# Kenya Black Rhino Metapopulation Workshop

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## WORKSHOP REPORT

1 May 1993

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# KENYA BLACK RHINO
# METAPOPULATION WORKSHOP

## WORKSHOP REPORT

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# KENYA BLACK RHINO METAPOPULATION WORKSHOP

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## SECTION 1
## SUMMARY AND RECOMMENDATIONS

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

# SUMMARY AND RECOMMENDATIONS

## INTRODUCTION:

This report presents the results of a Kenya Black Rhino Metapopulation Workshop that was conducted during November 1992 in Nairobi Kenya. The Workshop was a collaborative endeavor of the Kenya Wildlife Service (KWS) and the Captive Breeding Specialist Group (CBSG) of the Species Survival Commission (SSC) of the IUCN - The World Conservation Union. This report consists of various results from this Workshop as well as various reference material.

The purpose of the Workshop was to utilize available biological data and expert knowledge to assess the current situation and plans for the black rhinoceros in Kenya (*Diceros bicornis michaeli*). Participants in the Workshop included most of the persons who have been centrally involved with the black rhino program for KWS as well as rhino researchers and managers from other parts of Africa. A list of Workshop participants appears in Section 2.

Stochastic simulation computer models have been used for this assessment. Results of these analysis provide a basis for some recommendations for further development of the conservation strategy and recovery plan for the Kenya black rhino.

## PROBLEMS OF SMALL POPULATIONS

Small and fragmented populations are at high risk of extinction. In addition to the processes of unsustainable exploitation and habitat degradation that are usually the causes for the reduction in numbers and fragmentation of distribution, small populations are also subject to a number of stochastic problems that can also imperil viability. These stochastic problems include environmental, demographic, and genetic problems. Environmentally, fluctuations in conditions can disrupt survivorship and reproduction of individuals in the population. Periodically, more drastic fluctuations, i.e. "catastrophes", can devastate populations by more severely increasing mortality or decreasing reproduction. Demographically, even in the absence of environmental fluctuations, there can be intrinsic variation in the birth and death processes that in larger populations "average out", but in smaller populations can be fatally disruptive. Genetically, small populations lose genetic variation or diversity that is essential for fitness (survival and reproduction) under existing environmental conditions) and adaptability when environments change. Generally, the smaller the population is, the greater these problems are.

## MANAGEMENT AND PHVAs

Management can often moderate or remedy the problems of small populations to permit long-term survival or recovery, i.e. viability. When small populations are also fragmented into disjunct isolates, which are obviously even smaller, it is often useful to consider managing the separate demes or subpopulations interactively to some extent as a "metapopulation". Such management is likely to be more successful when as much as possible is known about the processes imperiling the population and the consequences of various possible management actions. A tool available for assessing population viability and management options is population and habitat viability analyses (PHVAs).

PHVAs use computer models which incorporate demographic and genetic characteristics of a population(s) and conditions in the environment to simulate probable fates of the population(s) under these described circumstances. The fate of the population is measured in terms of probability of extinction P(E) or survival P(S) and fraction of original genetic diversity (e.g., expected heterozygosity, (H) retained.

In terms of threatened populations, PHVAs:

(1) explore the extinction processes that operate on small and fragmented populations, and

(2) examine the probable consequences for the viability of the population of various management actions or inactions.

Thus, PHVA models can evaluate a range of scenarios for populations under a variety of management (or non-management regimes). As a result of the different scenarios explored, it is possible to recommend management actions that maximize the probability of survival or recovery of the population.

## KENYA BLACK RHINO PHVA

The Kenya black rhino population (*Diceros bicornis michaeli*) seems particularly appropriate for a PHVA analysis. Throughout Africa, the number of black rhino has declined by more than 95% over the last 20 years due mostly to poaching for the horn. The latest estimates contend that fewer than 3000, and perhaps closer to only 2000, black rhino survive in natural habitat on the entire continent of Africa. About 200 black rhino (~ 160 of them *D.b. michaeli*) reside in captive facilities around the world, mostly in North America and Europe.

The decline of this species has been particularly severe in Eastern Africa, which is inhabited by populations taxonomically described as the *Diceros bicornis michaeli* subspecies, geographic variety or ecotype. Approximately, 500 *D.b. michaeli* survive in natural habitat: about 100 outside Kenya; about 400 inside Kenya. The Kenya population is fragmented with the majority of rhino (about 300) residing in 11 disjunct areas known as "sanctuaries" that are intensely protected and increasingly managed (**Table 1** and **Figure 1**). Indeed, 6 of these sanctuaries are already entirely enclosed by fence; 3 are partially enclosed; and 2 are still open. About 160 of the black rhino in captivity are of East African origin.

## KENYA WILDLIFE SERVICE RHINO PLAN

At the time of the Workshop, the conservation strategy and recovery plan for this species provides for:

(1) protect and manage rhino in the system of 11 sanctuaries;
(2) manage the sanctuaries as a metapopulation by interchange of rhino where feasible and desirable to maintain genetic diversity and demographic integrity and productivity;
(3) expand sanctuary rhino from the current 285 to 500 by 1995 and then to ~700 by the Year 2000;
(4) use a sustainable harvest from the sanctuaries to recolonize other areas that can be secured in Kenya and perhaps eventually in Tanzania or other East Africa countries.
(5) restore the Kenya population to at least 2000 rhino.

## SUBSPECIES AND ECOTYPES

The black rhino in Kenya are considered part of a described subspecies (*Diceros minor michaeli*) or at least a defined geographical variety the eastern populations in Kenya and northern Tanzania. The IUCN SSC African Rhino Specialist Group has recommended that these eastern or michaeli populations be treated as conservation units separate from other black rhino subspecies or regional populations: the southern central populations extending from Natal through Zimbabwe and Zambia into southern Tanzania (*D.b. minor*); the southwestern populations in Namibia (*D.b. bicornis*); and the northern-western populations extending from the Horn of Africa to the Central African Republic and Cameroon (*D.b. longipes*). (du Toit et al 1987)

Research continues on the molecular genetic differences among these conservation units. Preliminary results are not unequivocally conclusive. A decision process needs to be developed based on the data generated by these studies. Presumably, the recommendations of African Rhino Specialist Group will be recognized as the highest authority on subspecies/conservation-unit decisions by rhino managers.

However, at this time there seems to be no compelling reason to consider interbreeding of the Kenya rhino with animals from any of the other populations. This observation applies to rhino both in the Kenya Sanctuaries and in the captive population outside Kenya.

Beyond, the geographical varieties, concern has also been expressed at the Workshop and elsewhere (du Toit et al.) that there may be significant ecotypes (e.g. highland versus lowland; xeric versus mesic) that would or should not be readily intermixed, e.g. translocating rhino from the Kenya highlands to lowland areas such as Ngulia. Again, data does not seem to be available to unequivocally resolve this question. The Workshop encourages collection of data on this issue as rhino are translocated. It is also recommended that rhino translocated from highland to lowland or vice versa be closely monitored for indications of possible stress and consequent remedial intervention during acclimatization periods.

## ROLE OF CAPTIVE POPULATIONS

Captive propagation is one component of a spectrum of management options that are available for threatened species such as the black rhino (**Figure 2**). Holistic strategies will incorporate both *in situ* and *ex situ* components. In general, captive population and programs can serve 3 major roles in holistic conservation strategies:

(1) living ambassadors that can educate the public at all levels and generate funds for *in situ* conservation.

(2) scientific resources that can provide information and technologies beneficial to protection and management of populations in the wild;

(3) genetic and demographic reservoirs that can be used if and when opportunity and need occurs to reinforce survival or recovery of populations in the wild either by revitalizing populations that are languishing in natural habitats or by re-establishing populations that have become extinct.

The third of these roles may often be a benefit for the longer term as return to the wild may not be a feasible or useful prospect for the immediate future. However, with a species like the black rhino that is declining so rapidly and much faster than its habitat is disappearing, captive refugia may be especially critical for survival and recovery of the species.

The demographic and genetic status of the captive population is summarized in Section 7. Globally, the captive population is just self-sustaining. Locally in the most intensively managed region (North America), the population has a positive rate of growth. The growth of the captive population has been restricted by a major medical syndrome characterized by hemolytic anemia and mucocutaneous ulceration. A summary of this syndrome and the intensive research in progress to investigate this problem is presented in Section 8. Recently, there have been results from this research that provide encouragement that remedy for the problem may soon be developed and growth of the captive population improved. Genetically, the captive population is extremely healthy with 98-99% of the genetic variation of the wild gene pool estimated to exist in captivity. An unequivocal conclusion from this summary is that there is no need at this time to move additional *D.b. michaeli* into captivity. In the future, it is possible that exchanges of rhino between the captive and wild population, as components of a global metapopulation for might be mutually beneficial.

## CONCLUSIONS AND RECOMMENDATIONS

- The KWS conservation strategy and recovery plan for black rhino seems viable. The metapopulation of sanctuaries will survive with high levels of genetic diversity for the 200 year period, especially if management occurs to mitigate the effects of possible catastrophes and to perform artificial migration of rhino among subpopulations to correct genetic (inbreeding depression) and demographic (local extinction) problems.

- Stated expectations that the sanctuary population can grow from 300 to 500 by 1995 and 680 by the year 2000 seems overly optimistic. In the absence of recruiting large numbers of rhino from outside of existing sanctuary populations, the current rate of growth predicted by the model under the most optimistic conditions is about 4.5% per year. This rate would produce a sanctuary population of about 360 by 1995 and 450 by the year 2000.

- Two of the current sanctuaries (Lewa Downs and Ol Jogi) are too small to accommodate populations large enough to be demographically and genetically stable for the 200 year period. If possible they should be enlarged, i.e. their carrying capacities (K) increased. In general, sanctuaries on the order of 50-100 rhinos are indicated for acceptable stability of their rhino populations over the 200 year period.

- Two of the current sanctuaries (Amboseli and Ol Pejeta) lack enough rhinos to serve as adequate founders, genetically or demographically, to permit acceptable recovery of viable populations. Supplementing the founder base of the populations in these sanctuaries is indicated. In general, at least 10 and preferably 16-20 founders are advisable.

- In terms of genetic and demographic viability and stability, larger populations are always beneficial, especially for longer time periods. Hence, longer-range goals (i.e. > 200 years) would likely require more populations of larger size, e.g. 20 sanctuaries with $K \geq 100$ rhino.

- Catastrophes, especially drought and poaching, severely reduce the probability of population survival and recovery. Management should attempt to reduce the frequency and severity of catastrophic episodes. Areas where such catastrophic episodes cannot be successfully managed cannot be considered secure "sanctuaries" for rhino. Ngulia, Laikipia, Mara, and Amboseli are in particular need of further careful evaluation and possible management of catastrophic factors if they are to serve as rhino sanctuaries.

- Migration, which will need to occur through managed translocation of rhino, does improve the viability of sanctuaries at significant risk, especially if catastrophes are also mitigated.

- Rhino translocated between different types of habitat (e.g. from highlands to lowlands) should be monitored for indications of stress and possible corrective interventions.

- Sustainable harvests are possible from several of the larger populations in more stable habitats (Solio and Nairobi) now and are expected from other sanctuaries (e.g., Nakuru, Ol Pejeta, Aberdare) in the future (**Table 12**).

- The PHVA modelling should be continued and extended as part of an adaptive management process for rhino. Preferably, KWS could develop further the capability to conduct the PHVA process itself. Alternatively, it would be possible for KWS to contract for these services to be performed.

- In a global sense, the systematics issues for black rhino should be investigated as vigorously as possible to clarify options and optima for conservation action. However, the continuing uncertainty and controversy seems to have no immediate indications for adjustments to the KWS rhino plans.

- The captive population should continue to be managed as well as possible to serve as an ultimate reservoir of genetic and demographic material if recovery efforts in the wild prove inadequate for this species. However, there is no need or justification to move any more East African black rhino into captive populations outside Kenya (or Tanzania) at this time.

## REFERENCES

du Toit, R.F., T.J. Foose, D.H.M. Cumming. 1987. Proceedings of the African Rhino Workshop, Cincinnati, Ohio, October 1986. Pachyderm 9. IUCN, Gland, Switzerland.

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## WORKSHOP REPORT

1 May 1993

## SECTION 2
## PROBLEM STATEMENT, AGENDA, PARTICIPANTS

# KENYA BLACK RHINOCEROS
*Diceros bicornis michaeli*

# METAPOPULATION AND HABITAT VIABILITY ASSESSMENT AND CONSERVATION ACTION PLAN WORKSHOP

## PROBLEM STATEMENT

The numbers of black rhino in Africa have declined 90% in the last 20 years. Only 3800 are estimated to survive on the entire continent. The major cause of the decline is poaching for the horn.

The decline of this species has been particularly severe in Eastern Africa which is inhabited by populations described as the *Diceros bicornis michaeli* subspecies or ecotype. Fewer than 100 *D.b. michaeli* are believed to survive outside Kenya; 370-400 are estimated inside Kenya.

The majority of the Kenya rhino (285) are located in 11 intensely protected areas designated "sanctuaries". Of these sanctuaries: 6 are entirely enclosed by fence; 3 are partially enclosed; and two are open. The range of population sizes in these sanctuaries is from 4 to 60. For the most part, these populations have been established with founders translocated from areas outside the sanctuaries. The range of estimated carrying capacities of these sanctuaries is 15 to 100. The total estimated ecological carrying capacity of the 11 sanctuaries is 680. The sanctuaries thus constitute a metapopulation of 11 small and fragmented subpopulations. As such, they are subject to risks of extinction from demographic, environmental, and genetic stochasticity.

The remainder of the Kenya rhino (85-100) occur outside the sanctuaries and most (50-70) are isolated and non-reproducing animals living in remote and largely unprotected areas. These animals are potential resources and candidates for translocation into the sanctuaries to reinforce the founder populations as needed and feasible.

There are about 150 *D.b. michaeli* in zoos worldwide. About 130 of these are in well organized captive propagation programs (SSP in North America; EEP in Europe; SSCJ in Japan).

The current conservation strategy and recovery plan for this species in Kenya is to expand the number of rhinos in the sanctuaries from an appropriate number and diversity of founders from the current 285 to 500 in 1995 and then to the sanctuary carrying capacity of 680 by 2000. The Kenya plan further aspires to manage the sanctuaries as a metapopulation by managed interchange of animals where feasible and desirable to maintain genetic diversity and demographic integrity and productivity. Thereafter, the plan is to use a sustainable harvest of surplus from the sanctuary populations to recolonize areas in the former range of the species in Kenya and perhaps neighboring Tanzania and Uganda. The ultimate goal of the Kenya plan is to restore a population of at least 2000 *D.b. michaeli* in Kenya and environs.

## GOALS

(1) Conduct a Population and Habitat Viability Analysis for the Kenya metapopulation(s) of black rhino.

(2) Assess the current Kenya rhino conservation plan using models (VORTEX, perhaps GAPPS and RAMAS) for quantitative evaluation of genetic, demographic, and environmental risks.

(3) Using the simulation models in conjunction with other information on the biology of the rhino and its environment, delineate a metapopulation strategy for black rhino in Kenya that will provide for maintenance of genetic diversity and demographic security over the short term (10-50 years) and recovery of evolutionary potential over the longer-term. This strategy will recommend:

- total metapopulation number
- number and sizes of subpopulations
- number and nature (sex, provenance, etc.) of founders for each subpopulation
- rate of migration (managed) among subpopulations

(4) Prepare a report of the analyses and results of the workshop with recommendations for achieving the above goals.

## OBJECTIVES

(1) Consolidate existing information on black rhino distribution, numbers, and habitat. As far as possible, this information will be assembled using maps of the various areas involved.

(1) Operationally review life history information of the species as needed for simulation models.

(3) Explicitly, and as far as possible quantitatively, identify and assess specific risks, deterministic and stochastic, to the black rhino and its habitat in various sanctuaries under existing and projected conditions.

(4) Assemble information to:
(A) assess human population growth around each area;
(B) identify current and planned land use patterns and their impact on protected reserves and rhino habitat;
(C) explore full range of possible poaching scenarios over next 20 years.

(5) Delineate current, planned, and possible/desirable levels of protection and management of reserves.

(6) Project the potential expansion or decline of black rhino population numbers under various management regimes.

(7) Evaluate the need/benefit of retrieving additional outlier rhino as founders for the sanctuary populations.

(8) Employing simulation models, determine numbers of black rhino and subpopulations required for various probabilities of survival and preservation of genetic diversity for specified periods of time (i.e. 50, 100, 200 years) and for eventual recovery of evolutionary potential.

(9) Consider habitat and carrying capacity requirements needed to achieve objectives of establishing population sizes needed for a viable population.

(10) Explore metapopulation manipulations that could be used to establish or maintain viable populations: e.g. managed migration among subpopulations; pedigree management of sanctuary populations.

(11) Examine obstacles (e.g. behavioral, logistic, financial problems) to and consequences of this approach.

(12) Consider how possible interventions in the wild population and its habitat might increase its rate of growth, maximize retention of genetic diversity, and reduce risk of extinction.

(13) Evaluate possible role of captive propagation as a component of the metapopulation strategy. In particular, consider how captive propagation could: A) contribute to expansion of population; B) enhance preservation of genetic diversity; C) protect population gene pool against fluctuations due to environmental vicissitudes in wild and D) provide animals for reinforcement of wild populations or establishment of new wild populations.

(14) Consider other ways the global zoo community can strategically but realistically assist the conservation of black rhino in Kenya.

(15) Formulate and/or evaluate criteria developed for establishment of new black rhino populations.

(16) Develop quantitative scenarios for harvest of animals from sanctuary populations for translocation to new areas.

(17) Identify problems and issues that need continuing research and analysis.

(18) Consider how social and rural development realities as well as educational and informational efforts can be effectively incorporated into action plans.

(19) Consider Kenya strategy in context of (A) plans for species elsewhere in Africa and (B) of subspecies issue.

(20) Produce a Conservation Strategy and Action Plan Document presenting the results and recommendations from the Workshop for various scenarios and courses of conservation action.

# KENYA BLACK RHINO PHVA/CAP WORKSHOP OVERVIEW

A Metapopulation Conservation Strategy Document will be prepared in draft form during the workshop. It is a goal of the workshop that this document be reviewed and revised by all participants during the workshop to achieve agreement on its content before departure. This document will include specific recommendations and priorities for management and research of both captive and wild populations. The Conservation Strategy will be developed by detailed examination of the natural history, biogeography, life history characteristics, status in the wild and captivity and threats to the species continued existence.

## Participants

The workshop will be conducted as a joint endeavor of the Kenya Wildlife Service and the Captive Breeding Specialist Group (CBSG). The list of invited participants includes the Chairman of the SSC African Rhino and Reintroduction Specialist Groups. Representatives of the African Rhino Specialist Group from several other African nations (Tanzania and Zimbabwe) have also been invited.

## Briefing Book

A briefing book will be distributed to all participants at the workshop. The book will contain summary information on: population biology concepts as they relate to developing conservation strategies (species survival plan, recovery plan); selected papers on the Kenya black rhino situation and recovery plan; natural and life-history of the black rhino; status of the wild and captive populations; and preliminary results of computer models evaluating the extinction vulnerability of rhino species (to be revised and refined during the workshop).

## Workshop Format

The duration of the workshop will be 3 full working days and then an additional day for a smaller group to complete preparation of the report. The workshop will be organized in an effort to combine available information on the biology and status of the species with analytical techniques that evaluate their conservation implications. Once the basic data are presented, analytical models will be prepared to simulate future population trends. These models will focus on estimating the probability of the species going extinct given various conditions and scenarios (Population Viability Analysis PVA). Conservation strategies for both captive and wild populations based on information obtained will be developed.

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## *AGENDA*

### DAY 1: SATURDAY 2 NOVEMBER 1992

**MORNING**

| | |
|---|---|
| 9:00 | Introductions, opening remarks and arrangements. (Leakey, Brett) |
| 9:30 | Goals, Problems, and Assignments for Workshop. (Brett, Seal, Foose) |
| 10:30 | Break |
| 11:00 | Basic Overview of Small Population Biology and Management (Foose, Lacy).<br>- Demographic, environmental, and catastrophic effects on persistence of small populations.<br>- Genetics and persistence of small populations.<br>- Species survival planning and collaborative management approaches for small populations.<br>- VORTEX, GAPPS and other models available for PHVA. |
| 12:00 | Overview of the Kenya Black rhino situation and current plan. (Brett, Wanjohi) |
| 13:00 | Lunch |

**AFTERNOON**

| | |
|---|---|
| 14:00 | Taxonomy, genetic analyses, population substructure (Ryder, Aman) |
| 15:00 | Review and assembly of population biology, life history and basic black rhino biology parameters for models. (Brett, Emslie, Hillman, et al.) |
| 15:30 | Break |
| 16:00 | Organize working groups. |

**EVENING**

Initiate working groups and simulation runs for black rhino.

## DAY 2: SUNDAY 3 NOVEMBER 1992

### MORNING

| | |
|---|---|
| **9:00** | Distribution and review of draft minutes from Day 1.<br>Present results from initial model simulations. |
| **9:30** | Consideration possible pedigree management of sanctuary populations. (Lacy). |
| **10:30** | Break |
| **11:00** | Consideration of reintroduction protocols and criteria (Price). |
| **12:00** | Consideration of possible role of captive propagation and other actions by global zoo community in recovery plan. (Foose) |
| **13:00** | Lunch |

### AFTERNOON

| | |
|---|---|
| **14:00** | Continue working sessions and model runs. |

### EVENING

Working groups work on documents.

## DAY 3: MONDAY 4 NOVEMBER 1992

### MORNING

| | |
|---|---|
| 9:00 | Distribution and review of draft minutes and reports from Day 2. |
| 9:30 | Discussion of Kenya populations and plans in relation other national strategies and continental action plan by AERSG. (Brett, DuToit, Emslie) |
| 10:30 | Break |
| 11:00 | Discussion of behavioral, logistic, financial, other impediments to metapopulation management. (Brett, DuToit) |
| 12:00 | Presentation of results from model simulations. Discussion of full range of scenarios, problems and potential solutions. Identification of conservation priorities.<br>Assemble first draft of final workshop document. |
| 13:00 | Lunch |

### AFTERNOON

| | |
|---|---|
| 14:00 | Presentation and review of final documents.<br>Identification of items that are dependent upon further data and analysis to be completed after the Workshop. Organize mechanism to continue process developed at Workshop.<br>Achievement of consensus on the Summary and Recommendations of the Conservation Strategy Document. |

### EVENING

Working groups continue to refine and finalize documents.

## DAY 4: TUESDAY 5 NOVEMBER 1992

### MORNING

Further modeling analysis, if required.

### AFTERNOON

?

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## *PARTICIPANTS*

### KENYA

| | |
|---|---|
| Richard Leakey | Kenya Wildlife Service (KWS) |
| Rob Brett | Kenya Wildlife Service |
| Jim Else | Kenya Wildlife Service |
| John Kagwi | Kenya Wildlife Service |
| Pius Mulwa | Kenya Wildlife Service |
| Sam Ngethe | Kenya Wildlife Service |
| Tim Oloo | Kenya Wildlife Service |
| Evelyn Wanjohi | Kenya Wildlife Service |
| Fred Waweru | Kenya Wildlife Service |
| Rashid Aman | National Museum of Kenya |
| Holly Dublin | World Wide Fund for Nature (WWF) |
| Rob Eley | Institute of Primate Research |
| Chris Gakahu | Wildlife Conservation International |
| Helen Gichohi | Wildlife Conservation International |
| Shirley Strum | Wildlife Conservation International |
| Esmond Bradley Martin | IUCN SSC/WWF |
| Steve Mihok | Tsetse Research Project ICIPE |
| Mark Stanley Price | African Wildlife Foundation |
| Alison Wilson | IUCN SSC Reintroduction Specialist Group |
| Kuki Gallmann | APRLS |

### OUTSIDE KENYA

| | |
|---|---|
| Ulysses S. Seal | IUCN Captive Breeding Specialist Group |
| Thomas J. Foose | IUCN CBSG |
| Robert C. Lacy | IUCN CBSG/Chicago Zoological Society |
| Richard Emslie | Ecoscot Consultancy Services/Natal Parks |
| Richard Kock | Zoological Society of London (ZSL)/KWS |
| Oliver Ryder | San Diego Zoological Society |
| Klaus Schmitt | University of Bayreuth |
| Kes Hillman-Smith | Garamba National Park |
| Raoul du Toit | Zimbabwe Natl. Parks and Wild Life Mgmt. |

### APOLOGIES

| | |
|---|---|
| Martin Brooks | IUCN African Rhino Specialist Group |
| Georgina Mace | Institute of Zoology (ZSL) |
| David Western | Wildlife Conservation International |

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## WORKSHOP REPORT

1 May 1993

## SECTION 3
## POPULATION AND HABITAT VIABILITY ANALYSES

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

# POPULATION AND HABITAT VIABILITY ANALYSES

## INTRODUCTION

Population and habitat viability analyses (PHVAs) use computer models which incorporate demographic and genetic characteristics of the population(s) and conditions in the environment to simulate probable fates of the population(s) under these circumstances. Fate of the population is measured in terms of probability of extinction ($P_E$) or survival ($P_S$) and fraction of original genetic diversity (specifically expected heterozygosity, H) retained.

