simulate are presented in **Chapter 3**. They display some remarkable characteristics. Despite the fact that the population is increasing, is restoring its age structure from the depletion of males in 1986, is being modified each year by the previous year's hunting and, in the latter years, is starting to be regulated by emigration, the mean tusk weight of trophies and the proportions of tusks in the various weight categories[4] making up the annual hunting quota have remained almost constant over the full study period. This presents a challenge for any selectivity function in the simulation model which attempts to select the tusks hunted each year on the basis of biological parameters.

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[1] *Definite* + *Probable* estimates (AfRSG 2007).

[2] Trophy hunting was formally initiated in Botswana in 1996.

[3] In *sensu strictu* even measurements made with a tape measure or on a weighing scale are estimates. However, the errors in such measurements are minor compared with (say) population estimates.

[4] In the key figures in the report, the weights of tusks have been converted from kg to lbs since these are the units of measurement which hunters have always traditionally used.

The results of the trophy hunting simulation process are presented in **Chapter 4**. We believe that the simulation techniques break new ground and are an improvement on previous models which we have developed.

In **Chapter 5** we examine the implications of the simulation results for the management of future trophy hunting in Botswana. The findings have broader application for elephant hunting anywhere in Africa.

Some of the 'challenges' facing the development of any simulation model for the Botswana elephants are shown in **Fig.1** on the next page. We have a set of estimates for the elephant population in northern Botswana extending from 1987-2006. The hunting data apply to the years 1996-2010. If we are correct in our assumption that the population was severely depleted of adult males in 1986, the population age structure will only recover from this depletion in the year 2025. Emigration from the population begins soon after the year 2000 but the asymptote at which population regulation is achieved is only reached by about 2050. This is not a simple data set where there are values for all of the variables over the same time period.

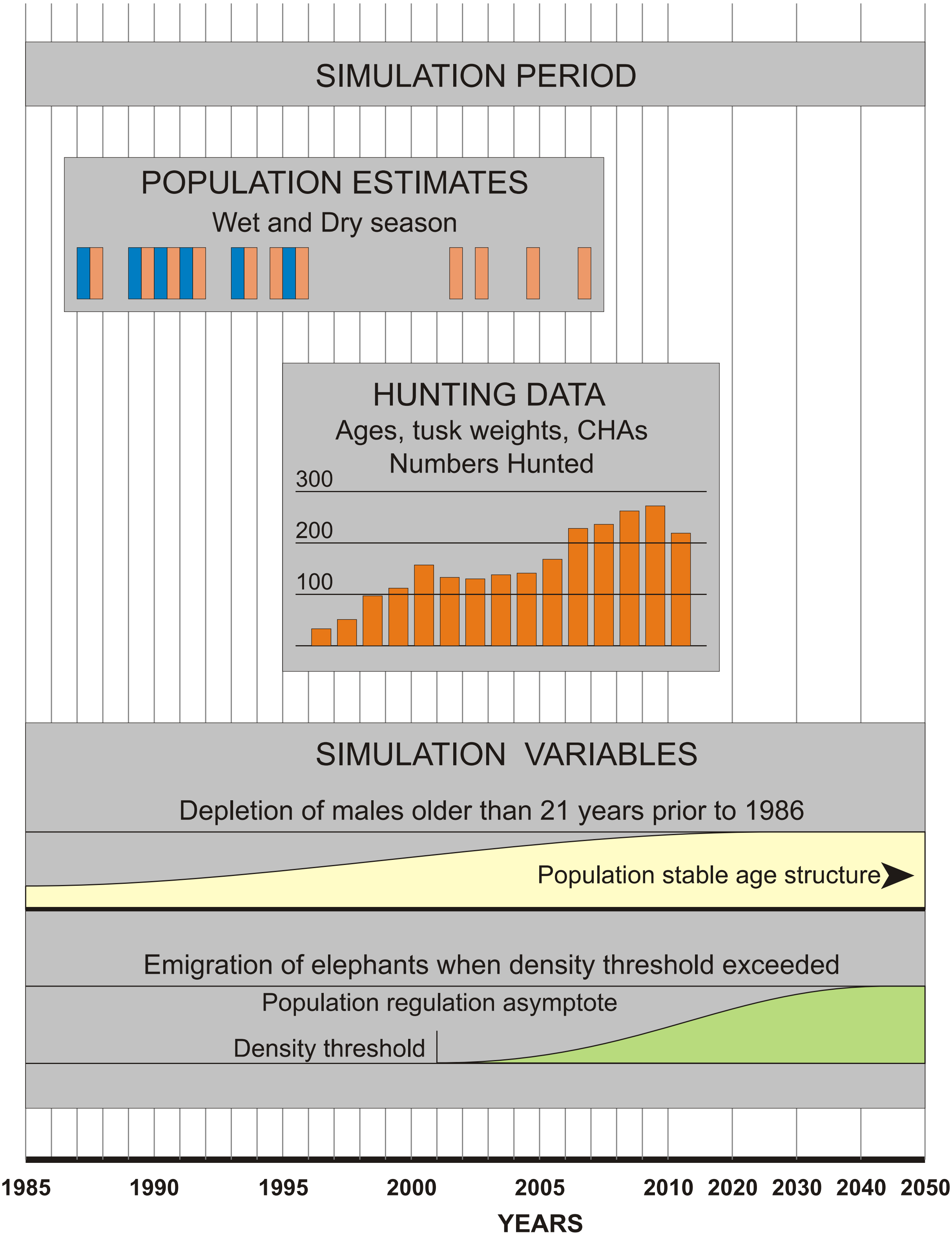

**Figure 1: Time frame for the study**

# 2. POPULATION DYNAMICS

The northern Botswana elephant population has sustained an exceptionally high rate of increase since 1986. Various methods of estimating the population growth rate are shown in **Appendix 1** (page 51) and it was found that the apparent rate of increase lies between 6.3-6.4%.

**Table 1: Dry season population estimates for the northern Botswana elephant population**

| Year | Season | Estimate | 95% Confidence Intervals Lower | 95% Confidence Intervals Upper | Standard Error |
|---|---|---|---|---|---|
| 1987 | Dry | 40,530 | 26,750 | 54,310 | 7,031 |
| 1989 | Dry | 59,896 | 42,806 | 76,987 | 8,720 |
| 1990 | Dry | 55,835 | 35,635 | 76,036 | 10,307 |
| 1991 | Dry | 68,771 | 50,571 | 86,971 | 9,286 |
| 1993 | Dry | 79,033 | 65,364 | 92,701 | 6,973 |
| 1994 | Dry | 78,304 | 61,477 | 95,131 | 8,585 |
| 1995 | Dry | 77,916 | 59,918 | 95,925 | 9,188 |
| 2001 | Dry | 116,988 | 95,196 | 138,799 | 11,128 |
| 2002 | Dry | 122,678 | 105,534 | 139,823 | 8,747 |
| 2003 | Dry | 109,471 | 91,028 | 127,914 | 9,410 |
| 2004 | Dry | 151,000 | 130,996 | 171,004 | 10,206 |
| 2006 | Dry | 154,658 | 133,404 | 175,911 | 10,843 |

*At the time of writing no full surveys of the population had been carried out since 2006*

In **Appendix 2** (page 63), the parameters determining population rate of increase[5] are examined critically. To achieve such a high growth rate over a period of twenty years requires values of these parameters which fall outside the recorded range for southern savanna elephant populations.

There is an alternative explanation. If the population were depleted in males older than 20 years in 1986 (and the cause of this depletion was removed after 1986) it would allow the population to exhibit a high growth rate over the time period for which the survey data apply. There are abundant anecdotal data to suggest that such depletion could well have occurred (Appendix 2). The effects of this depletion in 1986 would disappear by the year 2025 and the population would stabilise at a growth rate of about 5.9% per annum using growth parameters which are within the range of plausible values discussed in Appendix 2.[6] The curve showing this rate of population increase is shown in **Fig.2** on the next page where it is compared with other curves derived from best-fits to the data.

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[5] Age at first parturition, intercalving interval, adult mortality and juvenile mortality.

[6] This rate of population increase is achieved with an age of first parturition of 10 years, an intercalving interval of 44 months, adult mortality of 0.5% and juvenile mortality of 6%.

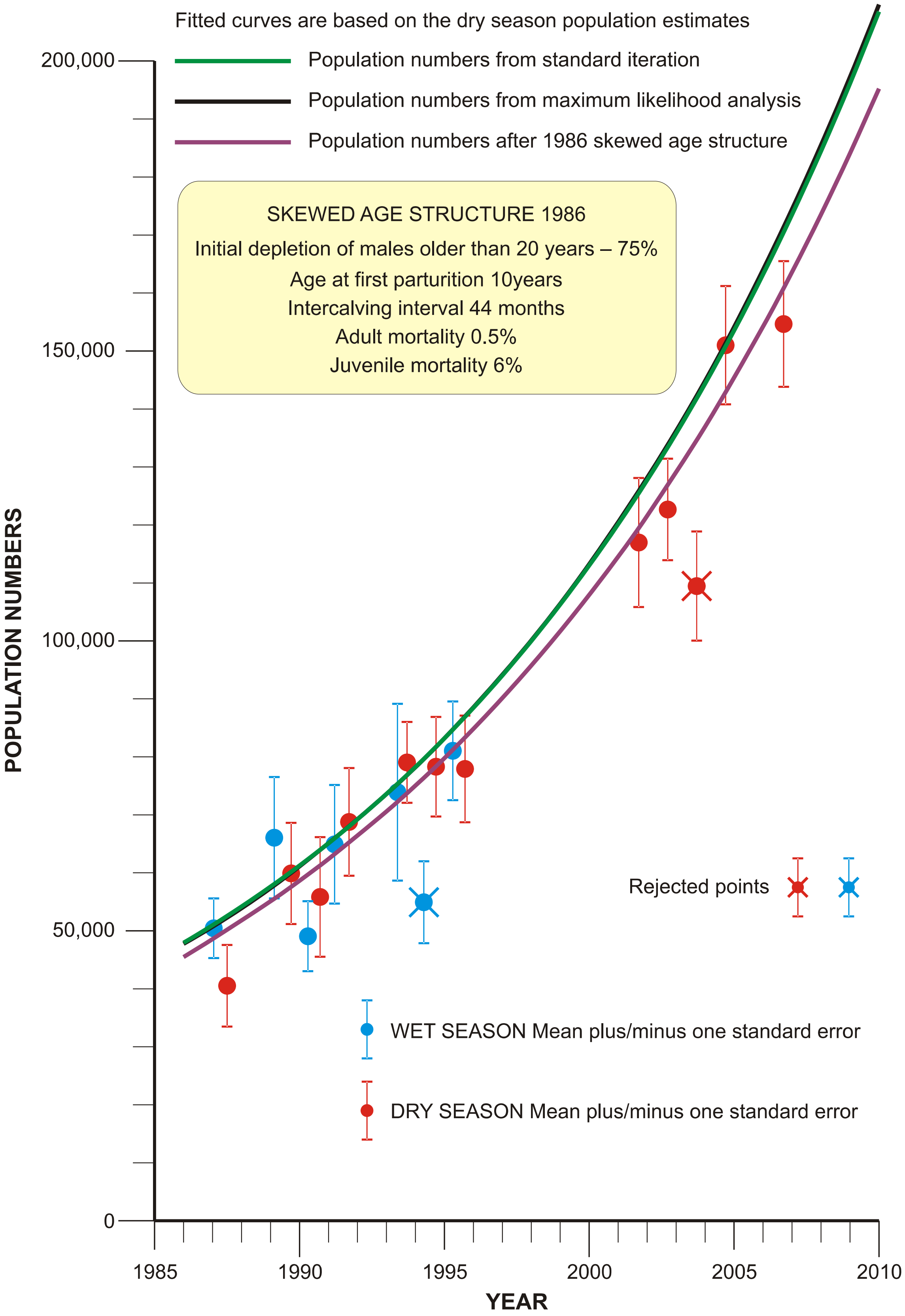

**Figure 2**: **Estimates for the northern Botswana elephant population**

A final variable affecting the northern Botswana elephant numbers is dispersal from the population into new areas in Botswana and into neighbouring countries (**Appendix 3** page 75). A surprising result from this analysis is that emigration from the population will ultimately regulate its numbers. In the simulation model we have assumed that emigration will begin when the population density exceeds 0.7/km$^2$ and 15% of the surplus animals above this threshold will leave Botswana (or move to new areas within Botswana) every year. This results in the population curve shown in **Fig.3** below.[7]

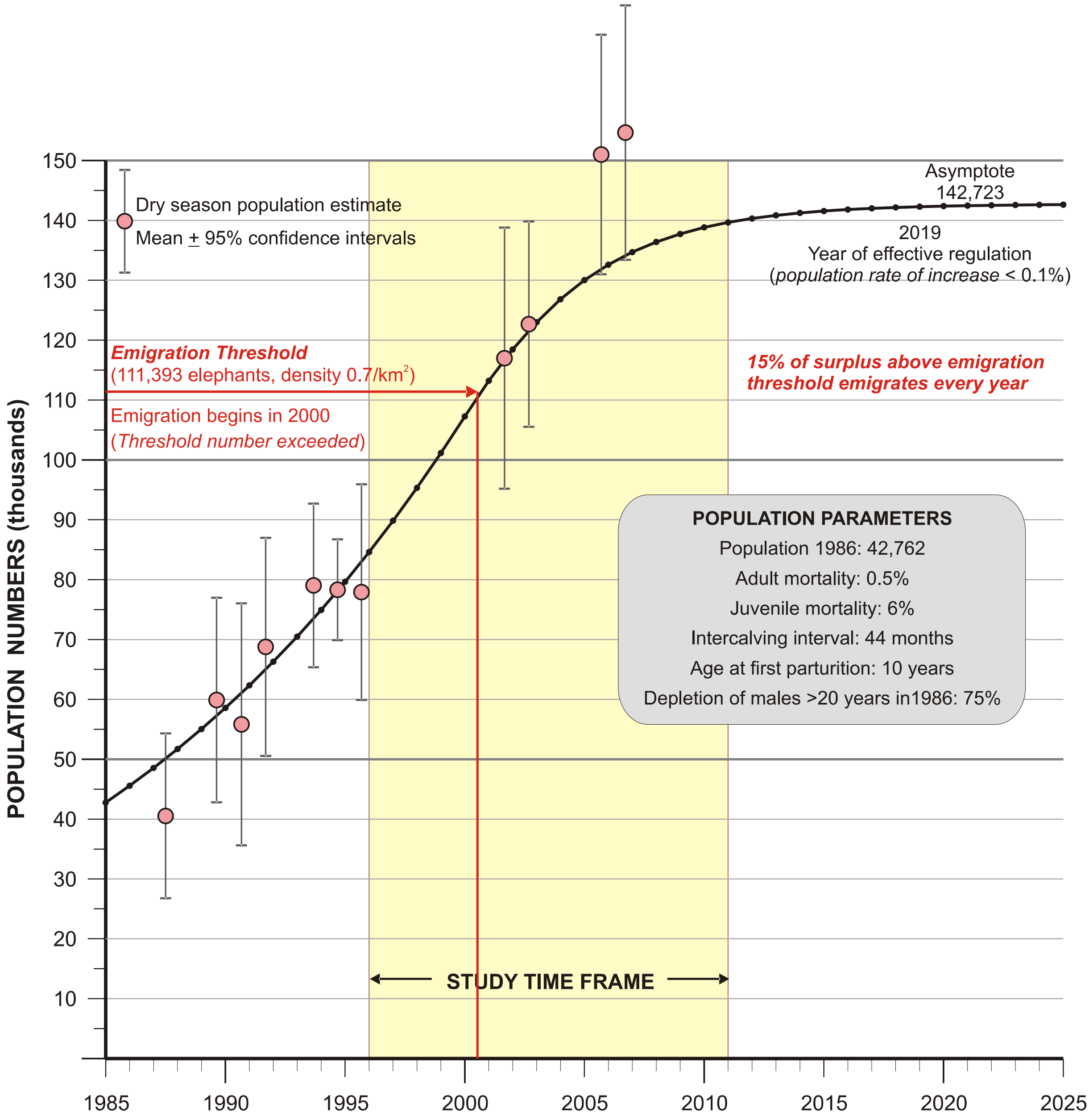

**Figure 3**: **Regulation of the population by emigration**

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[7] It may be noticed that the curve barely reaches the 95% confidence intervals for the 2004 & 2006 population estimates. This is deliberate. If the model is to be used for future predictions of hunting quotas, then the lower the population asymptote the more likely it is that the recommendations will be sustainable.

Whilst the population simulation model may satisfactorily explain the history of trophies obtained from the northern Botswana elephants, if it is to be useful then it should be able to predict the trophies which may be obtained in the future under various management quotas. And to do this requires plausible hypotheses about how the population will increase and how it will ultimately be regulated.

The population simulation model consists of 13 linked spreadsheets (**Fig.4** next page). The functioning of each spreadsheet is described in **Appendix 4** (page 80) and the details of the spreadsheet for trophy hunting are given in **Appendix 6** (page 90).

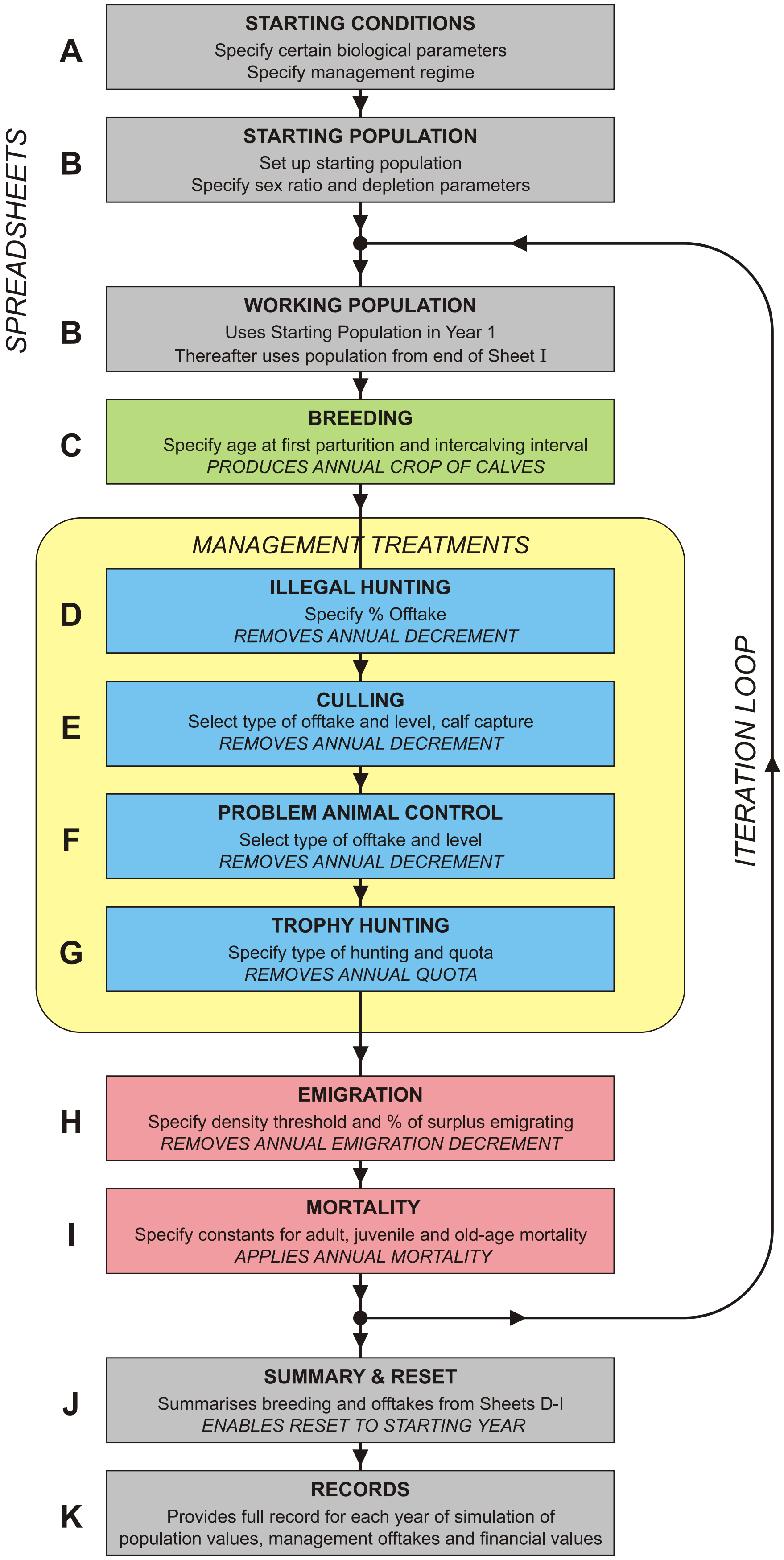

**Figure 4. Population Simulation Model**

## 3. TROPHY HUNTING 1996-2010

Elephant trophy hunting in northern Botswana began formally in 1996. Between 1986 and 1995 there was no organised hunting.[8] Prior to 1986, we have argued that the elephant population was depleted in numbers of adult males (**Appendix 3** page 75).

The elephant range in northern Botswana expanded over the period 1996-2010. For the purpose of this study we have assumed the range includes all of Ngamiland and Chobe Districts and the northern part of Central District. The area of 159,133km$^2$ given in **Table 2** on the next page is taken from the last full air survey of northern Botswana (DWNP 2006).[9] The size of the elephant range is not vital to the modelling process: the number is used only to set a threshold density for the onset of emigration.

National Parks and Game Reserves occupy some 15% of this area (22,115km$^2$ – Broekhuis 2008). However, the proportion of the total elephant population within parks is much higher – about one-third (DWNP 2006). This would imply that about two-thirds of the population are available for trophy hunting. We have used a higher proportion for the number of huntable elephants (75%), reckoning that there is continuous movement of elephants in and out of the protected areas.

The total hunting quotas set and the numbers actually hunted from 1996-2010 are shown in **Table 2** on the next page (columns 'set' and 'got').[10] **The number of elephants hunted is very low**. The number of trophies taken has increased from 0.04% of the total population in 1996 to a maximum of 0.2% of the population in 2009. Even taking into account the fact that the 'total population' is not available for hunting (i.e. a significant number are inside parks), the proportion of the huntable population is still very small – less than 0.3%. As a 'rule-of-thumb' hunting managers generally try to keep hunting quotas below 0.5% of the total population (Martin 2006a, *Appendix 7*): the quotas set and the numbers of animals hunted in northern Botswana are well below this level. This would partly account for the very high trophy quality obtained from the hunting over the 15 year period.

Between 1996 and 2009, there were 1,117 individual trophy tusks larger than 60lbs (27.3kg) taken in northern Botswana.[11] These are shown schematically in the CHAs where they were hunted in **Fig.5** (page 11). The data for 2010 are not shown on the map because of the drastic alteration in the number of CHAs available for hunting which took place at the start of 2010.

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[8] In the simulation model we have included a low level of background hunting (0.03% of the total population) for the period 1986-1995 to cater for problem animal control and illegal hunting.

[9] The area excludes two small survey strata in the Tuli area ... No 44 Mashtu and No 45 Tuli. The elephant range is probably significantly larger than 150,000km$^2$ as elephant have now moved into the northern parts of Ghanzi District and have penetrated further south into Central District.

[10] We have excluded the CHAs NG15 (not hunted over the study period although quotas were set), NG1-3 & 7 (quotas set for only part of the period and very few trophies taken), CT16 (citizen hunting area with few elephants actually taken) and CT27 (quota intended mainly for problem animal control and only about one-third of it was actually taken).

[11] The relationship between the larger single tusk and the size of the other tusk derived from the 2,219 tusks in the data base hunted between 1996-2009 is –

Combined weight of both tusks = 1.913 x Weight of the larger tusk

### Table 2. Trophy hunting quotas and elephant population size

| | | | | | |
|---|---|---|---|---|---|
| Total Area | 159,133 | km$^2$ | Parks | 22,114 | km$^2$ (15%) |
| *Total elephants 2006* | *153,620* | | *Parks* | *50,934* | *(33%)* |

Percentage used for "Huntable" 75%

| | Population | | | | QUOTAS | | |
|---|---|---|---|---|---|---|---|
| | Total N | Huntable N | Density /km$^2$ | Set N | Got N | % total % | % huntable % |
| 1996 | 84,605 | 63,454 | 0.53 | 77 | 33 | 0.04 | 0.05 |
| 1997 | 89,835 | 67,376 | 0.56 | 78 | 51 | 0.06 | 0.08 |
| 1998 | 95,329 | 71,497 | 0.60 | 168 | 99 | 0.10 | 0.14 |
| 1999 | 101,140 | 75,855 | 0.64 | 168 | 112 | 0.11 | 0.15 |
| 2000 | 107,257 | 80,443 | 0.67 | 168 | 157 | 0.15 | 0.20 |
| 2001 | 113,206 | 84,905 | 0.71 | 180 | 133 | 0.12 | 0.16 |
| 2002 | 118,451 | 88,838 | 0.74 | 192 | 131 | 0.11 | 0.15 |
| 2003 | 122,982 | 92,237 | 0.77 | 192 | 138 | 0.11 | 0.15 |
| 2004 | 126,825 | 95,119 | 0.80 | 192 | 141 | 0.11 | 0.15 |
| 2005 | 130,016 | 97,512 | 0.82 | 230 | 168 | 0.13 | 0.17 |
| 2006 | 132,594 | 99,446 | 0.83 | 284 | 228 | 0.17 | 0.23 |
| 2007 | 134,703 | 101,027 | 0.85 | 290 | 236 | 0.18 | 0.23 |
| 2008 | 136,387 | 102,290 | 0.86 | 307 | 262 | 0.19 | 0.26 |
| 2009 | 137,730 | 103,298 | 0.87 | 354 | 272 | 0.20 | 0.26 |
| 2010 | 138,837 | 104,128 | 0.87 | 341 | 219 | 0.16 | 0.21 |
| | | | TOTALS | 3,221 | 2,380 | | |

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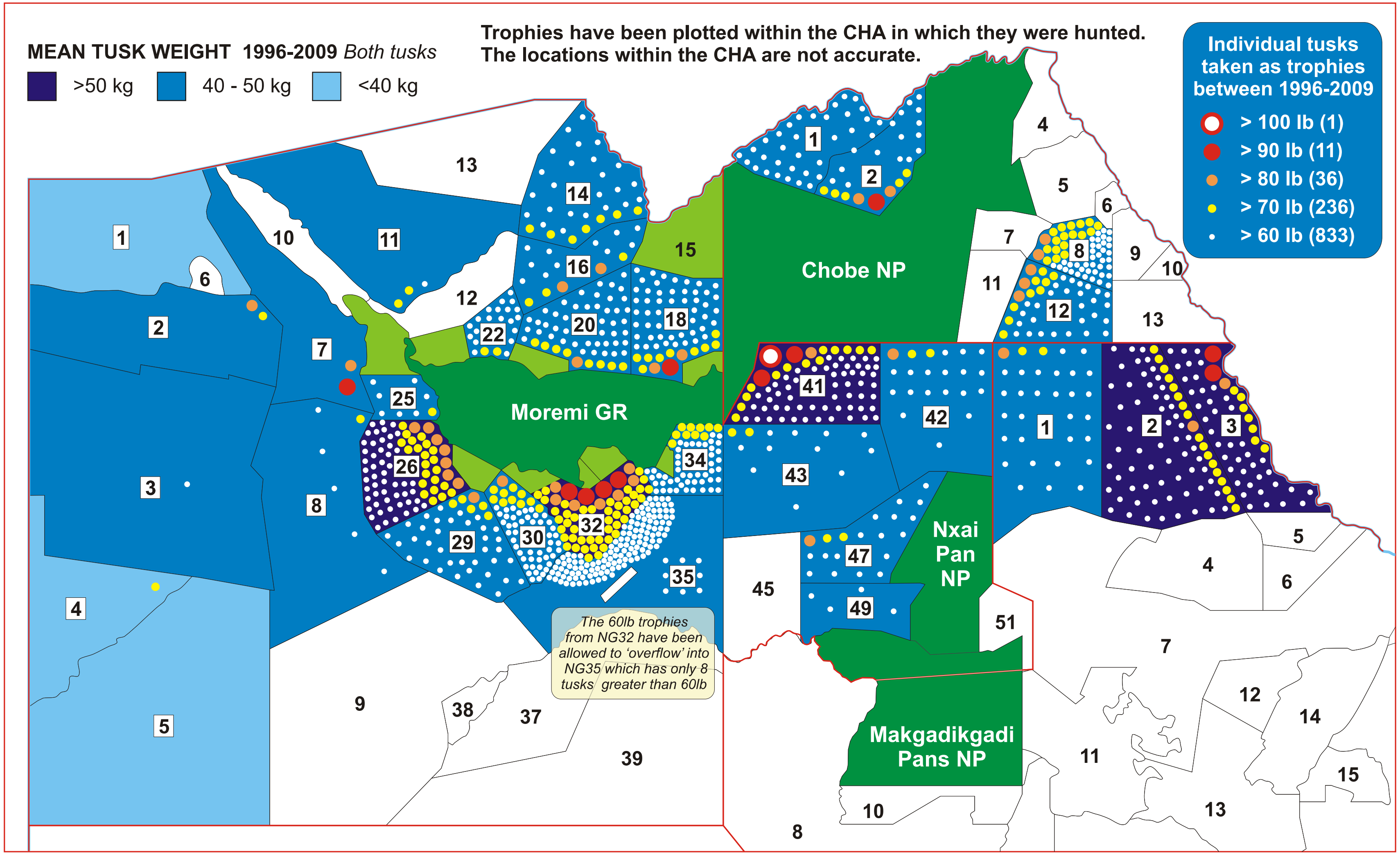

Trophies have been plotted within the CHA in which they were hunted. The locations within the CHA are not accurate.

The 60lb trophies from NG32 have been allowed to 'overflow' into NG35 which has only 8 tusks greater than 60lb

**Figure 5**: Distribution of hunting trophies taken in CHAs in northern Botswana 1996-2009

The mean tusk weight of all trophies taken over the period 1996-2010 is 25.39kg (**Fig.6** below). The consistency in the values from year to year is remarkable – the standard deviations about the mean are very narrow (± 0.61kg).[12] The larger standard deviations shown in Fig.6 are a measure of the variability in mean tusk weights obtained in the individual CHAs in each year. **The simulation model is required to duplicate this result.**

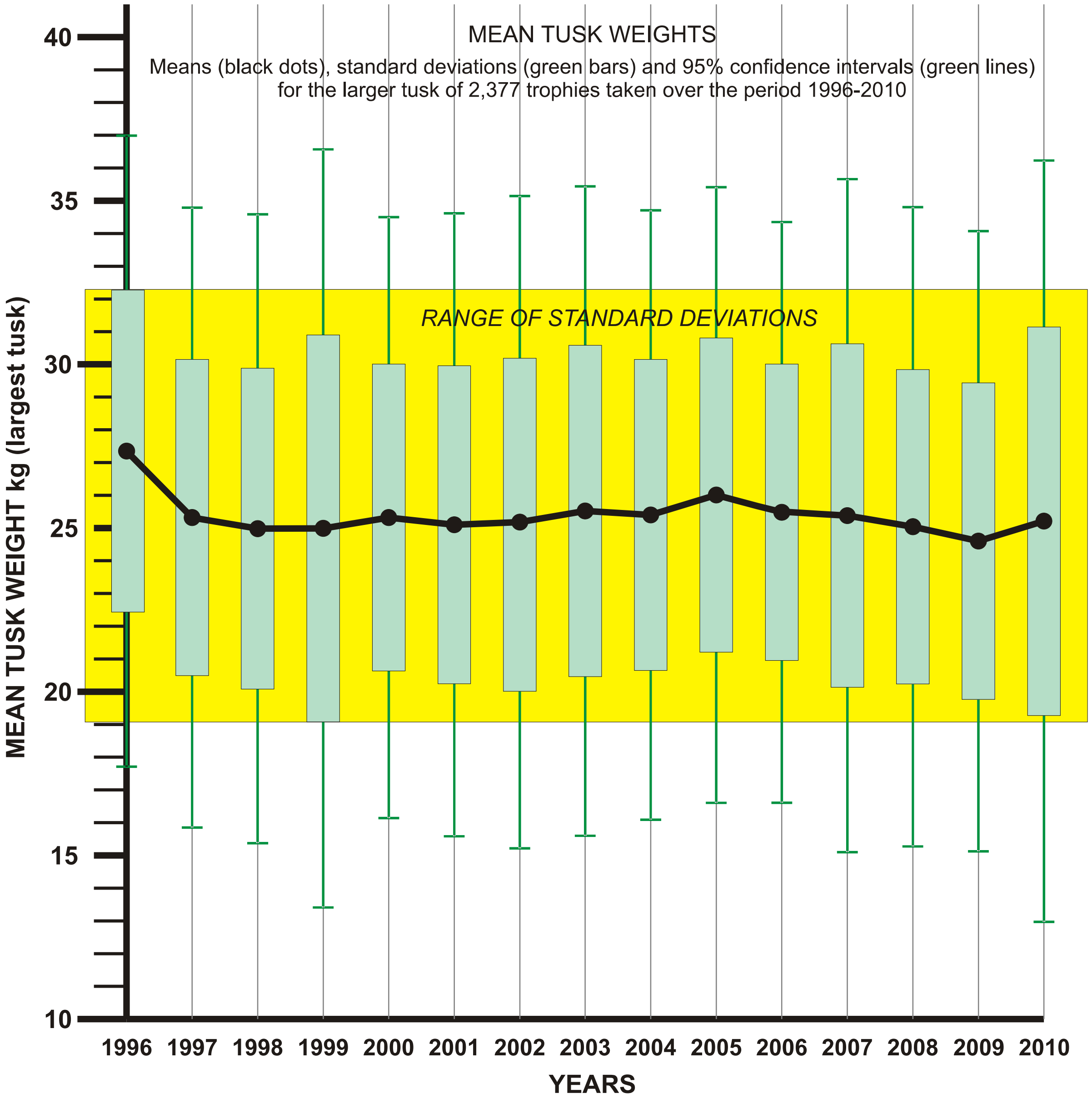

**Figure 6**: **Mean tusk weights for trophies hunted from 1996-2010**

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[12] The largest departure from an overall mean of 25.39kg was 27.35kg obtained in the year of inception of hunting (1996). It is based on the smallest quota (33 animals) and perhaps might have been expected from the first year of exploitation of a previously 'unhunted' population.

DWNP set quotas for 33 CHAs over the period 1996-2009. Of these, we excluded 7 at the outset (Footnote 10). It became clear from inspection of the data for the remaining CHAs that certain areas were providing most of the trophies and the largest tusks. We ranked the CHAs based on the number of trophies (Nh) and the largest tusks obtained from them over the 15 year period 1996-2010.[13] The number of trophies obtained from the 18 highest-ranked CHAs was 2,175 – 91.4% of the total number of trophies.

**Table 3. CHA rankings**

18 highest ranked CHAs

| Rank | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CHA** | **NG 32** | **NG 41** | **CH 1&2** | **CT 2** | **NG 34** | **NG 18** | **CH 8** | **NG 26** | **NG 30** | **CH 12** | **NG 20** | **CT 3** | **NG 29** | **CT 1** | **NG 42** | **NG 14** | **NG 47** | **NG 43** | |
| Index | 663 | 367 | 358 | 308 | 307 | 298 | 280 | 268 | 266 | 261 | 260 | 244 | 222 | 206 | 192 | 190 | 159 | 136 | |
| Nh | 182 | 156 | 174 | 118 | 171 | 128 | 114 | 52 | 106 | 130 | 106 | 95 | 105 | 122 | 123 | 89 | 106 | 98 | **2,175** |

Other CHAs

| Rank | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **CHA** | **NG 22** | **NG 16** | **NG 49** | **NG 4&5** | **NG 25** | **NG 8** | **NG 11** | **NG 35** | |
| Index | 111 | 102 | 67 | 43 | 31 | 20 | 18 | 18 | |
| Nh | 57 | 41 | 46 | 26 | 12 | 8 | 6 | 6 | **202** |

The data shown in **Fig.7** on the next page are from the 18 highest-ranked CHAs. The percentages which each tusk weight class forms of the total number of trophies hunted from 1996-2010 is shown in **Table 4** below.

**Table 4: Proportions of tusks of various size classes in the total numbers hunted**

| Weight Class | **12** | **3** | **4** | **5** | **6** | **7** | **8** | |
|---|---|---|---|---|---|---|---|---|
| | < 30lbs | 30-40lbs | 40-50lbs | 50-60lbs | 60-70lbs | 70-80lbs | 80-90lbs | > 90lbs |
| Numbers | 32 | 155 | 594 | 845 | 420 | 107 | 20 | 2 |
| Percent of total | 1.47 | 7.13 | **27.31** | **38.85** | **19.31** | **4.92** | 0.92 | 0.09 |

The percentages highlighted in bold font above are the key to the composition of the overall hunting offtake. These proportions have very little resemblance to the proportions of tusks occurring in the same weight classes within the population (**Table 5** next page). The table shows the numbers of tusks in the weight classes 2-8 in the male population in the year 2010. The numbers in bold font for weight classes 3-6 need to be compared with the proportions making up the overall hunting quota.

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[13] The index used for the ranking was – $Index = Nh + T_1 + 2T_2 + 4T_3 + 8T_4$
– where *N*h was the total number of trophies and $T_1 - T_4$ were the numbers of trophies with a combined weight greater than 2 x 50lbs, 2 x 60lbs, 2 x 70lbs and 2 x 80lbs respectively.

**Table 5: Numbers of tusks in weight classes in the population and numbers hunted**

| Weight Class | 2<br>30-40lbs | 3<br>40-50lbs | 4<br>50-60lbs | 5<br>60-70lbs | 6<br>70-80lbs | 7<br>80-90lbs | 8<br>>90lbs |
|---|---|---|---|---|---|---|---|
| Numbers in population | 2,999 | 2,082 | 1,425 | 543 | 889 | 345 | 1 |
| Numbers hunted | 26 | 67 | 95 | 45 | 10 | 5 | 1 |
| % of available trophies | 0.87 | **3.22** | **6.67** | **8.29** | **1.12** | 1.45 | 100.00 |

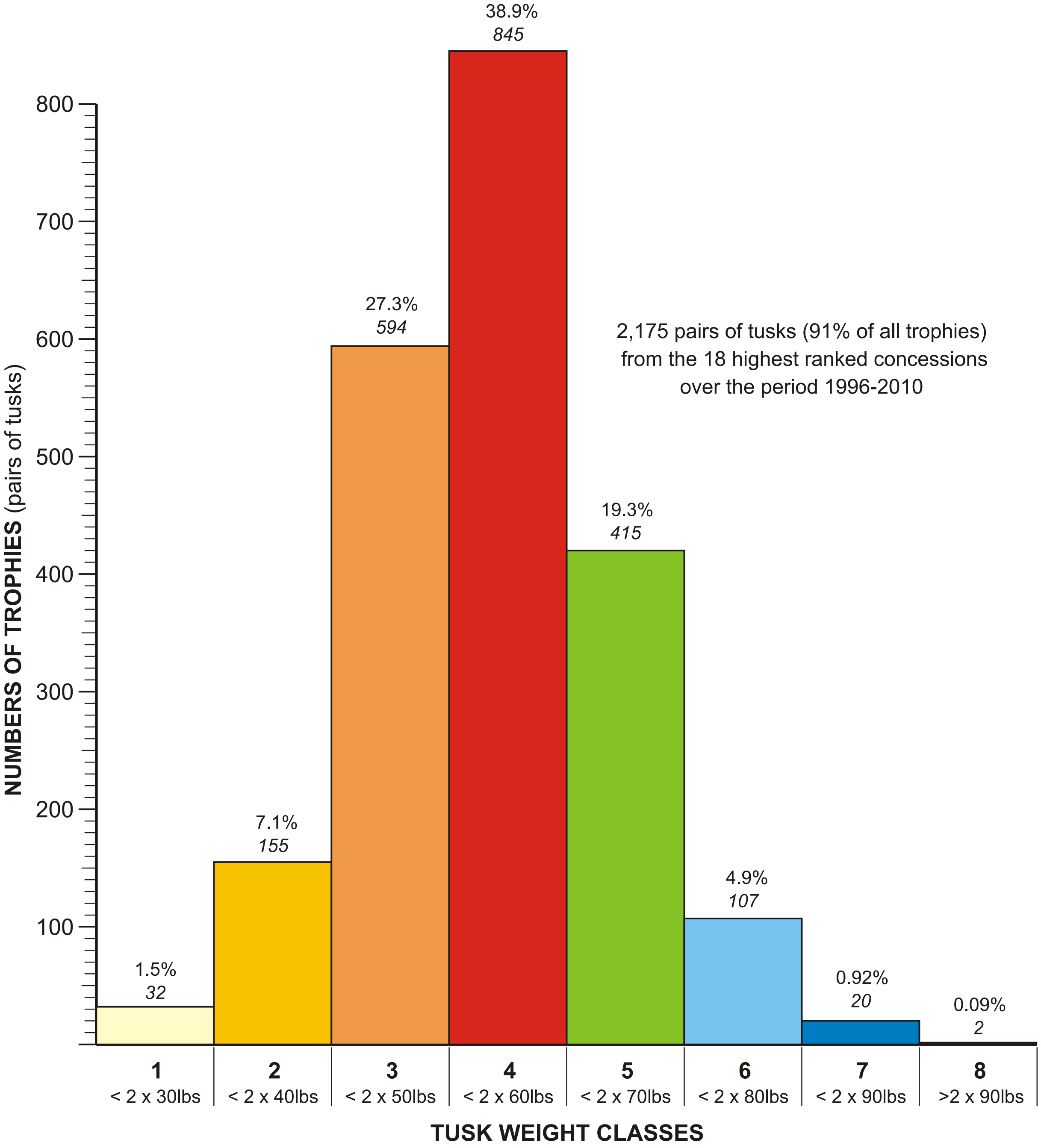

**Figure 7: Overall distribution of trophy tusk weights 1996-2010**

The proportions of tusk weights making up the total number of trophies hunted (**Table 4**) persists on a year-by-year basis.[14] Of the most important tusk weight categories (3-6), the proportions remain remarkably constant every year from 1997-2010. A quick visual inspection of weight classes 3-5 (orange, red and green bars) in **Fig.8** (next page) and **Fig.9** (page 17) will reinforce the conclusion.

**Table 6: Annual numbers hunted and proportions of tusk sizes 1996-2010**

**Numbers hunted from 18 top-ranked CHAs**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | N |
|---|---|---|---|---|---|---|---|---|---|
| 1996 | 0 | 0 | 6 | 4 | 8 | 3 | 0 | 0 | 21 |
| 1997 | 0 | 1 | 12 | 18 | 6 | 2 | 0 | 0 | 39 |
| 1998 | 1 | 10 | 19 | 26 | 16 | 3 | 0 | 0 | 75 |
| 1999 | 2 | 9 | 27 | 32 | 17 | 4 | 2 | 1 | 94 |
| 2000 | 0 | 13 | 39 | 49 | 27 | 10 | 0 | 0 | 138 |
| 2001 | 1 | 9 | 30 | 52 | 20 | 7 | 1 | 0 | 120 |
| 2002 | 4 | 7 | 36 | 49 | 24 | 5 | 1 | 0 | 126 |
| 2003 | 3 | 9 | 30 | 52 | 27 | 8 | 1 | 0 | 130 |
| 2004 | 3 | 4 | 38 | 52 | 29 | 3 | 2 | 0 | 131 |
| 2005 | 0 | 8 | 41 | 68 | 29 | 11 | 1 | 0 | 158 |
| 2006 | 0 | 12 | 59 | 81 | 44 | 7 | 1 | 0 | 204 |
| 2007 | 3 | 20 | 58 | 81 | 41 | 13 | 3 | 0 | 219 |
| 2008 | 2 | 14 | 70 | 92 | 52 | 15 | 1 | 0 | 246 |
| 2009 | 7 | 15 | 74 | 111 | 42 | 8 | 2 | 0 | 259 |
| 2010 | 6 | 24 | 55 | 78 | 38 | 8 | 5 | 1 | 215 |
| | 32 | 155 | 594 | 845 | 420 | 107 | 20 | 2 | 2,175 |
| % | 1.47 | 7.13 | 27.31 | 38.85 | 19.31 | 4.92 | 0.92 | 0.09 | 100 |

**Percentages of numbers hunted each year from 18 top ranked CHAs**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | N |
|---|---|---|---|---|---|---|---|---|---|
| 1996 | 0.00 | 0.00 | 28.57 | 19.05 | 38.10 | 14.29 | 0.00 | 0.00 | 100 |
| 1997 | 0.00 | 2.56 | 30.77 | 46.15 | 15.38 | 5.13 | 0.00 | 0.00 | 100 |
| 1998 | 1.33 | 13.33 | 25.33 | 34.67 | 21.33 | 4.00 | 0.00 | 0.00 | 100 |
| 1999 | 2.13 | 9.57 | 28.72 | 34.04 | 18.09 | 4.26 | 2.13 | 1.06 | 100 |
| 2000 | 0.00 | 9.42 | 28.26 | 35.51 | 19.57 | 7.25 | 0.00 | 0.00 | 100 |
| 2001 | 0.83 | 7.50 | 25.00 | 43.33 | 16.67 | 5.83 | 0.83 | 0.00 | 100 |
| 2002 | 3.17 | 5.56 | 28.57 | 38.89 | 19.05 | 3.97 | 0.79 | 0.00 | 100 |
| 2003 | 2.31 | 6.92 | 23.08 | 40.00 | 20.77 | 6.15 | 0.77 | 0.00 | 100 |
| 2004 | 2.29 | 3.05 | 29.01 | 39.69 | 22.14 | 2.29 | 1.53 | 0.00 | 100 |
| 2005 | 0.00 | 5.06 | 25.95 | 43.04 | 18.35 | 6.96 | 0.63 | 0.00 | 100 |
| 2006 | 0.00 | 5.88 | 28.92 | 39.71 | 21.57 | 3.43 | 0.49 | 0.00 | 100 |
| 2007 | 1.37 | 9.13 | 26.48 | 36.99 | 18.72 | 5.94 | 1.37 | 0.00 | 100 |
| 2008 | 0.81 | 5.69 | 28.46 | 37.40 | 21.14 | 6.10 | 0.41 | 0.00 | 100 |
| 2009 | 2.70 | 5.79 | 28.57 | 42.86 | 16.22 | 3.09 | 0.77 | 0.00 | 100 |
| 2010 | 2.79 | 11.16 | 25.58 | 36.28 | 17.67 | 3.72 | 2.33 | 0.47 | 100 |
| Mean | 1.32 | 6.71 | 27.42 | 37.84 | 20.32 | 5.49 | 0.80 | 0.10 | |
| Mean 97- | 1.41 | 7.19 | 27.34 | 39.18 | 19.05 | 4.87 | 0.86 | 0.11 | |

**The significance of this finding should not be underestimated.** While the population is changing dramatically from 1996-2010 ... recovering from depletion, beginning to disperse and being subjected to increasing hunting ... the proportions of different-sized tusks in the numbers hunted remains 'rock-steady'. **The major challenge for the simulation model is to reproduce this situation**.

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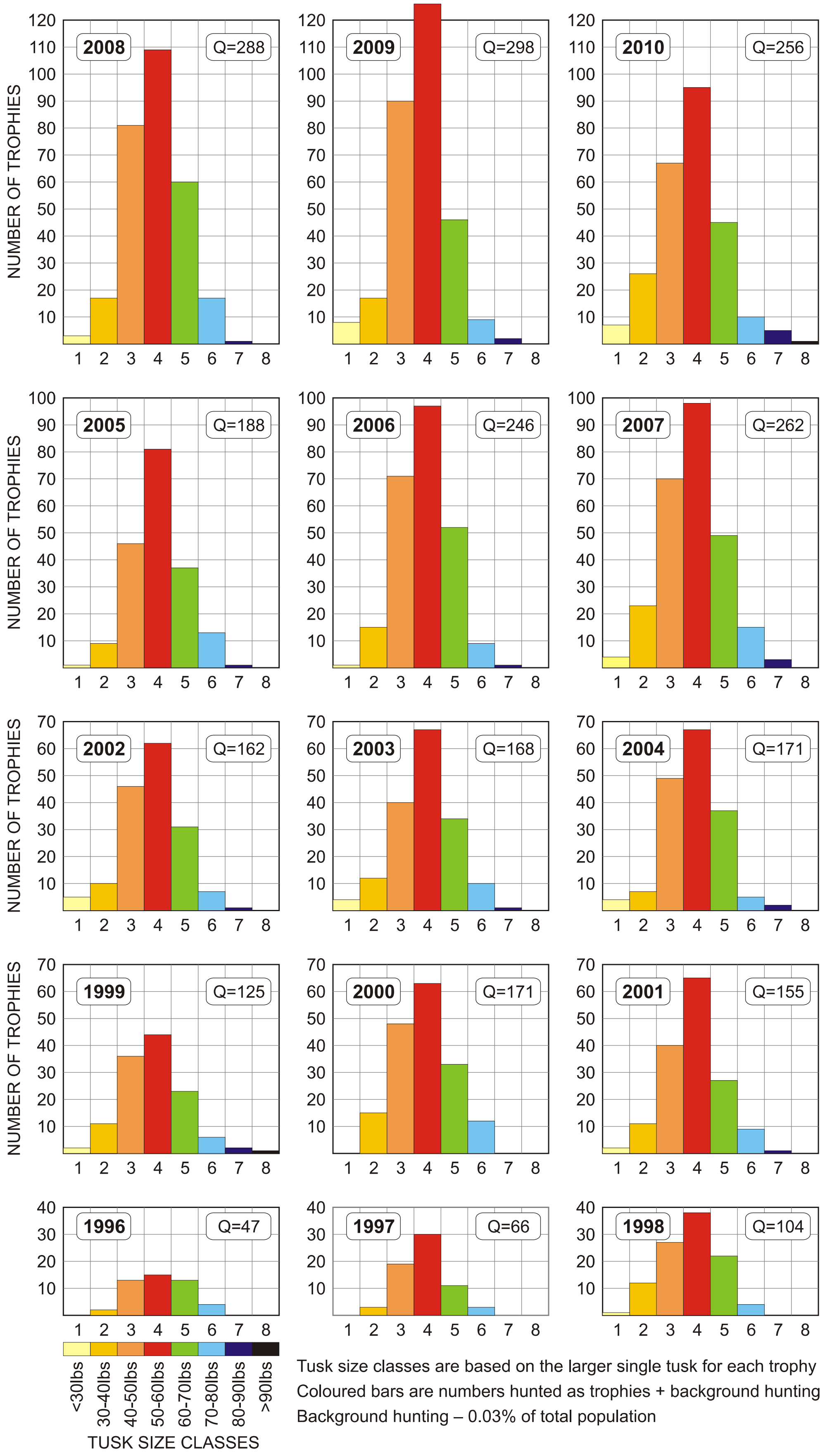
[14] ... with the exception of 1996. However, the observations in Footnote 12 apply.



Tusk size classes are based on the larger single tusk for each trophy
Coloured bars are numbers hunted as trophies + background hunting
Background hunting – 0.03% of total population

**Figure 8**: **Annual distribution of trophy tusk weights 1996-2010**

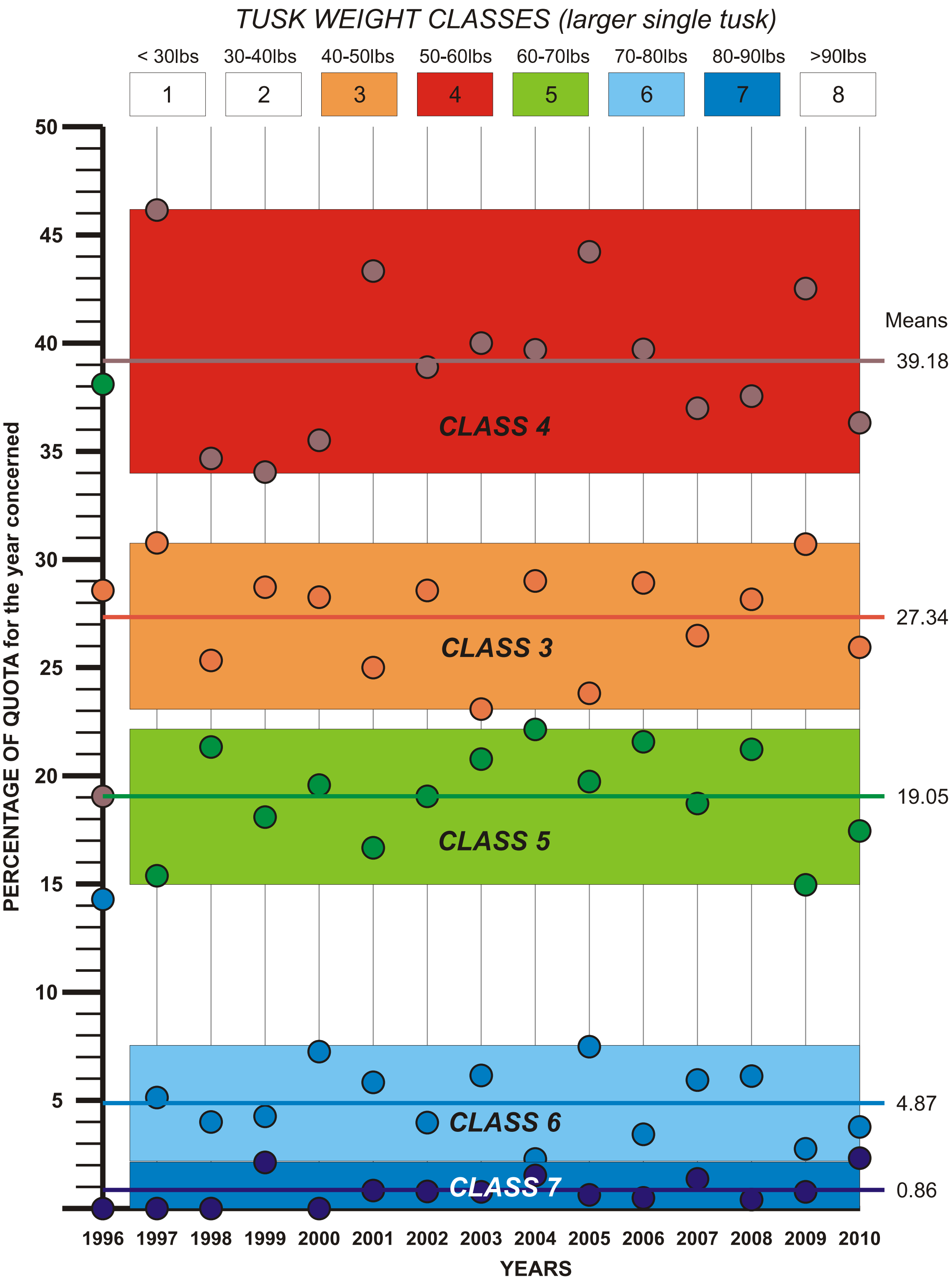


**Figure 9**: **Percentages of trophies in weight classes making up total quota**

To some extent this pattern breaks down when the individual hunting concessions are considered (**Figs.10 & 11** on the next pages). However, the numbers hunted in each concession are relatively small and it might be expected that there would be considerable variation from year to year and from concession to concession.

**Figure 10**: **Distribution of tusk sizes in individual CHAs (Rank 1-9)**

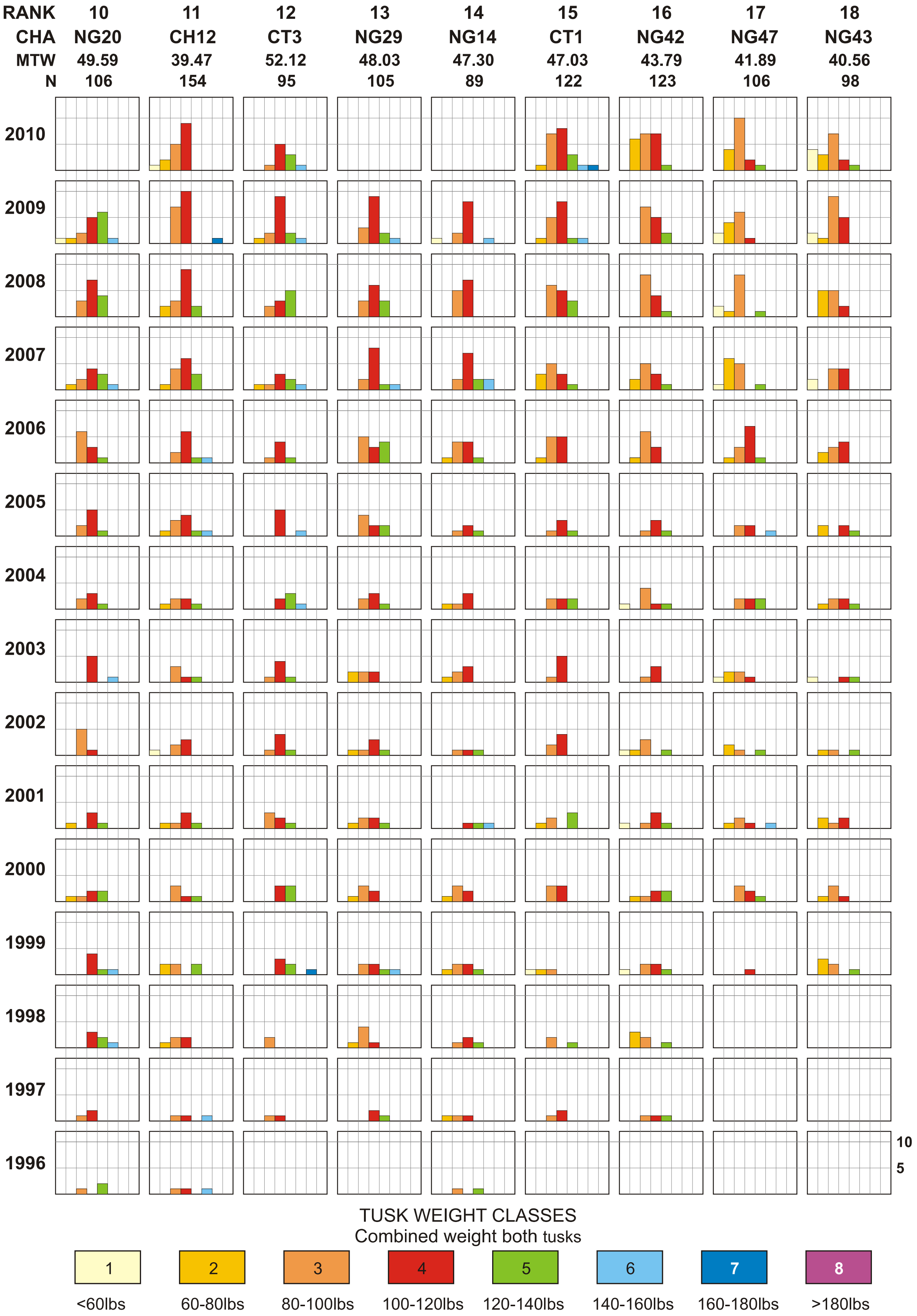


**Figure 11**: **Distribution of tusk sizes in individual CHAs (Rank 10-18)**

The high standard deviations attached to the mean tusk weights for the different age classes result in a wide range of tusk weights possible for any given age class. In **Fig.12** below, we show the distribution of tusk sizes which could be expected in a population of 90,000 animals which has a stable age structure, has not been subjected to hunting and has not suffered any depletion. Interestingly, there are more animals carrying tusks in Weight Class 8 (>90lbs) than there are in each of the three weight classes immediately below it.[15] However, the observation is somewhat academic: it is not the situation which pertains on the ground.

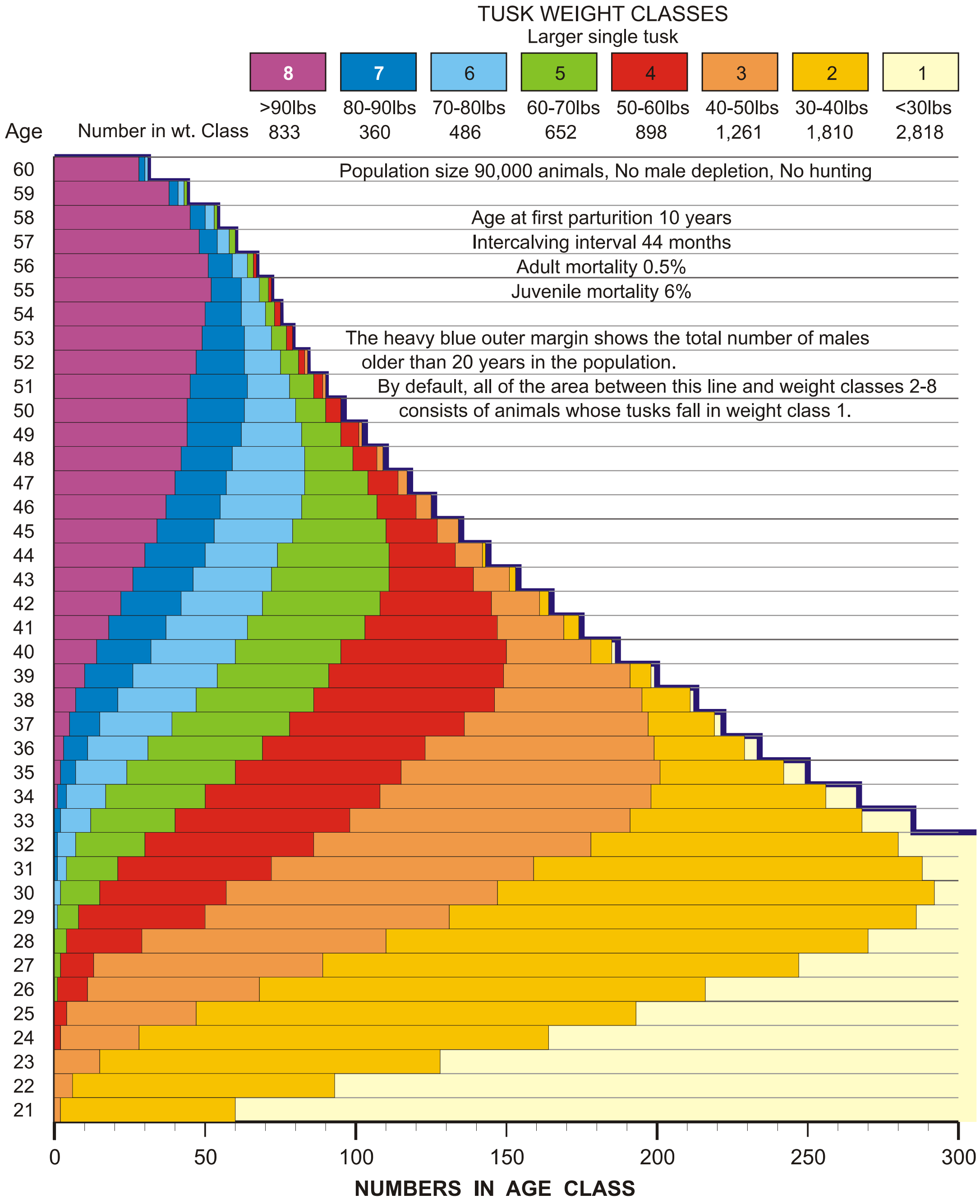


**Figure 12**: **Distribution of tusk weights in an unhunted, undepleted population**

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15. The relatively high numbers of animals carrying tusks in weight class 8 (greater than 90lbs) is misleading. The other weight classes (2-7) each cover a range of 10lbs. If weight class 8 tusks were further divided in to weight classes 90-100lbs, 100-110lbs and so on, it would produce a further set of layers in the figure more closely resembling those of weight classes 6 & 7.

The situation which pertained in northern Botswana in 1999 is more likely to have resembled the scenario shown in **Fig.13** below. The numbers in weight classes 5-8 are far lower than those in the undepleted, unhunted population (**Fig.12**) but they were more than sufficient to provide the quota of animals which were hunted in that year. This sets the stage for the simulation of trophy hunting which follows in the next chapter.

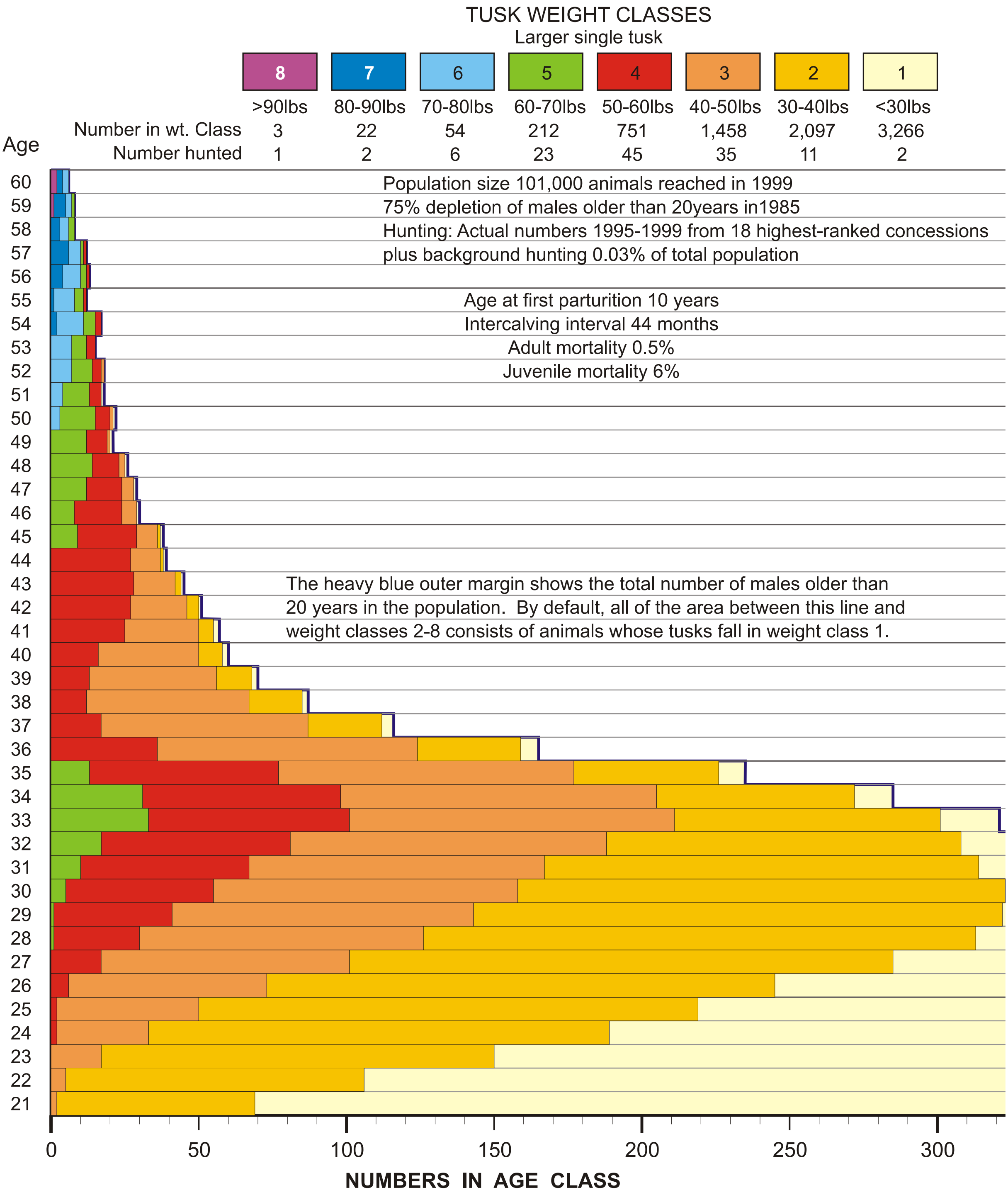

**Figure 13**: **Distribution of tusk weights in a depleted population with trophy hunting**

# 4. SIMULATION OF TROPHY HUNTING

In the previous chapter, it was shown that –

(1) despite the major population changes over the years 1996-2010 ... overall population increase, recovery from initial depletion, inception of emigration and increasing hunting intensity ... the mean tusk weight and the proportion of different sizes of tusks making up the hunting offtake has remained almost constant since 1997;

(2) there is a wide scatter of possible tusk weights for any given age of male elephant older than 20 years – a tusk greater than 90lbs may be produced by any male older than 34 years, a tusk in the 60-70lb category may come from any male between the ages 26-59 years;

(3) only a relatively small proportion of the available tusks in any weight class are needed to realise the observed number and size of trophies which were obtained from the population; and

(4) to simulate the hunting offtake requires a 'selectivity' function which takes a certain number of animals from each age class in each year in such a manner that it produces a mean tusk weight of 25kg and, of the total number hunted, roughly 30% must have tusks in the weight class 40-50lbs, 40% must lie between 50-60lbs and 20% must be between 60-70lbs.

This is a tall order. The required selectivity function cannot remain the same over the study period (1996-2010): it has to change from year to year as changes take place in the population and in the hunting quotas.

In the next four figures (**Figs.14-17**, pages 25-28) the 'development' of the population of males older than 20 years is shown for the years from 1996-2011. For each year there is a summary table giving the numbers of tusks available in weight classes 3-8, the number of animals to be hunted and the selection fraction needed for each weight class.[16] The figures show the continuing recovery from the 1986 depletion and the effects this has on the numbers of tusks in the various weight classes. The data are derived from the simulation model described in **Appendix 6** (page 90).

**Weight class 8** (tusks >90lbs): At the inception of trophy hunting in 1996, the model indicates that there were a small number of elephants (8) in the population with tusks greater than 90lbs. One of these was taken in 1999 and the remainder had disappeared by 2003.[17]

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[16] The selection fraction given in these tables is the average value obtained from 5 simulation runs of the model. Because the model uses random numbers to select the tusks no two runs are identical.

[17] A 100 pounder was, in fact, hunted in 2010. Such small numbers are almost impossible for the model to predict and there is always the possibility that one of the animals carrying tusks in weight class 7 (80-90 lbs) will defy the statistics and produce a 100 pounder. The question arises that if such elephants were not hunted as trophies where did they go? The answer is simple – they died of old age.

**Weight class 7** (80-90lbs): Small numbers of tusks in this size category persist through all the years 1996-2010 beginning at 26 in 1996, reaching a low of 2 in 2004 and rising to 17 in 2011 (in the model a quota of 300 elephants has been set for 2011 and the years after that). Theoretically, 80-90lb tusks can be produced by elephants 31 years old (**Fig.12**, page 20). However, it requires a population with no depletion in its age classes to achieve this. In all the years 1996-2010 very few Class 7 trophies appear in animals younger than 55 years. In 2011, a few appear in age classes 45-46 years.

**Weight class 6** (70-80lbs): Up until 2004 there are no Class 6 tusks in any age classes younger than 55 years. As the population recovers from its initial depletion in1986, the restoration of Class 6 tusks over the years 2005-2010 is remarkable: by 2010 every age class above 38 years contains 70-80lb tusks. These tusks appear first in the 38-41 year olds in 2005, with a distinct absence in age classes 42-50 persisting until 2008.

**Weight class 5** (60-70lbs): The effect of the initial depletion in1986 is to create an absence of Class 5 tusks around the 42 year old age class which persists up until 2003. However, the void is filled very rapidly after 2003. By 2004 every age class above 30 years contains a healthy number of Class 5 tusks. By 2010 there are more than 900 such potential trophies in the population – typically the numbers hunted annually are less than 50.

**Weight class 4** (50-60lbs): These are the 'bread-and-butter' tusks of the hunting industry with the highest proportion of trophies in the numbers hunted annually falling in this category (40%). They are not found in animals younger than 24 years but occur amongst elephants up to 58 years old. In the early years of hunting up to 1998 they were absent from the age classes centred on 36 years old but after 2000 they were present in all age classes where they might be expected. In the year 2010 there were some 1,400 such trophies in the population – typically the numbers hunted annually at this time were slightly over 100.

**Weight class 3** (40-50lbs): The bulk of the trophies in the population (ignoring tusks less than 40lbs) fall in this weight class (some 2,000 animals in 2010) and they comprise slightly under 30% of the animals hunted annually . Every age class from 21-50 years contains a proportion of them with the highest numbers occurring in the age classes around 33 years.

The data presented in **Figs.14-17** tell a fascinating story ... despite the apparent repetitiveness of a lot of very similar bar charts.

In 1996 hunting quotas are low and the population is in the early stages of recovering from its (assumed) depletion in 1986. All age classes up to 31 years old are fully recovered from depletion, age classes 32-38 are in transition,[18] and age classes 39 upwards are still in the original state of depletion (75%).

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[18] The 'transition' referred to is caused by the rounding function used to avoid an abrupt depletion in the age class which is first affected by depletion (see page 58).

As the years progress, the “tsunami” of restoration sweeps in from the left (west) with one age class after another being fully restored each year. By 2005 all age classes up 40 years old are fully restored, with 41-44 in transition and 45+ years still unaffected. If the hunting quotas had remained the same as in 1996, the westerly tsunami would have restored all age classes up to 45 years old in 2010. The effects of depletion only disappear completely in the year 2025 (page 4).

The hunting quotas have not stayed the same as they were in 1986. The initial quota of 21 animals hunted in 1996 in the top 18 CHAs doubled by 1997, quadrupled by 1999 and by 2009 was 12 times its original value (see table below).

| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 top CHAs | 21 | 39 | 75 | 94 | 138 | 120 | 126 | 130 | 131 | 158 | 204 | 219 | 246 | 259 | 215 |
| Ratio | 1.0 | 1.9 | 3.6 | 4.5 | 6.6 | 5.7 | 6.0 | 6.2 | 6.2 | 7.0 | 9.7 | 10.4 | 11.7 | 12.1 | 10.1 |

A new tsunami has swept in from the east. The two tsunamis meet head on and, as the effect of the original westerly tsunami disappears, a new equilibrium is produced where the hunting keeps all age classes depleted to some extent. Not unexpectedly, the depletion is greater in the oldest age classes which carry the largest tusks and becomes insignificant in the lower age classes (30 years old and below). The table below shows the percentage of the full numbers expected in each age class. The depletion is caused entirely by the hunting.[19]

| Age | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | 100 | 100 | 100 | 99 | 99 | 98 | 97 | 96 | 95 | 93 | 91 | 89 | 87 | 84 | 81 | 79 | 76 | 73 | 69 | 66 |

| Age | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | 62 | 58 | 54 | 51 | 48 | 46 | 44 | 42 | 40 | 38 | 36 | 34 | 33 | 33 | 32 | 32 | 31 | 31 | 31 | 30 |

The selectivity fractions in the tables in Figs.14-17 are plotted in **Fig.18** (page 29). If we examine the selection fraction needed for weight class 6 tusks (70-80lb) in the diagram, it needs to increase from some 7% of the available tusks in 1997 to 26% of the tusks in 2001 and decrease thereafter to about 3% in 2010. The selectivity function for weight class 5 tusks (60-70lbs) is very different: it needs to start at about 16% of the numbers available and then it should decrease more or less monotonically to 5% in 2010. The selectivity function for weight class 4 tusks (50-60lbs) increases erratically from 5% to 8% and that for class 3 increases from 1% to 4% over the entire period. All of the curves show fluctuations from year to year.

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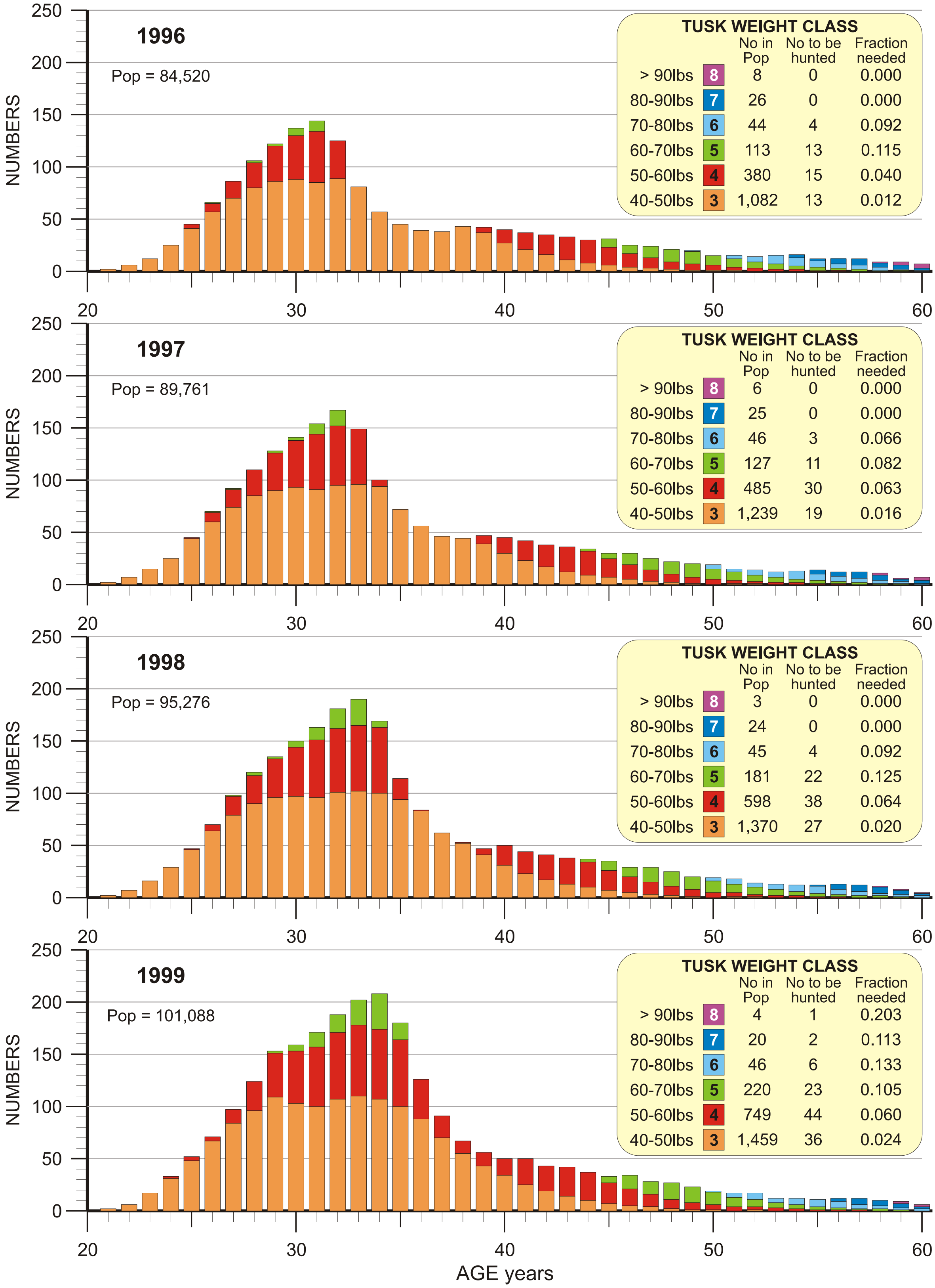
[19] The numbers hunted each year include a 0.03% background hunting quota.