Simulations for this PHVA of the Kenya black rhino population(s) have been performed using VORTEX software. A brief description of this software is presented in Section 10 and is described in more detail in Lacy 1993. A User's Manual is also available (Lacy and Kreeger 1992)

Population characteristics and environmental conditions are entered into the VORTEX models as parameters. Values of these parameters are obtained from various sources, especially information provided by managers and researchers of the population who participate in the PHVA Workshops. Thus, the parameters for this Kenya Black Rhino PHVA were formulated by a Population Modelling Working Group at the Workshop consisting of: Rob Brett, Evelyn Wanjohi, Richard Emslie, Esmond Martin, Tom Foose, and Bob Lacy. Additional refinement was provided by other Workshop participants as well as some published information on black rhino populations in Kenya and elsewhere in Africa.

## MODEL PARAMETERS

The major parameters of the VORTEX model and the values formulated by the Workshop are:

**Size and Identity of Populations:**

Two kinds of simulations have been performed:

- The first kind is of hypothetical small populations of various sizes to provide an overview of the general effect of population size on its fate (Tables 2 & 3; Figures 3-14);
- The other of specific populations that actually exist in Kenya and are considered part of the managed system of sanctuaries. Eleven specific populations (Tables 4-13; Figures 15-23) have been analyzed individually and collectively, as a metapopulation.

## Time Period:

The period of immediate interest is the next 100 years. However, the simulations have been conducted for 200 years to provide better perspective on population trends and fates. Status of the population have been reported at intervals of:

- 10 years in the graphs
- 50 years in the tables.

For each kind of population, VORTEX requires both

- **Initial Size ($N_0$)**, which is the current estimated number and
- **Carrying Capacity Size (K)**, which is the ultimate size the population can attain in that area.

Values of N and K have been formulated:

- For the nonspecific populations, K's of 10, 20, 30, 40, 50, 60, and 100; in each case the initial size N = K.
- For the 11 actual sanctuaries, the best information on current population size (and age/sex structure) have been used for the N's and the best guesstimates of ultimate carrying capacity of each area have been used for the K's. These latter guesstimates were provided by a Habitat Evaluation Working Group comprising: Holly Dublin, Chris Gakahu, Sam Ngethe, Mark Stanley Price, Shirley Strum, Fred Waweru (Refer to Section 6).

## Catastrophes:

A catastrophe is defined as an event or factor that causes changes in mortality (usually an increase) and/or fertility (usually a decrease) at levels outside the normal range of variation. In VORTEX, catastrophes are defined by:

- type: e.g., climatic calamity (drought, fire), disease epidemic, human decimation (poaching).
- frequency: how often the event or factor occurs; measured as percent (ranging from 0 to 100) representing expected rate of occurrence per 100 years, e.g. 10 indicates the event will on the average happen once every 10 years.
- severity: effect the catastrophe has on mortality (or conversely on survival) and fertility; measured as a number (usually a decimal) representing what fraction of normal survival or reproduction is achieved when the catastrophe occurs, e.g. 1 indicates the catastrophe has no effect; .5 indicates survival or fertility is 50% of normal; 0 indicating that the catastrophe completely eliminates reproduction or survival.

For the Kenya black rhino, 3 major kinds of catastrophes are identified:

- poaching,
- disease,
- drought.

Unfortunately, there are not good data to estimate the frequency or severity to be expected for any of these catastrophes. There was general agreement in the Habitat Working Group that the various catastrophes will probably affect the specific sanctuaries variably, i.e. not all sanctuaries are subject to all catastrophes. This variation is indicated in the tables and narrative of results of the simulation for the specific sanctuaries.

Where the catastrophes do occur, the best guess of the frequency and severity are:

| TYPE | FREQUENCY (%) | SEVERITY REPRODCT | SURVIVAL |
|---|---|---|---|
| Poaching | 5 | 1 | .67 |
| Disease | 1 | 1 | .6 |
| Drought | 10 | 0 | .8 |

The Working Group have provided some additional comments about the various kinds of catastrophes:

Poaching: The Working Group believes populations will differ significantly in susceptibility against poaching catastrophe. They envision no scenarios that would eliminate all populations. Official records indicate 15 rhino deaths from 1986-1991 are due to poaching. However, poaching pressure throughout Africa remains high and is intensifying in southern parts of the range. As populations there decline, it may be expected that poaching pressure in Kenya may increase. Hence, the VORTEX modelers have also explore some "worse case" scenarios for the non-specific populations of various sizes to indicate the effect of two higher levels of poaching, given below.

| TYPE | FREQUENCY | SEVERITY REPRODCT | SURVIVAL |
|---|---|---|---|
| Intensified Poaching 1 | 33 | 1 | .95 |
| | | (losing 5% of population every 3 years) | |
| Intensified Poaching 2 | 33 | 1 | .90 |
| | | (losing 10% of population every 3 years) | |

| | |
|---|---|
| Disease: | There is great difficulty in estimating the probability of this kind of catastrophe. No data are available on incidence of epidemic disease in rhinos in the wild. The Disease Working Group (Richard Kock, Steve Mihok, Richard Emslie, Raoul du Toit, Jim Else) formulated a guesstimate (above) which is applied to all sanctuary populations. Refer also to the Working Group Report on Disease in Section 6. |
| Drought: | The Habitat Working Group recommends applying this catastrophe selectively to sanctuaries as indicated in the Tables 5, 7, 9, 11. |

**Inbreeding:**

There are no data on the effects of inbreeding on rhinos. Hence the Working Group has utilized estimates from other mammal species. Referring to the best study of inbreeding effects in mammals (Ralls et al. 1988), the Working Group has selected the value (3.12 recessive lethals) reported for zebra, which is the closest relative to the rhino among the species for which data have been published. This value also represents a level near the median (3.14 recessive lethals) for the 40 mammal species examined. This level is used for both the hypothetical and actual sanctuary populations. To consider a worse case scenario, a level twice as severe (6.24) has also been examined in the case of the non-specific populations.

**Age at First Reproduction:**

| | |
|---|---|
| Female | 7 Years |
| Male | 10 Years |

These estimates are derived from Hitchins & Anderson data for Natal which was based on data from over 300 animals. The group acknowledges that it would be useful to have better estimates of variance in age at first breeding.

**Senescence:**

37 Years for both sexes

**Sex Ratio:**

.5

**Litter Size:**

1

## Female Reproduction:

Calculated rates for the sanctuaries produces an estimate of 24% of females breeding in any one year:

> In last 58 months, 101 births have been observed. There are approximately 91 adult females + 15 adults of unknown sex, so it is estimated there are roughly 99 females now. There were an estimated 87 adult females in 1988, the midpoint of the time interval under consideration for these calculations. So, 101 births from 87 females equals 1.6 births per female per 58 months or .24 births/female/year.

## Male Reproduction:

The Working Group estimates that, typically, 50% of the males reproduce in any year with the acknowledgement that better information is needed. But for Lewa Downs and Ol Jogi, they recommend a level of 30% because one or a few males could monopolize breeding in these very small populations.

## Variance in Reproduction:

Variance ± 10%.

## Mortality:

| | Females | |
|---|---|---|
| Age | Qx | SD |
| 0-1 | 10 | 3 |
| 1-2 | 4 | 2 |
| 2-3 | 6 | 2 |
| 3-4 | 3 | 1 |
| 4-5 | 1 | .5 |
| 5-6 | 1 | .5 |
| 6-7 | 1 | .5 |
| >7 | 1 | .5 |

| | Males | |
|---|---|---|
| Age | Qx | SD |
| 0-1 | 10 | 3 |
| 1-2 | 4 | 2 |
| 2-3 | 6 | 2 |
| 3-4 | 3 | 1 |
| 4-5 | 1 | .5 |
| 5-6 | 1 | .5 |
| 6-7 | 1 | .5 |
| 7-8 | 1 | .5 |
| 8-9 | 1 | .5 |
| 9-10 | 1 | .5 |
| >10 | 1 | .5 |

These schedules of mortality were derived from some simple calculations using actual data on deaths in the sanctuaries:

> There are 61 calves (0-42 months of age) as of 10/91. The number of births over last 42 months (.24 X 3.5 Yrs. X 87 adult females) = 73. 61/73 = 83.56 % survival to date. But some additional are expected to die. So a guesstimate of mortality from 0-42 months is 20%, which has been distribute as 10%,4%,6%, 3% over first 4 years of life.
>
> 28 deaths were recorded in the population from 1/1/1986 to 11/1/91 (58 months, i.e. about 5.8 deaths/year). Of these, based on the above calculations, it is expected that about 12 calves died over last 48 months. Thus, it is further expected there would be 16.6 calf deaths over 58 months. Hence, it is concluded there are 11.4 deaths of animals above age 42 month over last 58 months. So, there would have been 11.4 deaths out of population of 248 non-calves (304-56)at end of 1990. Adjusted for the number 2 years earlier (mid-point of the 4 year interval being considered) and assuming a 5% realized growth rate, the calculations indicate 248 X .95 X .95 = 224 non-calves with 11.4/224 = .05 mortality over 58 months. This translates into a 1% mortality per year for non-calves. (In terms of survival: $.99^{58/12} = .95$)
>
> These mortality rates, with the above reproductive rate, produce an annual deterministic growth rate (lambda) of 1.047.

**Correlation of Environmental Variation in Mortality and Reproduction:**

The VORTEX model permits environmental variation in survival to be correlated or not correlated with the environmental variation in fertility. For the Kenya black rhino, it is assumed they are correlated because they would be jointly correlated with weather.

**Density Dependence:**

The Working Group believes it does occur but the extent is probably not great and the function relating reproduction to population density is unknown. It is also intended to remove rhino from the enclosed sanctuaries before any negative density-dependant effects would occur. No density dependence has been incorporated into these analyses.

**Harvest and Supplementation:**

Various levels of harvest and supplementation of specific sanctuaries have been investigated as indicated in the tables. These levels were specified by Rob Brett as the Rhino Coordinator for the Kenya Wildlife Service, with one minor modification. KWS has considered moving 9 rhinos out of Solio for translocation to other sanctuaries over the next two years. The VORTEX computer program does not allow different numbers of animals to be moved each year. *so the* analyses were completed assuming *that 5 rhinos each year (10 total) would be removed from* Solio.

The rhinos to be added to several sanctuaries (Lewa Downs, Ngulia, and Ol Pejeta), would be obtained from those sanctuaries with surplus rhinos (Solio and Nairobi) and also from an additional four or more rhinos to be captured from non-sanctuary areas (e.g., Tana River area). Except for Lewa, which is scheduled to receive an additional breeding male, it was assumed that for both removals and supplementations the rhinos chosen would be half subadults (age 4) and half adults (females age 7, males age 10).

Removals and supplementations tested were:

Solio -5 each year for two years
(2 sub-adult females, 2 sub-adult males, 1 adult male)

Nairobi -4 each year for three years
(1 sub-adult and 1 adult female, 1 sub-adult and 1 adult male)

Lewa Downs +1 adult male
also tested (see **Table 13**): +4 each year for two years
(1 sub-adult and 1 adult female, 1 sub-adult and 1 adult male)

Ngulia +4 each year for three years
(1 sub-adult and 1 adult female, 1 sub-adult and 1 adult male)

Ol Pejeta +4 each year for three years
(2 sub-adult females, 2 sub-adult males)

# MODEL RESULTS

## DEMOGRAPHIC PERFORMANCE - LIFE TABLE CALCULATIONS

### Rates of Change (Growth or Decline):

Deterministic life table analysis of the birth and death rates estimated for the Kenyan black rhinos in sanctuaries produces a mean annual population growth of 4.7% (lambda = 1.047, r = .046), if catastrophes of disease, drought, and poaching are assumed never to occur. The growth rate observed from 1986 through 1990 in the sanctuaries was about 5% (data provided by R. Brett, KWS), closely in line with the life table projection. If possible catastrophes are incorporated into the life table (averaging the effects of episodic events over years), mean population growth rates are calculated as 4.3% (lambda = 1.043, r = .042) with disease epidemics, 2.6% (lambda = 1.026, r = .026) with disease and occasional poaching, 1.6% (lambda = 1.016, r = .016) with disease and droughts, and 0% (lambda = 1.00, r = .00) with disease, poaching, and droughts.

These deterministic calculations of population growth rates assume no annual fluctuations in birth and death rates, no inbreeding depression, a stable age distribution, and no random variation. Each of these factors could depress long-term population growth relative to the rate calculated from the life table.

### Age Distributions:

The age distribution predicted from the life table, in the absence of catastrophes, yields about 24% calves (less than 4 years of age), 14% subadults (4-6 years), and 62% adults (7 years and older). The actual age distribution at the end of 1990 was 18% calves, 20% sub-adults, and 62% adults. The slight discrepancy between the predicted and actual percents in the younger age classes could easily be due to stochastic variation in the number of births each year.

## SIMULATION RESULTS

The simulation results are presented in **Tables 2-13** and **Figures 3-23**. Each table presents the outcome for a number of scenarios or populations. Each case investigated is represented by a row in the tables. A case is defined by the conditions (representing varying input parameters) presented in several of the initial columns of the tables: the first three columns in **Tables 2 & 3**; the first five columns in **Tables 4-11** columns; the first four columns in **Table 12**; and the first four columns in **Table 13**.

The input parameters indicated in the tables are:

**LOCATION OR SIZE**
The black rhino sanctuary being modelled. In **Tables 2 & 3**, no specific populations are being modelled, rather the simulations explore the viability of hypothetical populations of various size.

**INBR. DEPR.**
In **Table 2**, two levels of inbreeding depression are examined as indicated: 3.12 lethal equivalents (**Table 2a**) and 6.24 lethal equivalents (**Table 2b**). (Refer to inbreeding section in "Population Biology Parameters" for further explanation.)
In **Tables 3-13**, the impact of inbreeding was set at 3.12 lethal equivalents.

**$N_0$**
The initial population sizes. In **Table** 13, the two levels of N listed for each population reflect initial sizes with and without an immediate translocation of additional founders to expand the number immediately to at least 20.

**K**
Carrying capacity, ultimate population sustainable, of the areas indicated.

**CATS**
Incorporation of catastrophes into the models:
Di = disease epidemic;
Dr = drought;
PW = poaching at the level projected by the Workshop.
PI1 = intensified poaching at level of 5% loss every 3 years
PI2 = intensified poaching at level of 10% loss every 3 years

**+ or -**
Initial addition of new founders or removal of surplus. Refer to text (above) for details on the time schedules and ages and sexes of animals proposed for translocation.

Other input parameters for the VORTEX model were constant in all scenarios examined at the values described in the section Model Parameters above.

The simulations for each case were repeated for:
- 500 replications in **Table 2 & 3**
- 250 replications in **Tables 4-11** and **13.**

All populations were simulated for 200 years, with results reported
- at 10 year intervals in graphical presentations;
- at 50 year intervals in tabular presentations.

The results of the population simulations are reported in terms of:

**Pop. growth (r)**
Population growth rate, prior to any carrying capacity truncation: positive values indicate population increase, negative values indicate population decrease. Both a mean, averaged across years and across replications and a standard deviation, **SD**, of variation across years and simulations are provided. Larger standard deviations, relative to the means, indicate greater instability for the population.

**P(E)**
Probability of extinction, i.e., the proportion of the simulated populations that became extinct.

$N_T$
The mean final size of those simulated populations that survive, presented as a mean and standard deviation **SD** across simulations.

**H**
The percent of the original gene diversity (expected heterozygosity) remaining in the surviving populations. For the metapopulation (last line of **Tables 3-11**), **H** gives the total gene diversity, both within and between subpopulations.

**Median Time to Extinc.**
The year in which the median (125th of 250 or 250th of 500) simulated population went extinct, reported only in those cases in which at least 50% of the simulated populations did not survive.

**Figures 3-22** present the simulation results graphically, with the probabilities of each population remaining extant (not yet extinct) displayed in part **a** of each figure, and the remaining proportion of the original heterozygosity shown in part **b** of each. Standard error bars are given with the means on the figures displaying heterozygosities.

## A. HYPOTHETICAL SMALL ISOLATED POPULATIONS:

**Tables 2 & 3** present the results of scenarios examined with hypothetical small isolated populations varying in size from 10 to 100 rhinos. These hypothetical populations could represent unmanaged populations inside or outside sanctuaries. If the effects of inbreeding on juvenile survival are as estimated for a zebra (3.12 lethal equivalents), if inbreeding has no further impact on adult survival or reproduction, and if poaching, disease, and drought catastrophes never occur (top section of **Table 2a**, and **Figure 3a**), then even very small populations of rhinos may be viable. Populations of 30 or more always survived through the 200-year simulations, and populations as small as 10 had a median time to extinction of 161 years. Mean growth rates (calculated from the annual increments before carrying capacity truncation) were depressed in the smallest populations, presumably because of inbreeding depression and an occasional lack of mates (demographic stochasticity). The mean growth rates projected in the simulations of the larger populations are only slightly less than that predicted from deterministic life table calculations, evidence that stochastic factors would be relatively minor for rhino populations of 100 or more animals.

The possible viability of very small rhino populations is in accord with observations that several very small populations have remained relatively stable or grown, once they were very carefully and diligently protected from poaching and other catastrophes. The biology of rhinos may afford greater buffering from stochastic processes that would be the case for almost any other species of animal.

The standard deviations in population growth rates among years and iterations of the simulations give an indication of the demographic stability of small rhino populations. Fluctuations in growth rates were greater in the smallest populations, with the standard deviation of the growth rate greatly exceeding the mean growth rate. Even in populations of 100, however, the standard deviation exceeded the mean growth rate, indicating that these populations would decline, for stochastic reasons, in at least one year in six. This demonstrates that long term stability does not necessarily require or indicate near constant population growth from year to year. Although close monitoring of populations may be essential to prevent imminent catastrophes, such as epidemic disease or poaching, modest fluctuations in numbers without apparent cause can be expected in even the healthiest of populations.

Genetic variation, assessed by percent of initial heterozygosity, was steadily eroded in the smaller simulated populations (**H** columns in **Table 2a**, and **Figure 3b**). A loss of 25% heterozygosity represents the same cumulative genetic loss that would be expected from matings between full siblings or parents with offspring. This rather severe inbreeding was reached within 50 years in populations of 10, about 100 years in populations of 20, and about 200 years in populations of about 30 to 40. Soulé et al. (1986) recommended that conservation programs strive to keep genetic variation above 90% of its initial value, in order to minimize inbreeding effects and to allow for continued adaptive evolution. That goal could be achieved for 50 years with a population of 30 rhinos, for 100 years with a population of 50, and for 200 years with a population of 100.

Workshop participants were not aware of any published reports on the effects of inbreeding on any rhino species. Therefore, considerable uncertainty remains concerning the likely impact of inbreeding. Simulation models were tested also (**Table 2b**, **Figures 7-10**) with double the number of lethal equivalents observed in the zebra, a value that is still within the lower three quartiles reported by Ralls et al. (1988) for 40 mammal species. The greater effects of inbreeding reduced mean population growth, while increasing variance in population growth, among the smaller populations. The higher impact of inbreeding also accelerated extinction of the smallest populations, although the effects were not apparent until after 50 years (compare **Tables 2a** and **2b**).

Catastrophes (drought, epidemic disease, and poaching), occurring with the frequency and impacts estimated by workshop participants, could have disastrous effects on the viability of small populations of black rhinos (**Table 2**, **Figures 4-6**). Long-term population trends were negative, numbers fluctuated to a much greater extent, and none of the population sizes tested were adequate to assure population survival for even 50 years (**Figure 6a**). The additional effect of higher inbreeding impacts were minimal, as demographic instability dominated population dynamics when catastrophes were considered (**Table 2b**, **Figures 8-10**). These results highlight the vulnerability of long-lived, slowly reproducing (K-selected) species to catastrophic losses, even if they occur with relatively low frequency and have seemingly modest impact. Protection of the rhino populations from such catastrophes should be the highest priority, something that has been well recognized and demonstrated by recent history in east Africa.

Because the fates of small populations of rhino are sensitive to catastrophes, and because poaching of rhino has recently intensified in southern Africa, the effects of several levels of poaching were examined, in addition to the level identified at the Workshop. **Table 3** and **Figures 11-14** show the impact of either a 5% loss every three years (Poaching Intensity 1) or a 10% loss every three years (Poaching Intensity 2). The lower level of poaching is unsustainable if imposed on top of occasional drought and disease catastrophes (second section of **Table 3**, and **Figure 12**), and increases instability of the smallest populations in the absence of other catastrophes (top of **Table 3** and **Figure 11**). The higher level of poaching is unsustainable (bottom half of **Table 3**, and **Figures 13 & 14**), except perhaps for short periods of time in the larger populations.

## B. VIABILITY OF THE RHINO SANCTUARIES:

**Tables 4-11** and **Figures 15-23** give the results of 250 simulations each of 8 scenarios for the 11 rhino sanctuaries in Kenya. In the absence of catastrophes, with no managed movement of animals among sanctuaries initially, and with no later migration among sanctuaries (**Table 4**, **Figure 15**), the metapopulation is projected to be quite stable, with a mean annual population growth of about 4%, and with minimal overall losses of genetic variation through 200 years.

The subpopulations in four of the sanctuaries, however, are individually at risk. The small populations that can be sustained at Lewa Downs and at Ol Jogi are not sufficiently large to be demographically or genetically stable. Both populations undergo large fluctuations in numbers (relative to the population size), lose genetic variation rapidly, and have moderate to high chances of extinction. In addition, the populations at Amboseli and, to a much lesser extent, Ol Pejeta, are in large areas of habitat but have so few animals at present to serve as founders that they are at risk of quick extinction. They will also lose considerable genetic variation before numbers could build up (if they are lucky enough not to go extinct). If they survive the next few decades and do expand to fill the habitat, further genetic losses will be relatively small and delayed extinction is not as likely.

Although many of the sanctuary populations may be viable as isolated units, most would lose more genetic variation than might be desirable, although not until the second century. The subpopulations are each expected to undergo at least moderate fluctuations in numbers, with population declines occurring in some years due solely to chance (stochastic) phenomena.

If catastrophes are added to the models, as estimated by the habitat working group at the workshop, the populations in many more of the sanctuaries would be vulnerable to extinction (**Table 5**, **Figure 16**). Only the sanctuaries considered free of risk of drought and poaching are projected to have high probabilities of persistence. Although the rhino populations in the sanctuaries subjected to drought and poaching would be expected to grow at about 3 to 4% per year in the absence of such catastrophes, the long-term prognosis is that these sanctuaries may be demographic "sinks" (mean $r < 0$) if occasional catastrophes do occur. Population growth would not be sufficient to replenish the populations between the expected episodes of drought and poaching, so restocking of these habitats may be necessary to speed recovery after such events. These results re-emphasize the conclusion that the top management priority should be to minimize the frequencies and severities of catastrophic episodes. Populations that cannot be kept almost free of such risks for at least decades cannot be considered to be secure "sanctuaries" for rhinos, e.g. Amboseli National Park.