1996 — TUSK WEIGHT CLASS

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 8 | 0 | 0.000 |
| 80-90lbs | 7 | 26 | 0 | 0.000 |
| 70-80lbs | 6 | 44 | 4 | 0.092 |
| 60-70lbs | 5 | 113 | 13 | 0.115 |
| 50-60lbs | 4 | 380 | 15 | 0.040 |
| 40-50lbs | 3 | 1,082 | 13 | 0.012 |

1997 — TUSK WEIGHT CLASS

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 6 | 0 | 0.000 |
| 80-90lbs | 7 | 25 | 0 | 0.000 |
| 70-80lbs | 6 | 46 | 3 | 0.066 |
| 60-70lbs | 5 | 127 | 11 | 0.082 |
| 50-60lbs | 4 | 485 | 30 | 0.063 |
| 40-50lbs | 3 | 1,239 | 19 | 0.016 |

1998 — TUSK WEIGHT CLASS

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 3 | 0 | 0.000 |
| 80-90lbs | 7 | 24 | 0 | 0.000 |
| 70-80lbs | 6 | 45 | 4 | 0.092 |
| 60-70lbs | 5 | 181 | 22 | 0.125 |
| 50-60lbs | 4 | 598 | 38 | 0.064 |
| 40-50lbs | 3 | 1,370 | 27 | 0.020 |

1999 — TUSK WEIGHT CLASS

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 4 | 1 | 0.203 |
| 80-90lbs | 7 | 20 | 2 | 0.113 |
| 70-80lbs | 6 | 46 | 6 | 0.133 |
| 60-70lbs | 5 | 220 | 23 | 0.105 |
| 50-60lbs | 4 | 749 | 44 | 0.060 |
| 40-50lbs | 3 | 1,459 | 36 | 0.024 |

**Figure 14**: **Tusks in weight classes 3-8 available in the population 1996-1999**

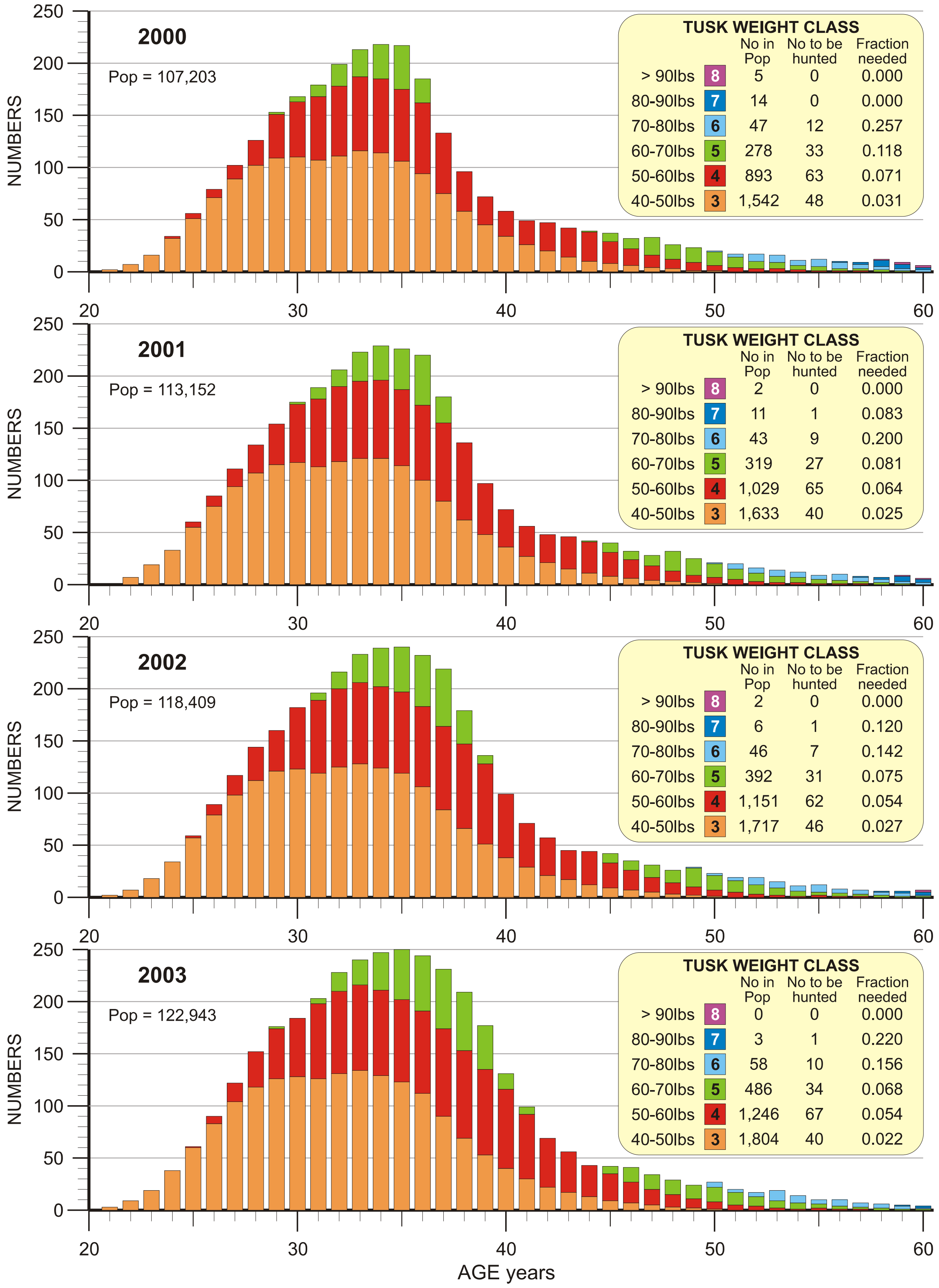


**Figure 15**: Tusks in weight classes 3-8 available in the population 2000-2003

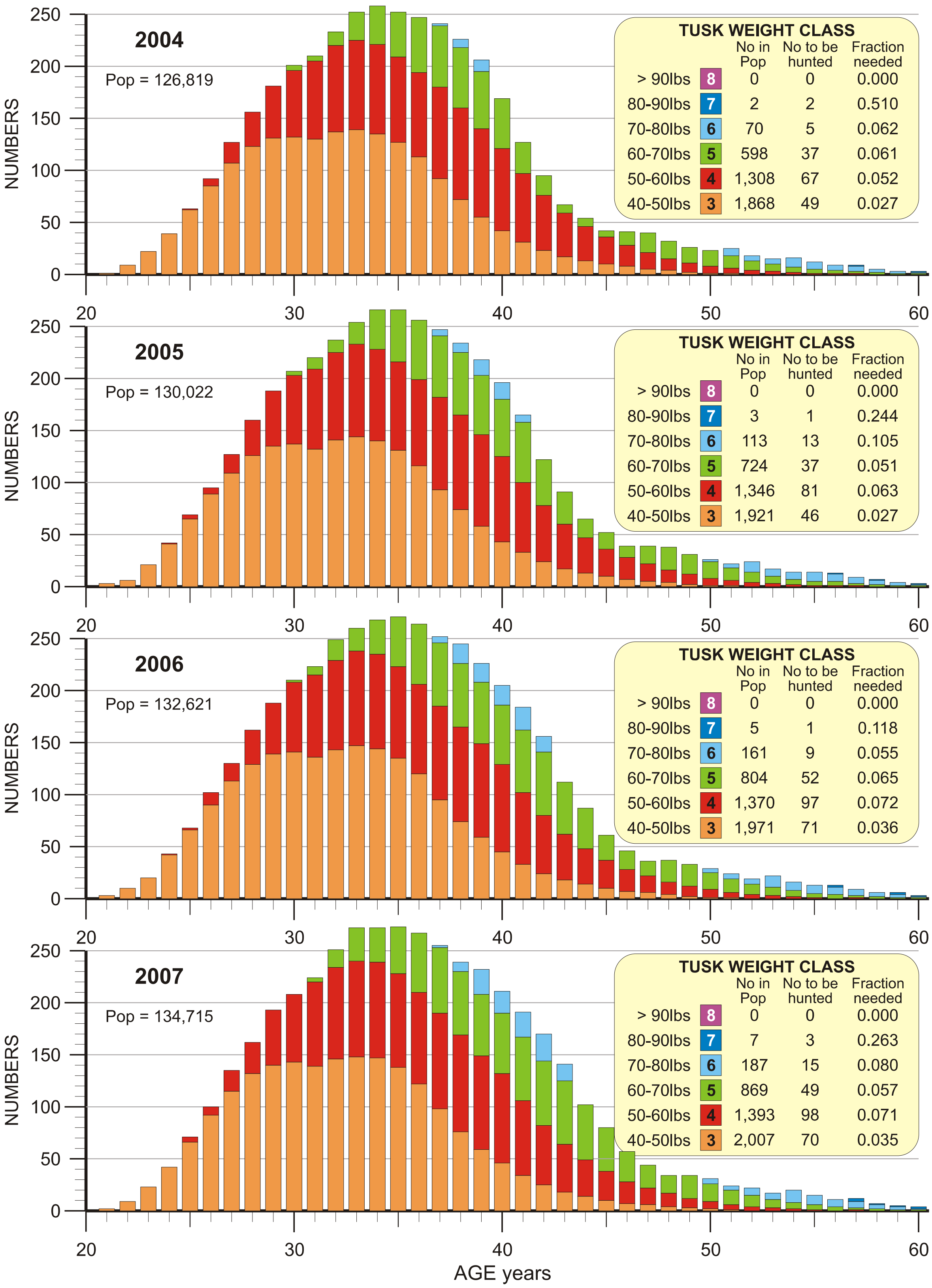
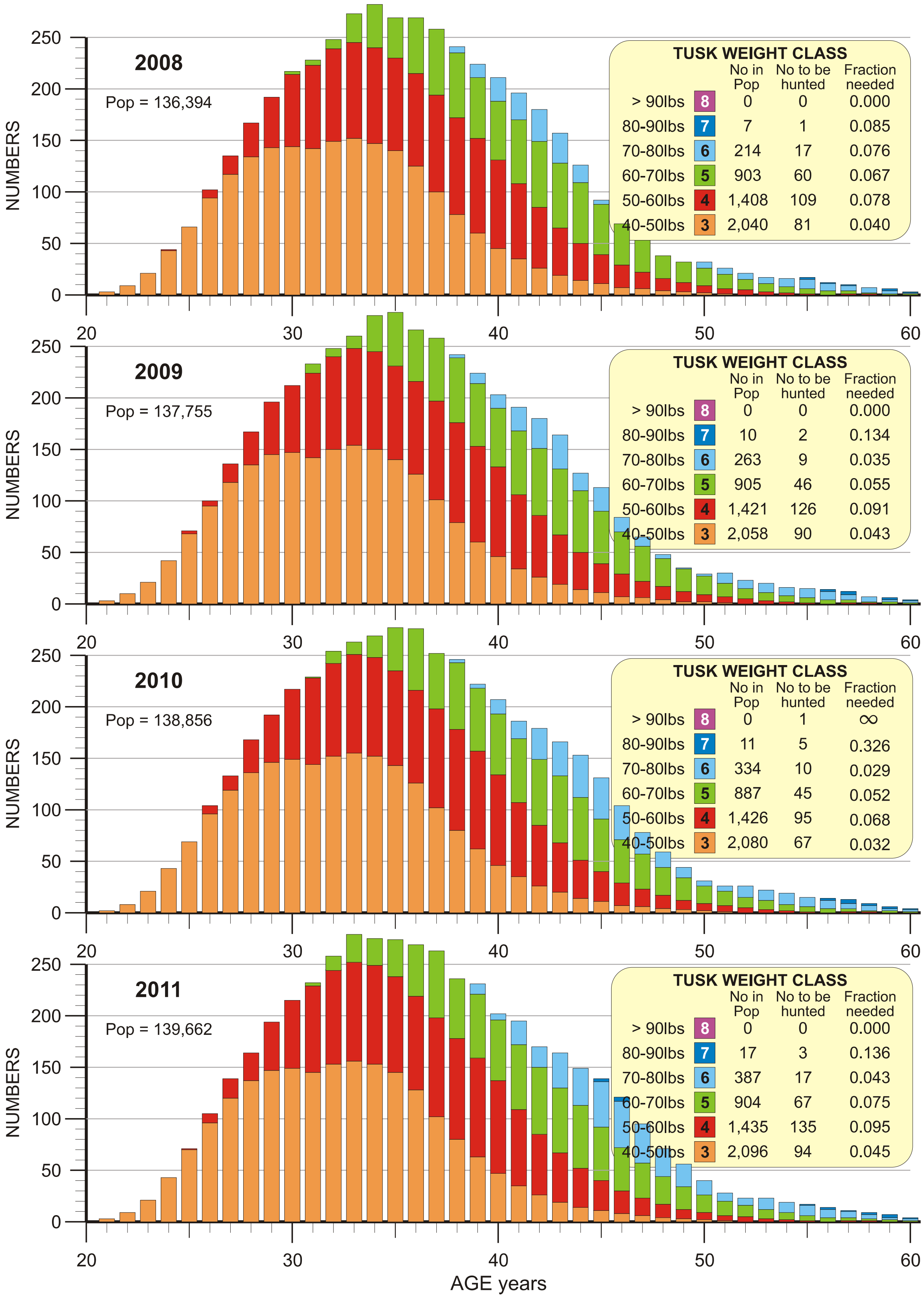


**Figure 16**: **Tusks in weight classes 3-8 available in the population 2004-2007**



2008

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 0 | 0 | 0.000 |
| 80-90lbs | 7 | 7 | 1 | 0.085 |
| 70-80lbs | 6 | 214 | 17 | 0.076 |
| 60-70lbs | 5 | 903 | 60 | 0.067 |
| 50-60lbs | 4 | 1,408 | 109 | 0.078 |
| 40-50lbs | 3 | 2,040 | 81 | 0.040 |

2009

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 0 | 0 | 0.000 |
| 80-90lbs | 7 | 10 | 2 | 0.134 |
| 70-80lbs | 6 | 263 | 9 | 0.035 |
| 60-70lbs | 5 | 905 | 46 | 0.055 |
| 50-60lbs | 4 | 1,421 | 126 | 0.091 |
| 40-50lbs | 3 | 2,058 | 90 | 0.043 |

2010

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 0 | 1 | ∞ |
| 80-90lbs | 7 | 11 | 5 | 0.326 |
| 70-80lbs | 6 | 334 | 10 | 0.029 |
| 60-70lbs | 5 | 887 | 45 | 0.052 |
| 50-60lbs | 4 | 1,426 | 95 | 0.068 |
| 40-50lbs | 3 | 2,080 | 67 | 0.032 |

2011

| | | No in Pop | No to be hunted | Fraction needed |
|---|---|---|---|---|
| > 90lbs | 8 | 0 | 0 | 0.000 |
| 80-90lbs | 7 | 17 | 3 | 0.136 |
| 70-80lbs | 6 | 387 | 17 | 0.043 |
| 60-70lbs | 5 | 904 | 67 | 0.075 |
| 50-60lbs | 4 | 1,435 | 135 | 0.095 |
| 40-50lbs | 3 | 2,096 | 94 | 0.045 |

**Figure 17: Tusks in weight classes 3-8 available in the population 2008-2011**

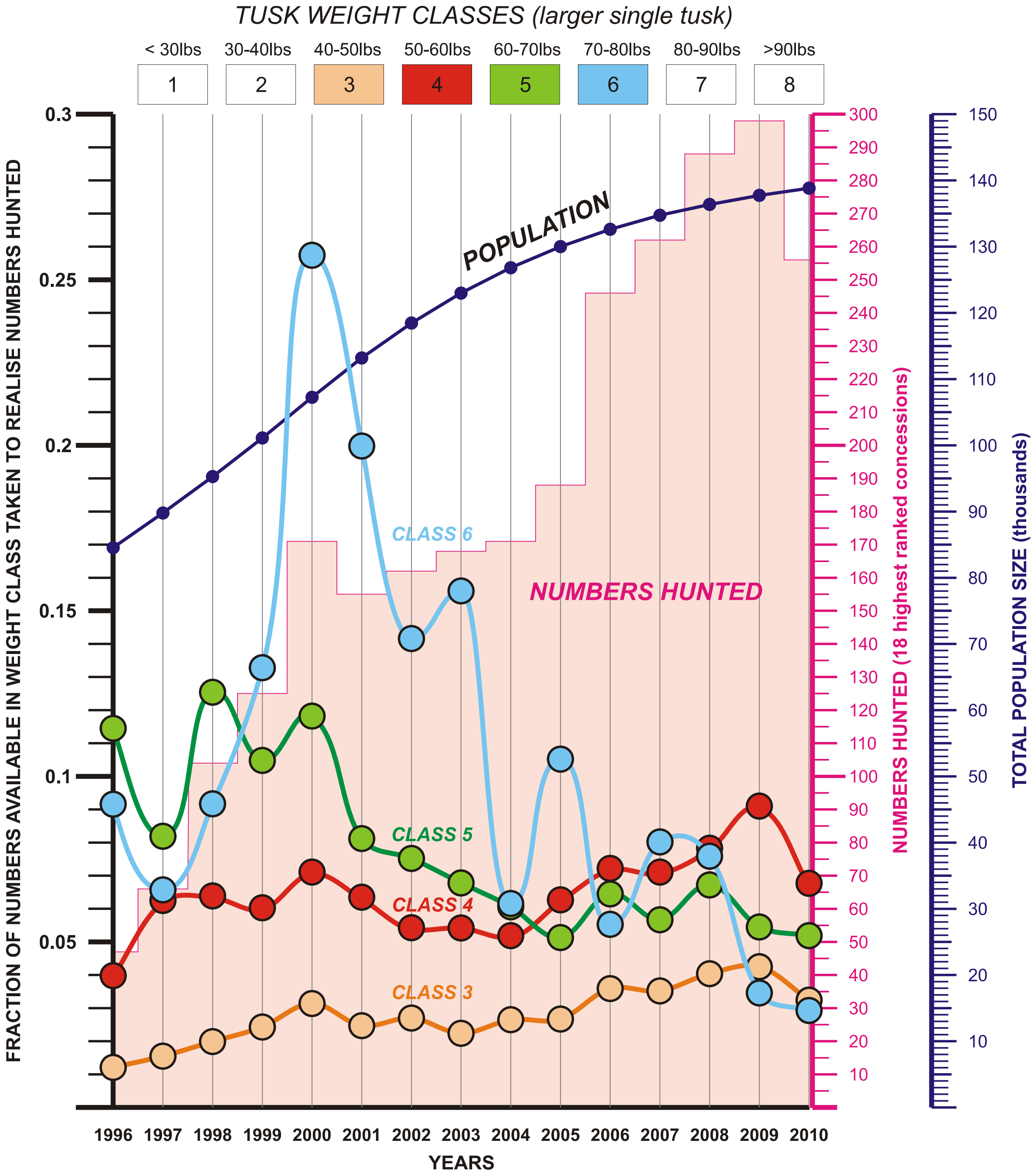


Figure 18: Selection fractions for tusk weight classes 1996-2010

There is no simple relationship amongst any of the biological parameters for the population which will produce a satisfactory selectivity curve. Considerable time was spent (wasted?) in this study trying to develop a selectivity function based on the quota size, the population density, the state of recovery from depletion, the mean tusk weights for different age classes and the level of 'background' hunting (Footnote 8). We also experimented with the age-tusk weight formula and the natural mortality in the oldest age classes. At the outset of the study we had the preconception that in any given hunting season the elephants carrying the largest tusks would be shot out first, followed by the elephants carrying medium-sized tusks and, finally, the elephants with less impressive tusks would make up the quota.[20] **One thing is clear – this is not what is happening**. It is not even happening over several seasons – i.e. if a 'big tusker' escapes the axe in the first hunting season, it might be expected that he will be taken in the next hunting season or the next. **An entirely different process is in place.**

Debbie Peake has observed that certain hunters consistently produce the largest trophies each year. This is attributed to their ability to gauge the size of tusks which an elephant is carrying to a fine degree. One hypothesis for the profile of hunted elephants' tusk sizes might be that it reflects the capabilities of the professional hunters in finding the largest tusks and recognising them when they see them. Thus **the selectivity function might reflect the best, the average and the poorest performance amongst professional hunters**.

An alternative hypothesis (which may not be in contradiction with the above) lies in the manner in which any safari concessionaire manages his annual quota. At the start of any hunting season, the safari operator will have a rough idea of the range of trophies which might be taken from his CHA. Let us assume that, before the hunting season starts, he has done some reconnaissance and knows how many 60, 70 and 80 pounders he has to offer clients. His business strategy is to part with the very big tuskers dearly. If a client will be satisfied with a 50 pounder then that is what he will get. The bigger trophies will be reserved for the more demanding clients. A more demanding client will get a 60 or 70 pounder. The most demanding clients will be the ones who take away trophies over 80lbs a side. Thus **the selectivity function which governs the proportions of tusk weight sizes in the quota is set by the demands and expectations of the hunting clients**.

Whichever of the two hypotheses is being tested, ultimately the answers lie in the actual outcome of the hunting. In the simulation model (**Appendix 6**, page 90) we have done the selection of the hunting trophies year by year simply by using the existing hunting data to calculate a fraction for each weight class and then using this fraction as the threshold for selection by random numbers. Not surprisingly, the correspondence between the actual hunting data and the simulated outcome is very close. The use of random numbers is annoying – it requires at least five repeated runs to obtain an average value for any particular analysis and the more the number of runs the greater is the precision of the estimate.

---

[20] This process is what we describe as 'Perfect Hunting'. It is explored further in the chapter on future management.

The outcome of simulating the mean trophy weight over the period 1996-2010 is shown in **Fig.19** below. The original curve for the hunting data was shown in **Fig.6** (page 12) and the model result has simply been superimposed on this curve. The model results are based on 10 simulation runs and the standard deviations in the mean tusk weights from 1997-2010 are very small (less than 0.5kg).

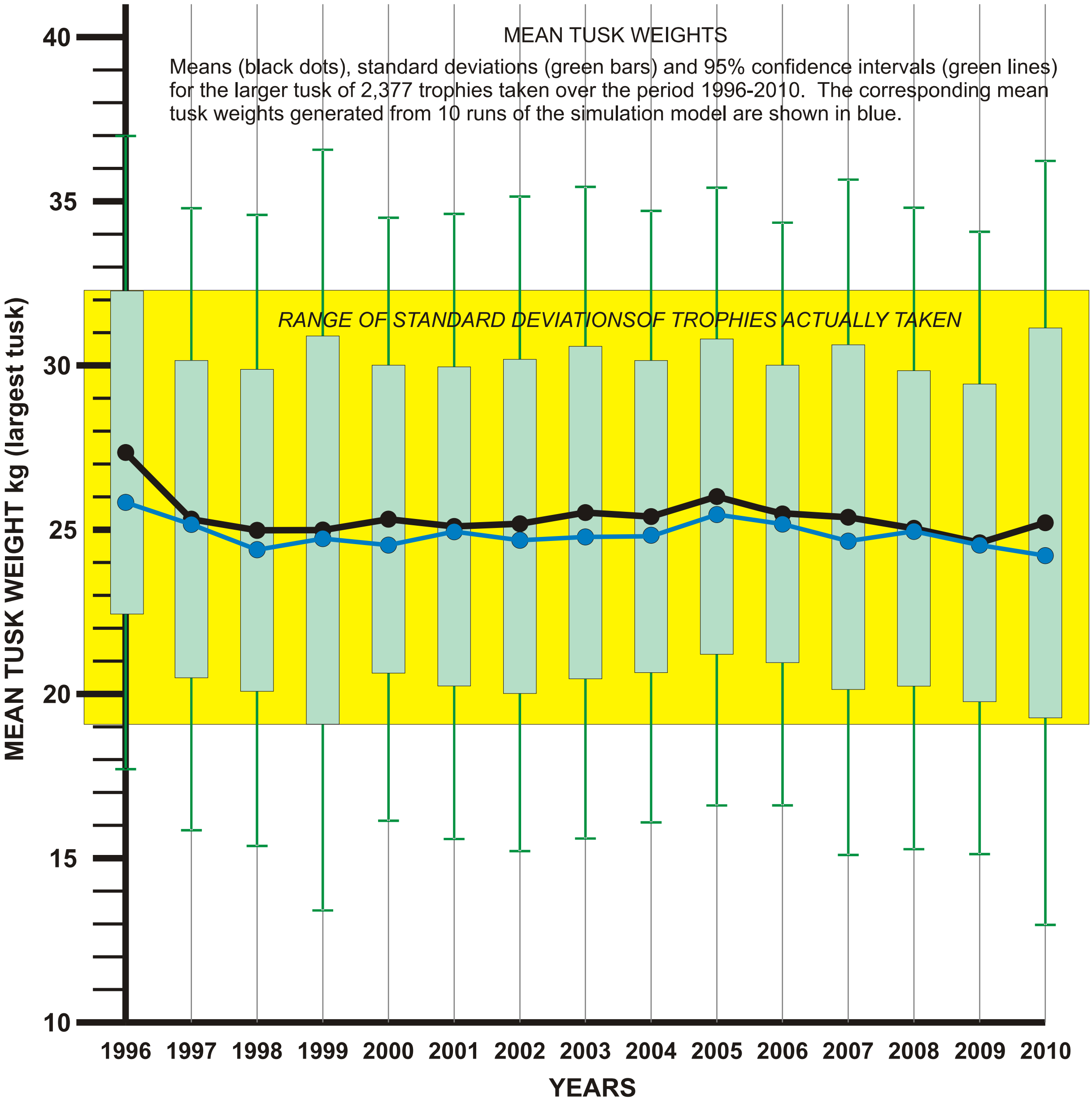
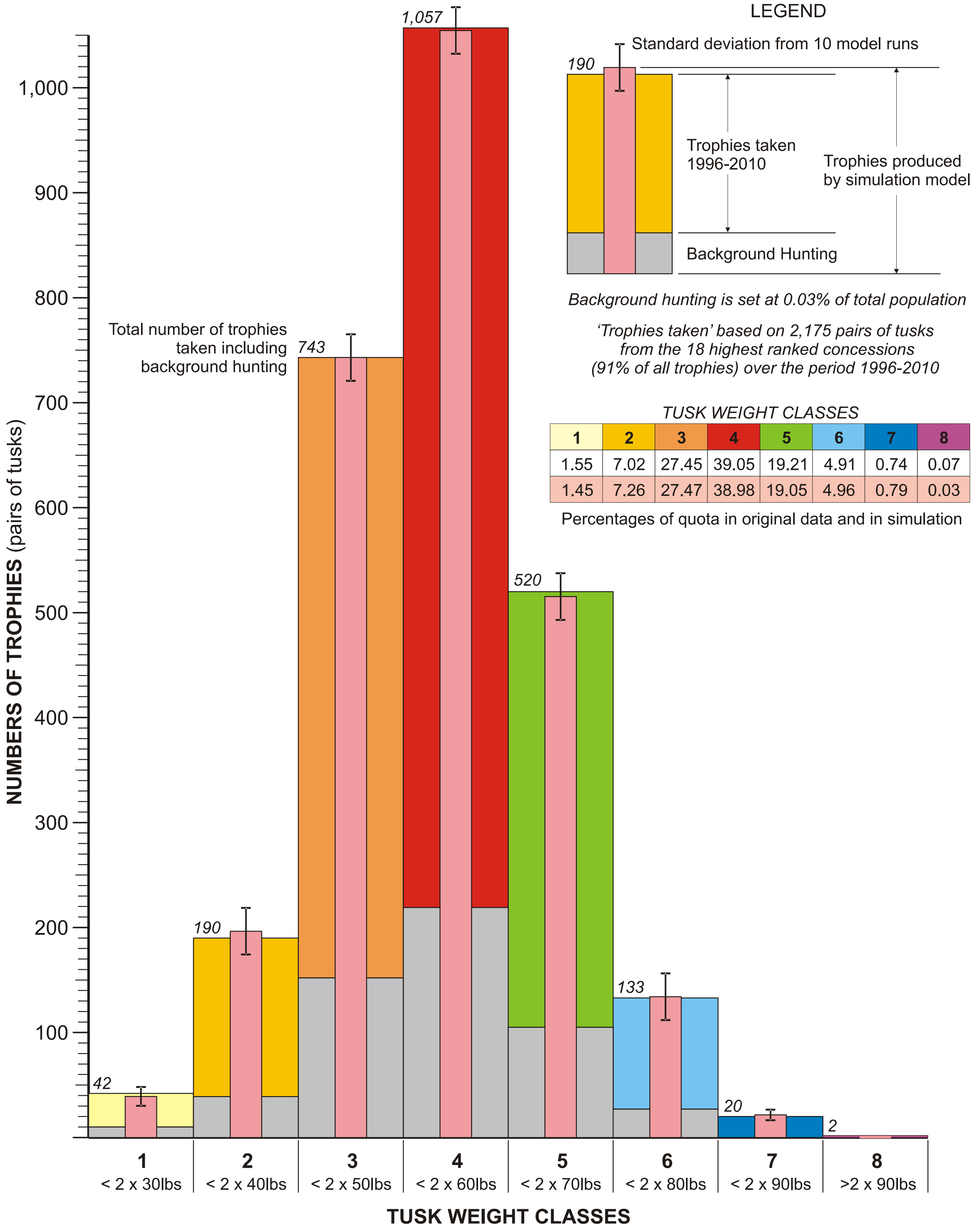


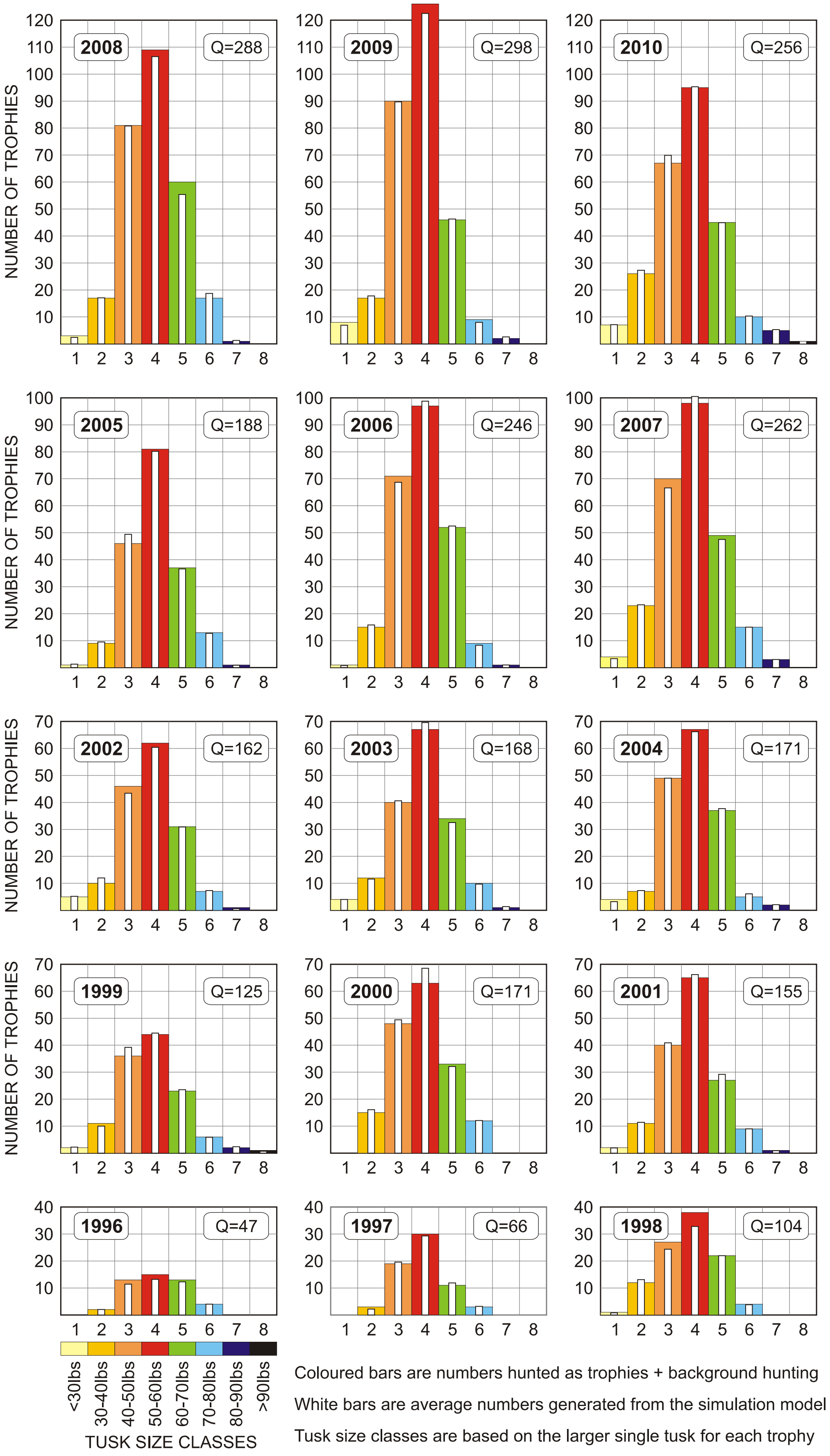
**Figure 19: Model simulation of Mean Tusk Weight 1996-2010**

In **Fig.20** on the next page, the overall proportions of tusks in the total number hunted from the highest-ranked 18 CHAs from 1996-2010 (shown in **Fig.7** page 14) are compared with the numbers generated by the simulation model. The proportions for each individual year (shown in **Fig.8** page 16) are compared with those generated by the model in **Fig.21** on the following page. **The correspondence is very close**.



| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 1.55 | 7.02 | 27.45 | 39.05 | 19.21 | 4.91 | 0.74 | 0.07 |
| 1.45 | 7.26 | 27.47 | 38.98 | 19.05 | 4.96 | 0.79 | 0.03 |

**Figure 20: Overall tusk weights generated by the model compared with the hunting data**



Coloured bars are numbers hunted as trophies + background hunting

White bars are average numbers generated from the simulation model

Tusk size classes are based on the larger single tusk for each trophy

**Figure 21**: **Tusk weights generated by the model annually 1996-2010**

### Summary

We have produced a simulation model which faithfully replicates what happened in the hunting industry from 1996-2010. We would have been much happier with the results had they been based on a selectivity function which used data independent of the hunting results. However, all arguments point to the fact that the hunting outcome (mean tusk weight and proportions of tusks in different size classes) is not a function of the variables which might be expected to determine the mean tusk weight and the tusk weight proportions over time, e.g. quota size, population growth, the state of recovery from initial depletion, the level of background hunting, the tusk weight formula and the extent of the initial depletion in 1986.

We have put forward two hypotheses why this might be so. The first is that the hunting outcome is a measure of the skills of the individual professional hunters. The second argues that the hunting outcome is a natural consequence of the business strategy of safari operators and, ultimately, a reflection of the demands of hunting clients. Neither of these hypotheses are very easy to test. To generate a selectivity function which is based on the skills of the present cohort of professional hunters would require information which is not contained in the present data base for this study. To claim that the selectivity function is a measure of the demands of the hunting clients would require the administration of a questionnaire survey which showed what are the different expectations of the members of the international elephant hunting fraternity. Perhaps, with further thought on the subject, some data might be collected to test the hypotheses. All of the foregoing suggests that we are dealing with a complex system where human factors are interacting with the biological, ecological and economic attributes of a large scale system.

Does the fact that we have ‘cheated’ and used the answers which were available to us from the hunting data to simulate the process make the exercise somewhat trivial? Not really. In the introduction (**Objective**, page 1), it was stated that if the present attributes of the hunting system could be simulated then the model could be used to test the sustainability of future hunting management. A pattern has been established from examination of the hunting data which can be used to test the consequences of changes in the system. If quotas continue to be increased, how long will it be before the present system (which has a mean tusk weight of 25kg and fixed proportions of tusk weight classes) can no longer be maintained? And, when the system is forced to change (e.g. more tusks from lower weight classes have to be taken to realise the quota), what are the limits before this process also becomes unsustainable? These are the questions addressed in the next chapter.

# 5. FUTURE HUNTING MANAGEMENT

The main objective in developing the population simulation model described in this study was to use it to predict the changes which might occur in the population as a result of changes in the hunting quotas.

We have used two models[21] to explore the issues –

(1) **Perfect Hunting** – under this model trophies are taken from the population strictly in order of size from the largest tusks to the smallest tusks available to satisfy the quota. The model is described briefly in **Appendix 6** (page 97). In the previous chapter it was made clear that this is not the process which is actually happening on the ground. However, there are good reasons for examining the effects of perfect hunting. This process sets the upper limits on what trophies can be taken from the population and, ultimately, provides the measure of sustainability of any particular hunting regime.

(2) **Actual Hunting** – under this model trophies are taken from the population in the proportions observed from the hunting data. The effects of 'actual hunting' from 1996-2010 on the population are described in some detail in the previous chapter. Thus far, the outcome has been eminently sustainable.

### Perfect Hunting

We have tested the 'what if' scenario of perfect hunting applied to the population since the starting year of 1986 and extending into the future up to 2100.[22] The results are shown in **Fig.22** and **Fig.23** (pages 37 & 38).

**1986-1995**: This is the period before formal trophy hunting started (first bar chart at the top of Fig.22). It is assumed that the male segment of the population was heavily depleted in 1986 (75% of the expected males older than 20 years missing from the population) and that the population began recovery from this depletion after 1986. Notwithstanding the depletion, had the population been subjected to a low level of background hunting (0.03%) over the ten years from 1986-1995 the resulting trophies would all have exceeded 90lbs up to 1989, after which there would have been an increasing proportion of Weight Class 7 tusks (80-90lbs) up until 1995. No other weight classes appear in the quota.[23]

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[21] Some minor changes have been made to the basic simulation model used in this chapter –

a. A revised age-tusk weight formula (Craig – March 2011) has replaced the previous formula described in Appendix 5. See postscript to Appendix 5.

b. The constants defining old-age mortality have be adjusted slightly as a result of the new tusk weight formula. See "post-postscript" to **Appendix 2** (page 74).

[22] Emigration from the population begins in 2003 and by 2050 the population is stationary at its asymptote of about 143,000 elephants.

[23] Throughout this chapter, the word 'quota' is used to refer to the numbers hunted rather than the numbers set annually by DWNP.

**1996-2010** (second bar chart of Fig.22): Over this period, the numbers hunted increased from 33 in 1996 to a maximum of 272 in 2009 (**Table 2**, page 10). Had 'perfect hunting' been in place, in the first year of hunting the quota would have consisted entirely of weight class 7&8 trophies, i.e. tusks greater than 80lbs. These weight classes disappear from the population very rapidly (by 1999) and over the main period of hunting (2000-2006) the quota consists entirely of class 6 tusks (70-80lbs). Class 7 trophies (80-90lbs) start to reappear in the population in 2007 (as it continues to recover from its initial depletion in 1986) and by the year 2010 make up about 25% of the quota.

It is significant that no trophies from any lower tusk weight classes appear in the result. This reinforces the conclusion (page 30) that the process determining the proportions of trophy sizes in the quota has very little do with the biological parameters of the population.

**2011-2100**: We examine six levels of the hunting quota from 0.1-0.6% of the total population. In each case the quota comes into effect from 2011 onwards.

(a) **0.1% quota** (third bar chart of Fig.22): Up to 2014 the quota consists entirely of weight class 7 (80-90lbs). The trophy size improves rapidly and from 2017 onwards the quota becomes weight class 8, i.e. tusks greater than 90lbs. However, the numbers are about half of what is being hunted at the moment (some 150 animals).

(b) **0.2% quota** (last bar chart of Fig.22): This is roughly equivalent to the numbers being hunted at present. According to the model, the quota should consist entirely of Class 7 tusks after 2015. From 2050 onwards Class 8 tusks appear in the quota reaching about 20 in the year 2100. This is a compelling argument for not increasing the quotas set by DWNP much beyond their present levels (some 300 animals).

(c) **0.3% quota** (first bar chart of Fig.23): At this level of hunting the first of major changes takes place in the population. By 2015 all of the Class 7 trophies have disappeared and up until 2024 the quota consists entirely of Class 6 tusks (70-80lbs). The numbers of these start to decline after 2024 and by 2100 the quota consists mainly of Class 5 tusks (60-70lbs). The size of the quota is about 450 animals.

(c) **0.4% quota** (second bar chart of Fig.23): Major changes continue. Class 7 trophies are gone from the population by 2013, Class 6 by 2019 and Class 5 by 2040. After this the quota (600 animals) consists entirely of Class 4 tusks (50-60lbs).

(d) **0.5% quota** (third bar chart of Fig.23): This might be termed 'the level of collapse' of the hunting industry. Class 7 trophies are gone from the population by 2012, Class 6 by 2016, Class 5 by 2023 and Class 4 by 2050. After this, the quota (750 animals) consists entirely of Class 3 tusks (40-50lbs).

(e) **0.6% quota** (last bar chart of Fig.23): Class 3 tusks appear in the quota even earlier (2022) and make up the major part of the quota until 2040 when Class 2 tusks (30-40lbs) start to appear. By 2100 Class 3 tusks have dwindled to 25% of the quota and Class 2 tusks make up 75% of the quota (slightly under 1,000 animals).

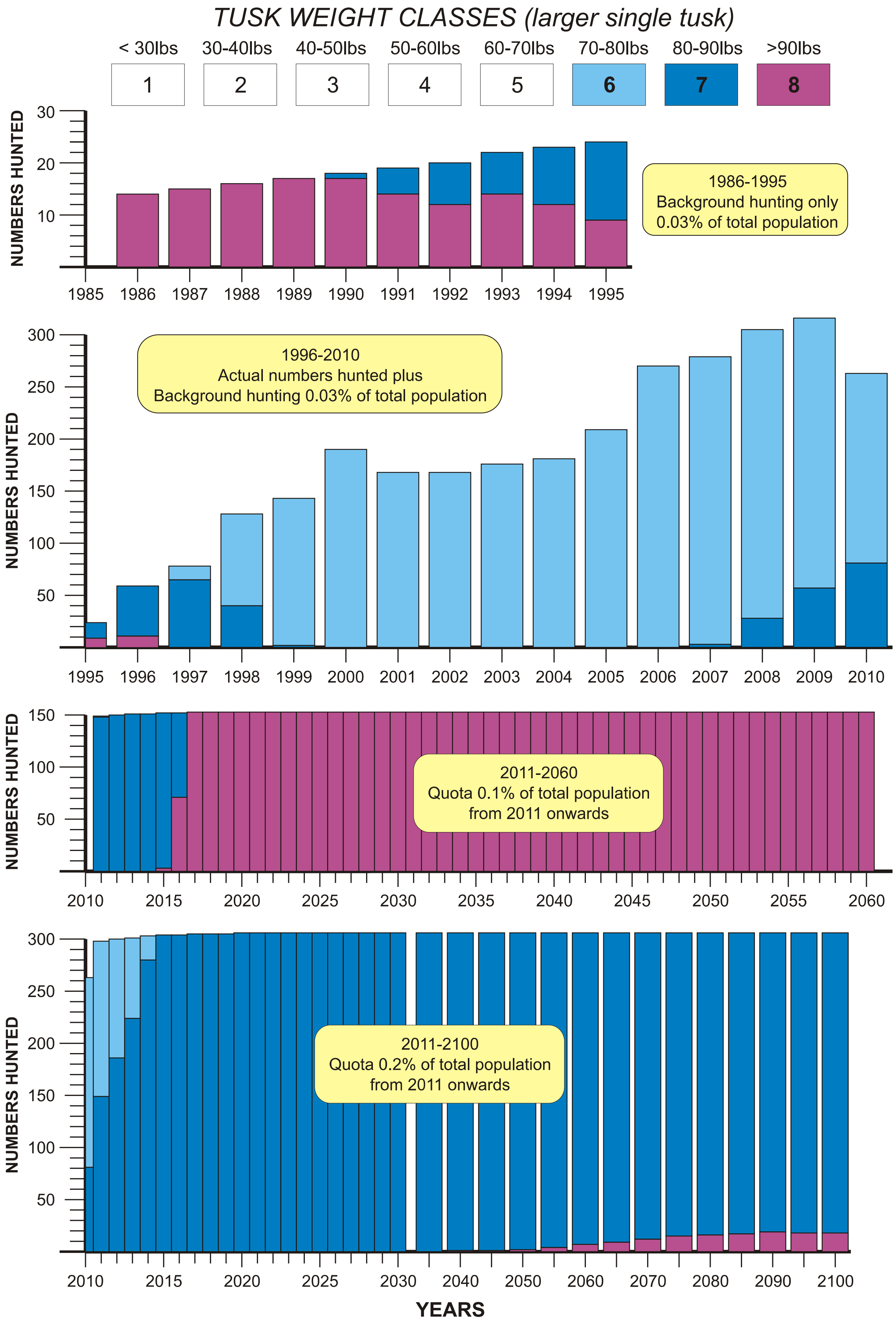
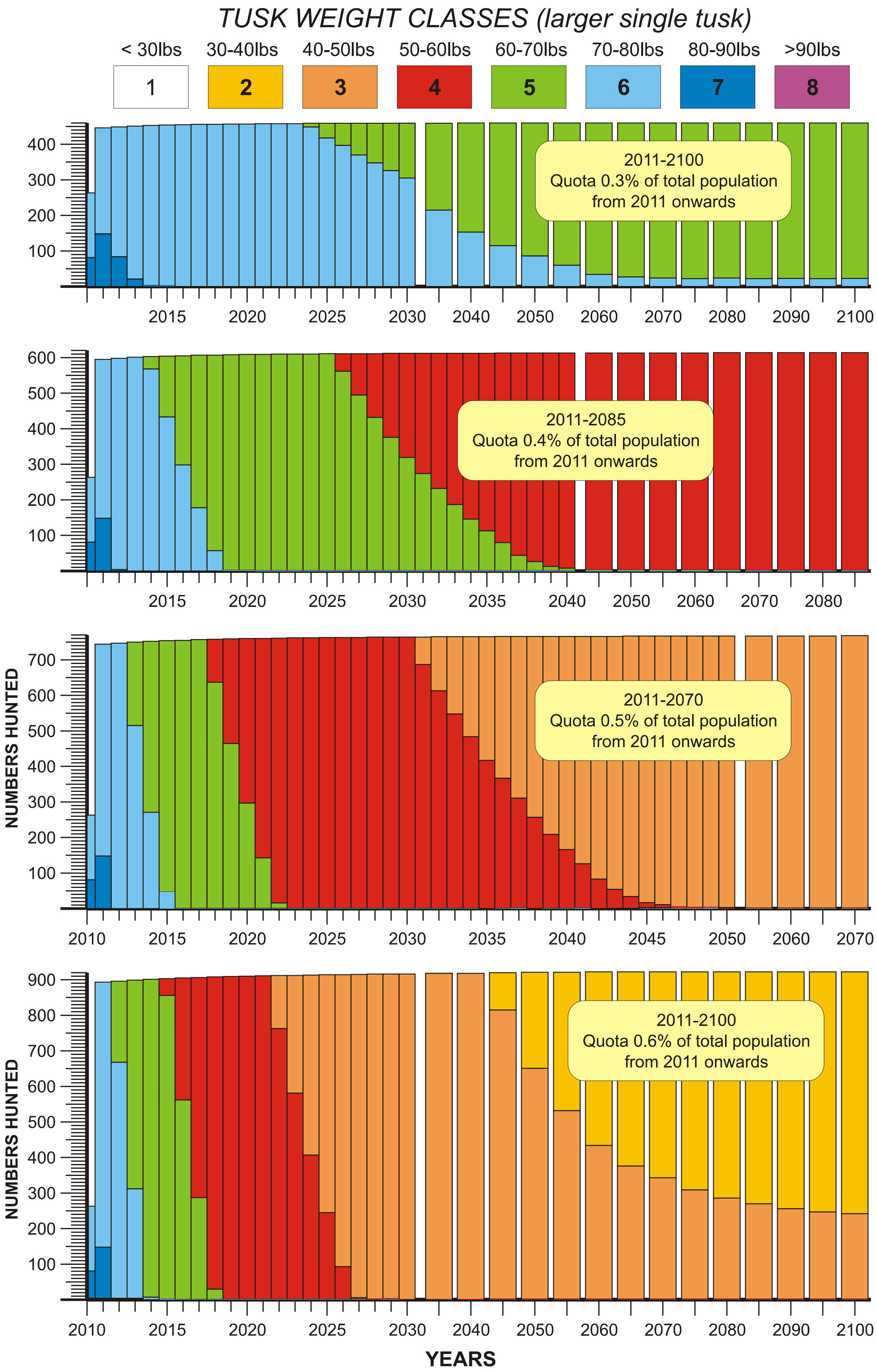


**Figure 22**: 'Perfect Hunting' – 1985-1995, 1996-2010, 2011-2100 (quota 0.1% & 0.2%)



*TUSK WEIGHT CLASSES (larger single tusk)*

2011-2100
Quota 0.3% of total population
from 2011 onwards

2011-2085
Quota 0.4% of total population
from 2011 onwards

2011-2070
Quota 0.5% of total population
from 2011 onwards

2011-2100
Quota 0.6% of total population
from 2011 onwards

**Figure 23**: ‘Perfect Hunting’ – 2011-2100 (quotas 0.3%-0.6%)

The mean tusk weights obtained for each of the above quota levels when the population has stabilised under the given quota are shown in **Fig.24** (below). At a quota of 0.1% of the total population, the mean tusk weight would be about 56kg (!!!). In contrast, at a quota of 0.6% the mean tusk weight falls to less than 19kg. This needs to be compared with the figure of 25kg obtained from the actual data.

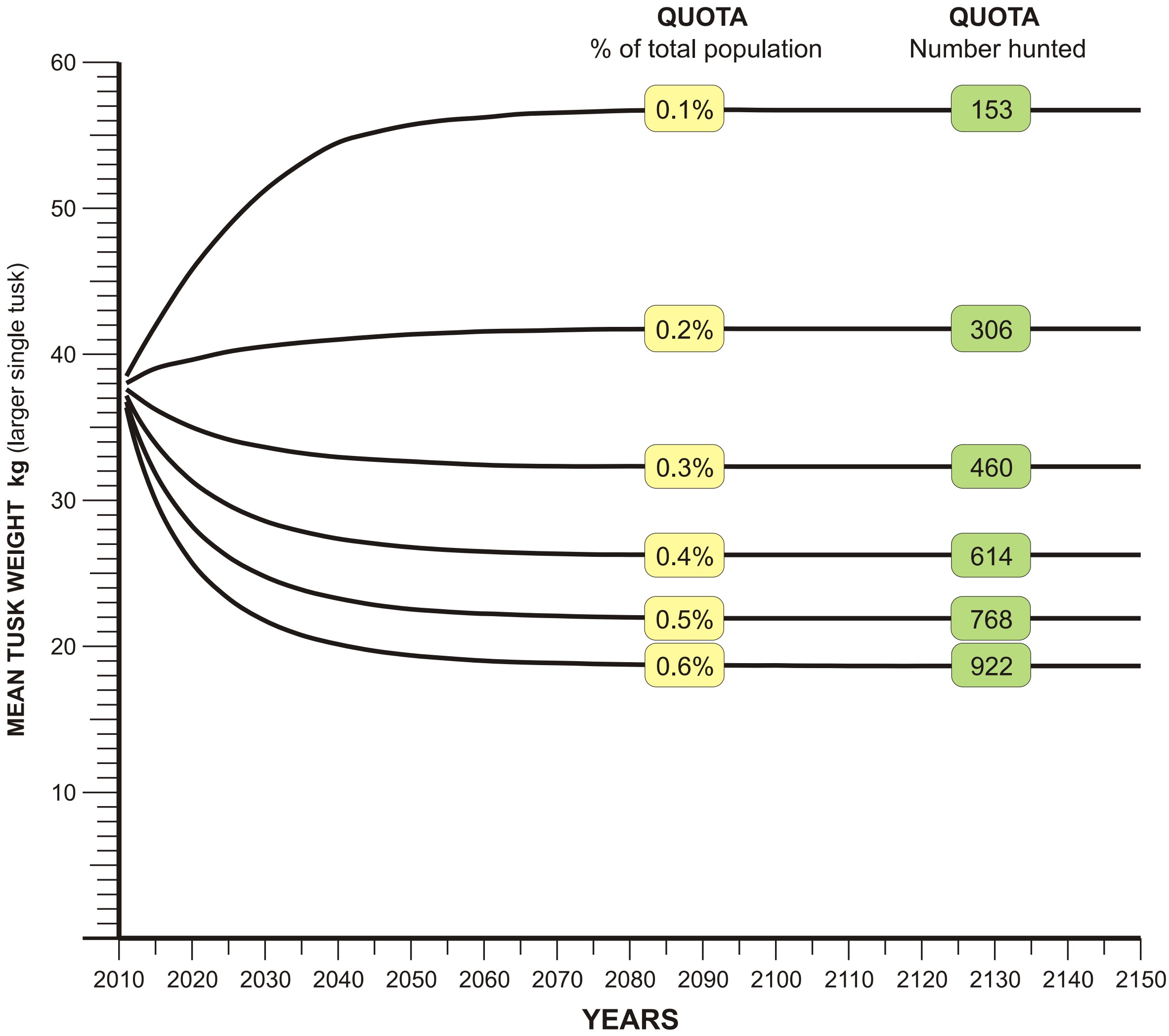


**Figure 24**: **'Perfect Hunting' – Mean tusk weights 2011-2150 for quotas 0.1%-0.6%**

Although a quota of 0.6% of the population might result in a very low mean tusk weight and no large trophies (Fig.23), this should not be confused with biological sustainability. There are an additional 3,000 elephants in the population in tusk weight class 1 (<30lbs) which theoretically could be hunted as trophies – however, the threshold quota for a high-quality trophy hunting industry would have been passed long before this.

### Actual Hunting

A key feature which has emerged from the analysis of the hunting data is the very constant proportions of the various tusk weight classes throughout the period from 1996-2010. In every year of hunting, weight class 4 (50-60lbs) makes up roughly 40% of the quota, class 3 (40-50lbs) makes up 30% and class 5 (60-70lbs) makes up 20% of the quota. All other weight classes contribute only about 10% of the quota. The simulation model uses this knowledge to generate the trophies selected each year.[24]

We hypothesized (page 30) that these proportions might reflect the demands of the hunting clients and that, accordingly, safari operators manage their individual concession quotas to meet the demands of these clients. In examining the likely effects of increasing hunting quotas, two alternative approaches have been used.

#### *Constrained hunting*

The first approach assumes that these proportions place constraints on the trophies which can be obtained. If there are insufficient animals in any particular weight class to provide the required number of trophies which the quota proportions dictate, then the deficit cannot be made up by taking trophies from any other weight classes. This might reflect the situation that if there are not enough high quality trophies available then the safari operator loses those clients which were seeking big tuskers and is unable to replace them with other clients prepared to accept medium and poor quality trophies. It is not unrealistic.

The effects of this constraint are shown in **Fig.25** on the next page. The expected numbers for each quota level from 0.2% (the quota level in 2010) to 1.5% in increments of 0.05% are shown by the skeleton framework in the figure. Where there are sufficient animals in the weight class to supply all or part of the required number, the framework is wholly or partially filled in with the appropriate colour. Weight class 8 is excluded from the figure, the numbers being zero in most cases or too small to show.

The proportions of the tusk weight classes given in **Table 4** (page 13) can be maintained up to a quota of 0.35% of the total population. When the quota reaches 0.4%, weight class 7 disappears followed by class 6 at a quota of 0.45% and class 5 at a quota of 0.6%. Class 4 falls below the required number at a quota of 0.65% and then continues decline slowly until it disappears by 1.5%. At this stage the entire male population falls in weight classes 1-3. The exercise become fairly meaningless beyond this level. There are thousands of animals in weight classes 1-3 and it requires huge quotas in order to deplete them below the point where the required number cannot be realised.

The percentage of the set quota which can be realised is 100% up to a quota of 0.35% (the blue line in Fig.24) and this percentage declines to about 35% when the quota reaches 1.5%. The decline in the mean tusk weight with increasing quota levels is not shown in the figure. It is not remarkable. Up to a quota level of 0.5%, the mean tusk weight is around 25kg and only falls below 20kg when the quota exceeds 1.3%.

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[24] Because the model uses random numbers to select the numbers to be hunted in each weight class (paragraph 4(e), page 92), there is a certain amount of 'noise' in Figs.25-27 caused by the year-to-year variability in the random numbers.

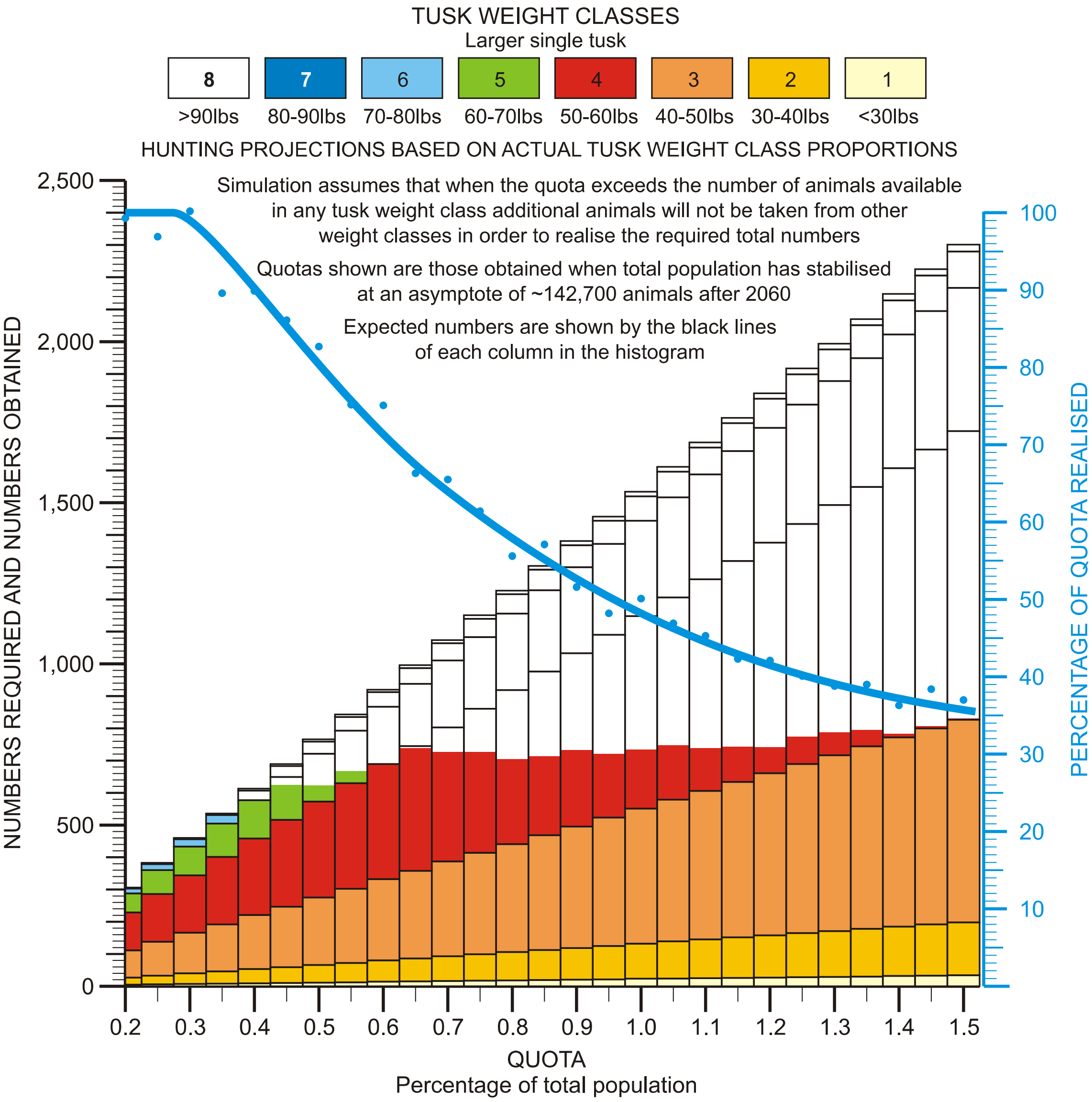


**Figure 25**: **'Actual hunting' constrained by present quota proportions**

### ***Unconstrained hunting***

In this alternative approach, it is assumed that if the required number of animals in any weight class (dictated by the quota proportions given in **Table 4**, page 13) cannot be realised, the deficit will be made up by taking animals from the weight class immediately below it. If this weight class cannot make up the numbers a cumulative deficit is transferred to the next lowest weight class and so on. The results are shown in **Fig.26** on the next page.

The results are fairly spectacular. As soon as any one weight class runs out of animals and the deficit is transferred to the weight class below it, it places a load on that class which quickly uses up its reserves. A sort of 'domino effect' operates causing the premature collapse of weight classes in sequence.

As for the previous case, the weight class proportions can be maintained up a quota of 0.35%. Thereafter, the demise of weight classes is fairly rapid as the quota is increased.

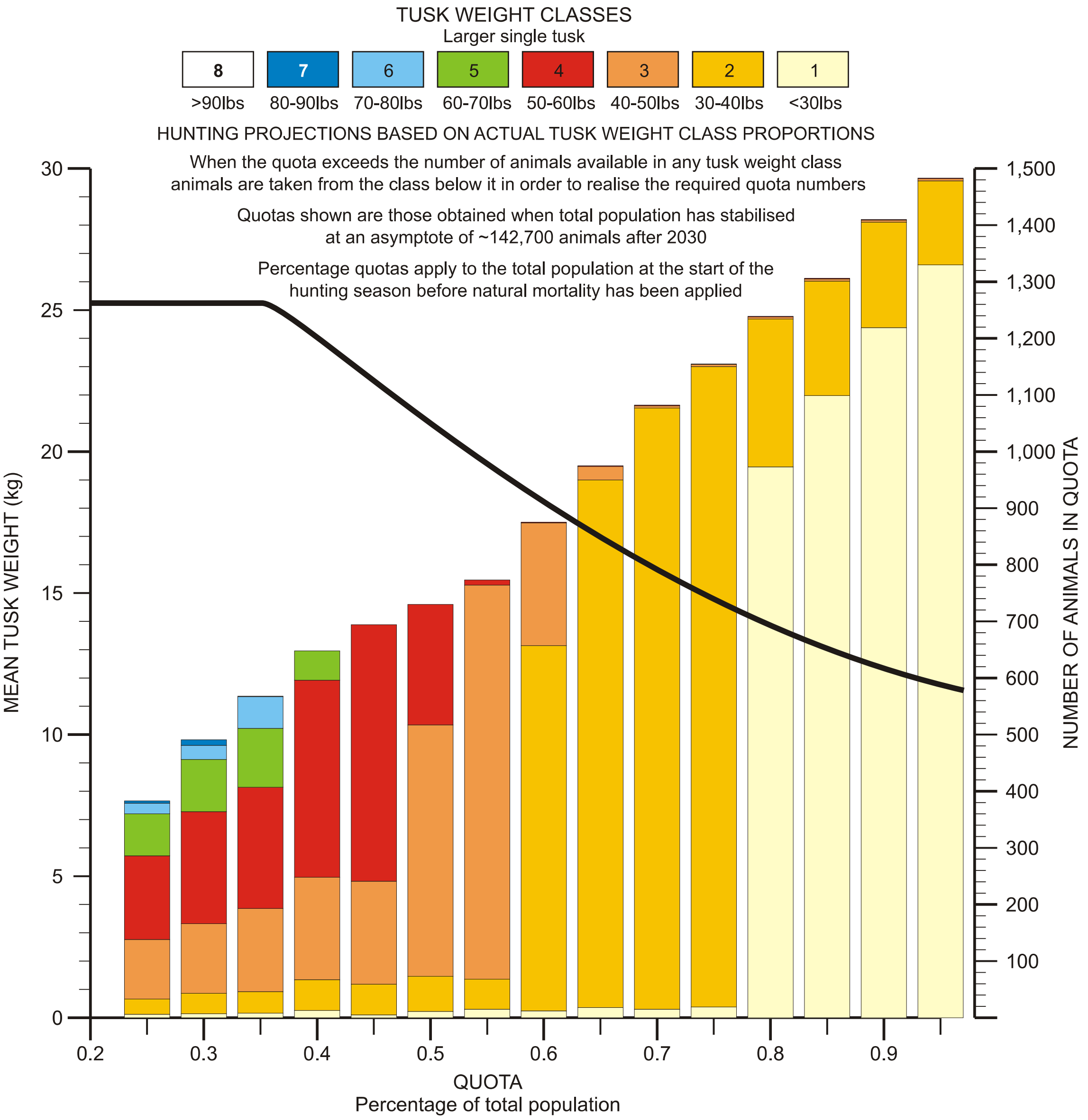
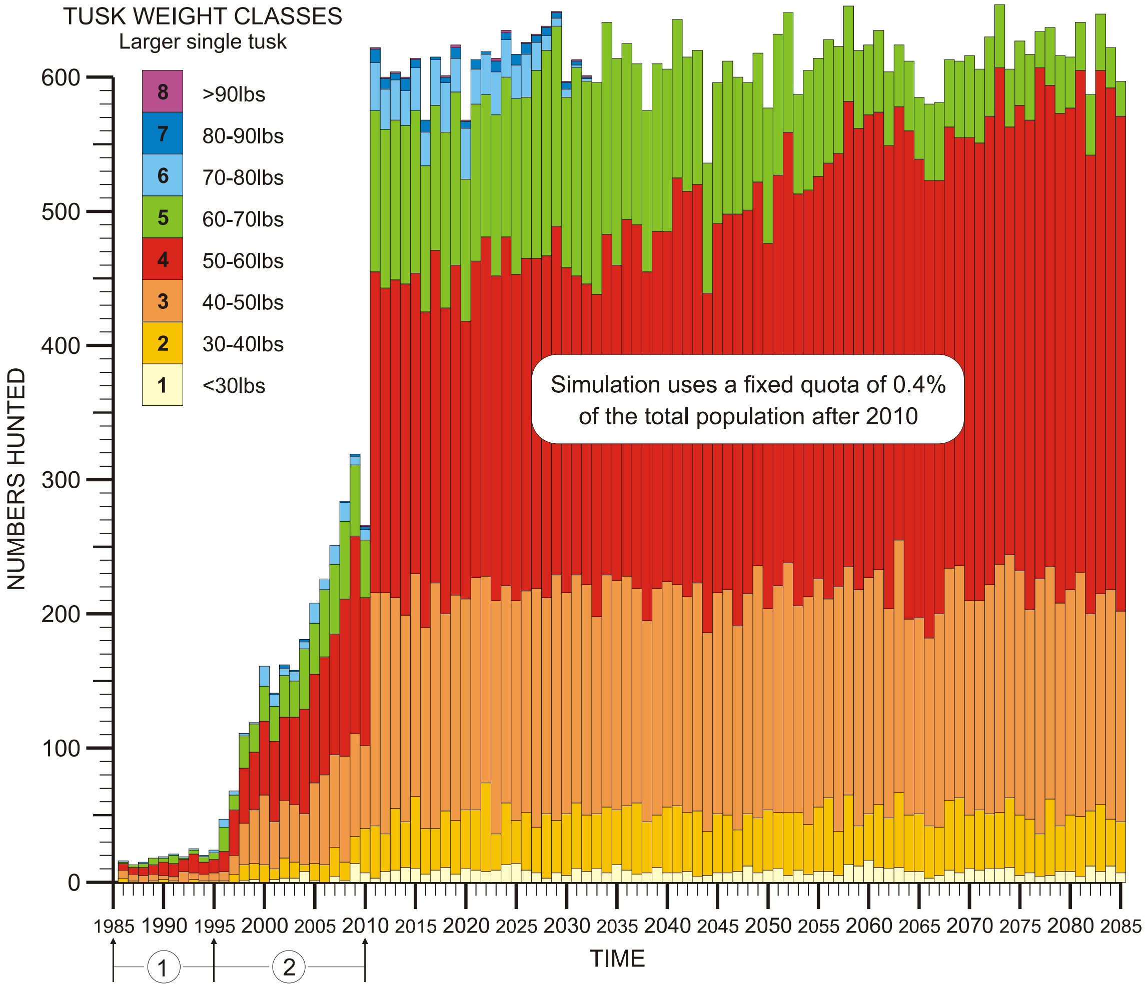


**Figure 26**: **'Actual hunting' unconstrained by present quota proportions**

Weight class 6 (70-80lbs) disappears at a quota of 0.4%, class 5 at a quota of 0.45% and class 4 has virtually gone when the quota reaches 0.55%. At this stage weight class 3 is providing most of the quota but the burden proves too much for it when the quota reaches 0.6% and the cumulative deficit has to be met by animals from weight class 2 (30-40lbs). This persists until the quota is raised to 0.8% when there is a crash in weight class 2 and the entire quota from there on comes from weight class 1 (tusks < 30lbs).

The mean tusk weight remains close to 25kg up to a quota of 0.4% but, with further quota increases, it descends steeply to less than 12.5kg at a quota of 1%.

What is not captured in either of the preceding two figures is the time scale over which the population response to a change in the quota level occurs. **Figure 27** (next page) is an attempt to illustrate this phenomenon over a period of 100 years (1985-2085).



① No trophy hunting. Background hunting 0.03% ② Trophy hunting. Background hunting 0.03%

Actual hunting using fixed quota proportions. Male depletion 75% at start in 1986.

Emigration begins 2003 at a density of 0.7/km$^2$ (111,000 animals). Asymptote 115,000 animals reached 2055

**Figure 27**: **'Actual hunting' (unconstrained) – projection under a quota of 0.4%**

The figure shows a low level of background hunting for the first 10 years until formal trophy hunting begins in 1996. Throughout the first 25 years the quota proportions slavishly follow the expected percentages, any variation being due to the effects of using random numbers for selection. In 2011, the quota is doubled from its level in 2010 to 0.4% of the total population.

For the next 20 years the population appears not to have noticed the increase in quota. It continues to maintain the key proportions of weight classes 3-5 and the cake has an attractive icing on it of weight classes 6 and 7 throughout this period. This 'icing' disappears after 2030 and the 'huntable' population consists entirely of weight classes 1-5. The potential numbers available from weight classes 1-3 are in the thousands: however, very few of these are hunted because the quota proportions of Table 4 do not demand it.

The decline of animals from weight class 5 (60-70lbs) begins imperceptibly in 2036 when approximately 125 animals out of the quota of 614 are in this class. The number drops to around 25 over the next 50 years. The increasing deficit is accommodated by the increase in trophies taken from weight class 4 which changes from about 240 animals in 2036 to 370 animals in 2085.

### Summary

In this chapter we have shown that –

(1) Hunting quotas cannot be increased much beyond 0.35% of the total population without significant changes in the proportions of tusk weights in the population. Above 0.35% (about 500 animals) the highly desirable trophies above 70lbs disappear from the population.

(2) The response of the population to a change in the quota is characterised by a long time constant. It is not so much dependent on the magnitude of the change as it is on the mere fact of a change. It may take more than 50 years before the proportions of tusks in the different tusk weight classes adjust to any significant change. The response is slightly faster when the age structure at the inception of the change matches that of the age structure which results from the change.

Interestingly, the effect of depletion in the male age classes older than 20 years in the population is rectified within 40 years, i.e. within the expected lifetime of a 20 year old elephant. Responses to a change in the hunting management regime take longer than this. This presents a problem for any manager relying (correctly) on adaptive management for making adjustments to the hunting quota. The time taken before the outcome of the changes is apparent generally exceeds the lifetime of the manager.

We have explored two approaches in examining the response of the population to changes in the hunting quota. Under a ‘perfect hunting’ regime the changes tend to take place slightly more quickly than under the ‘actual hunting’ regime which attempts to maintain the proportions of tusk weights in the quota. Ultimately, however, the ‘actual hunting’ regime cannot produce an outcome which is different to that of ‘perfect hunting’. It would be misguided to claim that there are conservation benefits from a hunting regime which spreads its offtake over a range of tusk weight classes. There may be economic benefits.

Conventional concepts of biological sustainability have little relevance to this subject. In the lower weight classes (animals carrying tusks less than 50lbs) there are thousands of animals in the population (**Table 5** page 14). Quotas exceeding 1% of the population are eminently sustainable in biological terms but impossible around which to build a high-quality elephant trophy hunting safari industry.

# 6. DISCUSSION

We live in a world which demands certainty. Bureaucrats want to know the correct quotas for elephant trophy hunting. Safari hunting operators want to be assured that their industry has a future. A broader public (both inside Botswana and internationally) are concerned about elephant conservation. This discussion will explain why certainty is the impossible dream in a variable and dynamic environment for trophy hunting.

We don't want this discussion to be a summary of the findings in the previous five chapters. That was given in the Abstract (page vii). Of course, it should highlight the key findings and point out the areas of weakness in the study. But it should go deeper. It should identify the imponderables in the analysis and show a way forward which gives both the DWNP and the operators the tools to cope with uncertainties.

### Population dynamics

The study concerns itself with the period from 1986 to the present date (25 years) and uses its findings to project into the future. The background canvas is an elephant range of some 160,000km$^2$ – all of northern Botswana – divided into a number of Controlled Hunting Areas (**Fig.5**). Hunting quotas have been set in 33 CHAs over the 25 year period and, of these, 18 have provided more than 90% of the trophies. Because these 18 concessions have shown consistent patterns over the years, we have based most of our analysis on them. The development of a simulation model for the period 1986-2010 has been weakened by the fact that key population survey data is sporadic and missing from 2006 onwards (**Fig.1**). Various dynamic processes are taking place in the population: recovery from an assumed depletion of adult males at the start, the response to increasing hunting quotas, normal population increase and population dispersal both within Botswana and into neighbouring countries. The need for reliable survey data has never been greater.

From the limited population census data, we have found that the population has shown an apparent rate of increase greater than 6% since 1987. **This is one of the highest growth rates recorded for African elephant**. We have done a sensitivity analysis on the factors likely to determine the rate of increase and observed that the combinations of mortality and fecundity which would sustain such a high growth rate over 25 years fall outside the range of recorded values from other elephant populations in southern Africa. Using the maximum values for fecundity and the minimum values for mortality from published data, we conclude that **the growth rate is best explained by a highly skewed age structure in 1986**. A depletion in the numbers of males over 20 years old would result in the observed population performance.

We remain uncomfortable with our own assumptions regarding mortality – particularly the mortality for old animals. The difficulty lies in the complete absence of data for senescence. We had hoped that the population model would provide some notional values for age-specific mortality from the hunting data but because the technique used to select the hunted animals relies on the hunting data, the model produces the correct number of trophies each year over a wide range of assumed mortality schedules.

Eventually the Botswana elephant population will regulate itself through homeostatic mechanisms or be regulated by environmental and/or anthropogenic factors. We have noted that dispersal is taking place from the population and has been doing so for at least the past 6 years. In the course of making provision for emigration in the population model, we noticed that **any emigration will ultimately regulate the population if it is sustained.** We qualify this by stating that this pertains when the population has exceeded some density threshold and emigration takes the form of a proportion of the surplus numbers above this threshold. The population will regulate itself at a level above the given density threshold determined by the percentage of the surplus which emigrates. This regulation will occur even for very small percentages of the surplus. This is a surprising finding (**Appendix 3**). We have used the asymptote which results from emigration to establish the long term outcome of various levels of hunting intensity. The true level of the asymptote for the Botswana population will only be established through repeated population surveys and underscores the importance of such surveys being done regularly.

### The hunting data

The quotas which have been set for trophy hunting from 1996-2010 (**Table 2**) reached a maximum of 0.2% of the total population in 2009. This is low by any regional standards where, for years, elephant managers have typically set quotas around 0.5% of the total population. **This accounts for the very high standard of the trophies which been taken over the past 15 years** and the DWNP should be complimented for the conservative approach they have taken.

**We reiterate the value of the trophy records maintained since 1996 by Debbie Peake**. Without these data this study could not have taken place.

Apart from the number of very large trophies, there are two remarkable features in the data: **firstly, the mean tusk weight of the trophies taken over 15 years has remained virtually constant at 25kg (55lbs)**. **Secondly, the proportions of tusk weights in a set of 8 weight classes has also remained constant over the same period** (**Table 6, Figs.8** & **9**). These proportions have very little resemblance to the proportions of tusks occurring in the same weight classes within the population (**Table 5**).

The significance of this finding should not be underestimated. The population changed dramatically from 1996-2010: it was recovering from depletion, beginning to disperse and being subjected to increasing hunting. Yet the proportions of different-sized trophies remained 'rock-steady'. The major challenge for the simulation model was to reproduce this situation.

It is to be noted that this pattern of tusk weight proportions is obvious when the results from all the CHAs are combined for each year (**Fig.8**). It is less obvious when the individual CHAs are considered (**Figs. 10** & **11**). We mention this variability amongst concessions because it has major ramifications for the future management of trophy hunting (discussed under **Future Management**, page viii, 49).

### Hunting simulation

Some novel techniques have been used in developing the simulation model (**Appendix 4**). These include the incorporation of normal distributions to provide for age-specific variations in intercalving intervals and age at first conception, the facility to begin in any year and select from a range of starting population age structures, the facility to apply varying degrees of depletion to the adult males in the population beginning at any age and, finally, the facility to define and apply emigration from the population.

The hunting spreadsheet is the most sophisticated part of the model (**Appendix 6**). The tusk weights above a minimum size for all the individual animals in each age class from 20-60 years are generated in an inverse normal distribution using the relevant probabilities. Selection of the tusks which will be taken is achieved by counting the numbers in each weight class and each age class, setting the fractions required and using random numbers above the calculated thresholds to choose the tusks. The only drawback to the model is the speed at which it can carry out all the required computations.

We show why the selection function for tusks cannot be based on the variables which might be expected to determine the mean tusk weight and the tusk weight proportions over time, e.g. quota size, population growth, the state of recovery from initial depletion, the level of background hunting, the tusk weight formula and the extent of the initial depletion in 1986 (**Figs.14-18**). By attempting to hand-tailor a selectivity function for each age class it became obvious to us that the function has to change continuously to achieve the correct proportions of tusks year by year.