The Kenya Wildlife Service has recognized that several of the sanctuaries (e.g., Ngulia and Ol Pejeta) have very few rhinos at present, even though they do have habitat sufficient to support viable populations. Moreover, several other sanctuaries (Solio and Nairobi) are presently at or above the carrying capacity of the habitat. The effects of the movement of some rhinos into the currently underpopulated habitats are shown on **Tables 6 & 7** and **Figures 17 & 18**. In the absence of catastrophes (**Table 6**, **Figure 17**), the proposed moves reduce the genetic losses from Ngulia and Ol Pejeta, and do remove the low possibility that the population at Ol Pejeta will go extinct before it grows to a more stable size. These beneficial effects are small, however, especially so in the case of Ngulia. The addition of a single (male) rhino to Lewa Downs decreases the probability of extinction during the next few decades, because the population has only a single male at present. The small Lewa Downs population has a high probability of extinction in later years, however, whether or not the current unbalanced sex ratio is rectified. (See below, under **Effect of Protection of Larger Areas of Habitat**, for discussion of alternative management strategies for Lewa Downs and Ngulia.) The removals of some animals from Nairobi and Solio are not projected to have any impact on the viability of those populations.

In the presence of occasional catastrophes (**Table 7**, **Figure 18**), the benefits of additional rhinos being added to Ngulia are more pronounced, but still do not afford adequate protection from the destabilizing effects of catastrophes.

## C. EFFECTS OF PERIODIC MIGRATION:

Migration among sanctuaries, even at the low rate of 1%, prevents substantial loss of genetic variation from the populations, and provides animals for augmenting and re-colonizing the smallest populations (**Table 8, Figure 19**). Because the model was analyzed with symmetrical probabilities of migration among each pair of populations, the smallest populations receive more migrants than they disperse, and they benefit most from the migration. For Ol Jogi and Lewa Downs, most of the recruitment and stability in the populations results from immigration, rather than births.

For a population growing from about 300 to about 500, a 1% rate of migration would require the movement of 3 to 5 rhinos per year. The model assumes that the migrations are random among populations, while managed migration would be tailored to the needs of each sanctuary and may have even more beneficial effects than indicated in the Tables.

Regular migration can stabilize the rhino populations even in the presence of occasional catastrophes in some sanctuaries (**Table 9, Figure 20**). It is worth remembering, however, that the sanctuaries subjected to catastrophes are demographic sinks (**Table 5**). Migration results in the continual restocking of these sanctuaries with animals from those populations not subjected to catastrophes. The metapopulation growth rate ($r = .027$) is depressed relative to that observed for the metapopulation in the absence of catastrophes ($r = .046$) because of the metapopulation dynamics between source and sink populations.

The simulations of the sanctuaries with 1% continual migration are affected almost not at all by the additional assumption of some managed adjustments of founder numbers (compare **Table 8** with **Table 10**, and **Table 9** with **Table 11**).

## D. AVAILABILITY OF RHINOS FOR TRANSLOCATION:

The analyses indicate little impact on the two largest populations, at Solio and Nairobi, if the suggested removals occur over the next three years (**Tables 6, 7, 10, 11; Figures 17, 18, 21, 22**). To examine the likely availability of rhinos from these and other sanctuaries from translocation to newly protected sites, the times until the capacity of each sanctuary would be reached and the expected annual surpluses available for translocation were calculated. The mean population growth rate of each sanctuary was projected to be the same as either the mean growth rates reported in **Table 6**, in which it was assumed that all sanctuaries would be fully protected from catastrophes and rhinos would be added to three populations over the next few years, or the mean growth rates reported in **Table 7**, in which it was assumed that vulnerability to catastrophes and initial adjustment of founder numbers would be as estimated at the Workshop. **Table 12** shows the growth rates, years at which capacity would be reached under these growth rates, and annual surplus. **Figure 23** illustrates these projections under the assumption that catastrophes would be as estimated by the Habitat Working Group.

The projections yield an estimated combined surplus of 20.4 rhinos per year (22.6 if Lewa is expanded to hold 60 rhinos) if no catastrophes occur, but many of those numbers will not be available for another decade or two. If catastrophes do occur periodically, 9.8 rhinos are projected to become available annually from the sanctuaries, but 5.5 of these would be needed to continually restock those populations that are subjected to unsustainable catastrophic losses.

## E. EFFECT OF PROTECTION OF LARGER AREAS OF HABITAT:

It is hoped that the large areas of habitat adjacent to the present Aberdare, Ngulia, and Lewa Downs populations can be adequately protected to allow recolonization by black rhinos. If habitat for hundreds of rhino could again be made safe for rhinos in the Aberdares, a large, demographically stable population could be maintained (**Table 13**). The population would be expected to exhibit greater average growth (due to less inbreeding depression) and more stable growth (less demographic stochasticity), and would lose minimal genetic variation over 200 years. (Although not modelled here, the amount of variation lost would likely be wholly offset by new variation introduced by rare mutations.)

At Ngulia, re-expansion of the rhino population into the surrounding habitats of Tsavo would have a similarly beneficial effect only if catastrophes could be prevented (middle section of **Table 13**). If occasional poaching recurs, the Ngulia population would not have the opportunity to expand into available habitat. The addition of 12 more founders to the Ngulia population would accelerate growth into newly protected habitat, but would have a lasting effect only if poaching were wholly prevented.

At Lewa Downs, a proposed increase of the protected area to accommodate 60 rhinos could substantially decrease the probability of local extinction, but would not assure persistence unless disease and drought catastrophes were prevented and at least one additional male breeder were added to the population (as planned) (see bottom section of **Table 13**). A recently proposed supplementation with 8 rhinos (rather than just one) would further speed growth to a stable size, and would reduce the loss of genetic variation during that growth phase.

## SUMMARY

Black rhinoceros breed and die so slowly that the populations can probably be maintained at smaller sizes than the "minimum viable population sizes" that have commonly been suggested in the literature for many other mammals (e.g., Belovsky 1987). Recovery from small numbers (as occurred in the greater one-horned rhino (*Rhinoceros unicornis*) in Asia and the Southern white rhino (*Ceratotherium simum*) in Africa) and relative stability of population size in habitat fragments that can sustain only small numbers should be possible for time periods on the order of 50-100 years.

Because of their life history, however, even rare episodes (once in a decade) of severe poaching, drought, or other catastrophes can destabilize the populations, as they would be unable to recover before subsequent catastrophes occurred.

Low levels of migration among isolated subpopulations can prevent inbreeding and concomitant losses of genetic variation from the subpopulations, and can help to stabilize the smaller isolates. A conclusion of these results is that viability of small and fragmented populations will require some interventive management to achieve viability.

The PVA modelling presented above only begins to explore the range of possibilities that were discussed at the workshop and which might be of interest and value in conservation and management. Other numbers of animals moved, and other levels of continued migration, could be examined. Varying levels of vulnerability to disease, drought, and poaching might also be usefully explored. As data are collected on the effects of inbreeding, or further data are collected on birth and death rates and on the capacity of habitats to support rhinos, more refined modelling should be possible.

The models presented above do provide a broad assessment of the viability of black rhino populations within the sanctuaries in Kenya under a variety of plausible scenarios. Projected growth rates, fluctuations in growth rates, and rates of loss of genetic variation can be compared to actual population performance in the coming years to help identify gaps in our understanding of the dynamics of small populations of rhinos as they are recovering from the decimation that occurred in the last few decades.

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# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## WORKSHOP REPORT

1 May 1993

## SECTION 4
## TABLES

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## TABLES

# Table 1.

| Rhino Area: | ----Males----- | | | | ----Females--- | | | | --Unknown Sex-- | | | | | -----Management------ | | | | | ---Breeding--- | | | 1986-90 | | 1990 | | Trans-90 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type & Name | AD | SA | CF | ST | AD | SA | CF | ST | AD | SA | CF | ST | TOT | A | D | CC | ML | S | SR | %CC | %C | + | - | + | - | In | Out | CR |
| RING-FENCED: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nakuru NP | 11 | 2 | 1 | 14 | 8 | 2 | 2 | 12 | | | 2 | 2 | 28 | 142 | 0.20 | 71 | 53 | | 1.17 | 63 | 17.8 | 6 | | 4 | | 4 | | 1 |
| Ngulia RS | 1 | 1 | 1 | 3 | 4 | 3 | | 7 | | | 1 | 1 | 11 | 73 | 0.15 | 73 | 55 | | 0.43 | 14 | 9.0 | 3 | 2 | 1 | | 1 | | 1 |
| Solio R GR | 14 | 4 | 6 | 24 | 21 | 2 | 4 | 27 | | | 5 | 5 | 56 | 56 | 1.00 | 56 | 42 | 14 | 0.89 | 71 | 26.8 | 23 | 6 | 6 | 1 | | 6 | 1 |
| Lewa Downs R RS | 2 | 2 | | 4 | 5 | 2 | 3 | 10 | | | | | 14 | 40 | 0.35 | 26 | 20 | | 0.28 | 43 | 21.4 | 4 | 1 | | 1 | 2 | | 1 |
| Ol Jogi R GR | 2 | 2 | 1 | 5 | 3 | 1 | 1 | 5 | | | 1 | 1 | 11 | 73 | 0.15 | 20 | 15 | | 1.00 | 100 | 27.2 | 4 | 1 | 1 | | | | 1 |
| Ol Pejeta R GR | 2 | 2 | | 4 | 1 | 3 | | 4 | | | | | 8 | 93 | 0.09 | 93 | 70 | | 1.00 | 0 | 0.0 | | | | | 5 | | 1 |
| Total | 32 | 13 | 9 | 54 | 42 | 13 | 10 | 65 | 0 | 0 | 9 | 9 | 128 | 477 | 0.27 | 339 | 255 | 14 | 0.83 | 67 | 21.9 | 40 | 10 | 12 | 2 | 12 | 6 | |
| PART-FENCED: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nairobi NP | 18 | 4 | 7 | 29 | 18 | 9 | 4 | 31 | | | 1 | 1 | 61 | 117 | 0.52 | 60 | 45 | 16 | 0.94 | 67 | 19.7 | 18 | 2 | 6 | | | 5 | 1 |
| Aberdare NP | 8 | 1 | 1 | 10 | 10 | 3 | 2 | 15 | 12 | | 3 | 15 | 40 | 70 | 0.57 | 100 | (100) | | 0.67 | 56 | 28.0 | 8 | | 3 | | | | 2 |
| Laikipia R | 18 | 5 | | 23 | 10 | 4 | 1 | 15 | 3 | 1 | 2 | 6 | 44 | 397 | 0.11 | 100 | (100) | | 1.53 | 30 | 6.8 | 6 | 1 | 1 | | | | 1 |
| Total | 44 | 10 | 8 | 62 | 38 | 16 | 7 | 61 | 15 | 1 | 6 | 22 | 145 | 584 | 0.25 | 260 | 245 | 16 | 1.02 | 55 | 14.5 | 32 | 3 | 10 | 0 | 0 | 5 | |
| UNFENCED: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Masai Mara NR | 4 | 4 | 4 | 12 | 9 | 1 | 2 | 12 | | | | | 24 | 1690 | 0.01 | 50 | (50) | | 1.00 | 67 | 37.5 | 11 | 2 | 4 | 2 | | | 1 |
| Amboseli NP | 2 | 1 | | 3 | 2 | 1 | 1 | 4 | | | | | 7 | 390 | 0.02 | 50 | (50) | | 0.75 | 50 | 14.3 | 3 | 3 | 1 | 1 | | | 1 |
| Total | 6 | 5 | 4 | 15 | 11 | 2 | 3 | 16 | 0 | 0 | 0 | 0 | 31 | 2080 | 0.01 | 100 | 100 | | 0.94 | 47 | 22.6 | 14 | 5 | 5 | 3 | 0 | 0 | |
| TOTALS | 82 | 28 | 21 | 131 | 91 | 31 | 20 | 142 | 15 | 1 | 15 | 31 | 304 | 3141 | 0.10 | 699 | 600 | 30 | 0.92 | 62 | 18.4 | 86 | 18 | 27 | 5 | 12 | 11 | |

Key:
AD=Adults (>6 y.o.)
SA=Subadults (4-6 y.o.)
CF=Calves (<4 y.o.)
ST=Subtotal (Sex)
TOT=Population total
A=Area of rhino reserve (sq km)
D=Density of rhino (per sq km)
CC=Carrying Capacity (Brett (1989) estimate)
ML=Management Level
S=Existing Surplus of Rhino (number of rhino exceeding ML (TOT-ML), available for translocation
SR=Known Sex Ratio (No.Males/No.Females)
%CC=Percentage of Adult Female (Cow) Rhinos with Calves
%C=Percentage of Calves in population
'+'=Total No. of Births for stated period
'-'=Total No. of Deaths for stated period
Trans-90=Total No. of translocations In and Out of sanctuary in 1990
CR=Census Rating (Du Toit 1989)
NP=National Park
NR=National Reserve
GR=Game Reserve
R=Private Ranch

Table 1 - Population Statistics for the black rhino in Kenya sanctuaries (at the end of 1990), and overall breeding performance from 1986 to 1990

## 2a. SMALL POPULATIONS OF RHINOCEROS

| Inbr. depr. | Catas. | K | Pop. growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| 3.12 | None | 10 | .014 | .105 | .06 | 9 | 2 | 73 | .22 | 8 | 2 | 58 | .70 | 6 | 2 | 33 | 161 |
| | | 20 | .025 | .073 | 0 | 19 | 2 | 86 | .01 | 18 | 2 | 77 | .06 | 17 | 4 | 60 | |
| | | 30 | .032 | .061 | 0 | 29 | 2 | 90 | 0 | 29 | 2 | 84 | 0 | 28 | 3 | 72 | |
| | | 40 | .036 | .056 | 0 | 39 | 2 | 93 | 0 | 39 | 2 | 87 | 0 | 39 | 3 | 77 | |
| | | 50 | .038 | .052 | 0 | 49 | 2 | 94 | 0 | 49 | 2 | 90 | 0 | 49 | 2 | 82 | |
| | | 60 | .039 | .050 | 0 | 59 | 2 | 95 | 0 | 59 | 2 | 91 | 0 | 59 | 2 | 84 | |
| | | 100 | .042 | .045 | 0 | 99 | 3 | 97 | 0 | 99 | 3 | 95 | 0 | 99 | 3 | 90 | |
| 3.12 | Dr,Di | 10 | -.011 | .177 | .46 | 7 | 3 | 70 | .85 | 5 | 2 | 52 | 1.00 | 10 | 0 | 50 | 53 |
| | | 20 | -.007 | .151 | .14 | 14 | 5 | 82 | .40 | 12 | 5 | 68 | .92 | 8 | 5 | 49 | 114 |
| | | 30 | -.004 | .140 | .03 | 21 | 7 | 87 | .21 | 18 | 8 | 76 | .69 | 13 | 9 | 59 | 165 |
| | | 40 | -.002 | 133 | .03 | 28 | 10 | 90 | .12 | 24 | 11 | 81 | .47 | 17 | 11 | 64 | |
| | | 50 | .001 | .128 | .01 | 36 | 13 | 92 | .07 | 32 | 14 | 85 | .34 | 25 | 15 | 70 | |
| | | 60 | .002 | .126 | .01 | 44 | 15 | 93 | .05 | 39 | 17 | 87 | .27 | 29 | 18 | 74 | |
| | | 100 | .005 | .119 | 0 | 76 | 24 | 96 | .01 | 67 | 28 | 92 | .13 | 59 | 30 | 84 | |
| 3.12 | PW | 10 | -.000 | .160 | .35 | 7 | 2 | 71 | .73 | 6 | 2 | 55 | .98 | 6 | 2 | 36 | 68 |
| | | 20 | .004 | .138 | .06 | 15 | 5 | 83 | .22 | 13 | 6 | 70 | .68 | 11 | 6 | 51 | 155 |
| | | 30 | .008 | .123 | .01 | 24 | 7 | 88 | .08 | 22 | 8 | 79 | .35 | 18 | 9 | 62 | |
| | | 40 | .012 | .115 | .01 | 33 | 9 | 91 | .02 | 31 | 10 | 84 | .15 | 26 | 12 | 71 | |
| | | 50 | .015 | .112 | 0 | 42 | 10 | 93 | .01 | 40 | 12 | 87 | .11 | 35 | 15 | 76 | |
| | | 60 | .017 | .106 | 0 | 51 | 12 | 94 | 0 | 49 | 14 | 89 | .04 | 44 | 16 | 79 | |
| | | 100 | .021 | 101 | 0 | 86 | 19 | 96 | 0 | 85 | 20 | 94 | 0 | 81 | 22 | 88 | |
| 3.12 | Dr,Di,PW | 10 | -.032 | .220 | .76 | 6 | 2 | 66 | .98 | 4 | 2 | 44 | 1.00 | -- | -- | -- | 30 |
| | | 20 | -.027 | .196 | .43 | 10 | 5 | 78 | .87 | 8 | 5 | 63 | 1.00 | -- | -- | -- | 56 |
| | | 30 | -.025 | .185 | .24 | 14 | 8 | 83 | .67 | 12 | 8 | 69 | .98 | 9 | 7 | 55 | 78 |
| | | 40 | -.022 | .179 | .13 | 19 | 11 | 86 | .52 | 15 | 11 | 73 | .96 | 9 | 7 | 60 | 98 |
| | | 50 | -.022 | .175 | .09 | 24 | 15 | 88 | .46 | 18 | 14 | 78 | .92 | 15 | 12 | 63 | 105 |
| | | 60 | -.021 | .171 | .06 | 29 | 17 | 90 | .36 | 21 | 16 | 79 | .90 | 12 | 9 | 65 | 119 |
| | | 100 | -.017 | .164 | .02 | 50 | 29 | 93 | .22 | 39 | 29 | 87 | .70 | 23 | 23 | 72 | 155 |

Note: deterministic r (from life table) = .046 without catastrophes or poaching; r = .016 with catastrophes; r = .030 with poaching; r = .000 with catastrophes and poaching

## 2b. SMALL POPULATIONS OF RHINOCEROS -- MORE SEVERE INBREEDING EFFECTS

| Inbr. depr. | Catas. | K | Pop. growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| 6.24 | None | 10 | .006 | .204 | .10 | 8 | 2 | 74 | .40 | 6 | 2 | 58 | .97 | 3 | 2 | 44 | 113 |
| | | 20 | .015 | .077 | 0 | 19 | 2 | 87 | .01 | 18 | 3 | 78 | .22 | 12 | 5 | 60 | |
| | | 30 | .024 | .061 | 0 | 29 | 2 | 91 | 0 | 29 | 3 | 85 | .01 | 25 | 6 | 73 | |
| | | 40 | .029 | .055 | 0 | 39 | 2 | 93 | 0 | 39 | 2 | 88 | 0 | 37 | 4 | 79 | |
| | | 50 | .032 | .051 | 0 | 49 | 2 | 94 | 0 | 49 | 2 | 90 | 0 | 48 | 3 | 83 | |
| | | 60 | .034 | .049 | 0 | 59 | 2 | 95 | 0 | 59 | 2 | 92 | 0 | 58 | 3 | 85 | |
| | | 100 | .039 | .044 | 0 | 99 | 3 | 97 | 0 | 99 | 3 | 95 | 0 | 99 | 3 | 90 | |
| 6.24 | Dr,Di | 10 | -.017 | .178 | .46 | 6 | 2 | 70 | .92 | 6 | 2 | 55 | 1.00 | -- | -- | -- | 51 |
| | | 20 | -.014 | .155 | .14 | 13 | 5 | 81 | .61 | 10 | 5 | 67 | 1.00 | -- | -- | -- | 88 |
| | | 30 | -.013 | .146 | .05 | 20 | 8 | 87 | .26 | 14 | 8 | 76 | .91 | 8 | 6 | 61 | 132 |
| | | 40 | -.009 | .137 | .03 | 28 | 10 | 90 | .17 | 21 | 12 | 81 | .75 | 12 | 8 | 64 | 160 |
| | | 50 | -.007 | .133 | .01 | 35 | 12 | 92 | .08 | 28 | 15 | 84 | .60 | 15 | 11 | 70 | 183 |
| | | 60 | -.005 | .130 | .01 | 43 | 16 | 93 | .07 | 35 | 17 | 86 | .52 | 21 | 17 | 73 | 195 |
| | | 100 | .001 | .119 | 0 | 74 | 25 | 96 | .01 | 65 | 28 | 92 | .17 | 46 | 30 | 83 | |
| 6.24 | PW | 10 | -.006 | .163 | .34 | 7 | 2 | 72 | .86 | 5 | 2 | 57 | 1.00 | -- | -- | -- | 66 |
| | | 20 | -.004 | .141 | .05 | 15 | 5 | 83 | .32 | 12 | 5 | 73 | .92 | 7 | 4 | 53 | 128 |
| | | 30 | -.000 | .127 | .02 | 24 | 7 | 89 | .10 | 20 | 9 | 79 | .64 | 12 | 8 | 64 | 179 |
| | | 40 | .004 | .119 | 0 | 32 | 9 | 91 | .04 | 29 | 10 | 84 | .36 | 19 | 11 | 69 | |
| | | 50 | .008 | .114 | 0 | 42 | 10 | 93 | .01 | 37 | 13 | 87 | .23 | 26 | 16 | 75 | |
| | | 60 | .010 | .110 | 0 | 50 | 13 | 94 | .02 | 46 | 15 | 89 | .15 | 36 | 18 | 79 | |
| | | 100 | .016 | .103 | 0 | 86 | 19 | 97 | 0 | 82 | 22 | 94 | .02 | 72 | 28 | 87 | |
| 6.24 | Dr,Di,PW | 10 | -.031 | .212 | .77 | 5 | 2 | 67 | .99 | 4 | 2 | 50 | 1.00 | -- | -- | -- | 33 |
| | | 20 | -.030 | .193 | .40 | 9 | 5 | 78 | .89 | 7 | 5 | 62 | 1.00 | -- | -- | -- | 58 |
| | | 30 | -.027 | .182 | .24 | 13 | 8 | 82 | .75 | 9 | 6 | 70 | 1.00 | -- | -- | -- | 72 |
| | | 40 | -.027 | .180 | .15 | 19 | 11 | 86 | .64 | 13 | 9 | 75 | .99 | 6 | 3 | 56 | 86 |
| | | 50 | -.026 | .173 | .09 | 22 | 14 | 88 | .52 | 14 | 11 | 77 | .99 | 4 | 2 | 68 | 98 |
| | | 60 | -.025 | .174 | .07 | 30 | 17 | 90 | .45 | 20 | 16 | 79 | .98 | 16 | 15 | 68 | 108 |
| | | 100 | -.023 | .169 | .03 | 45 | 28 | 93 | .27 | 29 | 25 | 86 | .84 | 15 | 15 | 74 | 131 |

Note: deterministic r (from life table) = .046 without catastrophes or poaching; r = .016 with catastrophes; r = .030 with poaching; r = .000 with catastrophes and poaching.