We have put forward two hypotheses why the proportions of tusk weights in the data are so constant from year to year. The first is that the hunting outcome is a measure of the skills of the individual professional hunters. The second argues that the hunting outcome is a natural consequence of the business strategy of safari operators and, ultimately, a reflection of the demands of hunting clients. Neither of these hypotheses is very easy to test. We are dealing with a complex system where human factors are interacting with the biological, ecological and economic attributes of a large scale system.

The simulation model replicates faithfully what happened in the hunting industry from 1996-2010 (**Figs.19-21**) This is not surprising because it uses the known results to carry out its tusk selection. We would have been much happier with the results had they been based on a selectivity function which was independent of the hunting data but perhaps there is no need to wear blinkers when the answers are staring one in the face.

The model shows the dynamic nature of the population age structure over the study period. As the years progress, the restoration of the male age classes which were depleted in 1986 sweep upwards through the age structure with one age class after another being fully restored each year. Had the hunting quotas remained the same as in 1996, all age classes up to 45 years old would have been fully restored by 2010 (the effects of depletion only disappear completely in the year 2025). However, the hunting quotas increased more than ten-fold over the period 1996-2010, exerting another type of depletion on the age structure which affected the oldest age classes first and moved downwards through the age structure. By 2010 this results in an uneasy equilibrium in the age structure where all age classes down to 30 years old remain significantly depleted, the effects being most severe in the age classes above 50 years (more than 60% depletion).

### Future hunting management

We used two approaches to examine the response of the population to changes in the hunting quota. A 'perfect hunting' regime (where trophies are taken from the population strictly in order of size from the largest tusks to the smallest tusks available to satisfy the quota) sets the upper limits on what trophies can be taken from the population and, ultimately, provides the measure of sustainability of any particular hunting regime. The 'actual hunting' regime attempts to maintain the proportions of tusk weights in the quota as they were found in the data. We used two variants of 'actual hunting': in the first, if any tusk weight class does not contain enough animals to meet the required part of the quota, animals cannot be taken from other weight classes to make up the difference; in the second, they can. Ultimately, however, the 'actual hunting' regime cannot produce an outcome which exceeds the limits established by 'perfect hunting'.

Two key results emerge from the simulation runs –

(1) **Hunting quotas cannot be increased much beyond 0.35% of the total population** without significant changes in the proportions of tusk weights. Above 0.35% (about 500 animals) the highly desirable trophies above 70lbs disappear from the population.

(2) **It takes a long time for the population to adjust to any change in the quota**. This is not so much dependent on the magnitude of the change as it is on the mere fact of a change. It may take more than 50 years before the population reaches a new equilibrium. This presents a problem for any manager relying (correctly) on adaptive management for making adjustments to the hunting quota. The time taken before the outcome of the changes is apparent generally exceeds the lifetime of the manager. **One of the most valuable attributes of a population model such as this is that it allows testing of the long-term effects of increasing quotas**.

**The impact of trophy hunting on the elephant population is negligible in biological terms**. Trophy hunting has no effect whatsoever on limiting population growth and is not a management tool to replace culling when an elephant population is judged to be overabundant.

**Conventional concepts of biological sustainability have little relevance to trophy hunting**. Long before the population of adult males becomes totally depleted, the safari industry which caused the depletion would have collapsed. In the lower weight classes (animals carrying tusks less than 50lbs) there are thousands of animals in the population (**Table 5**). Quotas exceeding 1% of the population are eminently sustainable in biological terms but totally incompatible with the notion of a high-quality elephant trophy hunting safari industry.

### Principles for management

It was not the intention of this study to make recommendations – that might be more appropriate for consultants. Our aim was primarily to understand the processes taking place in the elephant population and the hunting industry. However, it is not inappropriate to draw attention to the salient characteristics of the system.

**It is essential to recognise this is a dynamic complex system**. It involves people, economics and ecology. The rapidly evolving science of complex systems has developed principles which should be applied in cases such as this –

1. **Co-operation amongst stakeholders** (local communities, safari operators and state agencies) **is the vital ingredient for the industry to prosper** (Beinhocker 2007).

2. **Recognise the diversity (variability) in concessions** (Walker & Salt 2006). There is no single approach either to quota setting or to the administration of hunting which will result in the best outcomes from hunting across all the CHAs in northern Botswana. It is essential that the state agency (DWNP) should not adopt a 'cookie-cutter' approach (one-size-fits-all) to elephant trophy hunting. Its strategy should be to give safari operators the maximum leeway to find solutions in the best to the worst concessions.

3. **Create space for experimentation**. Even if existing safari hunting practices seem to be working, it is vital to keep trying alternatives (Levin 1999). This is part of the adaptation needed in a changing environment. The rôle of government here is to create this space and it requires the minimum of top-down control (Holling & Meffe 1996). For example, there is a huge pressure on safari operators at the moment caused by a hunting season limited to 6 months of the year combined with large elephant hunting quotas which are very difficult to sell in the time available. It would have no adverse effects if the length of the hunting season were increased so that this is not a constraint on realising the best from the industry.

4. **Policy-makers should position themselves at the laissez-faire end of the management continuum** (**Appendix 7**, page 98). The management continuum defined by Ruitenbeek & Cartier (2001) extends from Command-and-Control at one end of the spectrum (where all decisions are made by government) to Laissez-Faire at the other (where all decisions are made by local communities). If a workable co-management system is seen as a desirable objective (the first principle enunciated above), then it is essential that the major rôle is played by the primary local stakeholders.

   We surmise that if government were to adopt a laissez-faire approach to quota-setting that local communities and safari operators would start practices that benefit both their pockets and elephant conservation. Local communities would provide the check on any excesses which appeared likely to prejudice their long-term prospects for a sustainable livelihood from the resource. This should work if both the operators and the local communities feel they have security of tenure.

## Further work

A wide range of mean tusk weights are possible depending on the size of the hunting quota. Halving the present quota should eventually result in every trophy being over 90lb; doubling the quota would reduce the long-term mean tusk weight to under 60lbs (**Fig.24** 'perfect hunting'). The value of an elephant trophy escalates sharply with tusk weight. In a perfect world, it would appear that the quota size might be optimised to realise the highest overall value for the hunting industry.[25]

However, it is not a perfect world. It is a dynamic industry with huge variability amongst concessions, skills of professional hunters, business acumen of safari operators and the prices which can be realised for elephant trophy hunting.[26] Overarching all this are political uncertainties and the vagaries of the international market ... caused mainly by ill-informed pressure from green organisations. However, this is the world within which the Botswana stakeholders will have to operate.

There may be scope for a consultancy to examine the topic of quota optimisation. Such a consultancy should not see government as its primary client – it should be aiming to raise awareness of the issues and options amongst safari operators and local people. And it should be constrained by the principles outlined on the previous page.

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25. The diamond industry has been managed by de Beers for over 100 years to optimise the overall income. If too many diamonds are released into the market the price drops: if too few are sold the price increases but the overall income decreases. This process is an ongoing exercise in adaptive management – there is no formula that can be used to find the optimum. Diamonds have to be sold for it to work.

26. In a recent auction conducted by DWNP in Botswana (March 2011), 27 elephant trophy licences were sold for a total of US$876,000 – an average price of US$32,400 per elephant. The highest price for single trophy was US$38,500.

## Population Numbers and Rate of Increase

A crude best-fit model for the Botswana elephant population (Martin 2004) suggested that it reached its present level of some 150,000 elephants by increasing at a rate of about 6.6% from a population of some 8,000 animals in 1960.

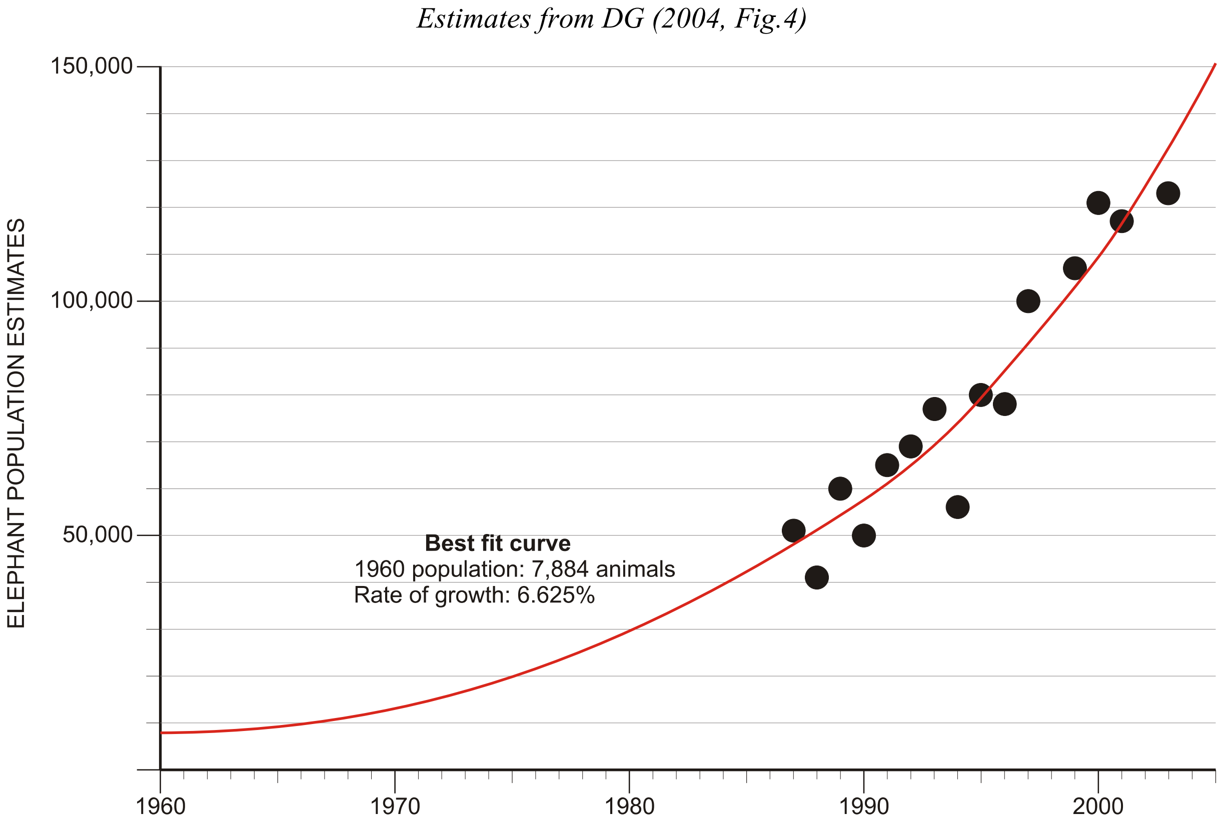

**Figure A1.1: Best fit curve forBotswana elephant population estimates (Martin 2004)**

Although the elephant population in northern Botswana has been surveyed in a number of years since the early 1970s, Gibson (*et al* 1998) considered the estimates prior to 1987 to be unsuitable for the analysis of population size and trends. For the analysis which follows, we required reliable estimates with confidence intervals. The final data set on which the analysis is based is shown in **Table A1.1** (next page).

It might be expected that the wet season estimates would be consistently lower than the dry season estimates because of the increased tree cover during the rains. However, examination of these data suggest that there is no sound basis for excluding the wet season estimates: in some years (1987,1989 & 1995) the wet season estimates are higher than those for the dry season. The estimates and standard errors are shown in **Fig.A1.5** (page 61).

## Table A1.1 Elephant population estimates 1987-2006

| Year | Season | Estimate | 95% Confidence Intervals Lower | 95% Confidence Intervals Upper | Standard Error |
|---|---|---|---|---|---|
| 1987 | Wet | 50,440 | 40,352 | 60,528 | 5,147 |
| | Dry | 40,530 | 26,750 | 54,310 | 7,031 |
| 1989 | Wet | 66,051 | 45,554 | 86,548 | 10,458 |
| | Dry | 59,896 | 42,806 | 76,987 | 8,720 |
| 1990 | Wet | 49,064 | 37,276 | 60,878 | 6,028 |
| | Dry | 55,835 | 35,635 | 76,036 | 10,307 |
| 1991 | Wet | 64,916 | 44,864 | 84,968 | 10,231 |
| | Dry | 68,771 | 50,571 | 86,971 | 9,286 |
| 1993 | Wet | 73,901 | 44,052 | 103,751 | 15,230 |
| | Dry | 79,033 | 65,364 | 92,701 | 6,973 |
| 1994 | Wet | 54,927 | 41,082 | 68,772 | 7,064 |
| | Dry | 78,304 | 61,477 | 95,131 | 8,585 |
| 1995 | Wet | 81,041 | 64,371 | 97,711 | 8,505 |
| | Dry | 77,916 | 59,918 | 95,925 | 9,188 |
| 2001 | Dry | 116,988 | 95,196 | 138,799 | 11,128 |
| 2002 | Dry | 122,678 | 105,534 | 139,823 | 8,747 |
| 2003 | Dry | 109,471 | 91,028 | 127,914 | 9,410 |
| 2004 | Dry | 151,000 | 130,996 | 171,004 | 10,206 |
| 2006 | Dry | 154,658 | 133,404 | 175,911 | 10,843 |

Notes

1. The wet and dry season estimates from1987-1995 are from Gibson (*et al* 1998)
2. The estimates from 2001-2006 are from DWNP, Gaberone and AfESG (2007)
3. The estimates for 1995 & 1999 in Blanc (*et al* 2005) were not included because of discrepancies
4. Standard errors were estimated from the lower and upper values of the 95% confidence intervals

## Population Rate of Increase

### Standard Iteration

A 'best fit to the data has been obtained by varying the starting population in 1986 and varying the rate of growth using a numeric optimiser (**Table A1.2** next page). The exercise was done for all of the estimates (wet and dry seasons) and for dry seasons only. The predicted values for the population take into account the time of the survey in each year.[27]

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[27] Adjusting the population predicted estimates according to the time of year presupposes that elephants breed uniformly throughout the year ... which is unlikely to be true. However, it is probably a slight improvement over the alternative which is to place the estimate at the beginning or end of the year.

## Table A1.2: Standard iteration for best fit

| | ALL | DRY |
|---|---|---|
| **Rate of growth %** | **6.199** | **6.317** |
| **Population start 1986** | **46,004** | **45,088** |
| **√(Sum of squares)** | **23,591** | **17,849** |

| Year | Season | Time | **Estimate** | ALL Predicted | Squared Differences | DRY Predicted | Squared Differences |
|---|---|---|---|---|---|---|---|
| | 1986.00 | 0.00 | | 46,004 | | 45,088 | |
| 1987 | 1987.04 | 1.04 | **50,440** | 48,978 | 2,136,992 | | |
| | 1987.50 | 1.50 | **40,530** | 50,347 | 96,373,299 | 49,428 | 79,168,172 |
| 1989 | 1989.13 | 3.13 | **66,051** | 55,516 | 110,990,743 | | |
| | 1989.71 | 3.71 | **59,896** | 57,498 | 5,750,600 | 56,587 | 10,947,729 |
| 1990 | 1990.29 | 4.29 | **49,064** | 59,551 | 109,975,188 | | |
| | 1990.71 | 4.71 | **55,835** | 61,062 | 27,321,763 | 60,162 | 18,722,498 |
| 1991 | 1991.21 | 5.21 | **64,916** | 62,926 | 3,959,849 | | |
| | 1991.71 | 5.71 | **68,771** | 64,847 | 15,397,718 | 63,962 | 23,122,126 |
| 1993 | 1993.38 | 7.38 | **73,901** | 71,684 | 4,915,847 | | |
| | 1993.71 | 7.71 | **79,033** | 73,135 | 34,782,071 | 72,299 | 45,348,490 |
| 1994 | 1994.29 | 8.29 | **54,927** | 75,747 | | | |
| | 1994.71 | 8.71 | **78,304** | 77,669 | 403,569 | 76,866 | 2,067,621 |
| 1995 | 1995.29 | 9.29 | **81,041** | 80,442 | 358,960 | | |
| | 1995.71 | 9.71 | **77,916** | 82,483 | 20,858,369 | 81,722 | 14,484,114 |
| 2001 | 2001.71 | 15.71 | **116,988** | 118,325 | 1,788,274 | 118,020 | 1,065,885 |
| 2002 | 2002.71 | 16.71 | **122,678** | 125,660 | 8,890,909 | 125,476 | 7,828,293 |
| 2003 | 2003.71 | 17.71 | **109,471** | 133,462 | | 133,416 | |
| 2004 | 2004.71 | 18.71 | **151,000** | 141,735 | 85,839,212 | 141,844 | 83,831,585 |
| 2006 | 2006.71 | 20.71 | **154,658** | 159,835 | 26,798,919 | 160,315 | 31,997,492 |
| 2007 | 2007.71 | 21.71 | | 169,759 | | 170,459 | |
| 2008 | 2008.71 | 22.71 | | 180,282 | | 181,227 | |
| 2009 | 2009.71 | 23.71 | | 191,457 | | 192,676 | |
| 2010 | 2010.71 | 24.71 | | 203,325 | | 204,847 | |

The wet season estimate for 1994 and the dry season estimate for 2003 were excluded from the calculations of best fit (see **Maximum Likelihood Analysis** – next page).

Both the best fit to the full set of data and to the dry season data indicate rates of population increase greater than 6% per annum (6.2-6.3%). To obtain the best fit, the starting population in 1986 is some 46,000 animals when all estimates are considered and some 45,000 when only the dry season data are used. The population curve is shown in **Fig.A1.6** (page 61).

### Maximum Likelihood Analysis

This technique was used by Martin (1992) to obtain the best fit to the elephant population estimates for Matabeleland North in Zimbabwe. It relies on measuring the probability of any given estimate being a certain distance away from the mean estimate for the year concerned.[28] As for the previous Standard Iteration analysis, a set of predicted population estimates were produced by varying the starting population and the rate of growth. The probabilities generated by comparing the predicted estimates with the actual estimates were multiplied together to obtain a probability index for all the estimates.

This is a powerful analytic tool because it yields a very narrow band of estimates for which the probability index is not effectively zero (**Fig.A1.2** below). It requires every predicted value to lie within the 95% confidence intervals for the actual estimate. Because it relies on multiplication of fractions[29] rather than the addition of sums of squares it is extremely sensitive.

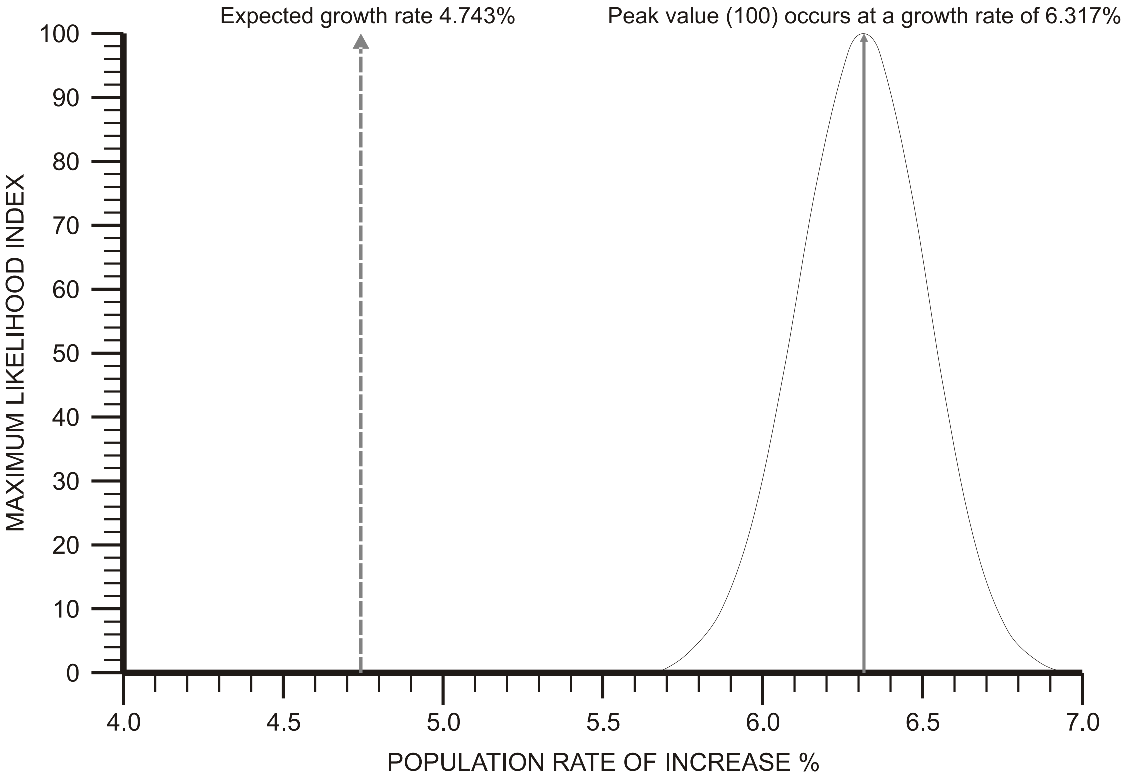

**Figure A1.2: Maximum Likelihood estimator**

The population estimates produced using the maximum likelihood estimator are shown in **Table A1.3** (next page). The results are for the full set of surveys and for the dry season surveys. Whereas in the standard iteration analysis the lowest value for the sum of squares is sought, in the Maximum Likelihood analysis the highest value for the Probability Index is required.

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[28] The probabilities were calculated using the NORMDIST function in a Quattro Pro spreadsheet. The function requires the mean value and the standard deviation for the estimate. The standard errors shown in Table A1.1 were used as an approximation of the standard deviations.

[29] Multiplying fractions together can result in very small numbers. A scaling factor of $10^4$ was used for the NORMDIST probabilities and $10^8$ for the Probability Index.

## Table A1.3: Estimates based on Maximum Likelihood

| | ALL | DRY |
|---|---|---|
| **Rate of growth %** | **6.350** | **6.359** |
| **Population start 1986** | **44,934** | **44,907** |
| **Probability Index** | **1.49888** | **1.23439** |
| **√(Sum of squares)** | **23,875** | **17,875** |

| Year | Time | **Estimate** | Std. Error | ALL Predicted | Probability | Squared Differences | DRY Predicted | Probability | Squared Differences |
|---|---|---|---|---|---|---|---|---|---|
| 1986.00 | | | | 44,934 | | | 44,907 | | |
| 1987.04 | 1.04 | **50,440** | 5,147 | 47,910 | 0.6869 | 6,400,293 | 47,885 | | |
| 1987.50 | 1.50 | **40,530** | 7,031 | 49,281 | 0.2615 | 76,586,482 | 49,258 | 0.2626 | 76,173,959 |
| 1989.13 | 3.13 | **66,051** | 10,458 | 54,467 | 0.2066 | 134,187,037 | 54,448 | | |
| 1989.71 | 3.71 | **59,896** | 8,720 | 56,459 | 0.4233 | 11,813,954 | 56,442 | 0.4230 | 11,932,074 |
| 1990.29 | 4.29 | **49,064** | 6,028 | 58,523 | 0.1932 | 89,481,421 | 58,508 | | |
| 1990.71 | 4.71 | **55,835** | 10,307 | 60,044 | 0.3561 | 17,717,743 | 60,031 | 0.3563 | 17,604,600 |
| 1991.21 | 5.21 | **64,916** | 10,231 | 61,921 | 0.3736 | 8,967,395 | 61,910 | | |
| 1991.71 | 5.71 | **68,771** | 9,286 | 63,857 | 0.3735 | 24,144,240 | 63,848 | 0.3733 | 24,235,186 |
| 1993.38 | 7.38 | **73,901** | 15,230 | 70,758 | 0.2564 | 9,877,774 | 70,757 | | |
| 1993.71 | 7.71 | **79,033** | 6,973 | 72,225 | 0.3552 | 46,344,878 | 72,226 | 0.3553 | 46,331,072 |
| 1994.29 | 8.29 | **54,927** | 7,064 | 74,866 | 0.0105 | | 74,871 | | |
| 1994.71 | 8.71 | **78,304** | 8,585 | 76,812 | 0.4577 | 2,226,304 | 76,819 | 0.4578 | 2,204,932 |
| 1995.29 | 9.29 | **81,041** | 8,505 | 79,621 | 0.4626 | 2,016,962 | 79,632 | | |
| 1995.71 | 9.71 | **77,916** | 9,188 | 81,690 | 0.3991 | 14,241,700 | 81,704 | 0.3988 | 14,348,498 |
| 2001.71 | 15.71 | **116,988** | 11,128 | 118,196 | 0.3564 | 1,459,918 | 118,273 | 0.3561 | 1,651,355 |
| 2002.71 | 16.71 | **122,678** | 8,747 | 125,702 | 0.4296 | 9,146,141 | 125,794 | 0.4280 | 9,708,861 |
| 2003.71 | 17.71 | **109,471** | 9,410 | 133,699 | 0.0154 | | 133,807 | | |
| 2004.71 | 18.71 | **151,000** | 10,206 | 142,189 | 0.2693 | 77,632,205 | 142,315 | 0.2722 | 75,422,733 |
| 2006.71 | 20.71 | **154,658** | 10,843 | 160,805 | 0.3133 | 37,789,089 | 160,974 | 0.3105 | 39,887,438 |
| 2007.71 | 21.71 | | | 171,035 | | | 171,227 | | |
| 2008.71 | 22.71 | | | 181,896 | | | 182,116 | | |
| 2009.71 | 23.71 | | | 193,447 | | | 193,696 | | |
| 2010.71 | 24.71 | | | 205,732 | | | 206,013 | | |

The results are very similar to those from the standard iteration analysis. In both the analysis of all survey estimates and dry season only estimates the starting population is about 45,000 animals and the growth rate for best fit is 6.3-6.4%. Two estimates (shaded in grey above) were rejected from the analysis because of their low probabilities.

Based on the square root of the sum of squares it should not be concluded that the standard iteration for all data gives a slightly better result than the maximum likelihood analysis (23,591 versus 23,875). When the predicted values from the standard iteration are ‘plugged in’ to the maximum likelihood analysis they yield a lower value for the probability index (1.35 versus 1.5), i.e. a starting population of 46,000 animals which grows at 6.2% is further away from the ‘true value’ than a starting population of 45,000 animals growing at 6.35%.

### Achieving the population rate of increase

The estimates for population rate of increase from the preceding analyses suggest that it lies between 6.20-6.36% – which is higher than most recorded elephant population growth rates.[30] If survey techniques had improved over the time span of the estimates this would provide one possible explanation. However, this seems unlikely: from 1993 onwards the standardised techniques of ULG (1995) were used in all surveys. If immigration into the population is ruled out,[31] the question arises whether an elephant population is capable of such a rate of increase.

Parker (1979) described the 'races' of savanna elephants in Africa based on the characteristics of their tusks. The Botswana elephants belong to the 'Western Savanna' group in southern Africa which extends from the Matabeleland North population in Zimbabwe, through Botswana to Namibia and Angola in the west. It seems reasonable to expect that they would have a reproductive performance similar to their neighbours.

A 'normal' elephant population with a fecundity of 0.25 (one calf every four years), mean age at first parturition centred on 12 years, a central mortality of 0.5% (see page 67) and a juvenile mortality of 8%, increases at a rate of 4.74% when it has achieved a stable age structure (**Appendix 2**, page 63). Allowing the maximum latitude in these parameters for the Botswana population,[32] still does not result in a population rate of increase as high as 6% pa (5.74% pa according to the population model described in **Appendix 3**).

Martin (2004) noted that a more plausible explanation for growth rates exceeding 6% might lie in a skewed age structure for the population prior to 1987. There is evidence to suggest that before the inception of sustainable hunting quotas in the late 1980s, the northern Botswana population had suffered a long history of overhunting for adult males both from citizen hunting and international sport hunting. The absence of large trophy animals in the population at that time was noted by numerous observers (P. Becker, *pers.comm.*, G.F.T. Child, *pers.comm.*, D.H.M. Cumming, *pers. comm.*, I.S.C. Parker, *pers. comm.*).

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[30] Calef (1988) detected the unusually high growth of the northern Botswana elephant population but failed to recognise the importance of a stable age structure in the population and attributed the growth rate mainly to a very high fecundity.

[31] If immigration were responsible for the high growth rate it would have had to come from Zimbabwe – the Zambian and Angolan populations were already depressed by 1987. Whilst this is theoretically possible, it is unlikely. Martin (1992b) showed that immigration from Botswana was necessary to explain the high growth rates of the Zimbabwe population from 1980-1991.

[32] Based on the sensitivity analysis in Appendix 2, the following parameters were used for the Botswana population: age at first parturition 10 years, inter-calving interval 45 months, adult mortality 0.5% and juvenile mortality 6%.

Using the population model described in **Appendix 4** (page 80), skewed age structures were produced by depleting the numbers of males older than 14 years in the population. Levels of depletion were varied from zero (i.e. the population had a stable age structure with equal numbers of males and females) to 90% (i.e. only 10% of the males in each age class which would normally be found in a population with a balanced stable age structure were present). A rounding function was used to avoid an abrupt depletion in the age classes 15-20 years. The age structures resulting from the depletion are shown in **Fig.A1.3** below.

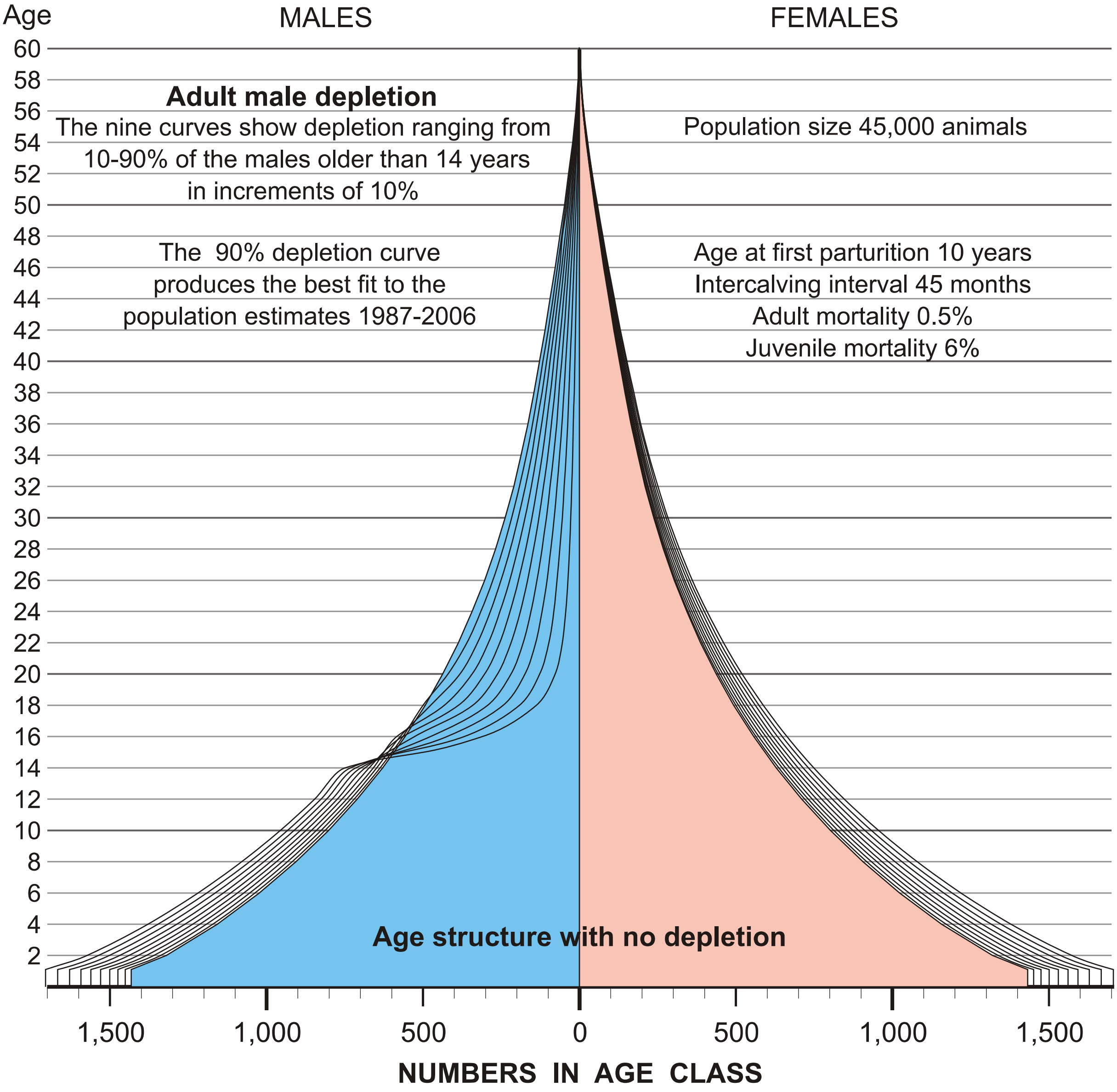

**Figure A1.3: Increasing degrees of depletion of adult males in the population**

The rates of population increase which follow these starting age structures in 1986 are shown in **Fig.A1.4** below. It is assumed that from 1986 onwards the overexploitation of adult males ceased, allowing the population to move towards a balanced stable age structure.

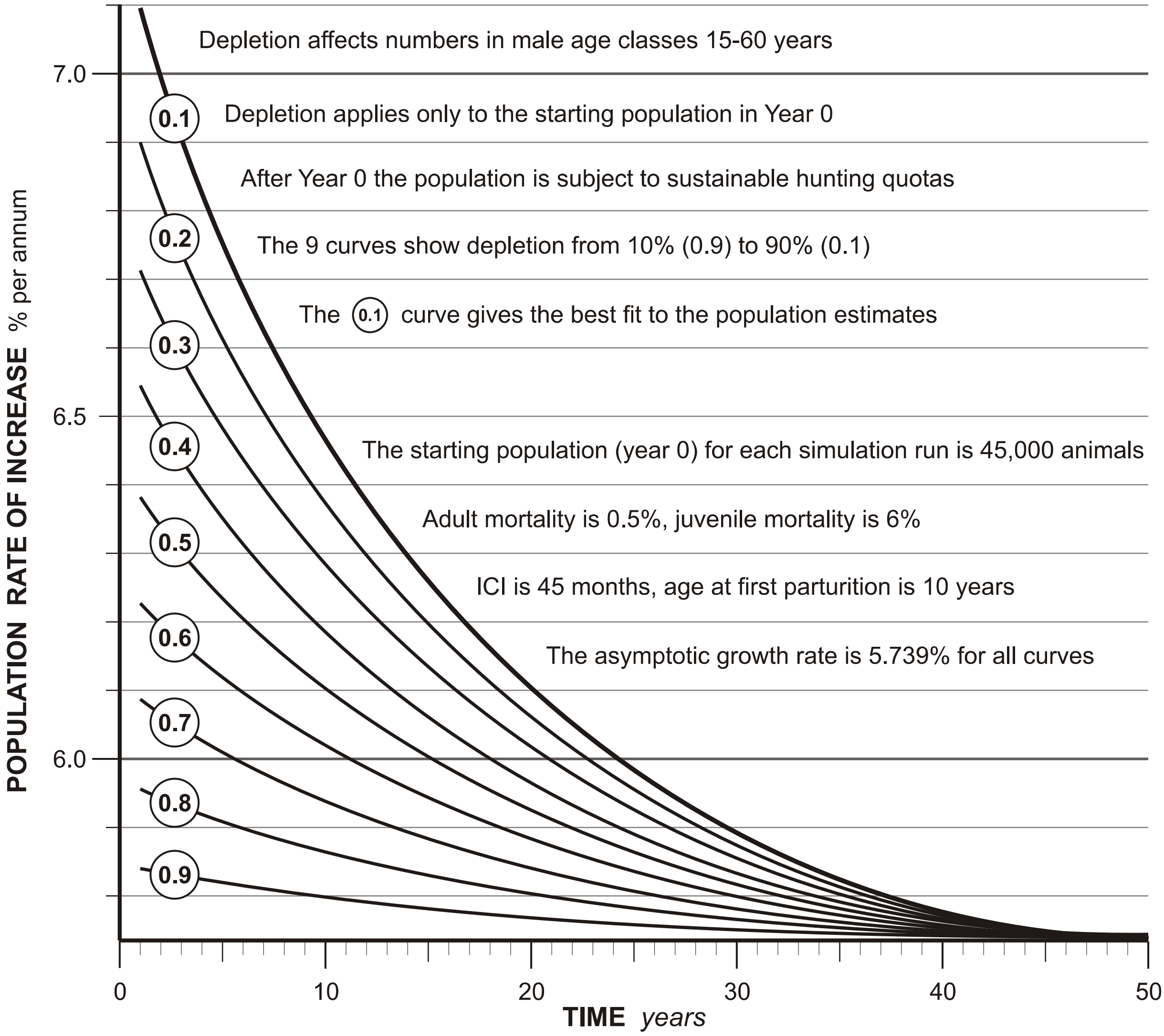

**Figure A1.4: Population rate of increase following a male-depleted age structure in 1986**

With the selected population reproductive parameters, initial growth rates exceeding 7% can be achieved for populations which have been subjected to 90% or more depletion of males older than 14 years and growth rates exceeding 6.5% can be achieved for populations which have been subjected to 60% or more depletion. Following the transition to a lower exploitation regime, it takes about 50 years (less than the lifetime of an elephant) for the rate of increase to reach an asymptote of 5.74%.

**It is important to note that if a skewed age structure is in place the numbers of adult females in the population is higher than would be expected from an unskewed population with a balanced sex ratio.** This accounts for the high initial growth rates.

The curves shown in Fig.A1.4 were examined to find which gave the best-fit to the dry season population estimates.[33] It was found that a depletion factor of 0.1 (90% depletion) produced the lowest sum of squared differences (**Table A1.4** below).

### Table A1.4: Effect of a skewed age structure in 1986 on population growth

**SKEWED AGE DISTRIBUTION**

**Depletion factor 0.1**

(Sum of squares) **17,668**

| Year | Dry Season **Estimate** | Model prediction | Squared Differences | Rate of Growth % |
|---|---|---|---|---|
| 1986 | | 43,089 | | 7.096 |
| 1987 | **40,530** | 49,149 | 71,774,784 | 7.001 |
| 1989 | **59,896** | 55,954 | 15,413,476 | 6.833 |
| 1990 | **55,835** | 59,662 | 15,342,889 | 6.757 |
| 1991 | **68,771** | 63,591 | 25,220,484 | 6.689 |
| 1993 | **79,033** | 72,164 | 43,546,801 | 6.567 |
| 1994 | **78,304** | 76,839 | 1,331,716 | 6.511 |
| 1995 | **77,916** | 81,793 | 17,783,089 | 6.459 |
| 2001 | **116,988** | 118,382 | 2,547,216 | 6.221 |
| 2002 | **122,678** | 125,818 | 10,536,516 | 6.190 |
| 2004 | **151,000** | 142,048 | 83,137,924 | 6.133 |
| 2006 | **154,658** | 160,278 | 25,532,809 | 6.086 |
| 2007 | | 169,396 | | 6.064 |
| 2008 | | 179,633 | | 6.043 |
| 2009 | | 190,453 | | 6.023 |
| 2010 | | 201,889 | | 6.004 |

When the hunting is reduced to a sustainable level in1986, the population growth rate immediately rises to a level of 7.1%. By the year 2010 it has dropped to 6.0% and decreases over about 50 years to an asymptote of 5.74% as the population assumes a stable age distribution.