## 3. SMALL POPULATIONS OF RHINOCEROS -- INCREASED INTENSITY OF POACHING

| Poaching Intensity Freq/Svrt | Catas. | K | Pop. growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| 33.3/.05 | None | 10 | .000 | .131 | .20 | 7 | 2 | 72 | .60 | 6 | 2 | 53 | .97 | 5 | 2 | 29 | 86 |
| | | 20 | .007 | .095 | .01 | 17 | 3 | 85 | .06 | 16 | 4 | 73 | .43 | 12 | 5 | 53 | |
| | | 30 | .014 | .075 | 0 | 28 | 3 | 90 | 0 | 26 | 5 | 82 | .05 | 22 | 7 | 68 | |
| | | 40 | .018 | .067 | 0 | 37 | 4 | 93 | 0 | 37 | 4 | 87 | .01 | 33 | 8 | 75 | |
| | | 50 | .020 | .062 | 0 | 48 | 4 | 94 | 0 | 47 | 4 | 89 | 0 | 45 | 8 | 80 | |
| | | 60 | .022 | .059 | 0 | 58 | 4 | 95 | 0 | 57 | 5 | 91 | 0 | 55 | 6 | 84 | |
| | | 100 | .025 | .053 | 0 | 97 | 4 | 97 | 0 | 97 | 5 | 94 | 0 | 96 | 5 | 90 | |
| 33.3/.05 | Dr,Di | 10 | -.025 | .188 | .66 | 6 | 2 | 68 | .96 | 5 | 2 | 47 | 1.00 | -- | -- | -- | 39 |
| | | 20 | -.023 | .171 | .28 | 10 | 5 | 78 | .76 | 8 | 5 | 62 | .99 | 6 | 6 | 47 | 69 |
| | | 30 | -.022 | .159 | .15 | 16 | 8 | 84 | .56 | 12 | 8 | 70 | .98 | 6 | 4 | 53 | 94 |
| | | 40 | -.020 | .153 | .08 | 21 | 11 | 87 | .40 | 16 | 10 | 75 | .94 | 9 | 5 | 56 | 111 |
| | | 50 | -.020 | .151 | .05 | 26 | 14 | 89 | .33 | 18 | 13 | 78 | .90 | 13 | 11 | 66 | 121 |
| | | 60 | -.018 | .146 | .03 | 32 | 17 | 91 | .26 | 24 | 17 | 80 | .81 | 16 | 15 | 68 | 136 |
| | | 100 | -.015 | .135 | .02 | 56 | 28 | 95 | .11 | 40 | 28 | 87 | .57 | 26 | 24 | 75 | 186 |
| 33.3/.10 | None | 10 | -.013 | .158 | .44 | 6 | 2 | 68 | .86 | 5 | 2 | 49 | 1.00 | -- | -- | -- | 56 |
| | | 20 | -.011 | .128 | .05 | 14 | 5 | 82 | .41 | 11 | 5 | 68 | .94 | 7 | 4 | 48 | 117 |
| | | 30 | -.007 | .113 | .03 | 22 | 7 | 88 | .13 | 18 | 8 | 76 | .67 | 11 | 7 | 58 | 170 |
| | | 40 | -.004 | .101 | 0 | 31 | 8 | 91 | .05 | 26 | 10 | 83 | .43 | 16 | 10 | 65 | |
| | | 50 | -.002 | .092 | 0 | 39 | 10 | 93 | .03 | 34 | 13 | 86 | .26 | 23 | 14 | 71 | |
| | | 60 | -.000 | .087 | 0 | 49 | 11 | 94 | .01 | 42 | 15 | 88 | .17 | 30 | 17 | 76 | |
| | | 100 | .005 | .074 | 0 | 84 | 15 | 97 | 0 | 79 | 21 | 93 | .02 | 65 | 26 | 86 | |
| 33.3/.10 | Dr,Di | 10 | -.045 | .209 | .87 | 4 | 2 | 62 | 1.00 | -- | -- | -- | 1.00 | -- | -- | -- | 26 |
| | | 20 | -.038 | .185 | .55 | 8 | 5 | 74 | .95 | 6 | 3 | 63 | 1.00 | -- | -- | -- | 48 |
| | | 30 | -.037 | .180 | .33 | 11 | 7 | 80 | .85 | 7 | 5 | 62 | 1.00 | -- | -- | -- | 63 |
| | | 40 | -.038 | .175 | .22 | 14 | 10 | 83 | .83 | 8 | 5 | 70 | 1.00 | -- | -- | -- | 70 |
| | | 50 | -.037 | .170 | .19 | 17 | 12 | 86 | .72 | 11 | 10 | 71 | 1.00 | 11 | 10 | 57 | 77 |
| | | 60 | -.035 | .167 | .12 | 20 | 13 | 87 | .64 | 13 | 11 | 76 | .99 | 6 | 6 | 51 | 86 |
| | | 100 | -.034 | .160 | .05 | 35 | 24 | 92 | .47 | 18 | 16 | 80 | .98 | 9 | 7 | 69 | 103 |

Note: deterministic r (from life table) = .029 no catastrophes, P11; r = -.001 Dr, Di, P11: r = .012 no catastrophes, P12; r = -.018 Dr, Di, P12.

## 4. RHINO SANCTUARIES, NO CATASTROPHIES, NO ADJUSTMENT OF FOUNDERS, NO MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| NAKURU | 29 | 52 |  |  | .038 | .052 | 0 | 51 | 2 | 94 | 0 | 51 | 2 | 90 | 0 | 51 | 2 | 82 |  |
| SOLIO | 59 | 56 |  |  | .039 | .051 | 0 | 55 | 2 | 95 | 0 | 55 | 2 | 91 | 0 | 55 | 3 | 83 |  |
| NAIROBI | 63 | 63 |  |  | .038 | .049 | 0 | 62 | 2 | 95 | 0 | 62 | 3 | 92 | 0 | 62 | 2 | 85 |  |
| MARA | 26 | 50 |  |  | .039 | .053 | 0 | 49 | 2 | 94 | 0 | 49 | 2 | 89 | 0 | 49 | 2 | 81 |  |
| OL JOGI | 11 | 18 |  |  | .024 | .077 | .01 | 17 | 2 | 84 | .02 | 16 | 3 | 73 | .10 | 15 | 3 | 55 |  |
| LEWA | 11 | 10 |  |  | .015 | .108 | .21 | 9 | 1 | 71 | .36 | 8 | 2 | 55 | .78 | 6 | 2 | 32 | 131 |
| NGULIA | 12 | 55 |  |  | .036 | .054 | 0 | 53 | 6 | 91 | 0 | 54 | 2 | 87 | 0 | 54 | 3 | 81 |  |
| OL PEJETA | 8 | 70 |  |  | .036 | .053 | .01 | 61 | 13 | 88 | .01 | 69 | 5 | 85 | .01 | 69 | 4 | 80 |  |
| LAIKIPIA | 38 | 100 |  |  | .040 | .045 | 0 | 99 | 3 | 96 | 0 | 99 | 3 | 94 | 0 | 99 | 3 | 89 |  |
| ABERDARE | 33 | 43 |  |  | .037 | .055 | 0 | 42 | 2 | 93 | 0 | 42 | 2 | 88 | 0 | 42 | 3 | 79 |  |
| AMBOSELI | 3 | 50 |  |  | .013 | .095 | .41 | 15 | 10 | 66 | .50 | 31 | 17 | 59 | .58 | 40 | 15 | 53 | 105 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| META-POP | 293 | 567 |  |  | .038 | .018 | 0 | 506 | 21 | 99 | 0 | 518 | 21 | 99 | 0 | 512 | 25 | 98 |  |

Note: deterministic r (from life table) = .046

## 5. RHINO SANCTUARIES, CATASTROPHES, NO ADJUSTMENT OF FOUNDERS, NO MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth: r |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| NAKURU | 29 | 52 | Di |  | .032 | .075 | 0 | 49 | 6 | 94 | 0 | 49 | 6 | 89 | 0 | 48 | 7 | 81 |  |
| SOLIO | 59 | 56 | Di |  | .033 | .074 | 0 | 54 | 5 | 94 | 0 | 53 | 6 | 90 | 0 | 52 | 8 | 82 |  |
| NAIROBI | 63 | 63 | Di |  | .033 | .072 | 0 | 60 | 7 | 95 | 0 | 61 | 6 | 91 | 0 | 59 | 7 | 84 |  |
| MARA | 26 | 50 | Di,P |  | .009 | .127 | 0 | 37 | 12 | 91 | .04 | 35 | 13 | 84 | .22 | 28 | 15 | 71 |  |
| OL JOGI | 11 | 18 | Di,Dr |  | -.008 | .157 | .19 | 12 | 5 | 78 | .57 | 10 | 5 | 63 | .94 | 8 | 4 | 50 | 91 |
| LEWA | 11 | 10 | Di,Dr |  | -.008 | .177 | .55 | 6 | 3 | 66 | .90 | 5 | 2 | 44 | 1.00 | -- | -- | -- | 43 |
| NGULIA | 12 | 55 | Di,Dr,P |  | -.026 | .195 | .42 | 14 | 11 | 78 | .80 | 10 | 9 | 66 | 1.00 | 6 | 0 | 28 | 58 |
| OL PEJETA | 8 | 70 | Di |  | .028 | .080 | .02 | 55 | 19 | 87 | .03 | 63 | 14 | 83 | .06 | 64 | 11 | 78 |  |
| LAIKIPIA | 38 | 100 | Di,Dr,P |  | -.023 | .173 | .15 | 34 | 27 | 89 | .42 | 27 | 23 | 79 | .87 | 17 | 21 | 73 | 111 |
| ABERDARE | 33 | 43 | Di |  | .032 | .078 | 0 | 41 | 5 | 93 | 0 | 40 | 6 | 87 | .01 | 39 | 7 | 78 |  |
| AMBOSELI | 3 | 50 | Di,Dr,P |  | -.039 | .244 | .97 | 5 | 3 | 61 | 1.00 | -- | -- | -- | 1.00 | -- | -- | -- | 14 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| META-POP | 293 | 567 | Above |  | .028 | .030 | 0 | 346 | 45 | 99 | 0 | 320 | 34 | 98 | 0 | 283 | 30 | 96 |  |

Note: deterministic r (from life table) = .042 with Disease, .026 with Di and Poaching, .016 with Di and Drought, and .000 with Di, Dr, and P

## 6. RHINO SANCTUARIES, NO CATASTROPHIES, MANAGED FOUNDER NUMBERS, NO MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| NAKURU | 29 | 52 | | | .038 | .052 | 0 | 51 | 2 | 95 | 0 | 51 | 2 | 90 | 0 | 51 | 2 | 82 | |
| SOLIO | 59 | 56 | | -10 | .039 | .051 | 0 | 55 | 2 | 95 | 0 | 55 | 2 | 91 | 0 | 55 | 2 | 83 | |
| NAIROBI | 63 | 63 | | - 8 | .038 | .049 | 0 | 62 | 2 | 95 | 0 | 62 | 2 | 92 | 0 | 62 | 3 | 85 | |
| MARA | 26 | 50 | | | .038 | .053 | 0 | 49 | 2 | 94 | 0 | 49 | 2 | 89 | 0 | 49 | 2 | 81 | |
| OL JOGI | 11 | 18 | | | .024 | .076 | 0 | 17 | 2 | 84 | .01 | 17 | 2 | 74 | .08 | 15 | 4 | 56 | |
| LEWA | 11 | 10 | | + 1 | .015 | .108 | .18 | 8 | 2 | 71 | .37 | 8 | 2 | 55 | .76 | 7 | 2 | 39 | 129 |
| NGULIA | 12 | 55 | | +12 | .038 | .051 | 0 | 55 | 2 | 94 | 0 | 54 | 2 | 90 | 0 | 54 | 2 | 82 | |
| OL PEJETA | 8 | 70 | | + 8 | .040 | .049 | 0 | 70 | 2 | 94 | 0 | 69 | 3 | 91 | 0 | 69 | 2 | 85 | |
| LAIKIPIA | 38 | 100 | | | .040 | .045 | 0 | 99 | 3 | 96 | 0 | 99 | 3 | 94 | 0 | 99 | 3 | 89 | |
| ABERDARE | 33 | 43 | | | .037 | .055 | 0 | 42 | 2 | 93 | 0 | 42 | 2 | 88 | 0 | 42 | 2 | 79 | |
| AMBOSELI | 3 | 50 | | | .014 | .094 | .44 | 15 | 11 | 65 | .50 | 32 | 16 | 60 | .56 | 41 | 13 | 55 | 99 |
| | | | | | | | | | | | | | | | | | | | |
| META-POP | 293 | 567 | | | .039 | .018 | 0 | 516 | 13 | 99 | 0 | 519 | 21 | 99 | 0 | 515 | 24 | 98 | |

Note: deterministic r (from life table) = .046

## 7. RHINO SANCTUARIES, CATASTROPHIES, MANAGED FOUNDER NUMBERS, NO MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| NAKURU | 29 | 52 | Di |  | .032 | .075 | 0 | 50 | 6 | 94 | 0 | 49 | 6 | 89 | 0 | 48 | 7 | 82 |  |
| SOLIO | 59 | 56 | Di | -10 | .034 | .074 | 0 | 53 | 7 | 94 | 0 | 53 | 7 | 90 | 0 | 52 | 8 | 83 |  |
| NAIROBI | 63 | 63 | Di | - 8 | .033 | .070 | 0 | 61 | 6 | 95 | 0 | 60 | 7 | 91 | 0 | 60 | 7 | 84 |  |
| MARA | 26 | 50 | Di,P |  | .010 | .127 | .01 | 38 | 13 | 91 | .03 | 33 | 15 | 84 | .23 | 30 | 15 | 73 |  |
| OL JOGI | 11 | 18 | Di,Dr |  | -.007 | .156 | .20 | 12 | 5 | 79 | .51 | 9 | 5 | 66 | .94 | 9 | 5 | 47 | 100 |
| LEWA | 11 | 10 | Di,Dr | + 1 | -.008 | .174 | .48 | 7 | 2 | 69 | .87 | 5 | 3 | 51 | 1.00 | -- | -- | -- | 52 |
| NGULIA | 12 | 55 | Di,Dr,P | +12 | -.022 | .179 | .18 | 24 | 16 | 87 | .48 | 19 | 16 | 76 | .93 | 13 | 15 | 65 | 104 |
| OL PEJETA | 8 | 70 | Di | + 8 | .035 | .071 | 0 | 67 | 7 | 94 | 0 | 66 | 8 | 90 | 0 | 66 | 8 | 84 |  |
| LAIKIPIA | 38 | 100 | Di,Dr,P |  | -.024 | .175 | .13 | 33 | 26 | 88 | .45 | 28 | 24 | 81 | .89 | 16 | 15 | 68 | 109 |
| ABERDARE | 33 | 43 | Di |  | .032 | .078 | 0 | 40 | 5 | 93 | 0 | 40 | 6 | 87 | 0 | 39 | 7 | 77 |  |
| AMBOSELI | 3 | 50 | Di,Dr,P |  | -.033 | .234 | .93 | 6 | 5 | 60 | .99 | 4 | 1 | 33 | 1.00 | -- | -- | -- | 15 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| META-POP | 293 | 567 | Above |  | .029 | .029 | 0 | 370 | 38 | 99 | 0 | 332 | 34 | 98 | 0 | 290 | 28 | 97 |  |

Note: deterministic r (from life table) = .042 with Disease, .026 with Di and Poaching, .016 with Di and Drought, and .000 with Di, Dr, and P

## 8. RHINO SANCTUARIES, NO CATASTROPHIES, NO ADJUSTMENT OF FOUNDERS, MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| NAKURU | 29 | 52 | | | .037 | .079 | 0 | 50 | 3 | 98 | 0 | 50 | 3 | 98 | 0 | 50 | 3 | 97 | |
| SOLIO | 59 | 56 | | | .028 | .076 | 0 | 54 | 3 | 98 | 0 | 54 | 4 | 98 | 0 | 54 | 3 | 97 | |
| NAIROBI | 63 | 63 | | | .019 | .073 | 0 | 59 | 5 | 98 | 0 | 59 | 4 | 98 | 0 | 59 | 5 | 97 | |
| MARA | 26 | 50 | | | .041 | .080 | 0 | 48 | 3 | 98 | 0 | 48 | 3 | 98 | 0 | 48 | 3 | 97 | |
| OL JOGI | 11 | 18 | | | .201 | .139 | 0 | 18 | 2 | 96 | 0 | 18 | 2 | 96 | 0 | 18 | 2 | 95 | |
| LEWA | 11 | 10 | | | .375 | .203 | 0 | 10 | 2 | 94 | 0 | 10 | 2 | 93 | .01 | 10 | 2 | 93 | 148* |
| NGULIA | 12 | 55 | | | .036 | .081 | 0 | 52 | 4 | 98 | 0 | 53 | 4 | 98 | 0 | 52 | 4 | 97 | |
| OL PEJETA | 8 | 70 | | | .023 | .082 | 0 | 64 | 6 | 98 | 0 | 65 | 6 | 98 | 0 | 64 | 6 | 97 | |
| LAIKIPIA | 38 | 100 | | | .004 | .068 | 0 | 75 | 13 | 98 | 0 | 78 | 12 | 98 | 0 | 76 | 12 | 97 | |
| ABERDARE | 33 | 43 | | | .054 | .085 | 0 | 42 | 3 | 98 | 0 | 42 | 3 | 97 | 0 | 42 | 2 | 96 | |
| AMBOSELI | 3 | 50 | | | .050 | .104 | 0 | 48 | 3 | 98 | 0 | 49 | 3 | 98 | 0 | 48 | 4 | 96 | |
| | | | | | | | | | | | | | | | | | | | |
| META-POP | 293 | 567 | | | .046 | .018 | 0 | 518 | 18 | 99 | 0 | 525 | 17 | 99 | 0 | 522 | 17 | 98 | |

Note: deterministic r (from life table) = .046; * Median time to first extinction, population usually recolonized.

## 9. RHINO SANCTUARIES, CATASTROPHES, NO ADJUSTMENT OF FOUNDERS, MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth: r |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| NAKURU | 29 | 52 | Di |  | .018 | .095 | 0 | 47 | 6 | 98 | 0 | 47 | 6 | 97 | 0 | 48 | 6 | 96 |  |
| SOLIO | 59 | 56 | Di |  | .012 | .093 | 0 | 49 | 7 | 98 | 0 | 49 | 7 | 97 | 0 | 49 | 7 | 96 |  |
| NAIROBI | 63 | 63 | Di |  | .006 | .090 | 0 | 53 | 9 | 98 | 0 | 54 | 8 | 97 | 0 | 53 | 9 | 96 |  |
| MARA | 26 | 50 | Di,P |  | .015 | .131 | 0 | 41 | 9 | 98 | 0 | 42 | 8 | 97 | 0 | 42 | 8 | 96 |  |
| OL JOGI | 11 | 18 | Di,Dr |  | .133 | .165 | 0 | 17 | 2 | 96 | 0 | 17 | 2 | 95 | 0 | 17 | 2 | 94 |  |
| LEWA | 11 | 10 | Di,Dr |  | .280 | .218 | 0 | 10 | 2 | 94 | .02 | 10 | 2 | 93 | .01 | 10 | 2 | 92 | 128* |
| NGULIA | 12 | 55 | Di,Dr,P |  | .009 | .163 | 0 | 38 | 11 | 97 | 0 | 38 | 10 | 97 | 0 | 38 | 11 | 96 |  |
| OL PEJETA | 8 | 70 | Di |  | .013 | .099 | 0 | 54 | 11 | 98 | 0 | 56 | 9 | 97 | 0 | 57 | 10 | 96 |  |
| LAIKIPIA | 38 | 100 | Di,Dr,P |  | .000 | .160 | 0 | 39 | 13 | 97 | 0 | 40 | 13 | 97 | 0 | 40 | 13 | 96 |  |
| ABERDARE | 33 | 43 | Di |  | .031 | .100 | 0 | 40 | 5 | 98 | 0 | 40 | 5 | 97 | 0 | 40 | 4 | 96 |  |
| AMBOSELI | 3 | 50 | Di,Dr,P |  | .018 | .176 | 0 | 36 | 9 | 97 | 0 | 36 | 10 | 97 | 0 | 36 | 10 | 96 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| META-POP | 293 | 567 | Above |  | .027 | .030 | 0 | 424 | 35 | 99 | 0 | 430 | 35 | 99 | 0 | 429 | 34 | 97 |  |

Note: deterministic r (from life table) = .042 with Disease, .026 with Di and Poaching, .016 with Di and Drought, and .000 with Di, Dr, and P;

* Median time to first extinction, population always recolonized.

## 10. RHINO SANCTUARIES, NO CATASTROPHES, MANAGED FOUNDER NUMBERS, MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) | | 50 yr results | | | | 100 yr results | | | | 200 yr results | | | | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | |
| NAKURU | 29 | 52 | | | .037 | .079 | 0 | 50 | 3 | 98 | 0 | 50 | 3 | 98 | 0 | 50 | 3 | 97 | |
| SOLIO | 59 | 56 | | -10 | .029 | .076 | 0 | 53 | 4 | 98 | 0 | 54 | 4 | 98 | 0 | 54 | 4 | 97 | |
| NAIROBI | 63 | 63 | | - 8 | .020 | .073 | 0 | 59 | 5 | 98 | 0 | 59 | 5 | 98 | 0 | 59 | 5 | 97 | |
| MARA | 26 | 50 | | | .041 | .080 | 0 | 48 | 3 | 98 | 0 | 48 | 3 | 98 | 0 | 48 | 3 | 97 | |
| OL JOGI | 11 | 18 | | | .203 | .139 | 0 | 18 | 2 | 96 | 0 | 18 | 2 | 96 | 0 | 18 | 2 | 95 | |
| LEWA | 11 | 10 | | + 1 | .377 | .200 | 0 | 10 | 2 | 94 | 0 | 10 | 2 | 94 | 0 | 10 | 2 | 93 | 171* |
| NGULIA | 12 | 55 | | +12 | .033 | .077 | 0 | 53 | 4 | 98 | 0 | 53 | 4 | 98 | 0 | 53 | 3 | 97 | |
| OL PEJETA | 8 | 70 | | + 8 | .017 | .073 | 0 | 65 | 6 | 98 | 0 | 64 | 6 | 98 | 0 | 65 | 6 | 97 | |
| LAIKIPIA | 38 | 100 | | | .005 | .067 | 0 | 77 | 13 | 98 | 0 | 78 | 12 | 98 | 0 | 77 | 12 | 97 | |
| ABERDARE | 33 | 43 | | | .055 | .085 | 0 | 42 | 3 | 98 | 0 | 42 | 2 | 97 | 0 | 42 | 3 | 96 | |
| AMBOSELI | 3 | 50 | | | .051 | .105 | 0 | 49 | 3 | 98 | 0 | 48 | 3 | 98 | 0 | 48 | 3 | 97 | |
| | | | | | | | | | | | | | | | | | | | |
| META-POP | 293 | 567 | | | .045 | .017 | 0 | 523 | 17 | 99 | 0 | 524 | 17 | 99 | 0 | 524 | 17 | 98 | |

Note: deterministic r (from life table) = .046; * Median time to first extinction, population always recolonized.

## 11. RHINO SANCTUARIES, CATASTROPHES, MANAGED FOUNDER NUMBERS, MIGRATION

| LOCATION | $N_0$ | K | CATS | + OR - | Pop growth (r) |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| NAKURU | 29 | 52 | Di |  | .019 | .095 | 0 | 47 | 6 | 98 | 0 | 47 | 6 | 97 | 0 | 47 | 6 | 96 |  |
| SOLIO | 59 | 56 | Di | -10 | .013 | .093 | 0 | 50 | 7 | 98 | 0 | 48 | 7 | 97 | 0 | 50 | 7 | 96 |  |
| NAIROBI | 63 | 63 | Di | - 8 | .008 | .091 | 0 | 54 | 9 | 98 | 0 | 54 | 8 | 97 | 0 | 54 | 8 | 96 |  |
| MARA | 26 | 50 | Di,P |  | .015 | .131 | 0 | 41 | 8 | 98 | 0 | 41 | 8 | 97 | 0 | 42 | 8 | 96 |  |
| OL JOGI | 11 | 18 | Di,Dr |  | .134 | .166 | 0 | 17 | 2 | 96 | 0 | 17 | 2 | 95 | 0 | 17 | 2 | 94 |  |
| LEWA | 11 | 10 | Di,Dr | + 1 | .283 | .215 | 0 | 10 | 2 | 94 | 0 | 10 | 2 | 93 | 0 | 10 | 2 | 92 | 154* |
| NGULIA | 12 | 55 | Di,Dr,P | +12 | .005 | .161 | 0 | 38 | 10 | 97 | 0 | 37 | 11 | 97 | 0 | 37 | 11 | 96 |  |
| OL PEJETA | 8 | 70 | Di | + 8 | .008 | .092 | 0 | 56 | 11 | 98 | 0 | 56 | 11 | 97 | 0 | 56 | 11 | 96 |  |
| LAIKIPIA | 38 | 100 | Di,Dr,P |  | .000 | .160 | 0 | 39 | 12 | 97 | 0 | 41 | 13 | 97 | 0 | 40 | 13 | 96 |  |
| ABERDARE | 33 | 43 | Di |  | .033 | .099 | 0 | 41 | 4 | 98 | 0 | 41 | 4 | 97 | 0 | 40 | 5 | 96 |  |
| AMBOSELI | 3 | 50 | Di,Dr,P |  | .019 | .173 | 0 | 37 | 9 | 97 | 0 | 37 | 10 | 97 | 0 | 36 | 9 | 96 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| META-POP | 293 | 567 | Above |  | .027 | .030 | 0 | 430 | 33 | 99 | 0 | 430 | 35 | 99 | 0 | 429 | 36 | 97 |  |

Note: deterministic r (from life table) = .042 with Disease, .026 with Di and Poaching, .016 with Di and Drought, and .000 with Di, Dr, and P;

* Median time to first extinction, population always recolonized.