If the population curve is projected to the year 2010, a population over 200,000 animals is predicted. However, the number resident in Botswana is likely to be less than this. Firstly, the population growth rate should have decreased as a result of achieving a stable age structure and, perhaps, some density dependent effects. Secondly, there is evidence of emigration from the population (Chase & Griffin 2004, Chase *et al* 2004, Martin 2004 and G. Owen-Smith *pers.comm.*).

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[33] The population simulation model runs in fixed increments of one year so that each prediction applies to the end of the calendar year. The comparisons made in Table A1.4 use the dry season aerial survey estimates and assume that these will be close to the end-of year population.

## Summary

Three different types of analysis have been used to obtain 'best-fits' to the northern Botswana elephant population survey estimates and explain the population rate of increase.

(1) Standard iteration where both the starting population at the end of 1986 and the rate of population increase are variables;

(2) Maximum likelihood analysis where probabilities are calculated for predicted population numbers being a certain distance away from the means estimated in the aerial surveys and then multiplied together to obtain a probability index; and

(3) Using a skewed age distribution in 1986 as the starting population and measuring the goodness-of-fit as the population grows towards a stable age distribution.

The three curves from these methods were applied to the dry season estimates and are shown in **Fig.A1.5** on the next page. The results from the curves are summarised in **Table A1.5** below.

**Table A1.5: Summary of curves fitted to Botswana elephant population estimates**

| | Population | | Rate of | √(Sum of | Probability |
|---|---|---|---|---|---|
| | 1986 | 2010 | Growth % | squares) | Index |
| **Wet and Dry season estimates** | | | | | |
| Standard Iteration | **46,004** | **203,325** | **6.199** | **23,591** | **1.35008** |
| Maximum Likelihood | **44,934** | **205,732** | **6.350** | **23,875** | **1.49888** |
| **Dry season only estimates** | | | | | |
| Standard Iteration | **45,088** | **204,848** | **6.317** | **17,849** | **1.22871** |
| Maximum Likelihood | **44,907** | **206,013** | **6.359** | **17,875** | **1.23439** |
| Skewed Age Distribution | **43,089** | **203,750** | **7.10-6.00** | **17,866** | **1.22693** |

The curves are remarkably similar, i.e. each method produces a good fit to the data with a starting population in 1986 of between 43,000-46,000 animals, a projected population in 2010 of 201,000-206,000 animals and population rates of increase lying between 6.2-6.4%.[34] However, the processes underlying the growth of the population differ markedly.

Both the standard iteration and the maximum likelihood methods assume a constant growth rate for the population. To achieve this growth rate requires sustained extreme values for the population parameters which, it is argued in **Appendix 2**, are highly unlikely. The skewed age structure model is more plausible because it allows the use of population parameters closer to the values established for populations elsewhere within the same geographic range. It also produces a marginally better fit to the survey estimates.

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[34] The population growth rates for the Skewed Age Structure population fall slightly outside this range, beginning at 6.8% in 1987 and decreasing to 6.1% in 2010.

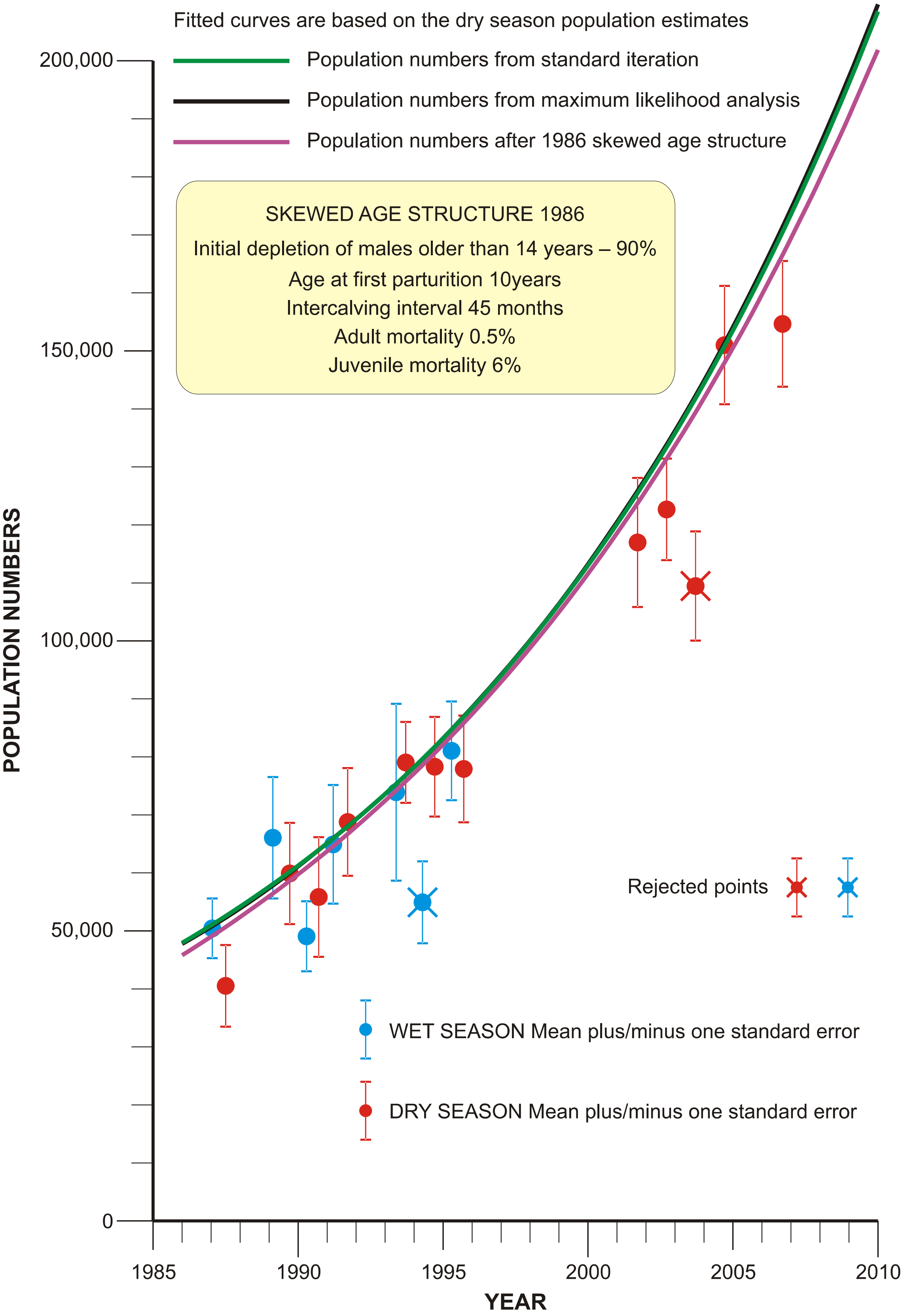

**Figure A1.5: Best-fit curves for northern Botswana elephant population estimates**

## Post Script

This appendix was written prior to the main work done in the study to find a hunting selectivity function which would result in the correct proportions of tusk weights. It was found that a 90% depletion in 1986 (**Table A1.4** page 59) made it impossible to obtain the required numbers of larger tusks which are in the hunting data. A depletion of 75% rectified this problem. The depletion function was further modified so that depletion only affected males older than 20 years (as opposed to the value of 14 years used in Appendix 1). To compensate for the slightly lower population rate of increase resulting from the reduced depletion, the intercalving interval was reduced from 45 months to 44 months. This results in a curve for the depleted population which differs slightly from that shown in Fig.A1.5 on the previous page and the final curve appears in the main report (**Fig.2** page 5).

## Reproductive Parameters

The biological parameters which determine the population dynamics of elephants and which are used in the population simulation model (**Appendix 4**, page 80) are summarised below.

### Longevity

Elephants are generally assumed to live to about 60 years old (Laws 1966). Recently, Moss (2001) recorded the death of an adult female whose age was over 60 years.

### Gestation

The gestation period for elephants is well-established as 22 months (Smithers 1983). This together with the lactational anoestrus period which follows parturition determines the intercalving interval.

### Seasonal breeding

Although elephants may produce calves in any month of the year, most populations have a distinct breeding peak during the rains.

### Sex ratio

Sex ratio at birth is 1:1 with minor variations recorded in the literature, usually in small populations. The overall sex ratio in the population may vary slightly in favour of females depending on the history of management and illegal hunting. Moss (2001) recorded significantly higher mortalities for males (which included anthropogenic mortality) than for females over their entire lifetime. In the population simulation model it has been assumed that natural mortality for males and females is the same throughout their lifetimes.

The next four parameters are the main determinants of the rate of increase of elephant populations. Van Aarde (2008, Tables 1A, 1B, 2,3) gives summary tables of values for these parameters recorded from elephant populations in South Africa and elsewhere in Africa. However, the data in these tables are not as useful as they might be. They include values from small populations and from short-term studies and these are given equal weight to values from large elephant populations and long-term studies.[35] The values given for survival are not sufficiently precise to allow meaningful values of adult mortality to be derived.[36]

**In this study of Botswana elephants, the values selected for the key reproductive parameters need to be such that they provide sustained population growth over 24 years (1987-2010) and they should be consistent with values derived from other large populations within the southern Africa region.**

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35. Martin (2010) cautions about conclusions drawn from small populations over short time periods with inadequate consideration of stable age structures.

36. Typical adult mortality in large elephant populations is usually a fraction of one percent but the data are only given to one percent accuracy.

To this end, the studies of elephants in Hwange National Park (Williamson 1976), Etosha National Park (Lindeque 1988), Kruger National Park (Smuts 1975, Whyte 2001, Freeman *et al* 2008), Luangwa Valley (Hanks 1972a) and the Zambezi Vally in Zimbabwe (Dunham 1988) appear to be **the most relevant to the Botswana elephant situation**.

Moss (2001) and Whitehouse & Hall-Martin (2000) are good examples of long-term studies of elephant populations. However, both the Amboseli and the Addo elephant populations are relatively small compared to the those listed above and occur in habitats which are very different to those in northern Botswana. The studies of the Uganda elephant populations (Perry 1953, Laws 1966, Laws 1969, Laws *et al* 1970) apply to a higher rainfall regime than in Botswana and, at the same time, provide the extreme examples of reproductive parameters in populations which have exceeded 'carrying capacity'.

In the investigation which follows, we are seeking three key values: firstly, the most 'typical' value for the parameter; secondly, the value for the parameter which falls within the recorded range of values and which gives the highest rate of growth for the population; and, thirdly, the value for the parameter which falls within the recorded range of values and which gives the lowest rate of growth for the population.[37]

## Fecundity

### *Age at first parturition*

Williamson (1976) found the mean age of sexual maturity[38] in Hwange National Park elephants to be 11 years. Lindeque (1988) gives the mean age at first conception for elephants in Etosha to be 10-12 years (i.e. age at first parturition of 12-14 years). In examining material from culled animals in Kruger National Park (KNP), Freeman *et al* (2008) found one six-year old female with a developed corpus luteum. The implication of this is that, assuming the animal was killed mid-year, she would have conceived in her sixth year of life. In the same sample, four females aged 10 years old had placental scars indicating that they had conceived at 8-9 years of age.[39] Both Smuts (1975) and Freeman *et al* (2008) found the mean age at first parturition in KNP to be about 12 years. Dunham (1988) estimated that the mean age at which females in the Zambezi Valley attained sexual maturity was 11-12 years in 1969-72 and 13-14 years in 1985 when the population was at a higher density. Hanks (1972a) found the mean age at sexual maturity for the South Luangwa elephants[40] to be about 14 years which implies an age at first parturition of about 16 years. Owens & Owens (2009) found the mean age at first birth to be 11.3 years for the North Luangwa elephants.

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[37] This last value is of little direct relevance to the Botswana population but is used in the sensitivity analysis to compare the relative impact of the four parameters on the rate of increase of the population.

[38] Several authors use the 'attainment of sexual maturity' as the yardstick for onset of breeding. It poses a quandary for a population modeller needing an estimate of 'age at first parturition'. Hanks (1972a) defines attainment of sexual maturity as the mean age at which a female first ovulates. Assuming that conception follows shortly after ovulation, the mean age at first parturition would accordingly be about two years later.

[39] The earliest age by which females had produced their first calf in Addo National Park was 10 years (Whitehouse & Hall- Martin 2001).

[40] The Luangwa Valley elephants were considered to be well in excess of 'carrying capacity' in 1972.

On the basis of these findings, we have chosen 12 years as the typical age of first parturition for a population which is below carrying capacity. In a population displaying rapid growth, the age of first parturition might be adjusted downwards to about 10 years. Van Aarde (2008) gives numerous examples, mainly from small populations, where this has been achieved. This is our value for the lower end of the range for age at first parturition: there is little justification in the literature for adjusting the value much lower than this.

Laws (*et al* 1975) recorded conception being delayed until about 20 years of age in a high density population in Uganda (Murchison Falls Park South). This is our upper end of the range for age at first parturition. It would obviously not be applicable to the Botswana elephant population in 1987. Moss (2001) found the mean age at first birth in the Amboseli population to be 14-15 years – another population perhaps suffering resource shortages.

### *Intercalving interval*

Female elephants in southern Africa generally produce a calf every four years throughout their main breeding lifetime. Fecundity declines in the last 10-20 years of life.

Lindeque (1988) derived average fecundities for the female elephants in Etosha National Park in 1983 and 1985 from two shot samples which included 103 and 214 females respectively. His finding was that, over their main breeding life span, the females were producing almost exactly one calf every four years (i.e. a fecundity of 0.25 including calves of both sexes). Williamson (1976) found a similar intercalving interval for the elephants of Hwange National Park. For Kruger National Park Smuts (1975) estimated the mean calving interval at 4.5 years – which is higher than the mean value of 3.8 years found by Freeman *et al* (2008). However, Freeman *et al* (2008, Table 3) found considerable variation in this parameter (2.3-5.3 years) over the years 1976-1995.[41] In the Zambezi Valley, Dunham (1988) found a high fecundity (mean calving interval 3.4 years) for the years 1969-1972 and an even higher value for 1984/85 (mean calving interval 2.8 years). However, his values fall within the range recorded by Freeman *et al* (2008) – which had a mean value of 3.8 years. The high 1984/85 fecundity may have been the result of synchronised breeding following a drought. Hanks (1972a) found a mean calving interval of 4 years for Luangwa Valley elephants between the ages of 20-40 years.[42]

For a typical southern African elephant population we have selected 4 years as the mean calving interval over the main breeding lifetime and 3.75 years as the minimum value. Although lower mean calving intervals have been recorded, it is doubtful whether they can be sustained for the time required (24 years) to explain the Botswana population rate of increase. The highest recorded mean calving interval is that of 9.1 years reported by Laws *et al* (1970) for Murchison Falls Park North.

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[41] Smuts (1975) data also show significant variation from year to year over the period 1970-1974.

[42] Hanks (1972) found a peak in fecundity for females aged 18-19 years (0.38 which is equivalent to an intercalving interval of 32 months). However, no such similar peak has been recorded in the other literature reviewed for this study. Whitehouse & Hall-Martin (2000) found a minor peak in fecundity for females aged 25-29 years for the Addo National Park elephants.

Data on the decline in fecundity in the latter years of an elephant's lifetime are provided by Hanks (1972a), Williamson (1976), Moss (2001) and Freeman *et al* (2008). The Luangwa Valley elephants' fecundity dropped from a value of 0.25 (up to 40 years) to 0.21 between 40-50 years and 0.17 between 50-60 years. The Hwange National Park elephants showed almost no decline in fecundity from 40-49 years but it decreased to 0.08 after 50 years. The Amboseli elephants younger than 40 years showed an average fecundity of about 0.22 (one calf every 4.5 years); this dropped to 0.196 between 40-50 years (one calf every 5.1 years) and to 0.098 between 50-60 years (one calf every 10.2 years). Animals older than 60 years continued to breed. Kruger National Park elephants showed a similar decline in fecundity after 50 years of age.

The population simulation model (**Appendix 4**, page 80) takes these values of senescent fecundity into account.

### Mortality

As a variable, mortality differs from fecundity and age at first parturition. Physically, most elephants will only be able to conceive once they have passed a certain age and will be highly likely to have produced their first calf within a few years of that age threshold. Similarly, it is almost impossible for them to produce calves more frequently than once every three years and it is most unlikely that the spacing between calves will be much more than six years. Both of these variables probably abide by a normal distribution and can be described with a mean and confidence intervals.

Both juvenile and adult mortality are 'open-ended' variables. There is no limit as to how high they can get. In a bad drought year juvenile mortality might be 100%; if a disease sweeps through a population both juvenile and adult mortality might be 100%. Statistically, it is possible to calculate the mean and confidence intervals for mortality in a number of separate elephant populations but there is a need to retain the awareness that the data apply to particular samples. The data tell nothing about populations which have suffered much higher mortalities and died out.

Because of this open-ended nature of mortality as a variable, it is capable of exerting a far greater influence on population growth than either fecundity or age at first conception.[43] Using the 'typical' fecundity values given earlier in this section, elephant populations cease to increase when the baseline adult mortality reaches about 5%.[44] At higher values than this they decline to extinction.[45]

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43. Hanks & McIntosh (1973) viewed the mean calving interval as the key parameter in affecting the rate of increase of elephant populations and assert that juvenile mortality is an important regulating for elephant populations. Moss (2001, quoting Croze *et al* 1981) emphasizes the importance of age at first parturition. The population modelling work in this study does not support these conclusions.

44. Van Aarde (2008, Table 3) reports adult mortalities well in excess of 5% for certain elephant populations without any elaboration on the significance of this.

45. Laws *et al* (1970) detected the set of conditions which foretold a population crash in the Murchison Falls Park South elephants.

We use a generic formula for age-specific mortality –

$$\textit{Age-specific mortality} = A + B\,e^{-C\,(Age-1)} + D\,e^{E\,(Age-F)}$$

where $A, B, C, D, E$ and $F$ are constants affecting natural mortality as follows –

$A$ is the baseline mortality for all age classes;

$B$ is the mortality in the first year of life (to which A is added);

$C$ defines the decrease in juvenile mortality as age increases;

$D$ sets the amplitude of old age mortality; and

$E$ sets the rate of escalation of old age mortality with age; and

$F$ is the age of onset of old age mortality.

With the constants set at the values shown in **Fig. A2.1** below, the second term in the formula is effectively zero after 6 years of age. The third term in the formula is zero (using a logical function) for all ages up to the value set for $F$.

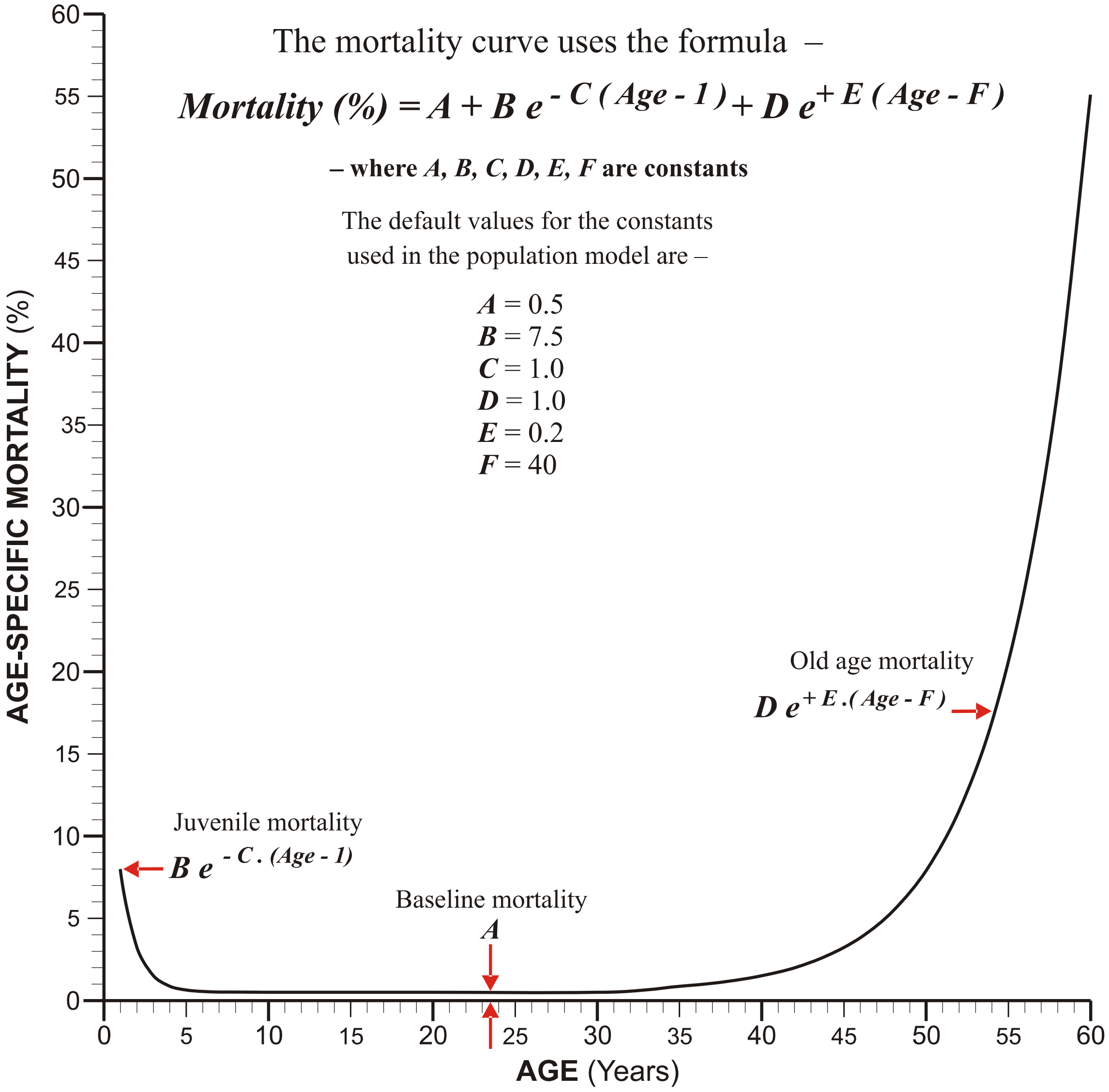

**Figure A2.1: A generic curve for defining age-specific mortality**

### *Adult mortality*

Data on adult mortality are scant. The studies on the key populations in Hwange National Park (Williamson 1976) and the Zambezi Valley (Dunham 1988) do not provide age specific survival curves. Lindeque (1988, Table 6.10) gives age-specific survival schedules for Etosha National Park which indicate a baseline mortality of 4.6% for elephants between the ages of 5-48 years. As the population was more or less stationary (not increasing) in 1983-85 this figure is not useful for an increasing population such as that of Botswana. Moss (2001) gives survivorship curves for the Amboseli elephants from which van Aarde (2008) concluded that baseline adult mortality was 1%. However, there is insufficient precision for this figure to be useful and most of the adult mortality was anthropogenic. Whitehouse & Hall-Martin (2000) show age-specific mortality increasing from 0.5% for animals aged 1-9 years to 3.1% for animals aged 40-49 years in Addo National Park. Their mean annual mortality for ages 1-49 years is 1.8%. This, too, is high compared with the natural mortality required to produce population growth rates in excess of 4%. Craig (1992) gives perhaps the most insightful analysis of the rôle of mortality in large increasing elephant populations (the Sebungwe region in Zimbabwe) and shows that it must be of the order of 0.5%. This is the value selected as our 'typical' value and as the lower limit for the parameter. As mentioned at the start of this subsection, mortality is an 'open-ended' variable so that there is no upper limit to the parameter.

### *Juvenile mortality*

This term is intended to refer to mortality in the first year of life. Data on calf mortality are difficult to collect in the field since carcases of young elephant are usually removed by predators within a few days. Moss (2001) is one of few studies based on direct observations of the disappearance of known individuals and our interpretation of her data suggests a mortality of 8.1% in the first year of life for Amboseli.[46] In a similar type of study, Whitehouse & Hall-Martin (2000) give a mortality of 6.2% in the first year of life for Addo National Park.

Juvenile mortality is most often deduced from elephant life tables. Lindeque (1988) found mortality in the first year of life for Etosha elephants to be about 30%: however, this population was not increasing. Dunham (1988) comments on the susceptibility of juveniles to mortality caused by drought. In Craig's (1992) analysis for the Sebungwe elephants he concludes that juvenile mortality must be low to explain the observed rates of population increase. Van Aarde (2008, Table 3) gives instances in a number of elephant populations where survival in the first year of life is equal to or greater than 94% – which implies a juvenile mortality less than 6%.

Our selected 'typical' value for juvenile mortality is 8% per annum and the lowest value for this parameter is 6%. The highest recorded value in the literature is 41% (van Aarde 2008, interpreting Hanks' (1979) data. However, values up to 100% mortality are possible.

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[46] Moss(2001) gives the survival of males up to 5 years of age as 82% and females as 89%. Taking the average of these percentages and fitting the generic mortality curve given on page 67 to the data requires the mortality in the first year of life to be 8.1%.

## Sensitivity analysis

In this subsection the population simulation model described in **Appendix 4** (page 80) is used to examine the sensitivity of the population rate of increase to changes in the key parameters. All of the simulation runs on which these figures are based were continued until the population had achieved a stable age distribution. In mathematical terms, the population rate of increase $y$ is a function of adult mortality $(x_1)$, juvenile mortality $(x_2)$, intercalving interval $(x_3)$ and age at first parturition $(x_4)$, i.e. –

$$y = Fn\,(x_1, x_2, x_3, x_4)$$

In **Table A2.1** (next page) and **Fig. A2.2** (page 71) we examine the partial derivatives –

$$\frac{\partial y}{\partial x_1} \quad \frac{\partial y}{\partial x_2} \quad \frac{\partial y}{\partial x_3} \quad \frac{\partial y}{\partial x_4}$$

– obtained by varying each of these parameters in turn, *ceteris paribus*.[47]

For each of the parameters, values which result in a rate of population increase greater than zero are shown in the upper of the two tables given for each parameter in Table A2.1. (bottom X axis in each of the four graphs making up Fig. A2.2). The ‘typical’ values are shaded in dark green in the table and the range of recorded values from those giving the highest population rates of increase to those giving the lowest rates are shaded in pale green. Cells shaded in grey are those which fall outside this range. They are included because, for some of the parameters, they demonstrate the very wide range of values which could be tolerated by the population before it actually declined, e.g. intercalving intervals of up to 14 years are sustainable.

Once the value for any population parameter exceeds the threshold at which the population can maintain itself, decline rates expressed as negative percentages have little meaning – the decline is better described in terms of a ‘half-life’ i.e. the time it take the population to halve in numbers. The tables in red font in Table A2.1 and the upper X axes and right-hand Yaxes in Fig.A2.2 show this half life for each parameter. The scales for all left-hand axes in Fig. A2.2 (rate of increase) and all right-hand axes (log scale showing half-life) are identical in all four graphs.

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[47] Wikipedia: “***Ceteris paribus*** is a Latin phrase, literally translated as "all other things being equal or held constant." ... A ***ceteris paribus*** assumption is often fundamental to the *predictive* purpose of scientific inquiry. In order to formulate scientific laws, it is usually necessary to rule out factors which interfere with examining a specific causal relationship. Under scientific experiments, the *ceteris paribus* assumption is realized when a scientist controls all of the independent variables other than the one under study, so that the effect of a *single* independent variable on the dependent variable can be isolated. By holding all the other relevant factors constant, a scientist is able to focus on the unique effects of a given factor in a complex causal situation.”

## Table A2.1: Changes in the rate of increase of an elephant population caused by varying the key population dynamics parameters

### (a) Effects of changes in baseline mortality on population rate of increase

A – Baseline mortality; R – Growth rate; $T_{0.5}$ – Time for population to halve in numbers

| A % | 0 | 0.1 | 0.2 | 0.3 | 0.4 | **0.5** | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R % | 5.27 | 5.17 | 5.06 | 4.95 | 4.85 | **4.74** | 4.21 | 3.68 | 3.15 | 2.63 | 2.10 | 0.00 | 1.57 | 0.51 | 0.00 |

Population halving time for mortality exceeding 5%

| A % | 5.1 | 5.2 | 5.5 | 6 | 7 | 8 | 9 | 10 | 14 | 15.3 | 17.2 | 20.0 | 24.4 | 32.6 | 52.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_{0.5}$ | 538 | 296 | 126 | 64 | 33 | 22 | 16 | 13 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

### (b) Effects of changes in juvenile mortality on population rate of increase

B – Juvenile mortality; R – Growth rate; $T_{0.5}$ – Time for population to halve in numbers

| B % | 1 2 | 4 | 6 |  | **8** | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 61 | 62 | 63 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R % | 5.23 | 5.16 | 5.02 | 4.88 | **4.74** | 4.60 | 4.24 | 3.87 | 3.10 | 2.27 | 1.37 | 0.37 | 0.26 | 0.15 | 0.04 |

Population halving time for juvenile mortality exceeding 63%

| B % | 64 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|
| $T_{0.5}$ | 1,263 | 495 | 129 | 76 | 52 | 46 | 41 | 38 | 34 |

### (c) Effects of changes in intercalving interval on population rate of increase

ICI – Intercalving interval (months); R – Growth rate; $T_{0.5}$ – Time for population to halve in numbers

| ICI | 36 | 39 | 42 | 45 | **48** | 50 | 60 | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 170 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R % | 5.99 | 5.63 | 5.31 | 5.02 | **4.74** | 4.57 | 3.83 | 3.22 | 2.71 | 2.27 | 1.88 | 1.23 | 0.70 | 0.25 | 0.06 |

Population halving time for intercalving interval exceeding 170 months

| ICI | 175 | 180 | 190 | 200 | 210 | 220 | 230 | 240 | 250 | 300 | 350 | 400 | 450 | 500 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_{0.5}$ | 2,276 | 698 | 312 | 210 | 163 | 135 | 116 | 103 | 93 | 67 | 54 | 51 | 45 | 40 |

### (d) Effects of changes in age at first parturition on population rate of increase

A1P – Age at first parturition (years); R – Growth rate; $T_{0.5}$ – Time for population to halve in numbers

| A1P | 8.0 | 8.5 | 9.0 | 9.5 | 10.0 | 10.5 | 11.0 | 11.5 | **12** | 15 | 20 | 25 | 30 | 35 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R % | 5.88 | 5.73 | 5.58 | 5.43 | 5.28 | 5.14 | 5.00 | 4.87 | **4.74** | 4.05 | 3.10 | 2.28 | 1.50 | 0.69 | 0.14 |

Population halving time for age at first parturition exceeding 38 years

| A1P | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_{0.5}$ | 1,299 | 282 | 149 | 103 | 88 | 60 | 53 | 49 | 45 | 42 | 40 | 38 |

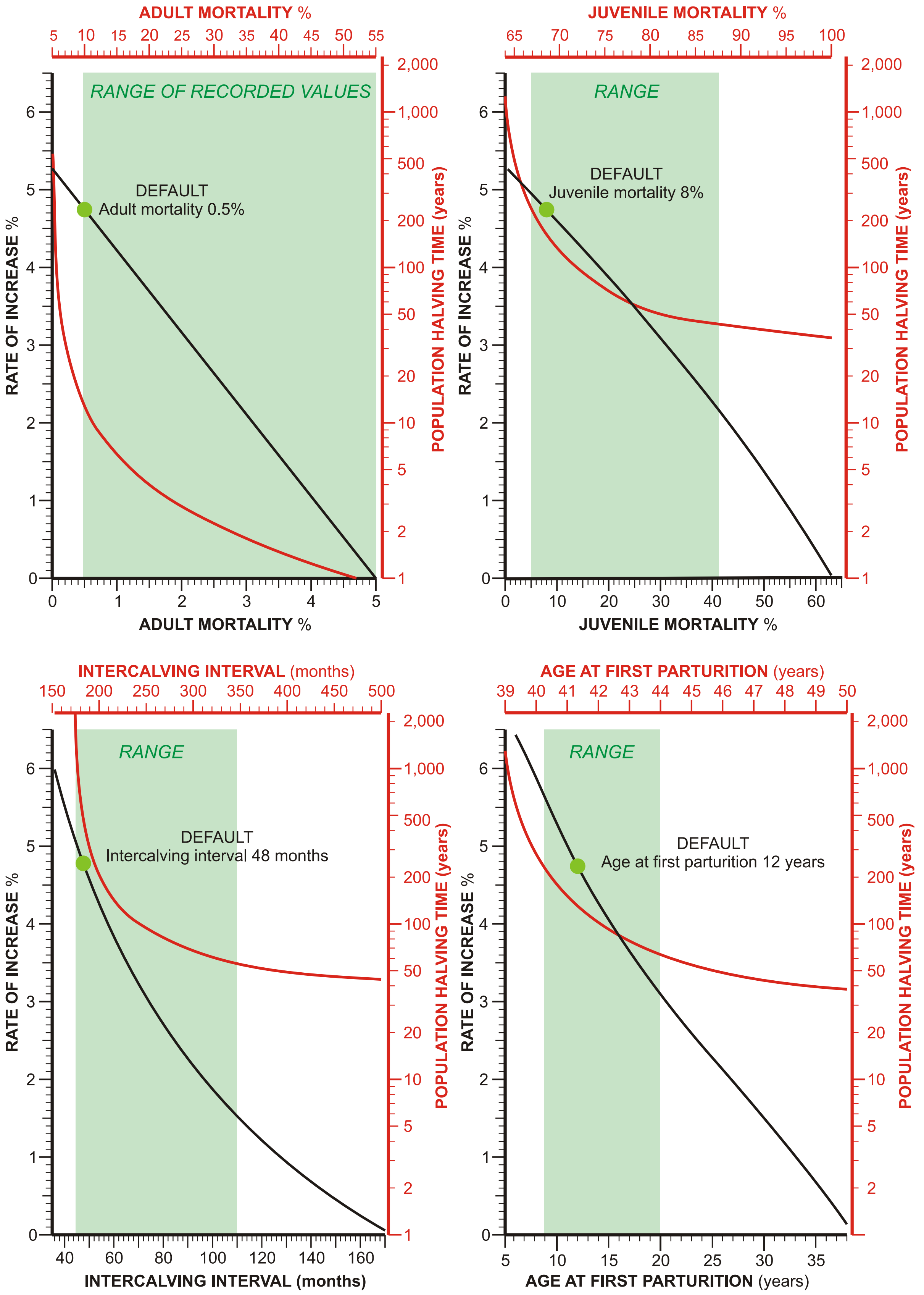


**Figure A2.2: Sensitivity analysis of key population dynamics parameters**

## Interpretation

### Baseline mortality

Table A2.1 (a) and the graph in upper left-hand corner of Fig. A2.2 demonstrate clearly the importance of adult mortality. With the other population parameters set to the default values, an elephant population can tolerate **a maximum of 5% adult mortality before it begins to decline**. When adult mortality is zero an elephant population will not increase more rapidly than 5.27% per year. In the various recorded cases in the literature where populations appear to have increased at higher rates than this, generally it is because they have not achieved a stable age structure or it is because the data apply to too short a time period. When adult mortality exceeds 5%, the half-life of the population may be very short: a mortality of 10% will cause the population to halve in 13 years; 20% will give a half-life of 4 years.

### Juvenile mortality

In contrast, elephant populations can tolerate high levels of juvenile mortality. With the other population parameters set to the default values, juvenile mortality would have to exceed 63% before the population ceased to increase. Moreover, the nature of the decline is very different to that arising from high adult mortality. Even when juvenile mortality is as high as 80%, the population has a half-life of more than 50 years. At the other end of the scale, a very low juvenile mortality does not result in a spectacular increase in the population growth rate: if juvenile mortality were as low as 1% (which is highly unlikely), it would only result in a rate of growth rate of 5.23%.

### Intercalving interval

An intercalving interval of 3 years would give rise to a population rate of increase very close to 6%. However, nothing in the scientific literature indicates that such a value could be sustained for very long. Freeman *et al* (2009) found the range of intercalving intervals exhibited by the Kruger National Park elephants over the period 1976-1995 was 2.29-5.92. Almost every year where the data showed an ICI less than 3 years was followed by a year where the ICI was greater than 4 years. Their overall mean for the twenty year period was an ICI of 3.8 years. It would appear that, in the majority of studies, annual fluctuations in intercalving intervals obscure the long-term mean for the parameter. Hanks (1972) and Laws (1969) show large variations in the numbers of elephants in different age classes which suggests that age-specific fecundity has varied considerably over the life time of the elephants concerned. It may be that the influence of environmental variables (rainfall in particular) will forever frustrate attempts to define a relatively constant state for population parameters and, hence, population age structures.

Whilst low intercalving intervals may, temporarily, give rise to high population growth rates, the converse situation is that elephant populations are remarkably robust to high intercalving intervals. Only when the ICI exceeds 170 months (14 years) would the population begin to decline. And when it does decline, even at an intercalving interval of 40 years (i.e. one calf per female in her lifetime) the half-life of the population is over 40 years. All of this is theoretical: there are no documented cases of inter-calving intervals exceeding 20 years.

### Age at first parturition

Of all four population parameters, age at first birth has perhaps the least influence on the population growth rate – notwithstanding Moss's (2001, page 154) assertion that 'a delay of even one year can slow population growth rates'. It requires little consideration to see why. A long-lived mammal which breeds at a fairly constant rate (one calf every four years) from the age of 12-48 years old is likely to produce 9 calves in its lifetime. This number will not be unduly influenced by the age at which it starts breeding up to the point where it is only able to produce 8 calves in its lifetime. For that to happen requires that it starts breeding at the age of 16 years.

If elephant populations produced their first calf at the age of 8 years old, *ceteris paribus*, it would result in a population growth rate of 5.88%. There no records in the literature of mean ages at first birth much less than 10 years old – which would result in a population growth rate of 5.28%. Far more commonly reported are ages of first birth around 12 years old which give a population growth rate of about 4.74%.

As with intercalving intervals, elephant populations can tolerate very late ages of first birth before they begin to decline. An age of first parturition of 20 years old for Murchison Falls Park South as reported by Laws (1969) still results in a positive rate of population increase of 3% – ignoring changes in other population parameters.

### Summary

The population rate of increase obtained by using 'typical' parameter values (pages 64-67) and those obtained by using the 'minimum' plausible values are shown in **Table A2.2** below.

**Table A2.2: Population rate of increase for default values and minimum values**

| | MORTALITY | | FECUNDITY | | Rate of population increase (%) |
|---|---|---|---|---|---|
| | Adult (%) | Juvenile (%) | ICI (months) | A1P (years) | |
| Default values | 0.5 | 8 | 48 | 12 | 4.743 |
| Minimum values | 0.5 | 6 | 45 | 10 | 5.739 |

ICI – Intercalving Interval A1P – Age at First Parturition

The 'minimum' values do not cause the population rate of increase to reach the level of 6.36% shown by the analysis in **Appendix 1** (page 56). To use lower 'minimum' values for the parameters would place the Botswana elephant population outside the range of documented values. This population is large and has shown a sustained growth rate higher than 6% since 1987 – which means that the odd sporadic case where an elephant population has demonstrated a short mean calving interval does not justify the continued use of such a value.