## 12. PREDICTED SURPLUS AVAILABLE FOR TRANSLOCATION

| Location | $N_e$ ± Founder adjustment | K | Catastrophes | Pop growth: r | Year at K | Mean available for harv. |
|---|---|---|---|---|---|---|
| NAKURU | 29 | 52 |  | .038 | 2007 | 2.0 |
|  | 29 | 52 | Di | .032 | 2010 | 1.7 |
| SOLIO | 59 - 10 | 56 |  | .039 | 1995 | 2.2 |
|  | 59 - 10 | 56 | Di | .034 | 1996 | 1.8 |
| NAIROBI | 63 - 12 | 63 |  | .038 | 1997 | 2.4 |
|  | 63 - 12 | 63 | Di | .033 | 1998 | 2.1 |
| MARA | 26 | 50 |  | .038 | 2009 | 1.9 |
|  | 26 | 50 | Di,P | .010 | 2079 | 0.4 |
| OL JOGI | 11 | 18 |  | .024 | 2013 | 0.4 |
|  | 11 | 18 | Di,Dr | -.007 | ---- | -0.1 |
| LEWA | 11 + 1 | 10<br>60 |  | .015<br>.037 | 1992<br>2035 | 0.1<br>2.3 |
|  | 11 + 1 | 10<br>60 | Di,Dr | -.008<br>-.002 | 1992<br>---- | -0.1<br>-0.1 |
| NGULIA | 12 + 12 | 55 |  | .038 | 2014 | 2.1 |
|  | 12 + 12 | 55 | Di,Dr,P | -.022 | ---- | -1.2 |
| OL PEJETA | 8 + 12 | 70 |  | .040 | 2023 | 2.9 |
|  | 8 + 12 | 70 | Di | .035 | 2028 | 2.5 |
| LAIKIPIA | 38 | 100 |  | .040 | 2016 | 4.1 |
|  | 38 | 100 | Di,Dr,P | -.024 | ---- | -2.4 |
| ABERDARE | 33 | 43 |  | .037 | 1999 | 1.6 |
|  | 33 | 43 | Di | .032 | 2000 | 1.3 |
| AMBOSELI | 3 | 50 |  | .014 | 2193 | 0.7 |
|  | 3 | 50 | Di,Dr,P | -.033 | ---- | -1.7 |

## 13. LARGE SANCTUARIES AT ABERDARE, NGULIA, AND LEWA

| LOCATION | $N_0$ | K | CATS | Pop. growth: r |  | 50 yr results |  |  |  | 100 yr results |  |  |  | 200 yr results |  |  |  | Median Time to Extinc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | mean | SD | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H | P(E) | $N_t$ | SD | H |  |
| ABERDARE | 33 | 43 |  | .037 | .055 | 0 | 42 | 2 | 93 | 0 | 42 | 2 | 88 | 0 | 42 | 3 | 79 |  |
|  | 33 | 43 | Di | .032 | .078 | 0 | 41 | 5 | 93 | 0 | 40 | 6 | 87 | .01 | 39 | 7 | 78 |  |
|  | 33 | 500 |  | .045 | .041 | 0 | 392 | 86 | 97 | 0 | 500 | 6 | 97 | 0 | 498 | 7 | 96 |  |
|  | 33 | 500 | Di | .039 | .065 | 0 | 316 | 120 | 97 | 0 | 481 | 58 | 96 | 0 | 488 | 39 | 95 |  |
| NGULIA | 12 | 55 |  | .036 | .054 | 0 | 53 | 6 | 91 | 0 | 54 | 2 | 87 | 0 | 54 | 3 | 81 |  |
|  | 12 | 55 | Di,Dr | -.005 | .143 | .13 | 25 | 16 | 83 | .31 | 26 | 17 | 75 | .66 | 21 | 15 | 64 | 143 |
|  | 12 | 55 | Di,Dr,P | -.026 | .195 | .42 | 14 | 11 | 78 | .80 | 10 | 9 | 66 | 1.00 | 6 | 0 | 28 | 58 |
|  | 24 | 55 |  | .038 | .051 | 0 | 55 | 2 | 94 | 0 | 54 | 2 | 90 | 0 | 54 | 2 | 82 |  |
|  | 24 | 55 | Di,Dr | .000 | .131 | .02 | 38 | 15 | 91 | .09 | 33 | 16 | 84 | .37 | 25 | 16 | 71 |  |
|  | 24 | 55 | Di,Dr,P | -.022 | .179 | .18 | 24 | 16 | 87 | .48 | 19 | 16 | 76 | .93 | 13 | 15 | 65 | 104 |
|  | 12 | 500 |  | .040 | .045 | 0 | 122 | 52 | 92 | 0 | 462 | 84 | 91 | 0 | 498 | 6 | 90 |  |
|  | 12 | 500 | Di,Dr | -.003 | .139 | .14 | 32 | 26 | 84 | .33 | 56 | 70 | 78 | .59 | 106 | 136 | 73 | 165 |
|  | 12 | 500 | Di,Dr,P | -.022 | .186 | .38 | 18 | 18 | 79 | .74 | 24 | 26 | 73 | .96 | 18 | 14 | 73 | 66 |
|  | 24 | 500 |  | .043 | .041 | 0 | 257 | 87 | 96 | 0 | 499 | 7 | 96 | 0 | 499 | 6 | 95 |  |
|  | 24 | 500 | Di,Dr | .003 | .124 | .01 | 69 | 51 | 92 | .07 | 120 | 125 | 87 | .26 | 194 | 166 | 85 |  |
|  | 24 | 500 | Di,Dr,P | -.020 | .171 | .13 | 31 | 30 | 87 | .44 | 33 | 45 | 78 | .84 | 17 | 17 | 66 | 112 |
| LEWA | 11 | 10 |  | .015 | .108 | .21 | 9 | 1 | 71 | .36 | 8 | 2 | 55 | .78 | 6 | 2 | 32 | 131 |
|  | 11 | 10 | Di,Dr | -.008 | .177 | .55 | 6 | 3 | 66 | .90 | 5 | 2 | 44 | 1.00 | -- | -- | -- | 43 |
|  | 12 | 10 |  | .015 | .108 | .18 | 8 | 2 | 71 | .37 | 8 | 2 | 55 | .76 | 7 | 2 | 39 | 129 |
|  | 12 | 10 | Di,Dr | -.008 | .174 | .48 | 7 | 2 | 69 | .87 | 5 | 3 | 51 | 1.00 | -- | -- | -- | 52 |
|  | 11 | 60 |  | .035 | .053 | .02 | 59 | 4 | 85 | .02 | 59 | 2 | 82 | .02 | 59 | 3 | 77 |  |
|  | 11 | 60 | Di,Dr | -.003 | .138 | .15 | 31 | 17 | 80 | .28 | 29 | 18 | 73 | .65 | 22 | 17 | 63 | 154 |
|  | 12 | 60 |  | .037 | .053 | 0 | 59 | 3 | 89 | 0 | 59 | 2 | 86 | 0 | 59 | 3 | 80 |  |
|  | 12 | 60 | Di,Dr | -.002 | .136 | .10 | 31 | 18 | 83 | .23 | 30 | 18 | 76 | .58 | 24 | 18 | 64 | 172 |
|  | 19 | 60 |  | .039 | .052 | 0 | 59 | 3 | 93 | 0 | 59 | 2 | 89 | 0 | 59 | 2 | 82 |  |
|  | 19 | 60 | Di,Dr | .001 | .133 | .05 | 39 | 18 | 88 | .13 | 33 | 18 | 81 | .40 | 27 | 17 | 69 |  |

Note: deterministic r (from life table) = .046 without catastrophes, .042 with Di, .016 with Di and Dr, and .000 with Di, Dr, and Poaching.

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## WORKSHOP REPORT

1 May 1993

## SECTION 5
## FIGURES

# KENYA BLACK RHINO METAPOPULATION WORKSHOP

## FIGURES

1 Map of Kenya Sanctuaries

2 Diagram of Options for Rhino Conservation

*Data in Figures 3-6 same as in Table 2a.*

3 Simulation of hypothetical small populations: no catastrophes, no poaching, 3.12 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

4. Simulation of hypothetical small populations: catastrophes, no poaching, 3.12 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

5. Simulation of hypothetical small populations: no catastrophes, workshop poaching, 3.12 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

6. Simulation of hypothetical small populations: catastrophes, workshop poaching, 3.12 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figures 7-10 same as in Table 2b.*

7. Simulation of hypothetical small populations: no catastrophes, no poaching, 6.24 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

8. Simulation of hypothetical small populations: no catastrophes, no poaching, 6.24 lethals
  a. Proportion of simulated populations extant (survive)
  b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

9. Simulation of hypothetical small populations: no catastrophes, no poaching, 6.24 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

10. Simulation of hypothetical small populations: no catastrophes, no poaching, 6.24 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figures 11-14 same as in Table 3.*

11. Simulation of hypothetical small populations: no catastrophes, poaching at increased level 1, 3.12 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

12. Simulation of hypothetical small populations: catastrophes, poaching at increased level 1, 3.12 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

13. Simulation of hypothetical small populations: no catastrophes, poaching at increased level 2, 3.12 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

14. Simulation of hypothetical small populations: catastrophes, poaching at increased level 2, 3.12 lethals
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*In Figures 15-22, individual populations and the metapopulation are labelled when the lines are sufficiently distinguishable.*

*Data in Figure 15 same as in Table 4.*

15. Simulations of sanctuary populations: no catastrophes, no founder adjustment, no migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 16 same as in Table 5.*

16. Simulations of sanctuary populations: catastrophes, no founder adjustment, no migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 17 same as in Table 6.*

17. Simulations of sanctuary populations: no catastrophes, founder adjustment, no migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 18 same as in Table 7.*

18. Simulations of sanctuary populations: catastrophes, founder adjustment, no migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 19 same as in Table 8.*

19. Simulations of sanctuary populations: no catastrophes, no founder adjustment, migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 20 same as in Table 9.*

20. Simulations of sanctuary populations: catastrophes, no founder adjustment, migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 21 same as in Table 10.*

21. Simulations of sanctuary populations: no catastrophes, founder adjustment, migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

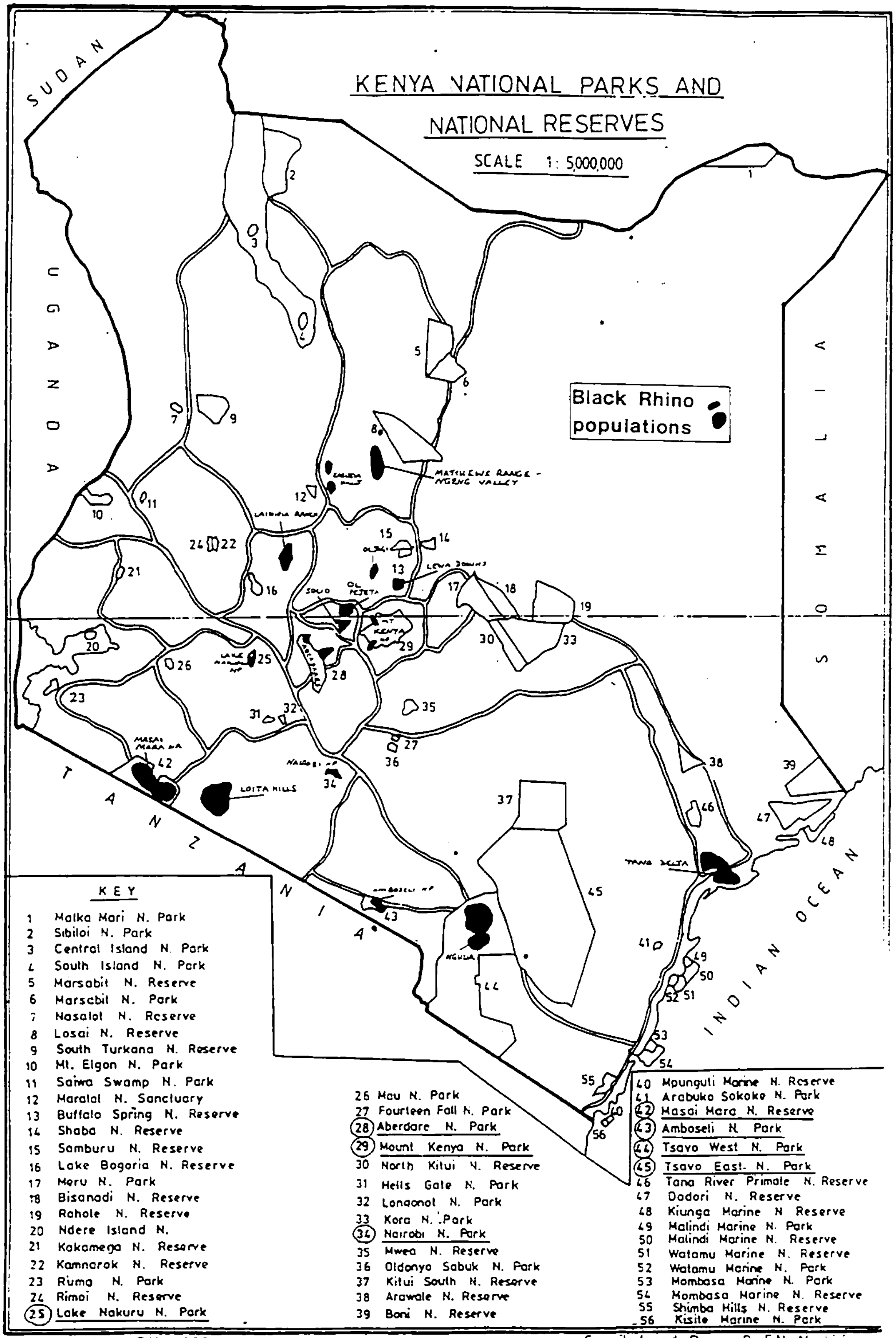
*Data in Figure 22 same as in Table 11.*

22. Simulations of sanctuary populations: catastrophes, founder adjustment, migration, 3.12
    a. Proportion of simulated populations extant (survive)
    b. Proportion of initial heterozygosity remaining in surviving populations (with standard error bars).

*Data in Figure 23 is same as in Table 13.*

23. Bar graph of sanctuaries with carrying capacity (K) and harvest as the bars. Founder adjustments and catastrophes, but no migration (i.e., same as in Table 7 and Figure 18). Each bar indicates the population size in 1992 (N-1992), the expected capacity (K), and the mean annual surplus expected after K is attained, and the year in which K is projected to be achieved. **** indicates that the population is expected to decline and hence never attain K.

Figure 1.

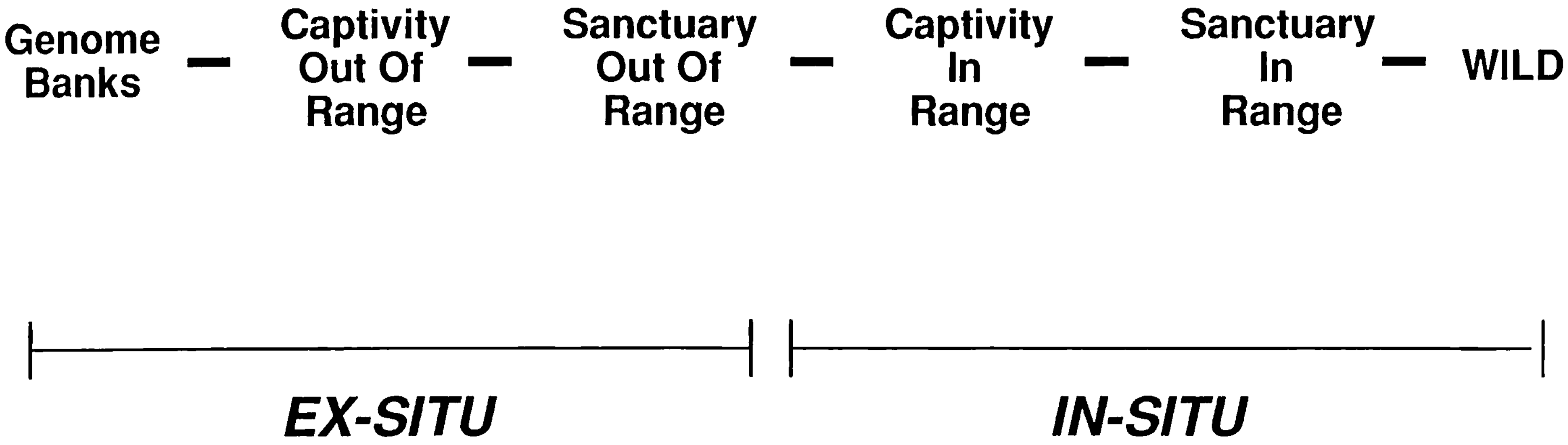


KWS—WPU—1990

Compiled and Drawn By F.N. Muchiri

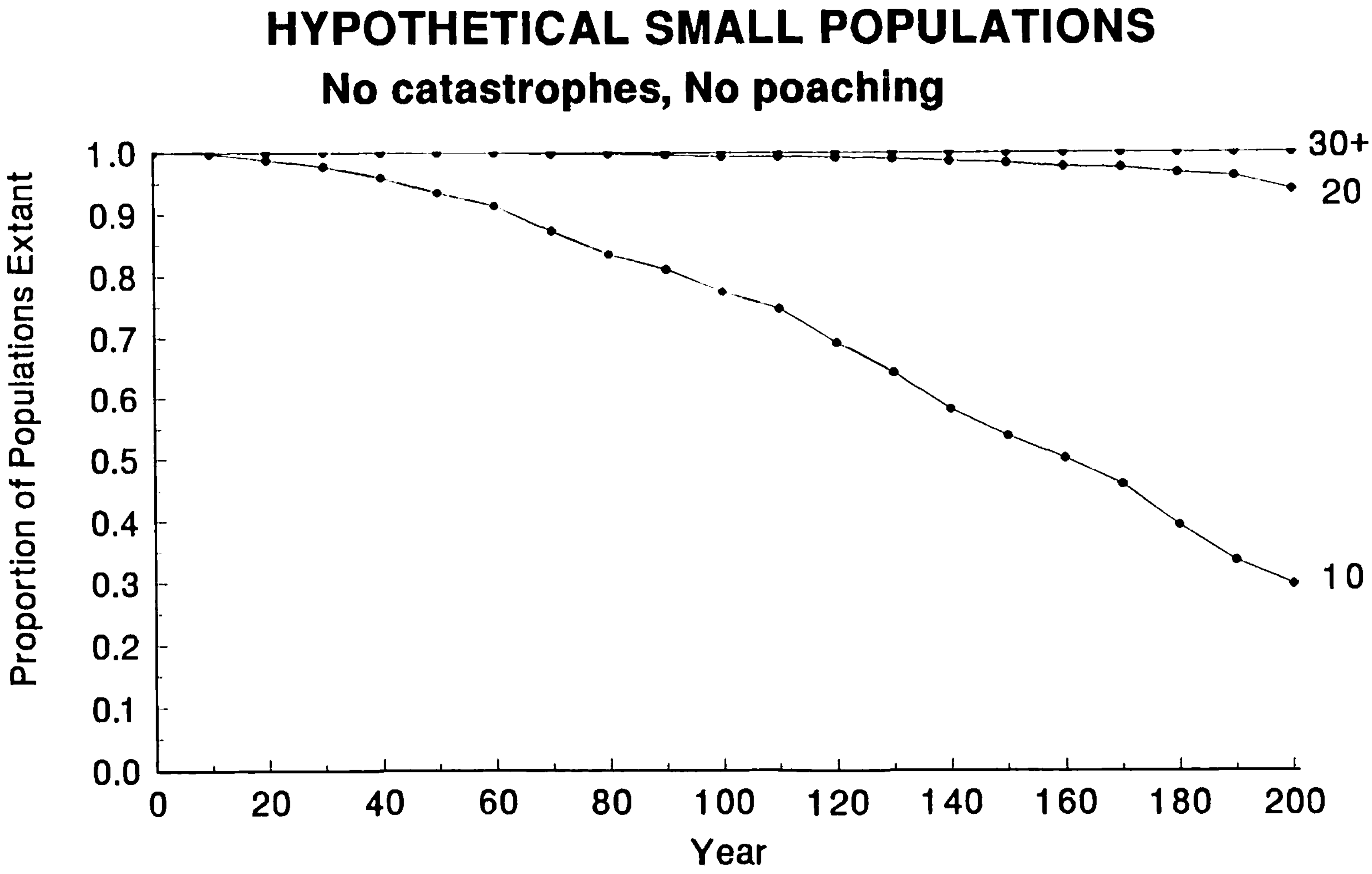
Figure 2.

# OPTIONS FOR RHINO CONSERVATION



Modified from Mark Stanley-Price (1991)

Figure 3a.



HYPOTHETICAL SMALL POPULATIONS
No catastrophes, No poaching

Figure 3b.

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, No poaching

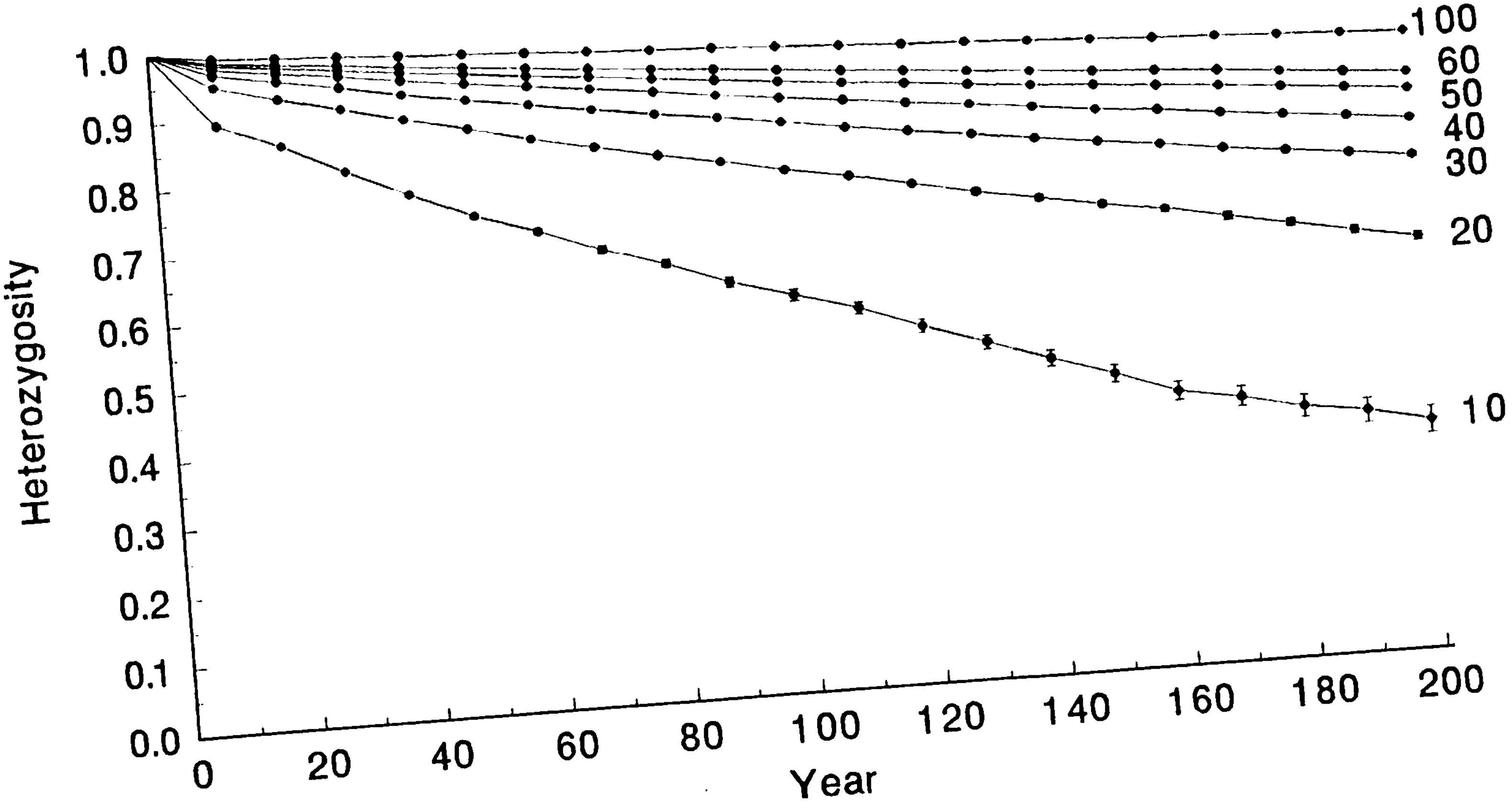


Figure 4a.

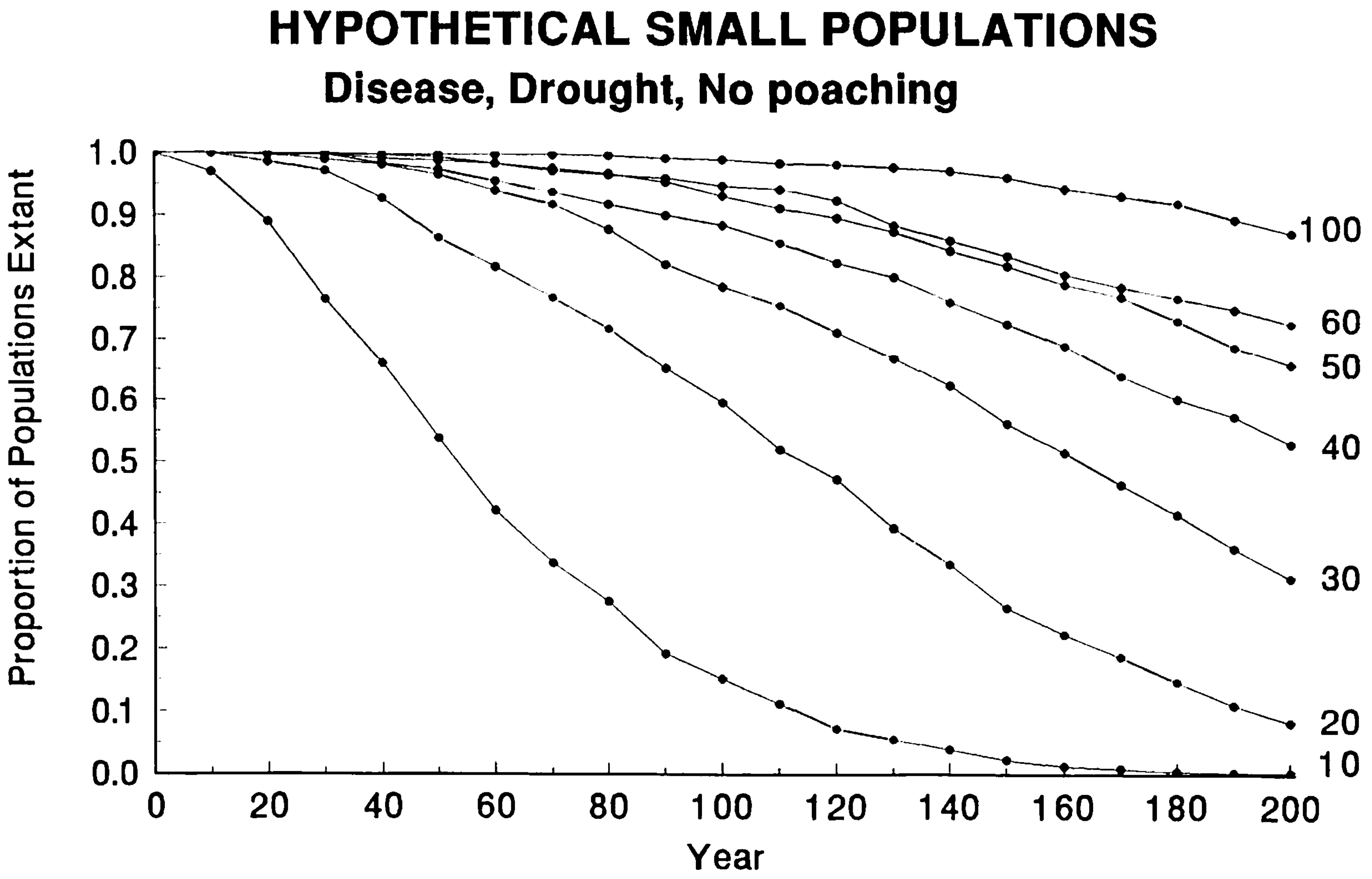
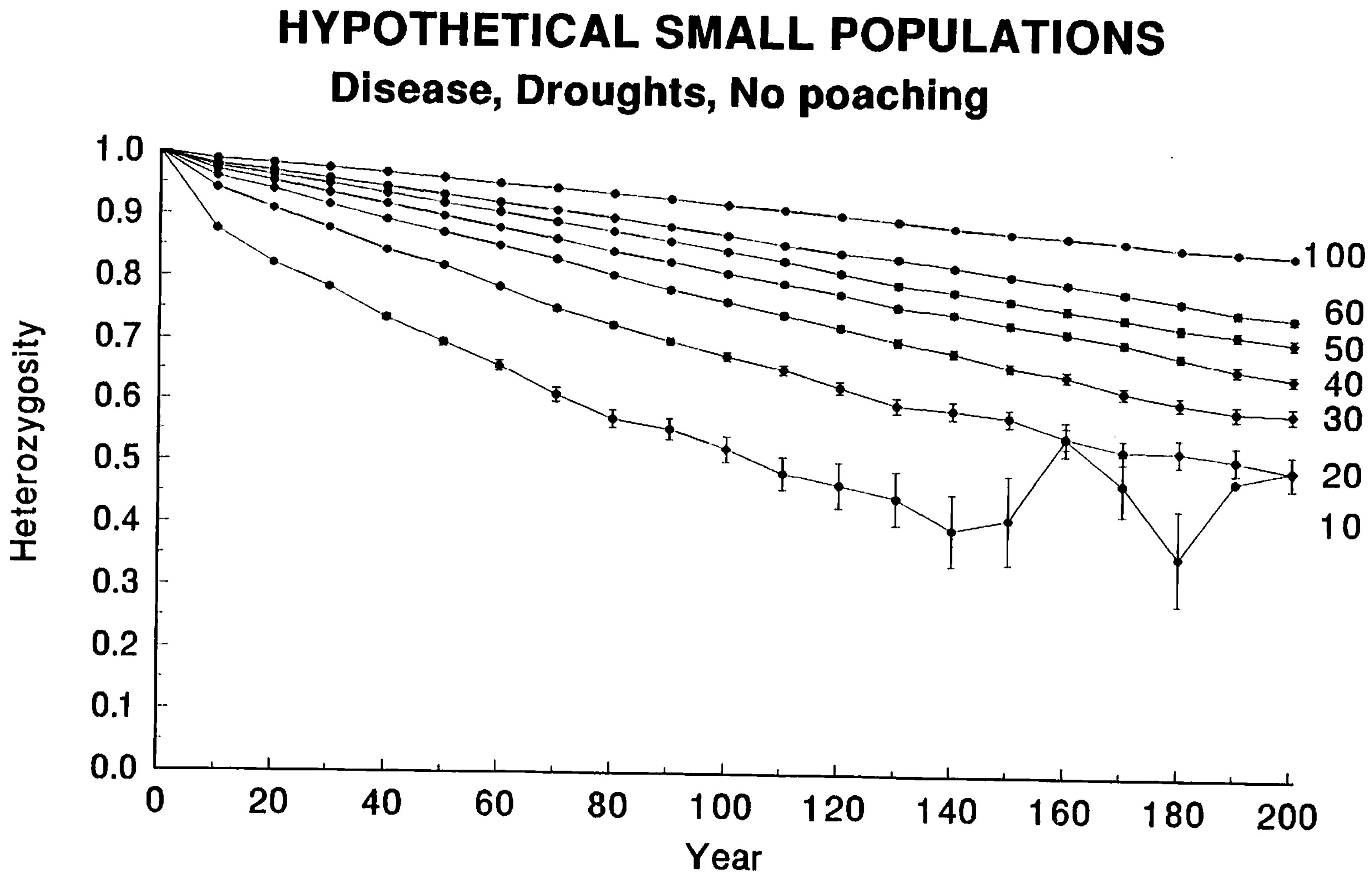

HYPOTHETICAL SMALL POPULATIONS
Disease, Drought, No poaching
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
20
10

Figure 4b.



HYPOTHETICAL SMALL POPULATIONS
Disease, Droughts, No poaching

Figure 5a.

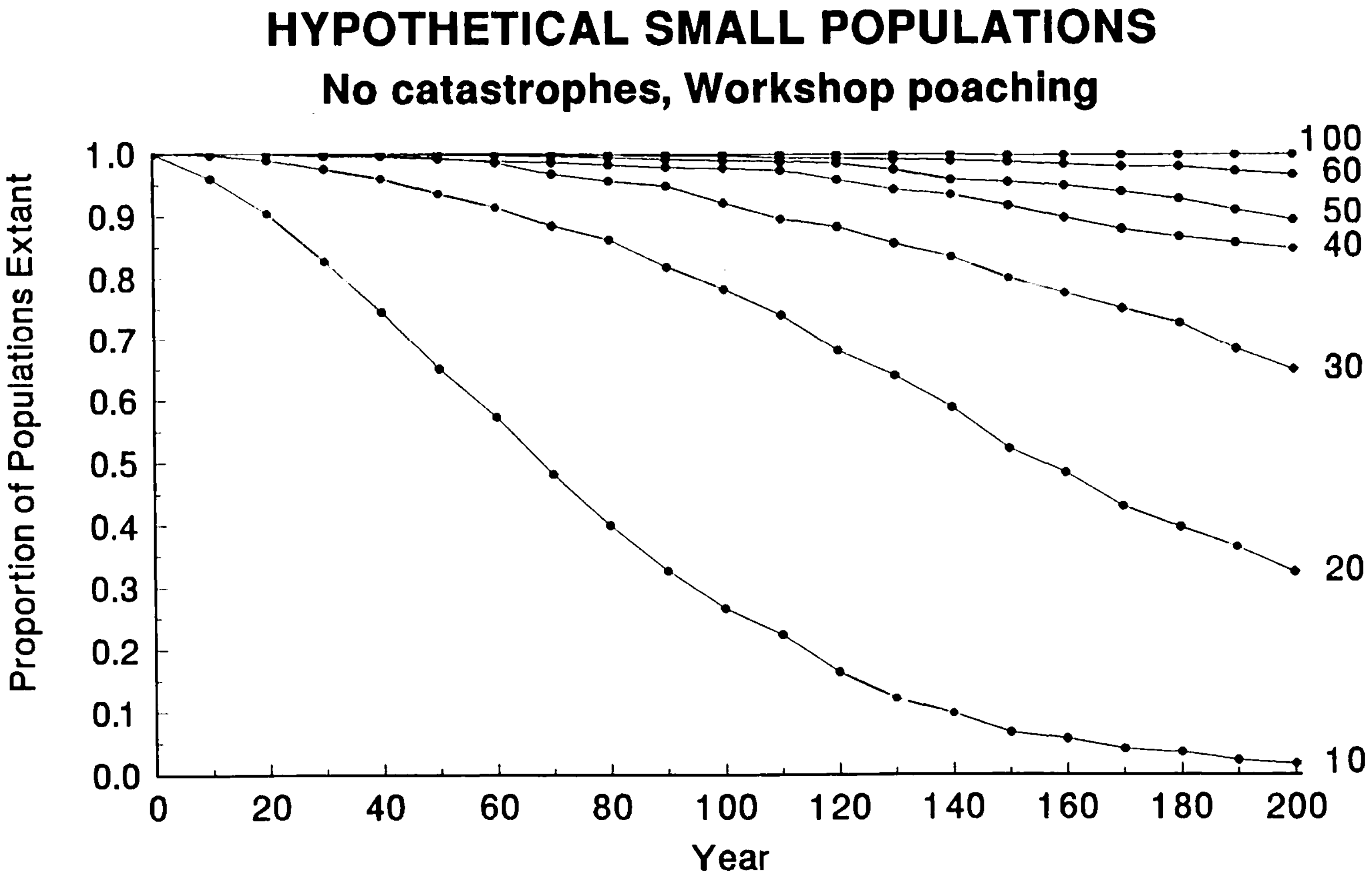

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, Workshop poaching
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
20
10

Figure 5b.

## HYPOTHETICAL SMALL POPULATIONS
### No catastrophes, Workshop poaching

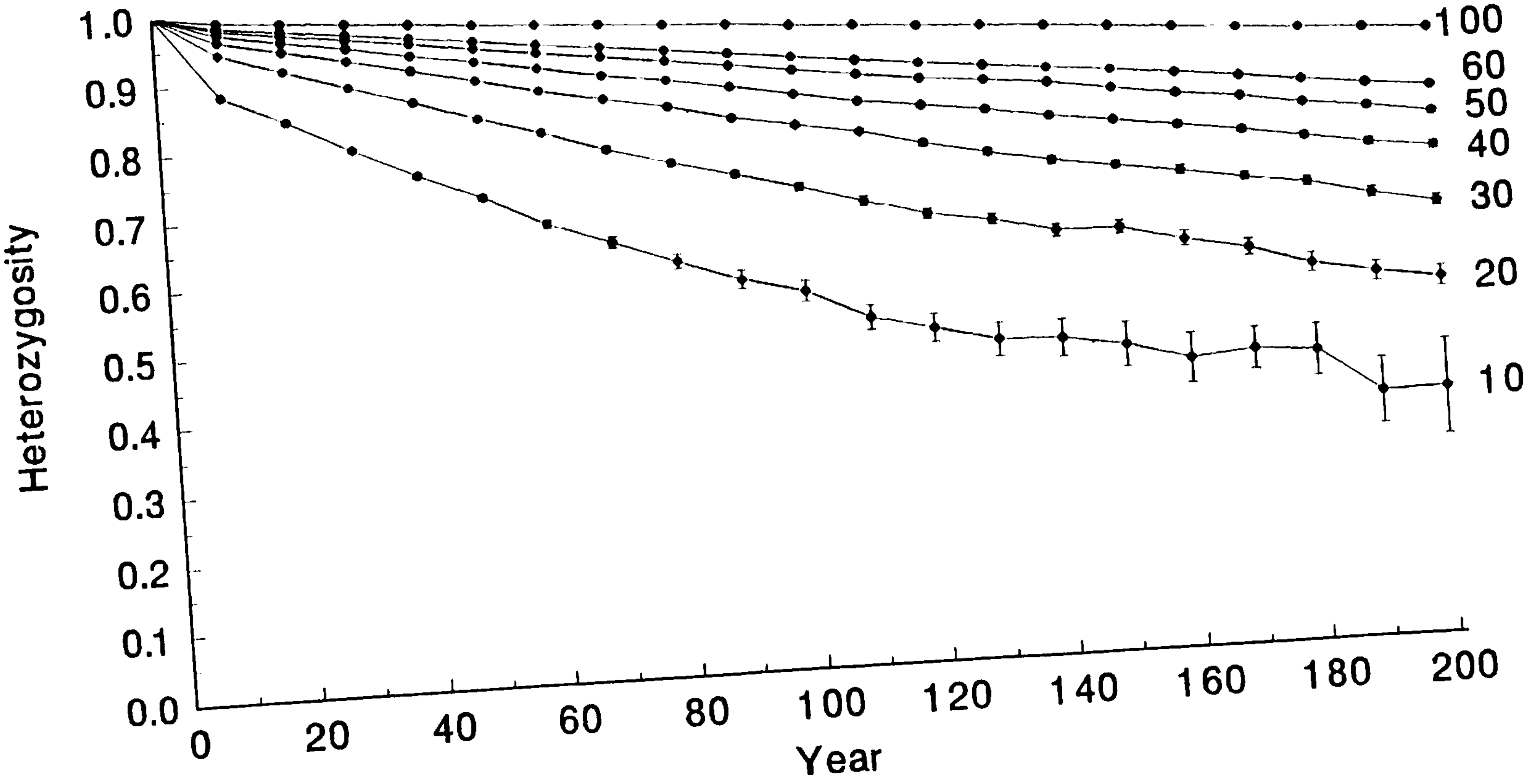
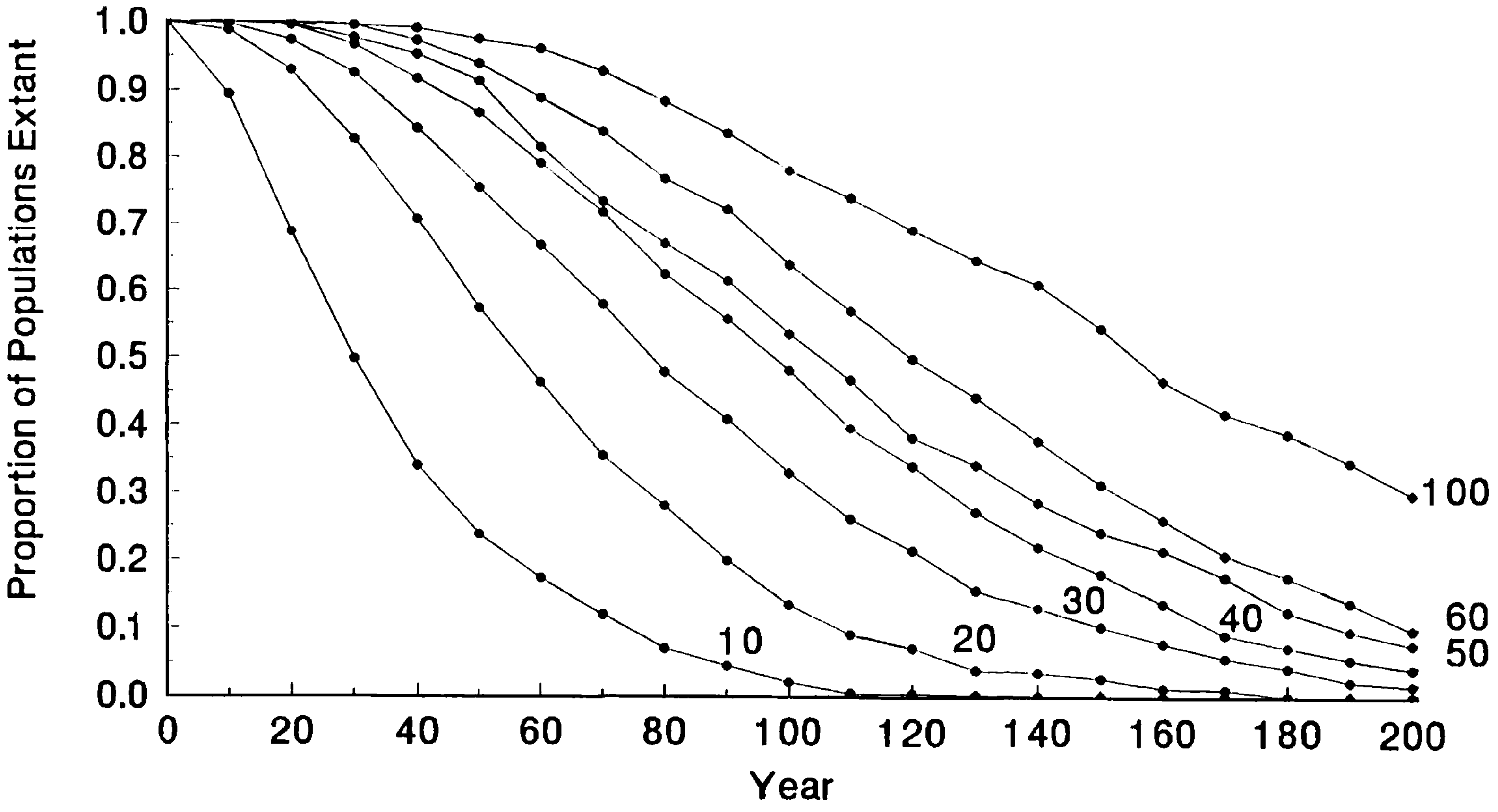


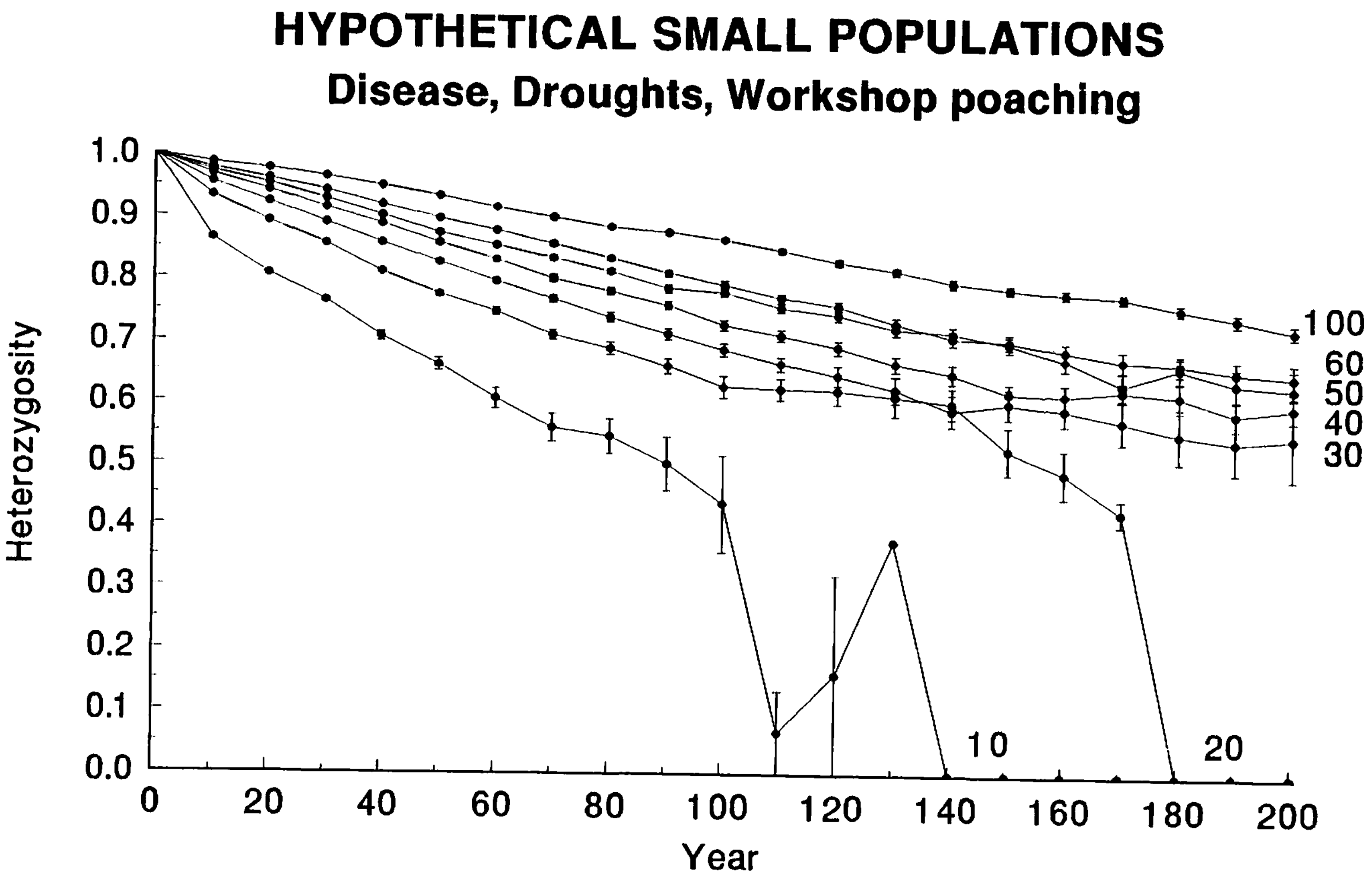
Figure 6a.