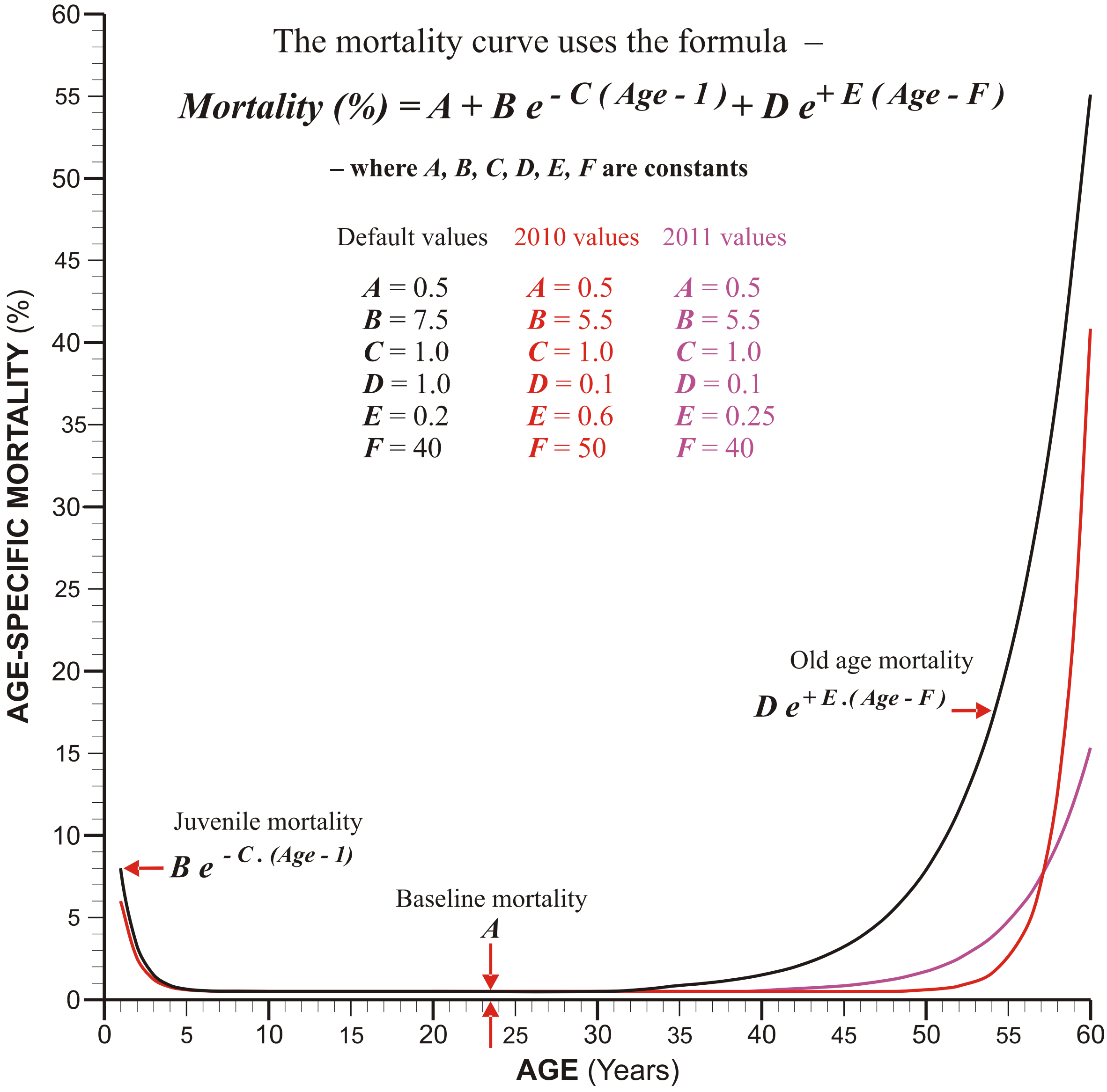
The arguments for a depleted age structure in 1986 (**Fig.A1.3**, page 57) become stronger. Such an age structure produces rates of population increase (**Fig.A1.4**, page 58) which are consistent with the Botswana survey estimates.

## Post Script

As with Appendix 1, this appendix was written prior to the main work done in the study to find a hunting selectivity function which would result in the correct proportions of tusk weights. It was found that the constants initially assumed for old-age mortality (Constants **D,E** & **F** in **Table A2.1** page 67) made it difficult to obtain the required numbers of larger tusks which are in the hunting data. Old-age mortality was adjusted to begin later in life (50 years) and have a steeper slope. The resulting curve (red line) is compared with the default curve of **Fig.A.2.1** (page 67) in **Fig. A2.3** below.

## Post Postscript

It was found necessary to make a further change in the profile of old-age mortality following the adoption of a revised age-tusk weight formula (**Appendix 5**, page 89). The new constants **D,E** & **F** are shown in the diagram below.



The mortality curve uses the formula –

$$Mortality\ (\%) = A + B\,e^{-C\,(Age - 1)} + D\,e^{+E\,(Age - F)}$$

– where *A, B, C, D, E, F* are constants

| Default values | 2010 values | 2011 values |
|---|---|---|
| $A = 0.5$ | $A = 0.5$ | $A = 0.5$ |
| $B = 7.5$ | $B = 5.5$ | $B = 5.5$ |
| $C = 1.0$ | $C = 1.0$ | $C = 1.0$ |
| $D = 1.0$ | $D = 0.1$ | $D = 0.1$ |
| $E = 0.2$ | $E = 0.6$ | $E = 0.25$ |
| $F = 40$ | $F = 50$ | $F = 40$ |

**Figure A2.3: Mortality curve used in simulation model**

# Emigration

Elephants from the northern Botswana population are now dispersing into Namibia (Martin 2004), southern Angola (Chase & Griffin 2004), south-western Zambia (Chase *et al* 2004) and north-western Zimbabwe. Owen-Smith (pers. comm. 2006) remarked on the very large numbers of elephant appearing in parts of the Caprivi where they had not been seen in the past 50 years.

A provision for simulating emigration has been included in the population simulation model (**Appendix 4**, page 80). At the outset of this exercise, the intention was simply to provide for a definable proportion of the population to emigrate permanently each year. The proportion was linked to the density of the population and it was expected that the result would be a continued increasing 'export' of a number of live animals. What was not appreciated was that, **for an increasing population, any sustained emigration will ultimately regulate its numbers**.

To demonstrate this, some starting assumptions are necessary –

(1) The available range for elephants in northern Botswana is 150,000km$^2$;

(2) Elephants will begin emigrating at some threshold density (presumably because resources become limiting). Given the available range, this density translates into a number of elephants ($\mathbf{E_{max}}$). When the population exceeds this number, emigration begins to take place. The population will not regulate at $\mathbf{E_{max}}$ but at some level above it when the number of dispersing animals is equal to the recruitment into the population each year.

(3) When emigration begins, a proportion ($\boldsymbol{q}$ %) of the surplus animals above $\mathbf{E_{max}}$ leave the resident population.

(4) Emigration is deemed to have started prior to 2004.

(5) The level of emigration prior to 2006 could not have been so high that the northern Botswana elephant population was prevented from achieving a population size of about 160,000 animals in 2006.

(6) The asymptote for projected population values should lie below a density of 2/km$^2$ (300,000 elephants). It stretches credibility to believe that northern Botswana could carry a population as high as this: more likely is a population crash before this ceiling is reached or regulation through density- dependent mechanisms (e.g. Laws 1966 – the Uganda elephants).

The type of population growth curve which is generated from this set of assumptions is illustrated in **Fig. A3.1** on the next page. Using the starting population developed in **Table A1.4** (page 59), setting the density threshold at 0.7 elephants/km$^2$ and setting the percentage of surplus animals above the density threshold which emigrate at 3%, results in the population regulating itself at a level of 275,000 elephants. Emigration begins in 1999 when the population first exceeds 105,000 animals and the population is effectively regulated by 2053 when the growth rate falls below 0.1% per annum. The curve follows the dry season population estimates (**Table A1.1** page 52) closely, remaining well within the 95% confidence intervals, and begins to depart from the extrapolated population growth curve after 2006.

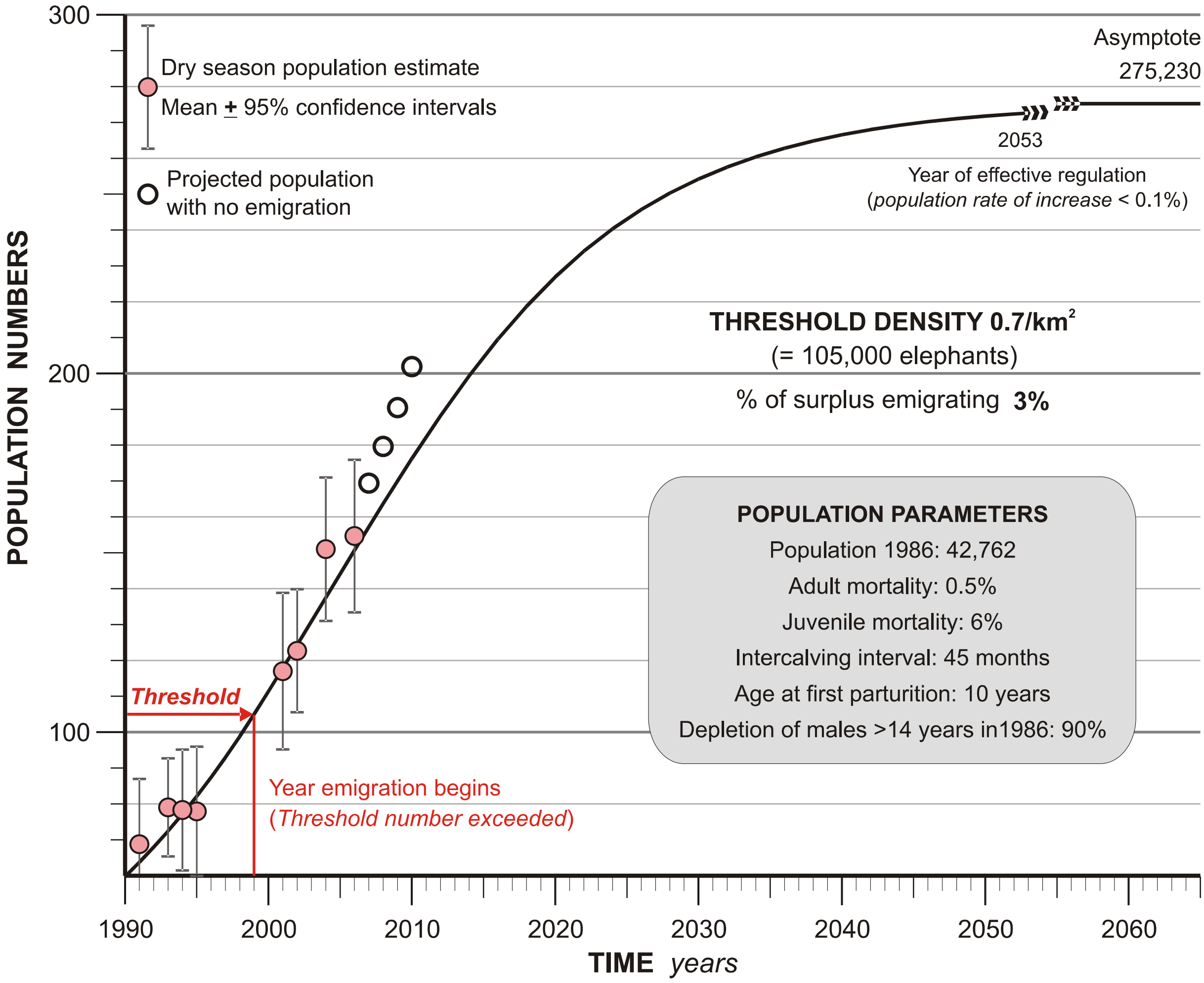


**Figure A3.1: Population regulation by emigration**

Initially we examined a range of threshold densities (densities above which emigration takes place) varying from 0.1-1.0/km$^2$ and a range of values of ***q*** varying from 5-50%. In all simulation runs the starting population in 1986 is assumed to be 42,762 animals (**Table A1.4** page 59) with a depleted male age structure (**Fig.A1.4** page 58) and the population reproductive parameters are those given in **Table A2.2** (page 73, 'Minimum values'). The results are shown in **Table A3.1** on the next page.

The cells shaded grey in Table A3.1 can immediately be ruled out as possible values. For threshold densities less than 0.4/km$^2$ the population levels off too early – below the values of the existing population estimates. For threshold densities greater than 0.8/km$^2$ no emigration takes place until after 2007 – which we know is inconsistent with the observed emigration beginning before 2002. The possible range of threshold densities reduces to 0.5-0.8/km$^2$, (i.e. population sizes of 75,000-120,000 animals) and the emigration percentages above the threshold density need to be less than 20% to remain within the assumed constraints.

This restricted range of densities and emigration percentages is examined in **Table A3.2** (page 78).

## Table A3.1: Emigration – initial examination

POPULATION REGULATES AT – (numbers)

| Density /km$^2$ | $E_{max}$ numbers | Year $E_{max}$ exceeded | Emigration percentage ($q$ %)<br>5 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|---|
| 0.1 | 15,000 | – | 29,200 | 21,612 | 17,820 | 16,540 | 15,906 | – |
| 0.2 | 30,000 | – | 58,300 | 43,106 | 35,588 | 33,072 | 31,776 | 31,040 |
| 0.3 | 45,000 | 1 | 87,618 | 64,814 | 53,384 | 49,606 | 47,702 | 46,558 |
| 0.4 | 60,000 | 6 | 116,784 | 86,372 | 71,204 | 66,140 | 63,594 | 62,068 |
| 0.5 | 75,000 | 10 | 145,964 | 108,002 | 88,974 | 82,658 | 79,504 | 77,596 |
| 0.6 | 90,000 | 14 | 175,194 | 129,602 | 106,776 | 99,198 | 95,380 | 93,114 |
| 0.7 | 105,000 | 16 | 204,442 | 151,162 | 124,564 | 115,732 | 111,296 | 108,620 |
| 0.8 | 120,000 | 19 | 233,514 | 172,738 | 142,360 | 132,236 | 127,190 | 124,146 |
| 0.9 | 135,000 | 21 | 262,746 | 194,388 | 160,170 | 148,794 | 143,090 | 139,666 |
| 1.0 | 150,000 | 23 | 291,970 | 215,956 | 177,972 | 165,310 | 158,972 | 155,182 |

YEARS TO REGULATE (Growth rate falls below 0.1%)

| Density /km$^2$ | $E_{max}$ numbers | Year $E_{max}$ exceeded | Emigration percentage ($q$ %)<br>5 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|---|
| 0.1 | 15,000 | – | 34 | 27 | 16 | 8 | 20 | – |
| 0.2 | 30,000 | – | 33 | 5 | 14 | 11 | 8 | 7 |
| 0.3 | 45,000 | 1 | 44 | 27 | 15 | 10 | 8 | 6 |
| 0.4 | 60,000 | 6 | 48 | 32 | 20 | 16 | 13 | 11 |
| 0.5 | 75,000 | 10 | 52 | 36 | 24 | 20 | 17 | 15 |
| 0.6 | 90,000 | 14 | 55 | 39 | 28 | 23 | 20 | 18 |
| 0.7 | 105,000 | 16 | 58 | 42 | 30 | 25 | 23 | 21 |
| 0.8 | 120,000 | 19 | 60 | 44 | 33 | 28 | 25 | 24 |
| 0.9 | 135,000 | 21 | 63 | 47 | 35 | 30 | 27 | 26 |
| 1.0 | 150,000 | 23 | 64 | 48 | 37 | 32 | 29 | 28 |

As in Table A3.1 above, there are only a limited range of values in the cells of **Table A3.2** (next page) which satisfy the constraints imposed by the initial assumptions. Combinations of threshold densities and emigration percentages which result in the population regulating above 300,000 animals are 'out of range'. Similarly, combinations of threshold densities and emigration percentages which result in the population regulating below 160,000 animals in 2006 (the last air survey estimate of the population) are also 'out of range'.

For a threshold density of 0.8 elephants/km$^2$, the acceptable emigration percentages are from 4%-12% which result in the population being regulated between 163,000-264,000 animals. This is a convenient threshold density to display the various levels at which the population will regulate depending on the percentage of the surplus above 120,000 animals (**Fig. A3.2** page 79).

## Table A3.2: Emigration – detailed range of values

| Population density (/km$^2$) | 0.5 | 0.6 | 0.7 | 0.8 |
|---|---|---|---|---|
| Emigration threshold ($E_{max}$) | 75,000 | 90,000 | 105,000 | 120,000 |
| Year emigration starts | 1994 | 1997 | 1999 | 2002 |
| Emigration percentage (***q*** %) | POPULATION REGULATES AT – | | | |
| 2 | 259,970 | 311,974 | 363,892 | 415,936 |
| 3 | 196,678 | 236,010 | 275,230 | 314,570 |
| 4 | 164,950 | 198,004 | 230,988 | 264,006 |
| 5 | 145,968 | 175,180 | 204,440 | 233,512 |
| 6 | | 159,952 | 186,634 | 213,302 |
| 7 | | 149,104 | 173,910 | 198,802 |
| 8 | | | 164,414 | 187,938 |
| 9 | | | 157,106 | 179,488 |
| 10 | | | 151,167 | 172,738 |
| 11 | | | | 167,260 |
| 12 | | | | 162,602 |
| 13 | | | | 158,742 |

| Emigration percentage (***q*** %) | YEAR REGULATION EFFECTIVE | | | |
|---|---|---|---|---|
| 2 | 2058 | 2062 | 2065 | 2067 |
| 3 | 2046 | 2050 | 2053 | 2055 |
| 4 | 2037 | 2041 | 2045 | 2047 |
| 5 | 2029 | 2034 | 2038 | 2041 |
| 6 | | 2029 | 2033 | 2036 |
| 7 | | 2025 | 2028 | 2032 |
| 8 | | | 2025 | 2028 |
| 9 | | | 2023 | 2026 |
| 10 | | | 2021 | 2024 |
| 11 | | | | 2022 |
| 12 | | | | 2021 |
| 13 | | | | 2020 |

The population curves for a threshold density of 0.5 elephants/km$^2$ (emigration beginning when the number of elephants exceeds 75,000) are the least likely because they begin regulating too early and do not fall within the confidence intervals for the 2004 and 2006 air survey estimates. The curves for a threshold density of 0.6 elephants/km$^2$ barely fall within these confidence intervals. All of the curves for threshold densities of 0.7/km$^2$ and 0.8/km$^2$ fit closely with the population estimates and, depending on the selected emigration percentage, will produce populations which regulate between 160,000-300,000 elephants. There is no easy way to be more precise than this.

The family of curves for a threshold density of 0.8 elephants/km$^2$ shown in Fig.A3.2 on the next page are all plausible. For all of the curves, emigration begins when the population exceeds 120,000 animals. For population modelling purposes we have selected the most central curve which uses a percentage of 6% of the surplus above the threshold number (120,000 elephants). The population regulates at a level of 213,000 animals which it effectively reaches by 2036.

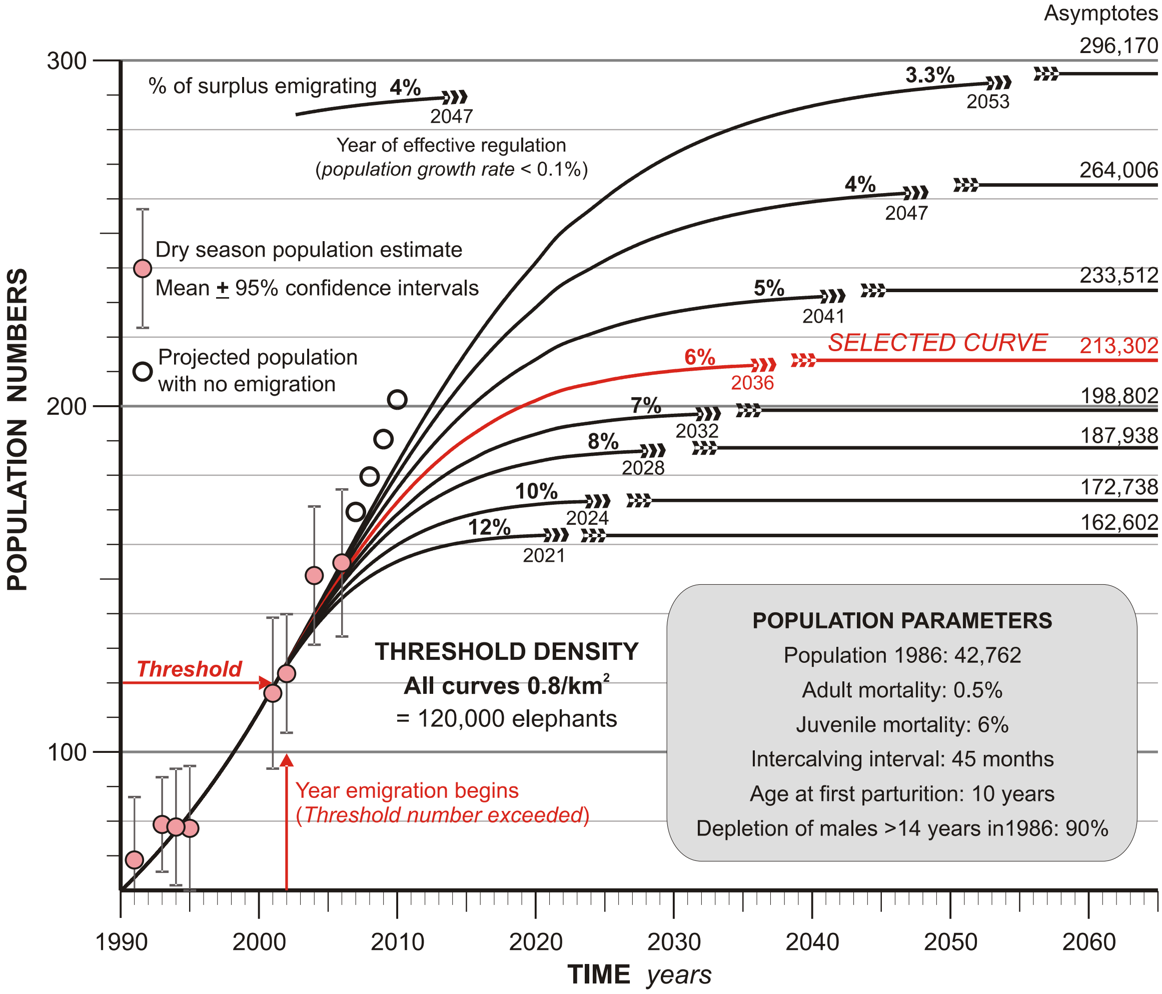


**Figure A3.2: Emigration curves for a threshold density of 0.8 elephants/km$^2$**

This exploration of mechanisms to define emigration and the population curves which result from it may appear highly speculative. We justify the exercise on the grounds that, whilst the population simulation model may satisfactorily explain the history of trophies obtained from the northern Botswana elephants, if it is to be useful then it should be able to predict the trophies which may be obtained in the future under various management quotas. And to do this requires plausible hypotheses about how the population will increase and how it will ultimately be regulated.

## Post Script

In the course of modelling the trophy hunting the emigration parameters were modified slightly. The threshold density was set at 0.7/km$^2$ giving a threshold number of 111,393 animals above which emigration takes place. The population exceeds this number in the year 2003. The number of elephants emigrating each year was set at 15% of the surplus above the threshold and this regulates the population at some 142,200 animals by the year 2025. The population growth curve for these parameters is shown in **Fig.3** (page 6) in the main report.

# Population Simulation Model

The population simulation model used in this study is similar to that used in developing the Namibian Elephant Management Plan (Martin 2004) which was refined in the Elephant Management Plan for Savé Valley Conservancy in Zimbabwe (Martin 2006a) and has been further modified here. The model consists of 12 linked spreadsheets which operate as a 'birth-pulse' system (**Fig.4** page 8). It behaves in a manner similar to the Leslie matrix (Leslie 1984) but the calculations of births and deaths are separated into successive operations because it is designed to cycle within the row operations of a computer spreadsheet. A single key-press causes the model to carry out all the calculations for one year and advance to the next year.

The functioning of the spreadsheets shown Fig.4 are as follows –

**A** – The main reproductive, management and financial parameters are defined here (except where otherwise stated on the sheet) and, for any particular simulation run, the management functions can be enabled or disabled (e.g. if it is desired to carry out a simulation run with no hunting and no emigration from the population, this is specified here).

**B** – The **starting population** is defined here by setting the overall size of the population and the numbers in all male and female age classes. The model runs on a counter for each iteration and in the first year it uses the population defined here. In all successive years, the 'running cohort' is the population from the year before (obtained after completion of the mortality calculations on spreadsheet **I**).

Various options are provided for the starting population. It can have a stable age structure or be any 'custom' population defined by the user. The overall sex ratio of the population can be adjusted to give any desired ratio of males to females.[48] Specifically for the Botswana situation, the degree of depletion of males older than any specified age can be set to any desired proportion (see **Fig.A1.3**, page 57).

Whatever combination of options is selected for the starting population, the final stage on this spreadsheet is to adust its overall size so that it is exactly equal to the size specified at the start of the sheet and the numbers in all the age classes are integers. This is achieved by rounding the population so that there are no fractions and, when the total of the rounded numbers does not match the specified number (as is usually the case), animals are added to or deducted from the age classes. The selection of which age classes to increase or decrease is done by ranking the fractional numbers before rounding and selecting the values which were closest to being included or excluded.

**C** – The annual **breeding** of the population is done on this sheet. The intercalving interval is specified in months and converted to a fecundity value (12/ICI) which is the average number of calves (of both sexes) produced per year per female. The mean age at first conception is specified together with a standard deviation which allows a spread of fecundities either side of the mean.

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48. To achieve the desired sex ratio only the number of males is adjusted. Later, in the same spreadsheet, the size of the population is adjusted to satisfy the initial size specified.

Provision is made for defining a peak in fecundity values for any particular age class and, by defining a standard deviation and scaling factor, the effect of this peak can be very sharp (i.e. affecting only a few age classes) or broadly spread over a number of age classes. The decline in fecundity with old age is catered for by specifying the mean age for the onset of decline and a standard deviation which determines how sharply fecundity declines with increasing old age.

The modelling technique used here is novel, relying on a probability of calving for each age class which is the sum of the probabilities for three different normal distributions (**Fig.A4.1** next page).

Age at first parturition is defined by a mean and standard deviation and a cumulative normal distribution (logistic curve) shapes the probabilities of calving for ages each side of the mean (Curve ① in Fig.A4.1). For ages less than the defined age at first parturition minus two standard deviations the value of this curve is effectively zero: for ages greater than the defined age at first parturition plus two standard deviations the value of this curve is effectively unity. The logistic curve can be shifted in either direction on the x axis simply by changing the mean age at first parturition.

A peak in fecundities can be defined for any age class by setting the age, standard deviation and a scaling factor which determines the magnitude of the peak (Curve ② in Fig.A4.1). A standard normal distribution is shaped around this mean with the standard deviation setting the width of the curve and a scaling factor setting the height of the peak. The normal distribution can be shifted in either direction on the x axis simply by changing the age at which the peak occurs. If a peak is not desired the scaling factor is set to zero.[49]

The decline in fecundity with old age also uses a cumulative normal distribution (Curve ③ in Fig.A4.1) with the mean age for onset of decline and the standard deviation being defined. As with age at first parturition, the logistic curve can be shifted in either direction on the x axis simply by changing the mean age at which fecundity begins to decline. Low values for the standard deviation allow the decline to be very steep and high values enable it to be spread over one or two decades.

When Curve ③ is subtracted from Curve ①, it results in a probability distribution which starts at zero, rises to a plateau of unity and then declines towards zero at the end of life (Curve ①- ③ in Fig.A4.1). When the values for this distribution are multiplied by the mean fecundity it results in age-specific fecundities.

When Curve ② is added to the previous curve, it can no longer be called a ‘probability distribution’ because it may contain values greater than unity. However, the resulting distribution can be multiplied by the mean fecundity to give values greater than the mean fecundity for certain age classes (Curve ① + ② - ③ in Fig.A4.1). This is illustrated in **Fig.A4.2** (page 83).

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[49] Several authors describe a peak in fecundity at a particular age (e.g. Hanks (1972) – 18-19 years; Whitehouse & Hall-Martin (2000) – 25-29 years; Laws *et al* (1970) – 31-35 years). However, we have not incorporated this feature into our analysis although the simulation model provides for it, preferring the interpretation of Moss (2001) who found fecundity to be ‘relatively constant from the ages of 16-40 years’.

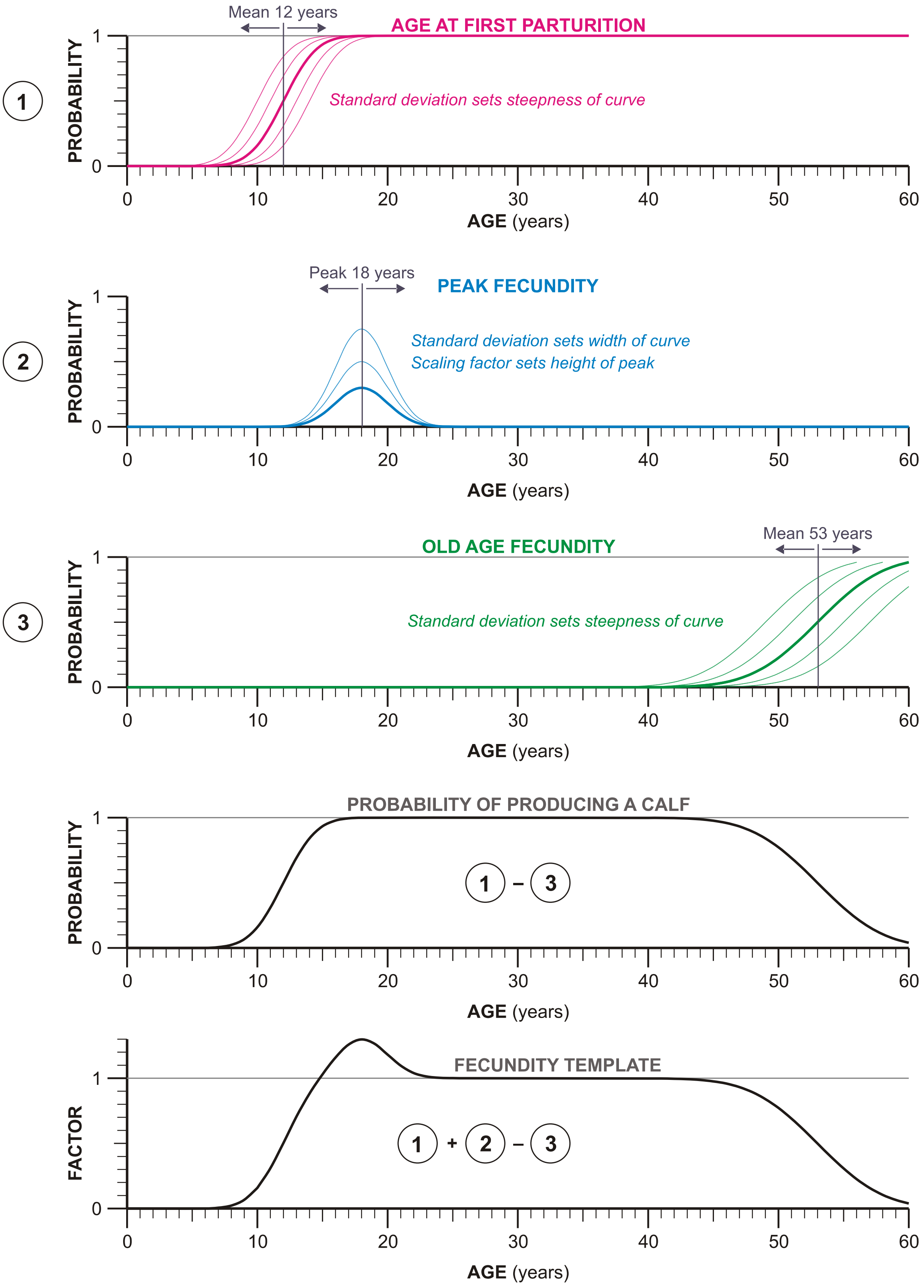

**Figure A4.1: Use of three normal distributions to set up age-specific fecundities**

Fecundities for each age class are arranged in a row vector and multiplied by the numbers of females in each age class. The resulting vector is summed to give the total crop of calves which is then halved to give numbers of male and female calves (if a sex ratio at birth other than 1:1 is specified the crop of calves is divided into the appropriate proportions). The numbers in each age class of the existing vectors of males and females are then advanced by one cell (i.e. each animal ages by one year) and the new crop of calves is inserted in the first cell of each vector. This is the population at the start of the management year.

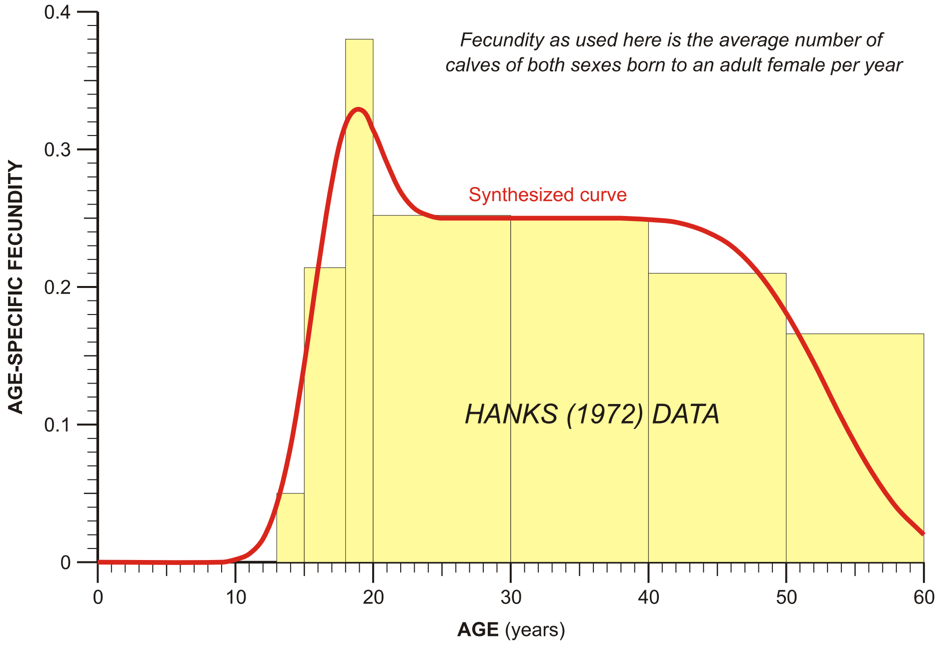

**Figure A4.2: Synthesized age-specific fecundity curve**

The next four spreadsheets each deal with a particular management activity. All of these spreadsheets contain algorithms which ensure that an integer number of animals is deducted from each age class using the technique described for Spreadsheet **B** (page 80).

**D** – The losses due to **illegal hunting** are calculated and subtracted from the population. The assumption is that illegal hunting affects all age classes equally – which might be true if hunting were for meat or to eradicate unwanted elephants. It would not be true if illegal hunting were for ivory. This spreadsheet was not used in the simulations – it was assumed that illegal hunting was negligible northern Botswana. The Background hunting quota used in the Hunting spreadsheet (Sheet **G**) also caters for a low level of illegal hunting.

**E** – **Culling** entails the removal of animals in breeding herds (all males up to the age of 10 years and all female age classes). The inclusion of males older than 10 years in the numbers culled (i.e. they happen to present in a cow herd at the time of culling) is determined by a probability function which is less than unity and which decreases with increasing age of males. This sheet allows the specification of a percentage offtake, or a fixed number from the population, or the surplus above a specified carrying capacity to be removed in any selected year.

Provision is made for a specified number or proportion of calves between the ages of 3-10 years to be captured and sold as live animals as part of the culling operation.

The financial returns from ivory, meat and skin derived from culling are calculated.

Since there is no culling taking place in Botswana, this sheet was not used in the main analysis. If management policies changed it might have some application. If complete breeding herds were to be captured and translocated, the culling spreadsheet could be used to assess the impact on the population.

F – **Problem animal control** (PAC) includes males and females older than 14 years of age in the simulation model. Options are provided to remove a fixed number or percentage or a number related to the elephant density. This sheet has also not be used in this study as the numbers of elephants killed as 'problem animals' in northern Botswana is low. Problem animals tend to be handled under the hunting quotas issued for Controlled Hunting Areas. The provision of a quota for 'Background hunting' in the Hunting spreadsheet also caters for a limited PAC offtake.

G – **Sport hunting**: Since this is the main application of the simulation model in this study, the techniques used for simulating trophy hunting are presented separately (**Appendix 6**, page 90). The sheet allows for specification of a percentage offtake, or a set of percentage offtakes specified as part of a 'hunting regime' or automatic quota setting through the control system defined on Sheet **L**. Mean tusk weights from the hunting offtake are calculated from age-specific allometric schedules.

This completes the spreadsheets analysing the management regime. For each sheet the total and net income to be expected from sale of meat, skin and ivory is calculated and, for trophy hunting, the income generated from trophy fees and daily rates is estimated.

H – **Emigration**: This is a new sheet which has not been included in previous models (Martin 2004 & 2006). It provides for emigration from the population when its density exceeds a certain threshold. The specified density is converted to a number of elephants and when the population exceeds this number emigration begins. The numbers leaving the population are a specified percentage of the surplus animals above the threshold number. Emigration is assumed to affect both sexes and all age classes in the same proportion.[50] The rationale for inclusion of emigration in the model and the effects of the selected threshold and proportion emigrating are explored in **Appendix 3** (page 75). Emigration is applied to the population before natural mortality.

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50. To some extent this is a simplification. Observed dispersal from elephant populations usually consists of mature males at the start and this is later followed by cow herds.

**I** – **Natural mortality** is the last of the spreadsheets in which population numbers are modified in the course of an annual cycle. The model assumes that age-specific mortality is the same for both sexes in the absence of any data for the Botswana elephants which might indicate otherwise.[51] The age-specific mortality schedule uses the formula given in **Appendix 2** (page 67) and the analysis is performed simply by multiplying the numbers in each age class by the age-specific mortality in a row vector operation. As with the previous spreadsheets, an algorithm operates to ensure that an integer number of animals is deducted from each age class using the technique described for Spreadsheet **B** (page 80).

This sheet also calculates the total amount and value of ivory both on the living elephants and from the animals expected to die naturally.

After natural mortality has been applied, the final population vectors (males and females) become the starting population for the next year.

**J** – This sheet summarises each year of management giving the numbers at the start of the year, the numbers of animals dying in each category of management and through natural mortality, and the population at the end of the year. The population growth rate is calculated and the results are displayed graphically .

The spreadsheet software is set to 'manual operation', and the model is advanced one year at a time by a keypress. By keeping the key depressed, the model will run continuously within the speed limitations of the computer. Any particular run of the model is terminated on this page by the Reset button.

**K** – This sheet keeps an overall record of the results for each year in any simulation run, including all of the population dynamics information, the management information (offtakes, mean tusk weights etc.) and a full financial record of all gross and net income earned from management.

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51. Moss (2001) found male mortality was significantly higher than female mortality for all age classes in the Amboseli elephants in Kenya. However, the conditions affecting this population differ from those affecting the Botswana elephants. From the low Amboseli population growth rate it can be deduced that the elephants are probably at a density where self-regulating mechanisms are operating.
.