HYPOTHETICAL SMALL POPULATIONS

Disease, Drought, Workshop poaching

Figure 6b.



HYPOTHETICAL SMALL POPULATIONS
Disease, Droughts, Workshop poaching
Heterozygosity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
10
20

Figure 7a.

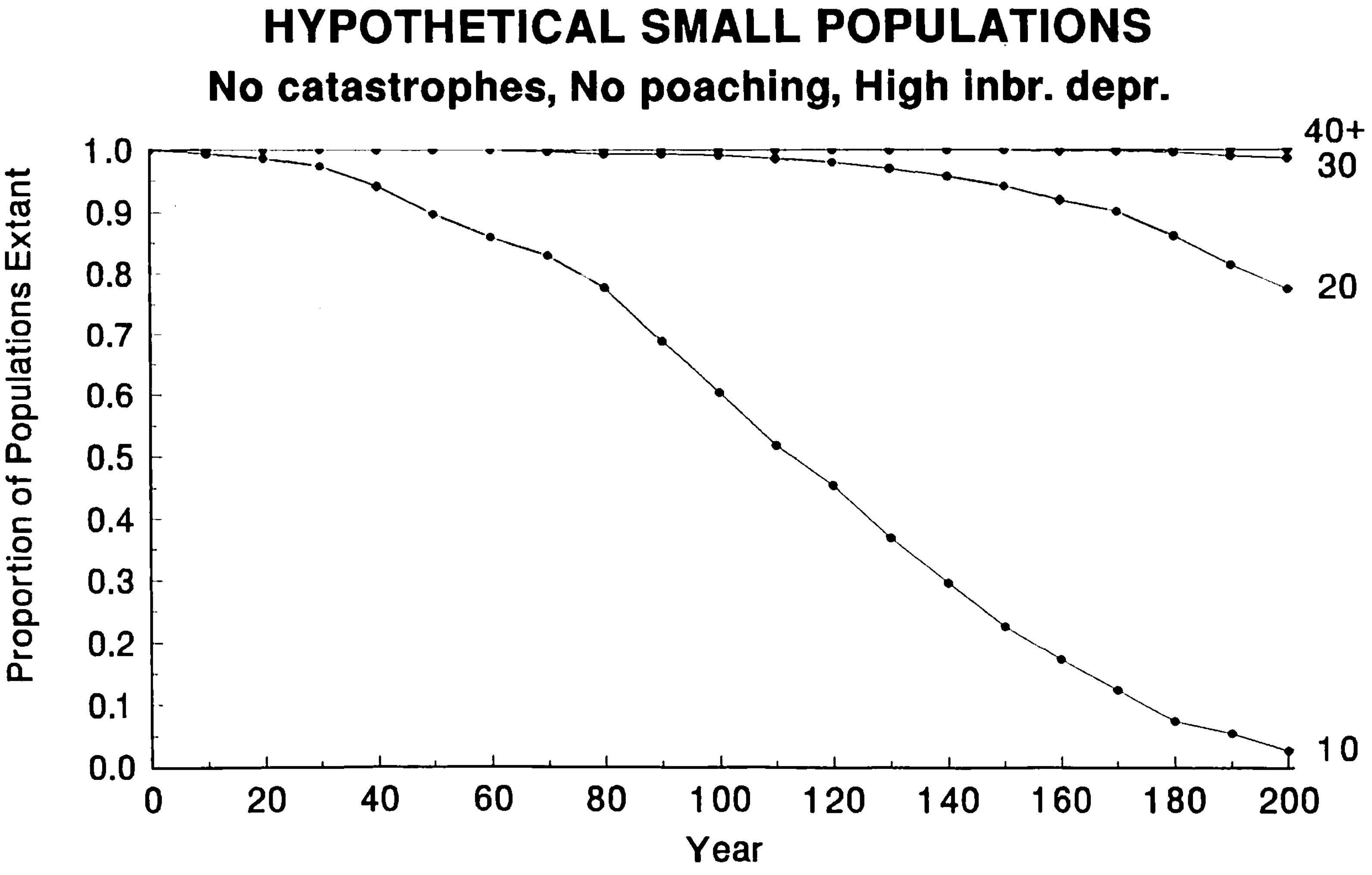
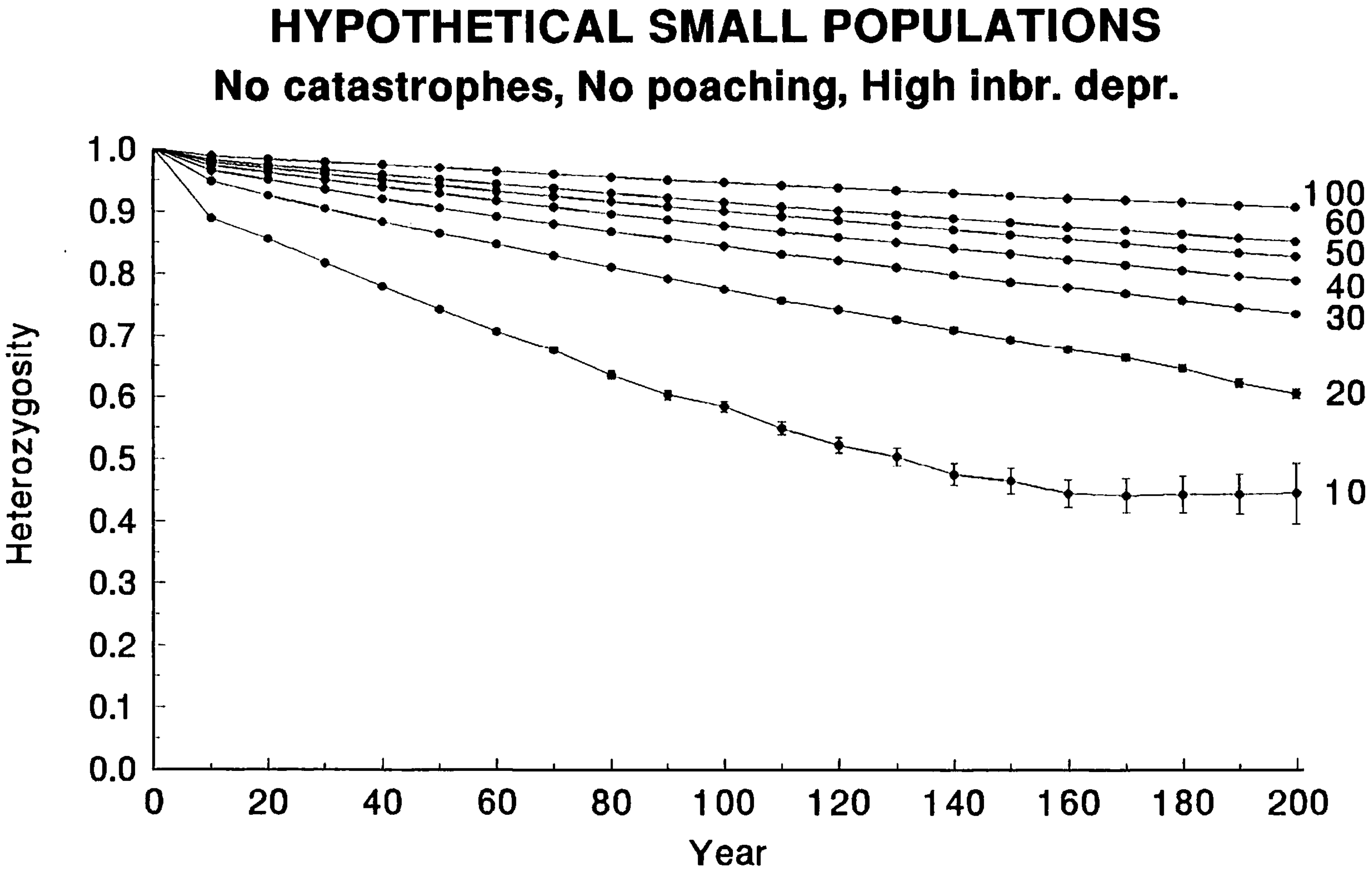

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, No poaching, High inbr. depr.
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
40+
30
20
10

Figure 7b.



HYPOTHETICAL SMALL POPULATIONS

No catastrophes, No poaching, High inbr. depr.

Figure 8a.

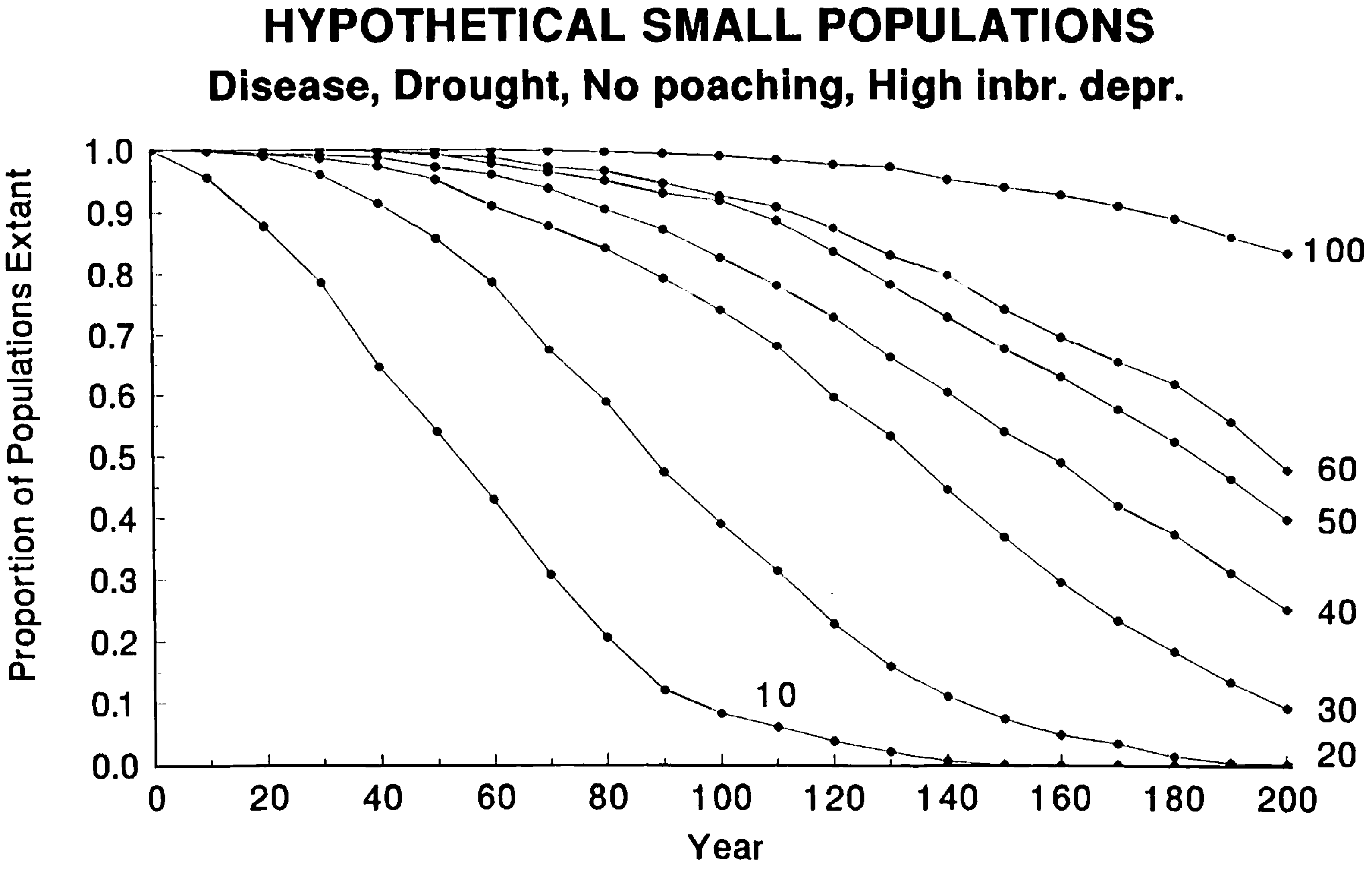

HYPOTHETICAL SMALL POPULATIONS
Disease, Drought, No poaching, High inbr. depr.
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
20
10

Figure 8b.

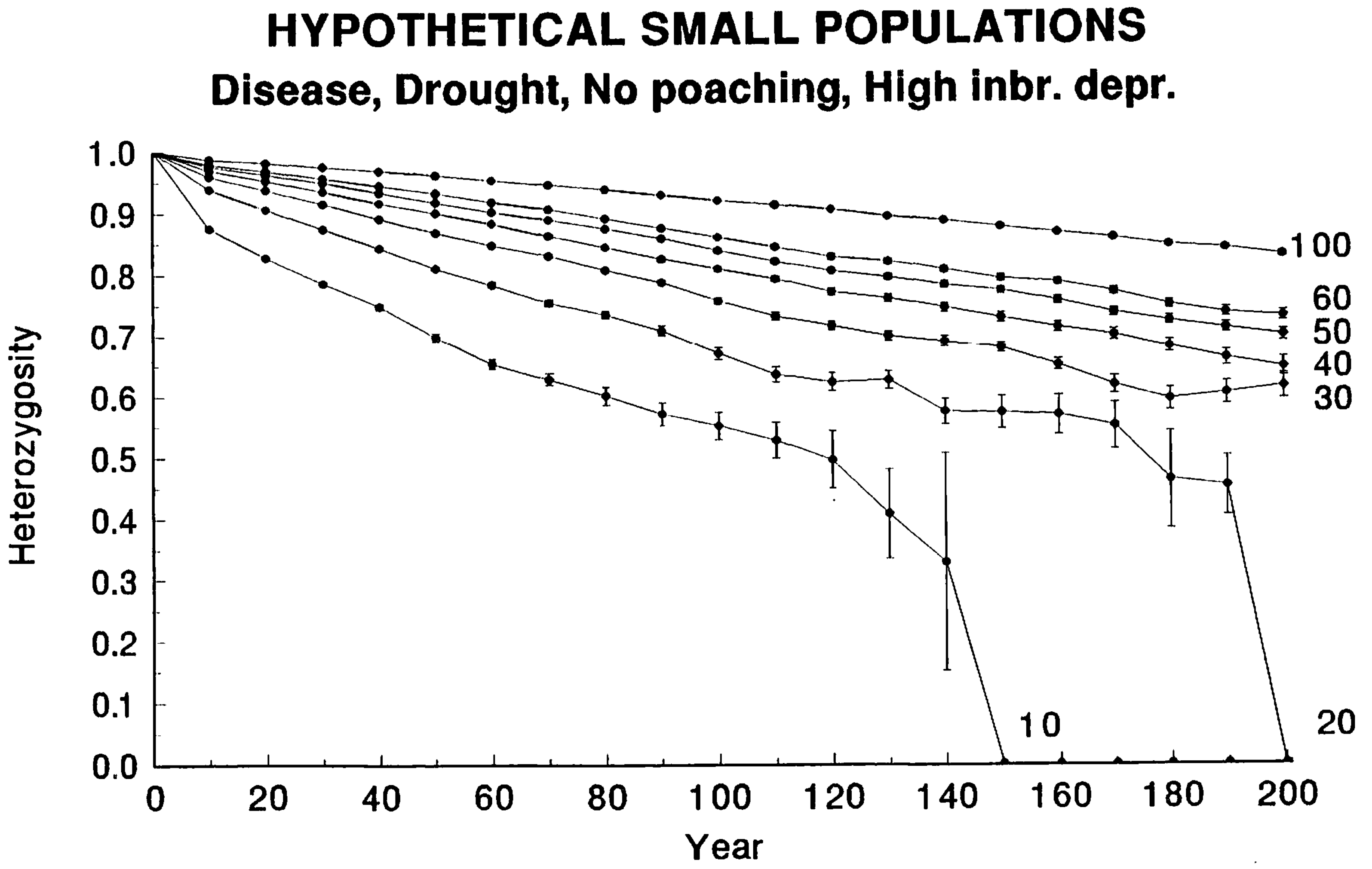

HYPOTHETICAL SMALL POPULATIONS
Disease, Drought, No poaching, High inbr. depr.
Heterozygosity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
10
20

Figure 9a.

## HYPOTHETICAL SMALL POPULATIONS

### No catastrophes, Workshop poaching, High inbr. depr.

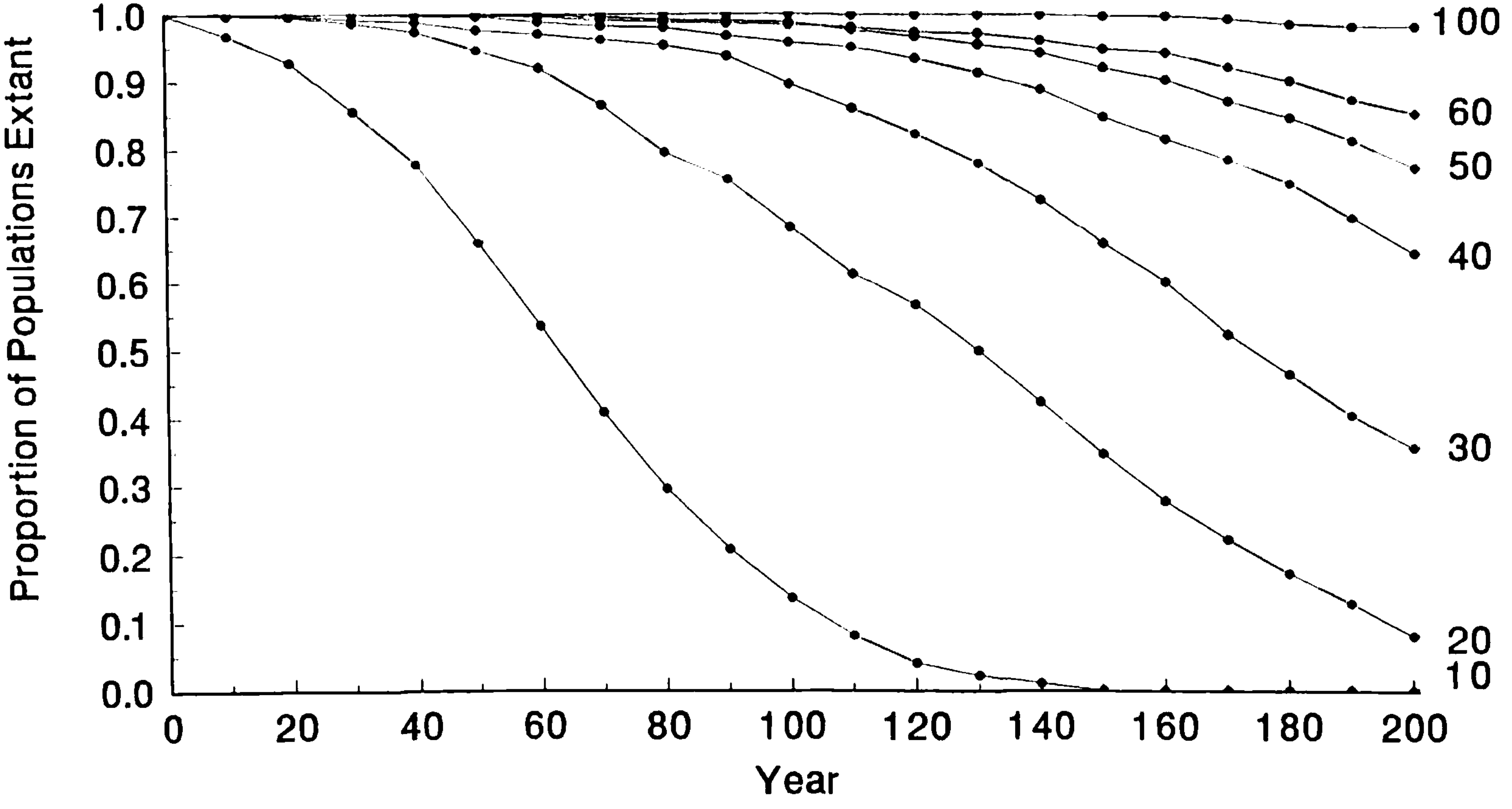


Figure 9b.

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, Workshop poaching, High inbr. depr.

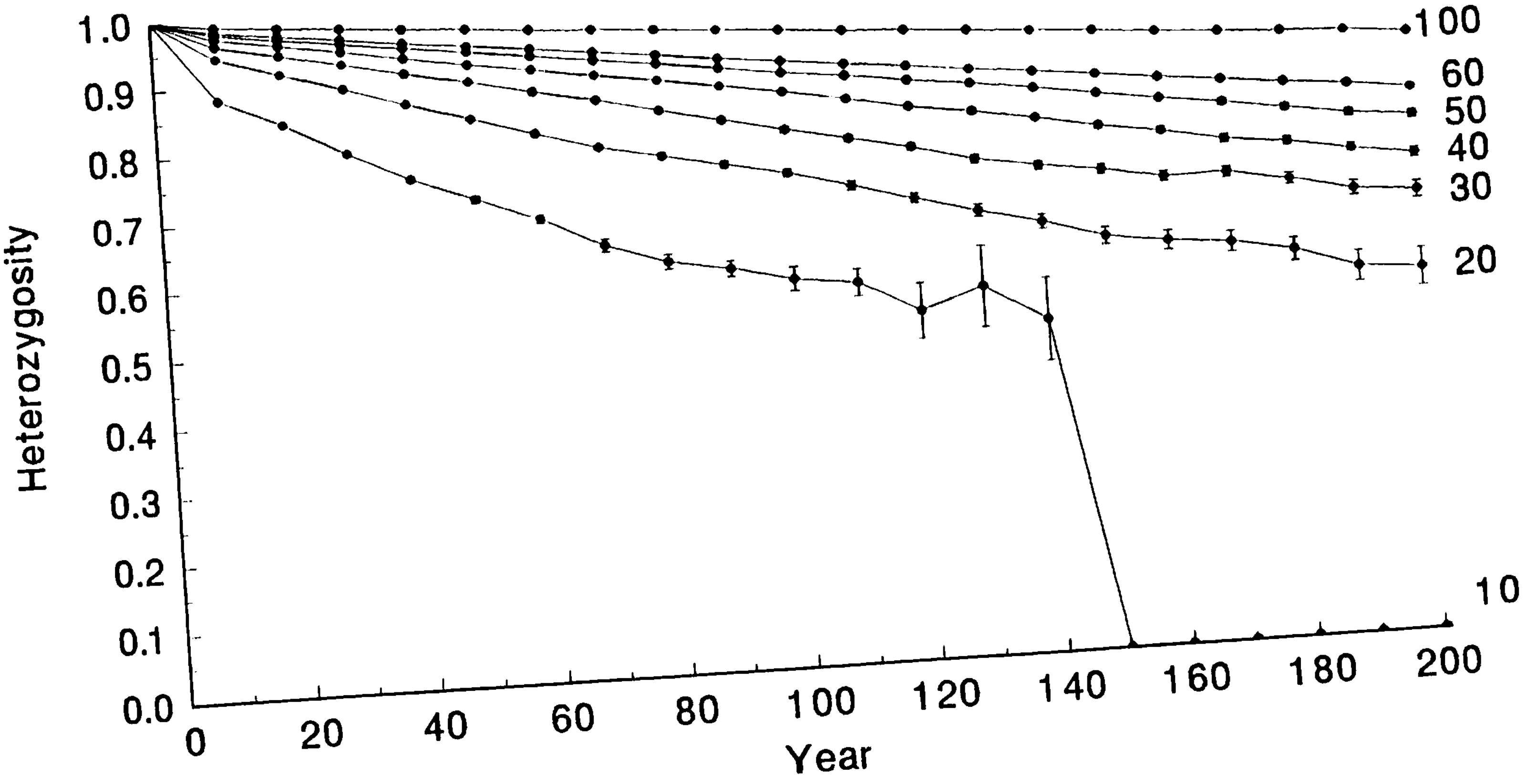


Figure 10a.