## Tusk Weight versus Age

Attempts have been made using limited data sets to construct the relationship between elephant tusk weight and age (Perry 1954, Elder 1970). The largest data set assembled (1,116 male tusks and 1,399 female tusks) is that collected by R.M. Laws from elephants culled in Kenya, Tanzania and Uganda between 1965-1969 . These data were analysed by Pilgram & Western (1986) to give the relationship for a single male elephant tusk –

$$Age = e^{(1.76 + 0.58 \ln weight)} \text{ years}$$

This converts to –

$$Tusk\ weight = 0.04596\ Age^{1.7241} \text{ kg}$$

However, when this relationship is plotted on the scatter diagram with the original regression line (Pilgram & Western 1986, Fig.4) it does not coincide exactly with the line. To achieve a ‘perfect’ match the constants need to be modified very slightly to –

$$Tusk\ weight = 0.04535\ Age^{1.731} \text{ kg} \quad (1)$$

This is the relationship we initially intended to use in the population simulation model. It is less than ideal because the data are derived from eastern rather than southern Africa. Parker (1979) described various ‘races’ of African elephants based on their tusk characteristics. The northern Botswana population falls in his category of “western savanna elephants” and displays distinctly different tusk characteristics from those used to derive the relationships defined by Pilgram & Western (1986). Botswana tusks tend be greater in circumference but shorter in length than “eastern savanna elephants”.

Craig (this study) assembled sufficient data from Botswana and the Sebungwe region in Zimbabwe to allow the development of an alternative formula –

$$Tusk\ weight = 0.0663\ Age^{1.645} \text{ kg} \quad (2)$$

This is the relationship we have used in the population simulation model and the two curves are shown in **Fig.A5.1** (page 89).

The method of simulating hunting (**Appendix 7**, page 98) requires a measure of the scatter of tusks for any given age. We used Pilgram & Western’s original data in two stages to arrive at a measure of the standard deviation of the relationship. Firstly, two curves were drawn by eye to include all of the male tusks shown in Pilgram & Western (1986, Fig.4). These were treated as the upper and lower 95% confidence intervals and the curves were described by allometric relationships of the same form as shown in Equation (1) above, i.e –

$$Std\ Dev = A\ .\ Age^{B}$$

The age-specific standard deviations were derived by dividing the upper and lower confidence intervals for each age by 1.96 (**Method 1**). An examination of the resulting relationships suggested that the curves for both the upper and low confidence intervals shared an exponent not greatly different to that describing the mean tusk weight (i.e. 1.731), although they are not symmetrical about the mean.

We then repeated the exercise using the value of 1.731 as the index controlling the rate of increase of the standard deviations (**Method 2**). The difference between the results from the two exercises was negligible (**Table A5.1** below).

**Table A5.1: Derivation of upper & lower standard deviations for age-specific tusk weights**

| | A | B | SS |
|---|---|---|---|
| Upper Standard Deviation | | | |
| Method (1) | 0.0177 | 1.7588 | 5.902 |
| Method (2) | 0.0196 | 1.7310 | 5.918 |
| Lower Standard Deviation | | | |
| Method (1) | 0.0140 | 1.6801 | 0.415 |
| Method (2) | 0.0115 | 1.7310 | 0.507 |

SS – sum of squared differences derived by comparing the standard deviations derived graphically with the standard deviations predicted by the allometric formula

For Pilgram & Western's data the following expressions give good approximations of the standard deviations above and below the mean –

$$\textit{Upper Standard Deviation} = 0.0196 \,.\, \textit{Age}^{\,1.731}$$

$$\textit{Lower Standard Deviation} = 0.0115 \,.\, \textit{Age}^{\,1.731}$$

The 95% confidence intervals given by these formulae are shown in **Fig.A5.1** (page 89). The asymmetrical relationship between the upper and lower standard deviations is not of much importance in the modelling of the trophy hunting in Botswana – we are primarily concerned with the upper standard deviations because the overwhelming number of trophies come from animals carrying tusks which are greater than the mean for every age class. However, the simulation model takes into account both standard deviations and if the tusk weight is below the mean the lower standard deviation is used.

The key values from Pilgram & Western's and Craig's formulae appear in **Table A5.2** .

**Table A5.2: Comparison of age-tusk weight relationships**

| | Tusk wt kg = A. Age$^B$ | | 95% Confidence intervals | | Standard deviations | |
|---|---|---|---|---|---|---|
| | A | B | Upper | Lower | Upper | Lower |
| P&W (1986) | 0.0453 | 1.731 | 0.0384 | 0.0225 | 0.0196 | 0.0115 |
| Craig (2010) | 0.0663 | 1.645 | 0.0441 | 0.0265 | 0.0225 | 0.0135 |

All formulae use the same exponent B and the values given in columns 3-6 are for the constant A

## **Post Script** (1st April 2011)

The Craig Age-Tusk weight formula referred to in the preceding text (page 86) was developed in November last year. This formula was used in all the main simulation runs described in Chapters 3 and 4. In March this year Craig advised as follows –

> *The result I got initially was based on a regression of log weight upon log age. However, regression assumes the independent variable is measured with absolute precision and the deviations are due to the dependent variable. This is the opposite of what we have where weight is measured with absolute precision but age is not and I have become aware of how poor the precision of estimated age is and always will be. That will lead to the slope being too shallow. So the logical thing to do is regress age upon weight and invert the equation to get the expression we want. The problem then is we still have imprecision in weights (drying out; rounding off; mislabelling jaws; uneven spread; etc.) and that will tend to make the line a bit too steep. So I've compromised and instead of using a regression line I've taken the principal axis of the scatter. Rather than minimising squared deviations about the line on one of the axes, this minimises the squared deviations perpendicular to the line itself. It's the line that would be closest to what you'd draw by eye and can be used as a measure of a functional relationship when there is variation on both axes. Doing this I get –*

$$\textit{Tusk weight} = 0.05713\ \textit{Age}^{\,1.72325}\ \text{kg}$$

> *– which is close to Pilgram & Western (1986) for the slope but not for the intercept, which may be because of the different scale of ages allocated.*

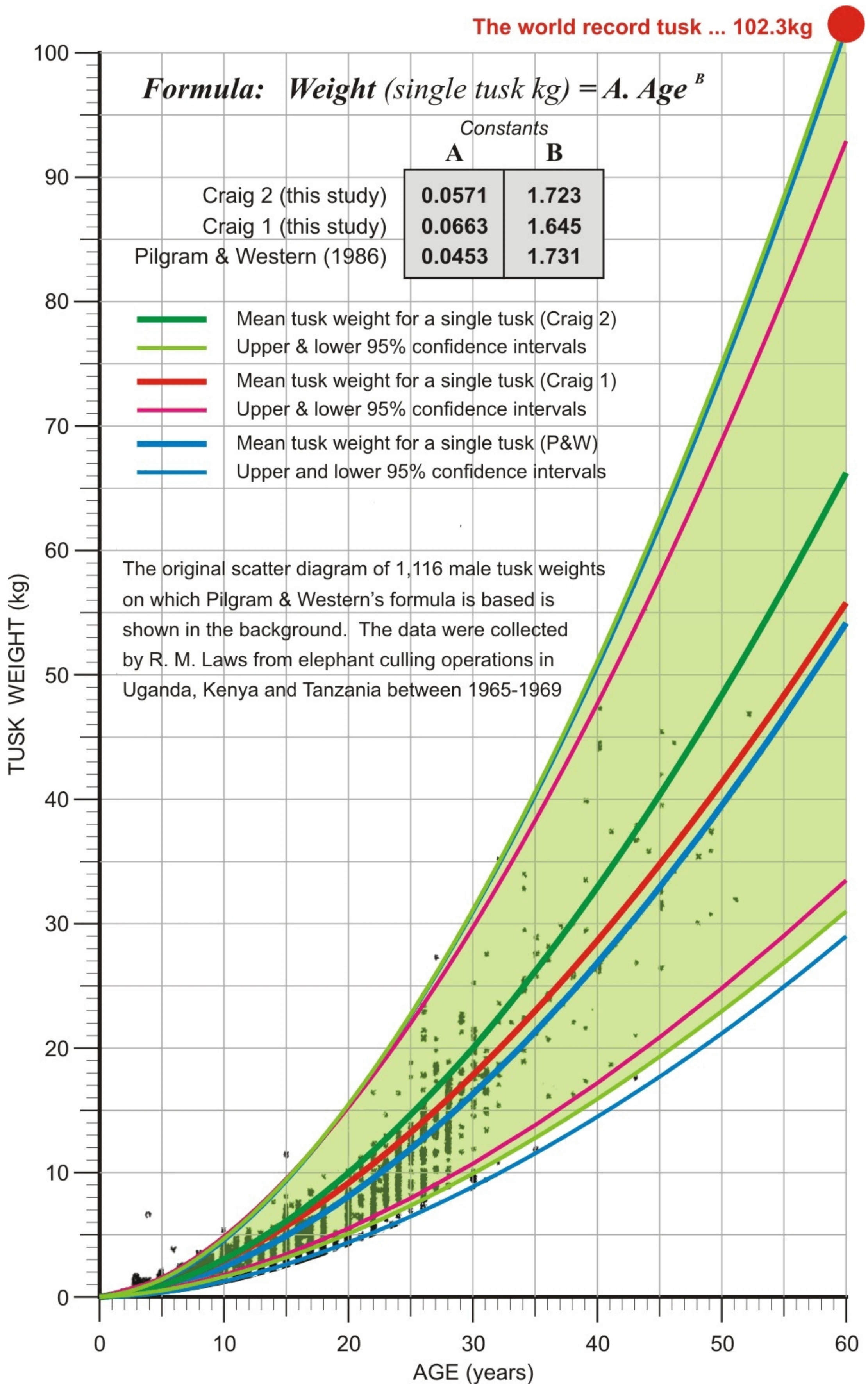
Craig's previous formula (Craig 1), this new formula (Craig 2) and Pilgram & Western's formula are shown in **Fig.A5.1** on the next page together with the curves for the upper and lower 95% confidence intervals.

The new formula has been incorporated into the simulation model for all the future predictions given in Chapter 5. The simulation model requires the upper and lower standard deviations associated with this formula (paragraph (3)(b), page 91) and the values used are –

$$\textit{Upper Standard Deviation} = 0.016067\ .\ \textit{Age}^{\,1.72325}$$

$$\textit{Lower Standard Deviation} = 0.010358\ .\ \textit{Age}^{\,1.72325}$$

The new formula (Craig 2) generates more large tusks in the upper age classes than the previous formula (Craig 1). To compensate for this, another revision has been made to the old-age mortality formula discussed on page 74.



***Formula:*** **Weight** *(single tusk kg)* = **A. Age** $^B$

*Constants*

| | A | B |
|---|---|---|
| Craig 2 (this study) | **0.0571** | **1.723** |
| Craig 1 (this study) | **0.0663** | **1.645** |
| Pilgram & Western (1986) | **0.0453** | **1.731** |

The original scatter diagram of 1,116 male tusk weights on which Pilgram & Western's formula is based is shown in the background. The data were collected by R. M. Laws from elephant culling operations in Uganda, Kenya and Tanzania between 1965-1969

**Figure A5.1: Male Tusk Weight versus Age**

# Techniques for Simulation of Trophy Hunting

The basic functioning of the simulation model was described in **Appendix 4** (page 80). This appendix describes the calculations carried out in spreadsheet **G** of the model.

### Initial conditions

A range of options for any simulation run are presented and the user selects the combination of options that are needed for the particular analysis –

(1) The year in which the simulation run will start[52] (thereafter the model runs in fixed increments of one year);

(2) Whether the model will use the actual quotas from the hunting data over the years 1996-2010 or a specified percentage of the population. If actual quota data is to be used, the option is given to use the total numbers hunted (Column 'Got' in **Table 2**, page 10) or the numbers hunted in the 18 highest-ranking concessions (Column N in **Table 6**, page 15). This table appears at the top of the spreadsheet and is referenced during the simulation run.[53]

| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full nos | 33 | 51 | 99 | 112 | 157 | 133 | 131 | 148 | 141 | 168 | 228 | 236 | 262 | 272 | 219 | *300* |
| 18 top CHAs | 21 | 39 | 75 | 94 | 138 | 120 | 126 | 130 | 131 | 158 | 204 | 219 | 246 | 259 | 215 | *300* |

(3) The level of 'Background hunting' is specified as a percentage of the total population. Background hunting (Bg – Footnote 8) is assumed to take place in every year of any simulation run and is added to the quotas given in the table above. It provides for a small offtake of animals in the years 1986-1995 before the first quotas were set.[54] If this is set to zero, the trophy outcome in 1996 is a crop of 100 pounders (which is not what happened)!

If it is desired to test the outcome of a quota which is a fixed percentage of the total population rather the actual numbers hunted, this percentage is set under Bg. We use it specifically in the next chapter where we examine future hunting projections.

The total quota to be hunted in any given year of the simulation run appears as the sum of the options selected under (2) & (3) above.

(4) The tusk weight-age formula is selected. A table similar to **Table A5.2** (page 87) is shown where Pilgram & Western's formula, Craig's formula or a user-specified formula can be chosen. Included in the table are the constants need to calculate the upper and low standard deviations.

(5) The proportion of the total population which is inside protected areas is specified. This allows calculation of the 'huntable' population outside parks (see paragraph 3, page 9).

---

[52] In our tests we usually start the model in 1986 which is the year before the first population survey estimate (**Table 1**, page 4).

[53] In simulation runs which go beyond the year 2010, the model uses the quota number set for 2011. This number can be altered during the course of the run.

[54] Typically in most of the simulation runs in this study, Bg has been set at 0.03% of the total population. This is large enough to prevent the crop of 100 pounders in 1996 referred to above.

(6) The minimum tusk weight to be used during the simulation run is specified. If it is desired that the model should generate all of the tusks for weight classes 2-8 (see **Table 5** page 14), this needs to be set at 14kg. However, this results in thousands of tusks being generated and can slow down the speed at which the simulation model runs. Generally, in most of the simulation runs it is only necessary to generate slightly more tusks than will be hunted in the year concerned and the minimum tusk weight can manipulated during the run to ensure maximum computer speed.

### Model operation

The Quattro Pro software used in the model is set to Manual and Row-wise Calculation. Each key-press of F9 advances the model by one year. The figures shown in the tables which follow are for the year 2004. The model has run since 1986 when the starting population was 42,762 animals with the males older than 20 years depleted by 75%.

(1) A vector with 60 cells at the top of the sheet contains the population brought forward from the previous spreadsheet (Sheet F – Problem Animal Control) –

| Age | 1 | 2 | 3 | 4 | 5 | ➤ | 38 | 39 | 40 | 41 | 42 | ➤ | 56 | 57 | 58 | 59 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Males | 4577 | 4062 | 3738 | 3485 | 3265 | ➤ | 340 | 292 | 252 | 181 | 127 | ➤ | 13 | 13 | 8 | 7 | 4 |
| Females | 4577 | 4062 | 3738 | 3485 | 3265 | ➤ | 419 | 391 | 365 | 341 | 318 | ➤ | 125 | 113 | 98 | 81 | 60 |

| | |
|---|---|
| **Total males** | **64157** |
| **Total females** | **67920** |
| **Total population** | **132077** |

(2) The 'huntable' population of males older than 20 years (population outside protected areas) is calculated (see (5) on the previous page) and appears in a vector with 40 cells –

| Age | 21 | 22 | 23 | 24 | 25 | ➤ | 38 | 39 | 40 | 41 | 42 | ➤ | 56 | 57 | 58 | 59 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Males | 897 | 845 | 792 | 745 | 699 | ➤ | 255 | 219 | 189 | 136 | 96 | ➤ | 10 | 10 | 6 | 6 | 3 |

| | |
|---|---|
| **Total males** | **10739** |

(3) There follows a group of 8 rows which contain the key numbers needed to calculate the tusk weights in each age class for individual elephants. The rows are shown in the table on the next page and the abbreviations are given below –

(a) **MTW** – Mean tusk weight which is calculated from the selected age-tusk weight formula (paragraph (4) on the previous page);

(b) **USD** – the Upper Standard Deviation which applies to all tusks above the MTW;

(c) **LSD** – the Lower Standard Deviation which applies to all tusks below the MTW;

(d) **SAS%** – the percentage of the population which would be present in each age class of the males in an undepleted, unhunted population with a stable age structure. This figure is taken from the proportions of females in each age class in the population.

(e) **P0** – these are the projected numbers of males expected in a stable age structure population of this size calculated from the SAS% above.

(f) **P1** – these are the actual numbers of males (according to the model) present in each age class from 21-60 years taken from (2) on the previous page.

(g) Ratio **P1/P0** – this the ratio of **P1** (para (f) above) to **P0** (para (e) above). It is a measure of the degree of depletion in the age class and sets the entry point for calculating probabilities (explained further in **Probabilities**, page 94).

(h) ▼ Nabla – this is the increment attached to each animal in the age class which is used for calculating probabilities. This is explained further in the section **Probabilities**.

$$\blacktriangledown = \mathit{1/P0_i}$$

| Age | 21 | 22 | 23 | 24 | 25 | ➤ | 38 | 39 | 40 | 41 | 42 | ➤ | 56 | 57 | 58 | 59 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MTW** kg | 9.9 | 10.7 | 11.5 | 12.4 | 13.2 | ➤ | 26.3 | 27.5 | 28.6 | 29.8 | 31 | ➤ | 49.8 | 51.3 | 52.8 | 54.3 | 55.8 |
| **USD** kg | 3.37 | 3.63 | 3.91 | 4.19 | 4.49 | ➤ | 8.93 | 9.32 | 9.72 | 10.12 | 10.53 | ➤ | 16.9 | 17.4 | 17.91 | 18.42 | 18.93 |
| **LSD** kg | 2.02 | 2.18 | 2.35 | 2.52 | 2.7 | ➤ | 5.37 | 5.6 | 5.84 | 6.08 | 6.33 | ➤ | 10.16 | 10.46 | 10.76 | 11.07 | 11.38 |
| **SAS%** | 0.91 | 0.85 | 0.8 | 0.76 | 0.71 | ➤ | 0.32 | 0.3 | 0.28 | 0.26 | 0.24 | ➤ | 0.1 | 0.09 | 0.07 | 0.06 | 0.05 |
| **P0** | 900 | 845 | 793 | 748 | 701 | ➤ | 314 | 293 | 274 | 256 | 239 | ➤ | 94 | 85 | 74 | 61 | 45 |
| **P1** | 897 | 845 | 792 | 745 | 699 | ➤ | 255 | 219 | 189 | 136 | 96 | ➤ | 10 | 10 | 6 | 6 | 3 |
| **P1/P0** | 0.997 | 0.999 | 0.999 | 0.996 | 0.997 | ➤ | 0.812 | 0.747 | 0.69 | 0.531 | 0.402 | ➤ | 0.106 | 0.118 | 0.08 | 0.1 | 0.07 |
| Nabla ▼ | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | ➤ | 0.003 | 0.003 | 0.004 | 0.004 | 0.004 | ➤ | 0.011 | 0.012 | 0.014 | 0.016 | 0.022 |

(4) There follows four large arrays (40 columns corresponding to the age classes 21-60 and 500 rows which provide sufficient space to generate all of the tusk sizes down to weight class 2 (14kg) when the population has reached its asymptote of about 150,000 animals. It requires considerable computer capacity and speed to be able to carry out the calculations for one year in a reasonable time ... say 5 seconds. The operations carried out in the four arrays are –

(a) the **probabilities** attached to there being a tusk in a particular age class which is above the minimum tusk weight specified in paragraph (6) on the previous page are tabulated in order from highest to lowest in each cell in each row and column of the array;

(b) these probabilities are used to **generate a set of tusk weights** (in kg for a single tusk) in the columns for each age class;

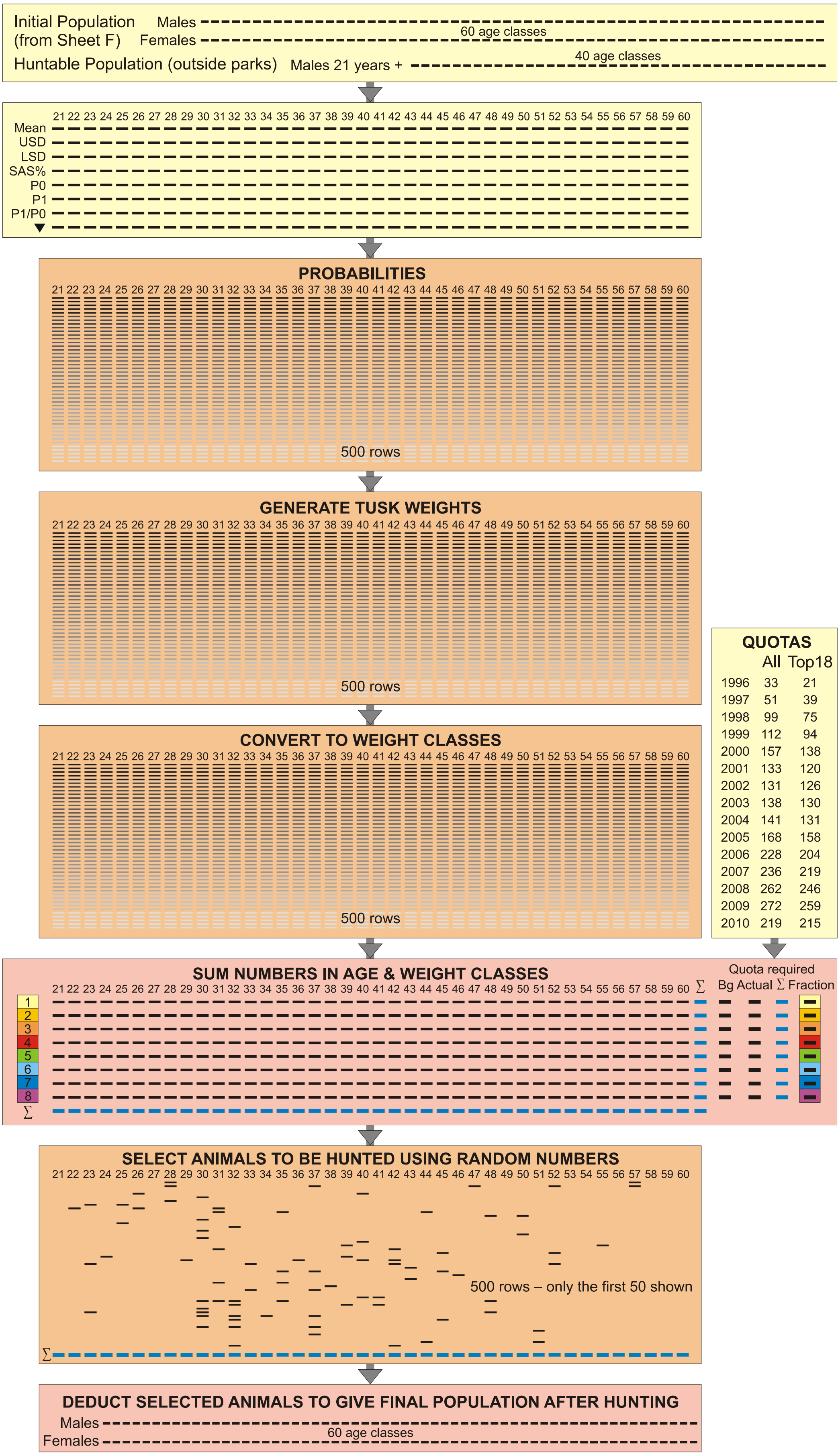
(c) these tusk weights are **classified into a set of 8 weight classes** (in lbs) for each cell;

(d) the numbers of tusks in each weight class and in each age class are then counted in a small array (40 columns x 8 rows) and the fraction which is required to generate the correct number of animals which were actually hunted is calculated;

(e) random numbers are used to **select the animals which will be hunted** in each age class in that particular year using the threshold set in (d) as the criterion for acceptance;

(f) the selected animals are then totalised for each age class and deducted from the population.

The process is shown schematically in **Fig.A6.1** on the next page –



**QUOTAS**

| | All | Top18 |
|---|---|---|
| 1996 | 33 | 21 |
| 1997 | 51 | 39 |
| 1998 | 99 | 75 |
| 1999 | 112 | 94 |
| 2000 | 157 | 138 |
| 2001 | 133 | 120 |
| 2002 | 131 | 126 |
| 2003 | 138 | 130 |
| 2004 | 141 | 131 |
| 2005 | 168 | 158 |
| 2006 | 228 | 204 |
| 2007 | 236 | 219 |
| 2008 | 262 | 246 |
| 2009 | 272 | 259 |
| 2010 | 219 | 215 |

**Figure A6.1: Functioning of the Hunting Spreadsheet**

Some of the analytic techniques referred to in **Fig.A6.1** (previous page) require explanation.

### Probabilities

The generation of a set of probabilities for the occurrence of tusks in any particular age class relies on the assumption of a normal distribution for the tusk sizes within that age class. A cumulative normal distribution with a mean tusk weight of 28.64kg and upper and lower standard deviations of 9.72 & 5.84kg respectively is shown in **Fig.A6.2** below. These are the values which would apply to the 40 year old age class in the model. The slight 'knee' in the curve which occurs at the mean is due to the transition from the lower standard deviation (LSD) to the upper standard deviation (USD) which occurs at the mean.

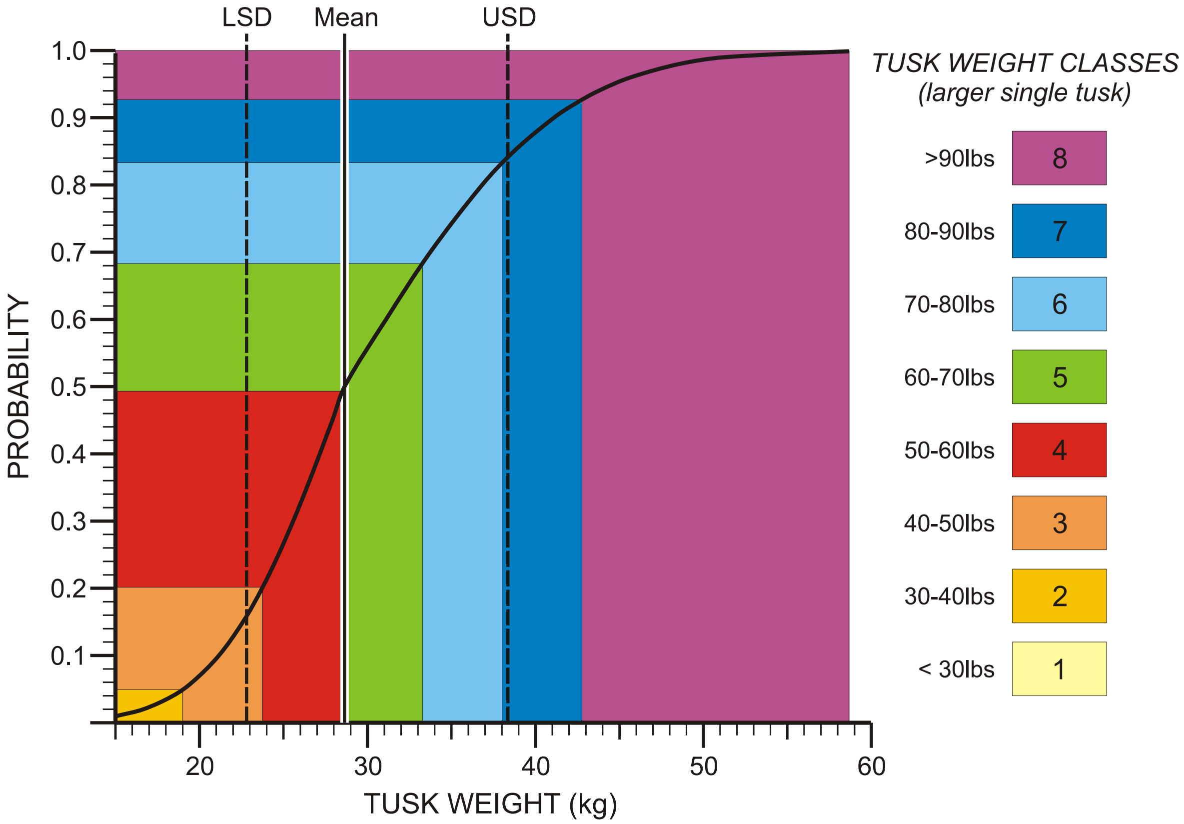


**Figure A6.2: Cumulative normal distribution for tusks in 40 year old age class**

If all the animals which should be present in the age class are in the age class (i.e. the male population has not suffered unduly from depletion or trophy hunting), a curve such as that shown in the figure might be expected. For the purposes of explanation, let us assume that 100 animals is the expected number in the age class. The value of nabla (paragraph (h) page 92) would be 0.01. If there are 100 animals in the age class, they should carry the complete range of tusk weights shown in the figure from a probability of 0.01 to 0.99. If the population was very slightly depleted – say 90 animals were present – there would be no tusks in weight class 8 (over 90lbs) in that age class. If there were only 50 animals present, the probability becomes 0.5 and there would be no animals carrying tusks in weight classes 5-8 (i.e. no tusks greater than 60lbs). There are no tusks shown for weight class 1 – the probability of a 40 year old animal carrying a tusk less than 30lbs is less than 0.01.

In the model the probabilities which are generated for each class begin at the value of ratio of the actual numbers to the expected numbers (e.g. 0.5 if only half the expected numbers are present) and each animal is assigned a probability obtained by deducting the value of nabla from this successively until the probability reaches 0.01. The deductions stop before the 0.01 level is reached if the tusk weight which would result from any given probability is less than the specified minimum tusk weight (paragraph (6) page 91).

### Generation of tusk weights

The probabilities which have been generated by this method (see **Fig.A6.1**) are then used to generate the corresponding set of tusk weights by inserting the probability value into an inverse normal distribution function (Quattro Pro software) –

Tusk weight (kg) = @NORMINV (Probability, Mean tusk weight, Standard Deviation) [55]

The curve for the inverse normal function is shown in **Fig.A6.3** below. As in Fig.A6.2 the values are for the 40 year old age class.

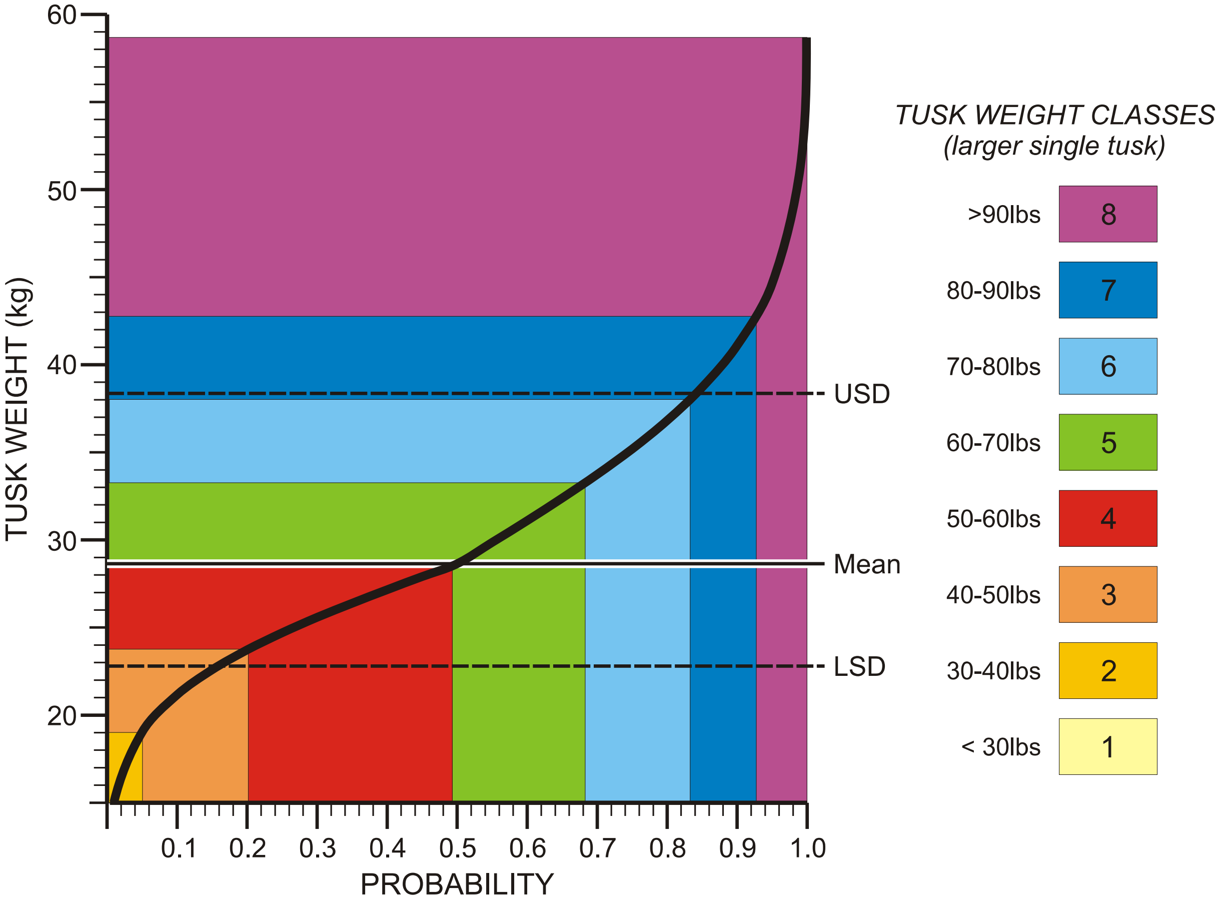


**Figure A6.3: Inverse normal function used to generate tusk weights**

---

[55] The scatter of elephant tusk weights about the mean is asymetrical (**Appendix 5**, page 87). The formula uses the upper standard deviation for probability values greater than 0.5 and the lower standard deviation for values less than 0.5.

### Conversion to tusk weight classes

The tusks which were generated above are then converted into tusk weight classes 1-8 in the third large array shown in **Fig.A6.1** (page 93). The formula for the conversion is –

Tusk weight class = @IF(P836, @IF(P836<14.26, 1, @IF(P836<19.01, 2, @IF(P836<23.76, 3, @IF(P836<28.51, 4, @IF(P836<33.27, 5, @IF(P836<38.02, 6, @IF(P836<42.77, 7, 8))))))),"  ")

– where P836 is the tusk weight in 298th cell in the 25 year old age class !

### Calculation of selection fraction

Selection of tusks is done by taking a fraction of the tusks in each weight class. The numbers of tusks in each weight class and in each age class are counted in a small array (40 columns x 8 rows, **Fig.A6.1**). The numbers of trophies which were actually hunted in each weight class in each year is known from the tusk weight data. To these are added the numbers assumed to have been taken in the category ‘Background Hunting’.[56] The required fraction is simply –

Fraction = (Total numbers hunted in weight class) / (Total numbers present in weight class)

### Selection of tusks

Random numbers are used to select the tusks. For each weight class the relevant fraction is applied and the operation is performed on the tusk weights in the array referred to at the top of this page. The formula which is used for each cell is –

```
@IF(@AND(P1086=1, @RAND<=$BE$1545), P583,
@IF(@AND(P1086=2, @RAND<=$BE$1546), P583,
@IF(@AND(P1086=3, @RAND<=$BE$1547), P583,
@IF(@AND(P1086=4, @RAND<=$BE$1548), P583,
@IF(@AND(P1086=5, @RAND<=$BE$1549), P583,
@IF(@AND(P1086=6, @RAND<=$BE$1550), P583,
@IF(@AND(P1086=7, @RAND<=$BE$1551), P583,
@IF(@AND(P1086=8, @RAND<=$BE$1552), P583,  " "))))))))
```

– where P583 is the tusk weight being tested and \$BE\$1545-\$BE\$1552 are the required fractions

### Deduction of the hunted animals

The selected animals are totalised in each age class and deducted from the initial population which appeared at the start of Spreadsheet G (**Fig.A6.1**).

---

[56] The total Background quota (Bg) in each year is also divided into weight classes using the average percentages established in **Table 6** (page 15).

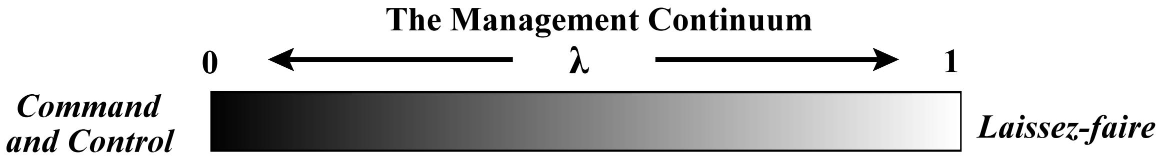
## Perfect Hunting

The model which has just been described uses the known information from the tusks actually hunted to generate the annual numbers hunted. We have developed an alternative model which carries out ‘Perfect Hunting’. By this, we mean that in every year of hunting the largest tusks are taken from the population strictly in the order in which they occur. This model is used in investigating the sustainability of various quota levels in **Chapter 5** (*Future Management*).

The model uses most of the essential steps described for **Fig.A6.1**. and it is not intended to describe the model in the same detail as for the previous model. However, after the generation of tusk weights in the second large array, a RANK function is used to select the largest tusks which will satisfy the numbers expected to be hunted. The selected trophies are then converted to weight classes in the same manner as described for the previous model and hunting offtake is summarised in terms of age classes and weight classes. Finally, the trophies are deducted from the population in the same manner as for the previous model.

# Précis of *The Invisible Wand*

**Jack Ruitenbeek and Cynthia Cartier (2001)**[57]



The authors define a management continuum where λ = 0 when all authority for resource management is centralised in government and λ = 1 when all authority is localised. Values between 0 and 1 imply a degree of sharing. From numerous case studies, the authors observe that where regimes have been imposed by central governments, none of the models (e.g. co-management, private ownership, state control) appear to generate local well-being or resource protection and ask whether **an extreme *laissez-faire* hands-off approach may be as good a management strategy as any**.

The principle theme of the *Invisible Wand* is analogous to Adam Smith's *Invisible Hand*.[58] Recognising that there is more to human behaviour than simple economic motivation, under conditions of *laissez-faire* management in complex bio-economic systems the altruistic pursuit of the common interest leads to the emergence of the common good – in this case sustainability – as opposed to efficient prices. **The authors argue that adaptive co-management will emerge naturally from such systems**.

If adaptive co-management is naturally emergent, most policy interventions are likely to do more harm than good. There should be **two main aims of policy** –

(a) **To protect the conditions for emergence of adaptive co-management**; and
(b) **To raise awareness of the options and issues amongst stakeholders**.

Devolution of authority and responsibility promotes the emergence of adaptive co-management. Although it is seen by some as a policy tool, it can be argued that **devolution is itself an emergent property from a democratising society**.

---

57. This summary is taken from Martin (2006b). **Preparation of new Sustainable Use Principles and Indicators for the Southern Africa Sustainable Use Specialist Group**.

58. Smith hypothesized that the myopic pursuit of individual economic self-interest turns out to be of economic benefit to society as a whole. Desirous of bettering their condition, self-interested individuals unwittingly and collectively cause the emergence of the common good and hence the wealth of nations – provided they are free to pursue their self-interest, unfettered by governments.(Smith 1776).

Policies should contribute to the consciousness of individuals within a complex system. Individuals must be aware that –

(a) they are capable of learning;

(b) they are capable of adapting; and

(c) they are part of a complex system and simple cause-effect relationships may not apply.

A part of this consciousness is the feeling that, as individuals in a complex system, they are not powerless.

Because of internal interactions and feedback mechanisms, **complex systems generate surprises** which cannot be predicted by reductionist science. Complex systems which have persisted for a long time show a remarkable degree of resilience – they tend to self-correct. The key point in a complex system is that causality disappears and **it may be impossible to tell whether any particular policy intervention has produced the expected result**.

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