## HYPOTHETICAL SMALL POPULATIONS

### Disease, Drought, Workshop poaching, High inbr. depr

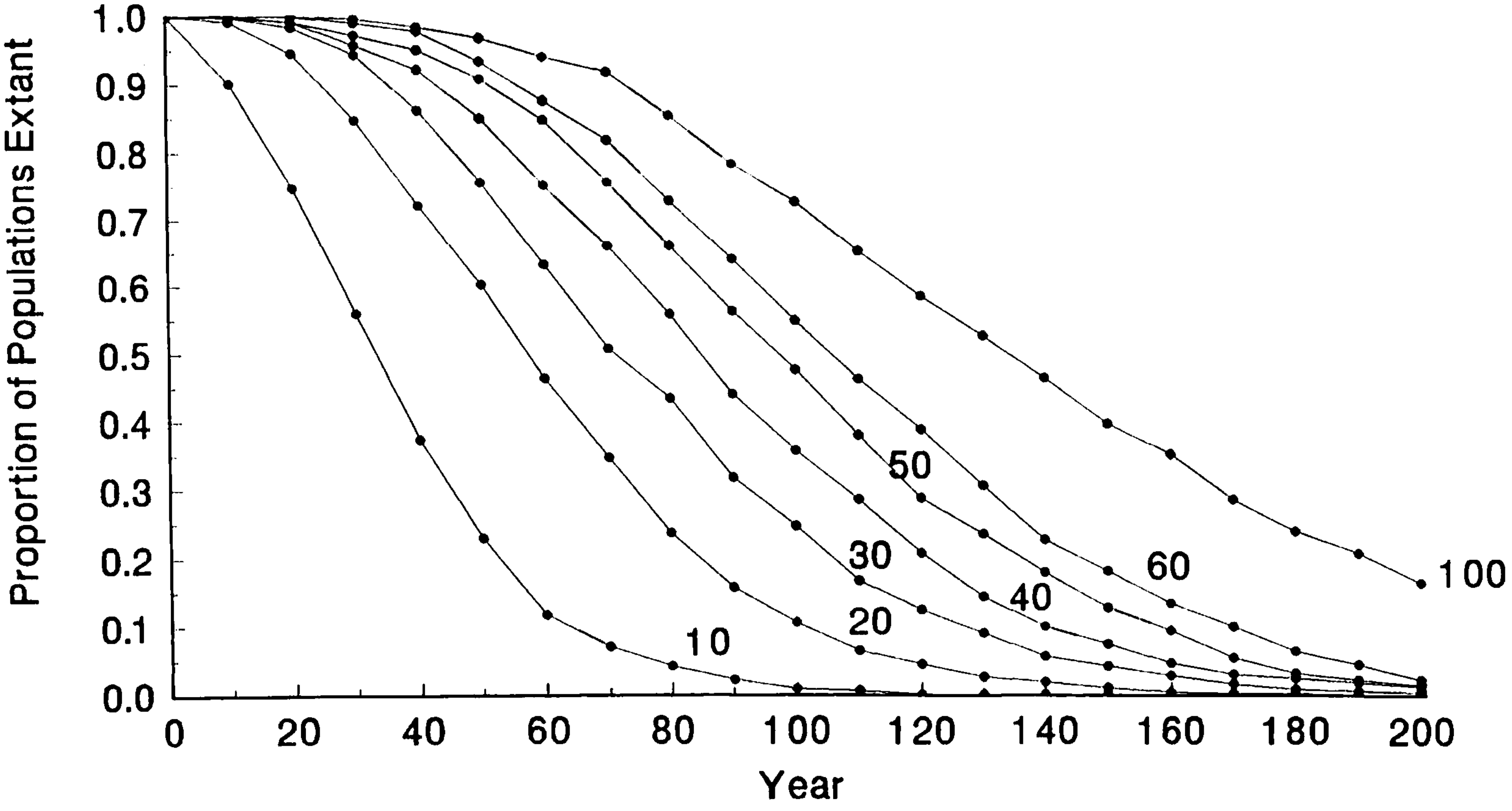


Figure 10b.

## HYPOTHETICAL SMALL POPULATIONS

### Disease, Drought, Workshop poaching, High inbr. depr

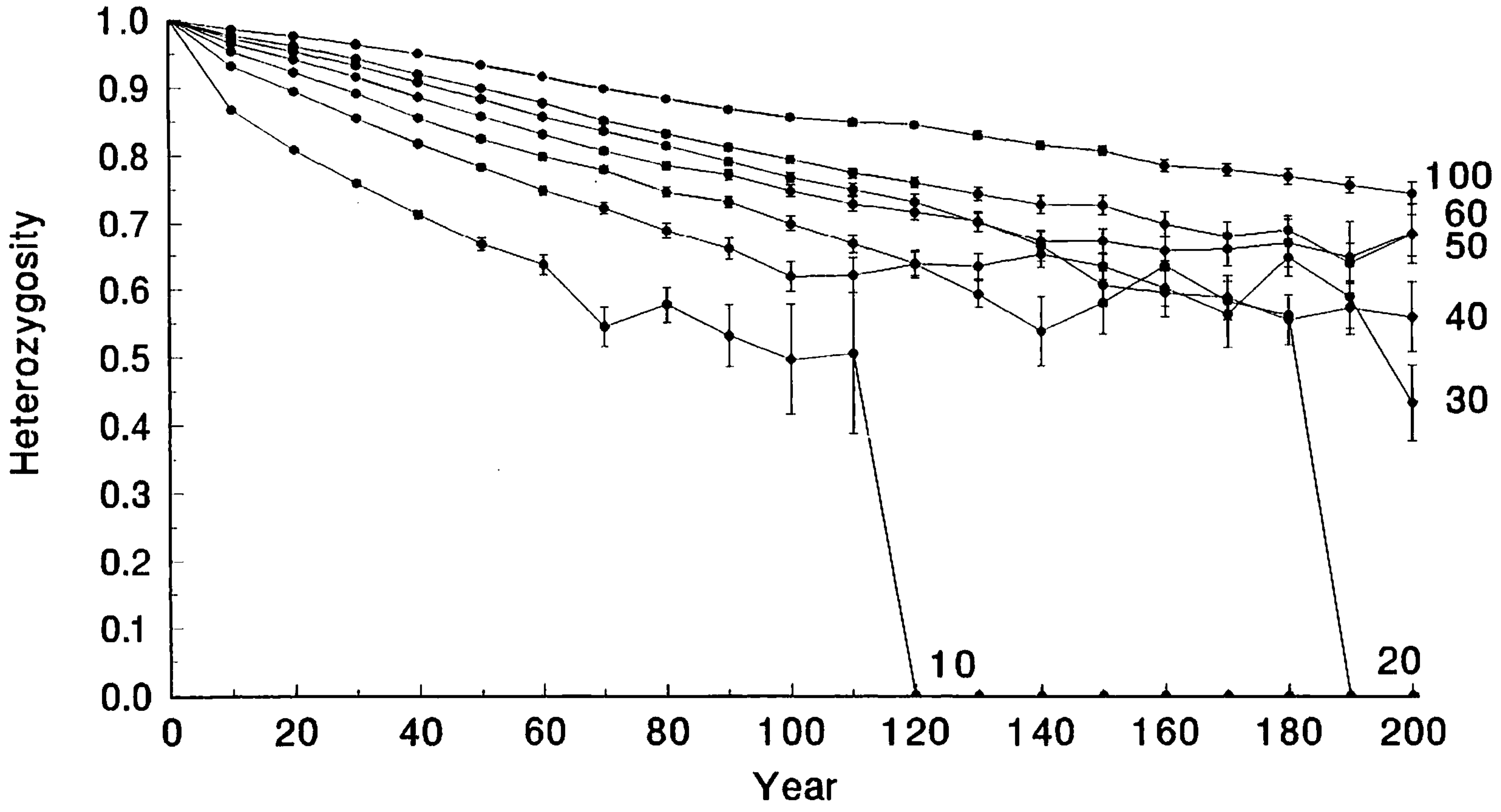


Figure 11a.

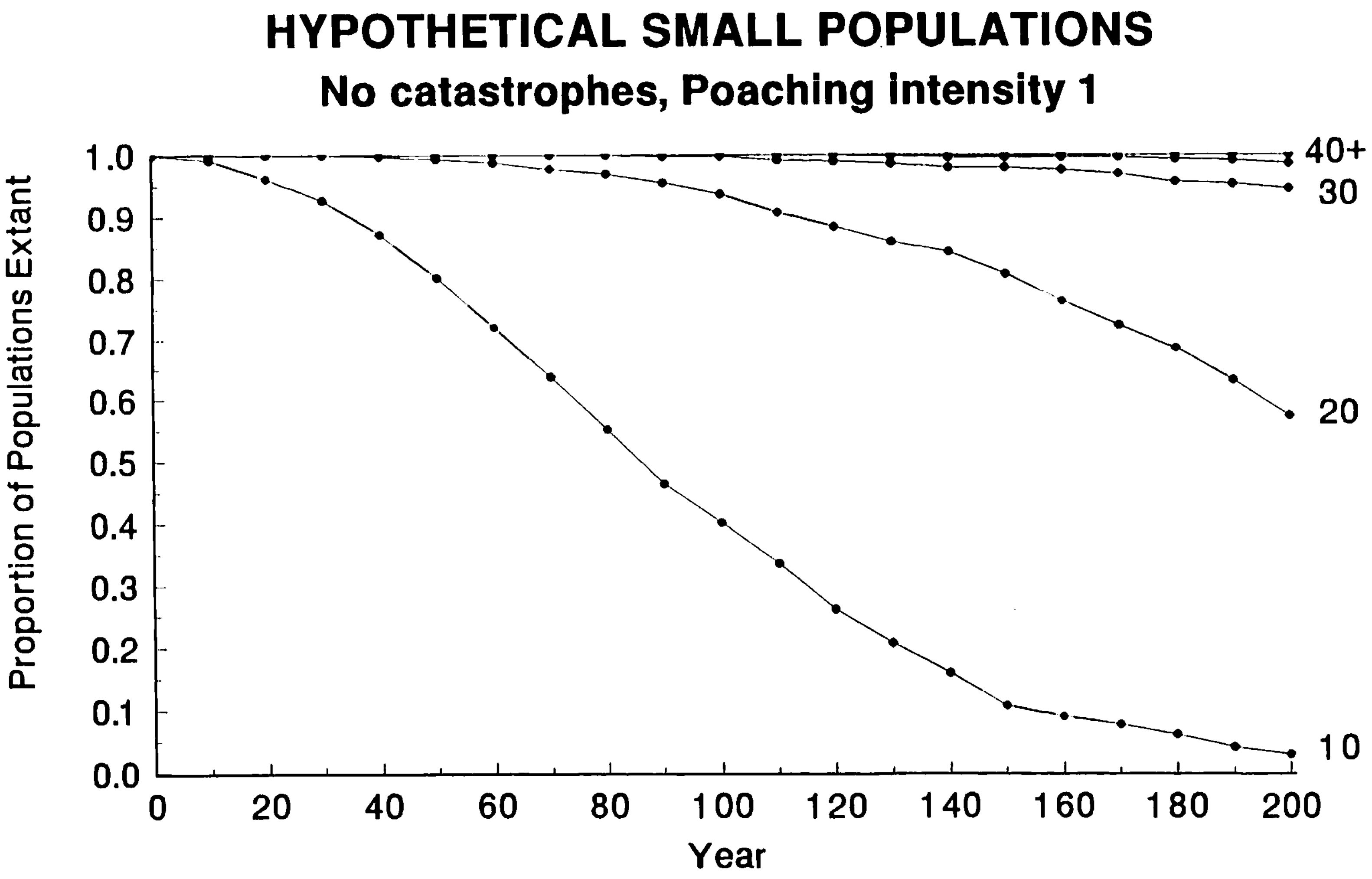
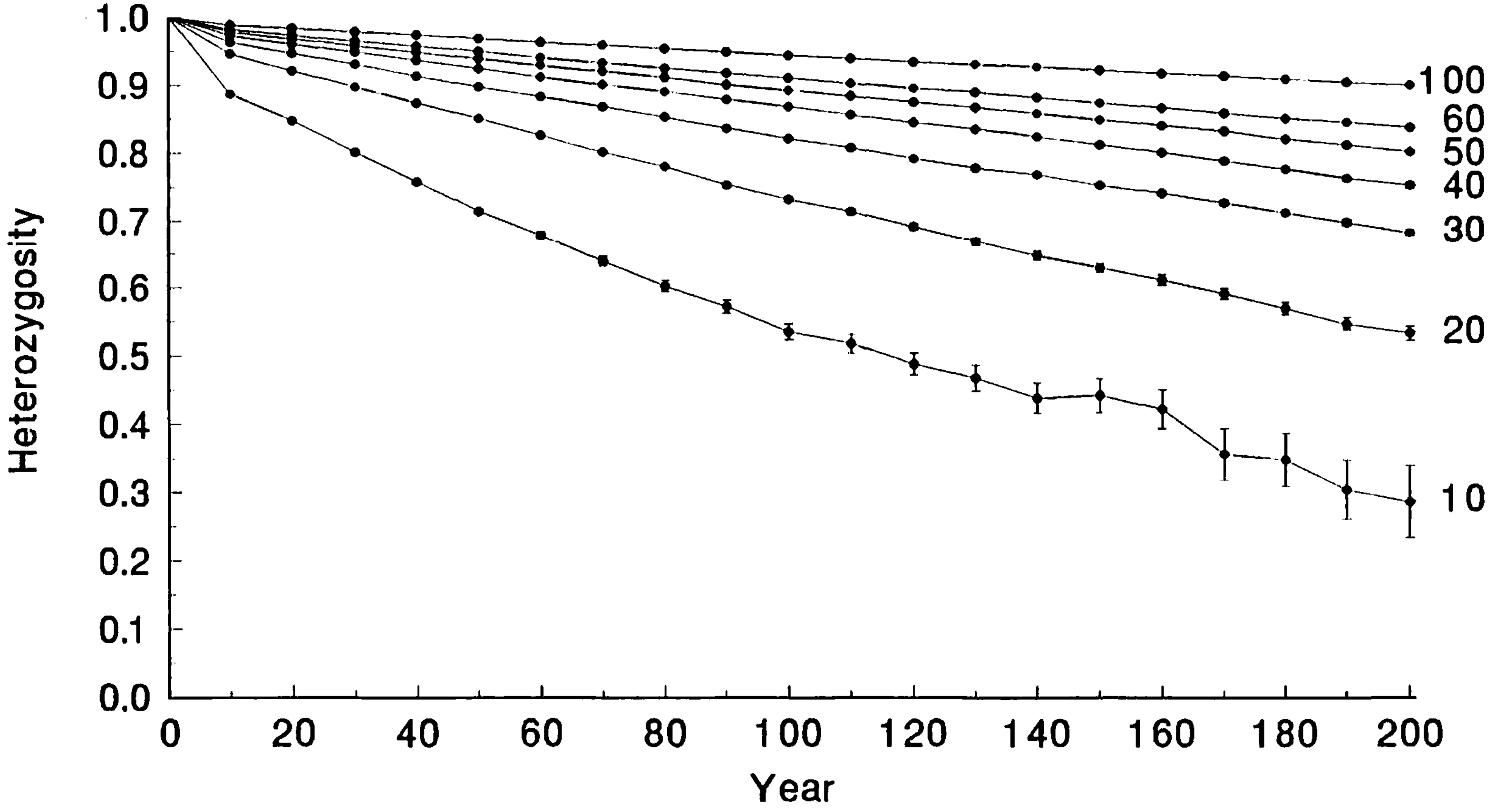

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, Poaching intensity 1

Figure 11b.



HYPOTHETICAL SMALL POPULATIONS

No catastrophes, Poaching intensity 1

Figure 12a.

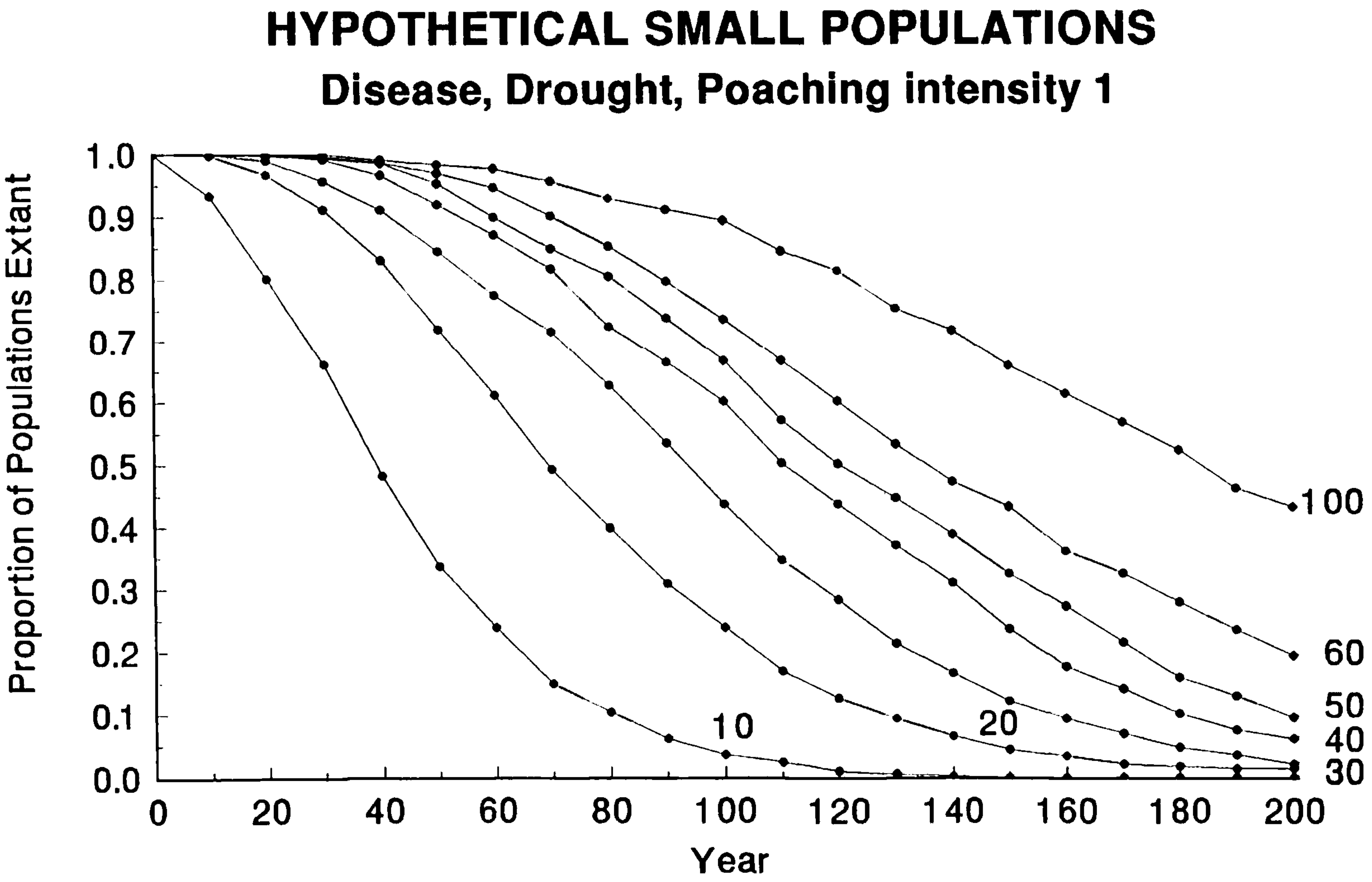
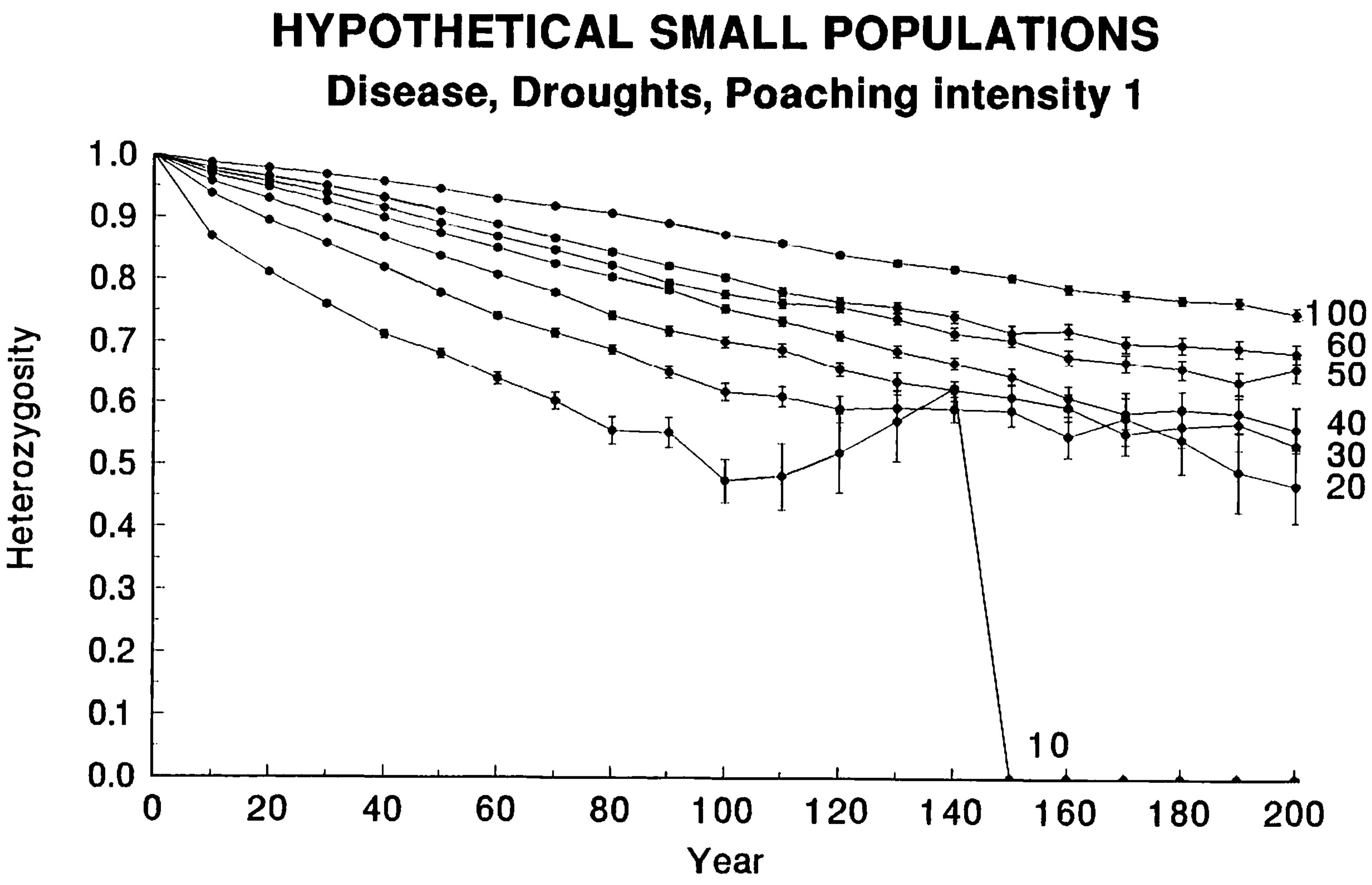

HYPOTHETICAL SMALL POPULATIONS
Disease, Drought, Poaching intensity 1
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
10
20
100
60
50
40
30

Figure 12b.



HYPOTHETICAL SMALL POPULATIONS
Disease, Droughts, Poaching intensity 1

Figure 1 3a.

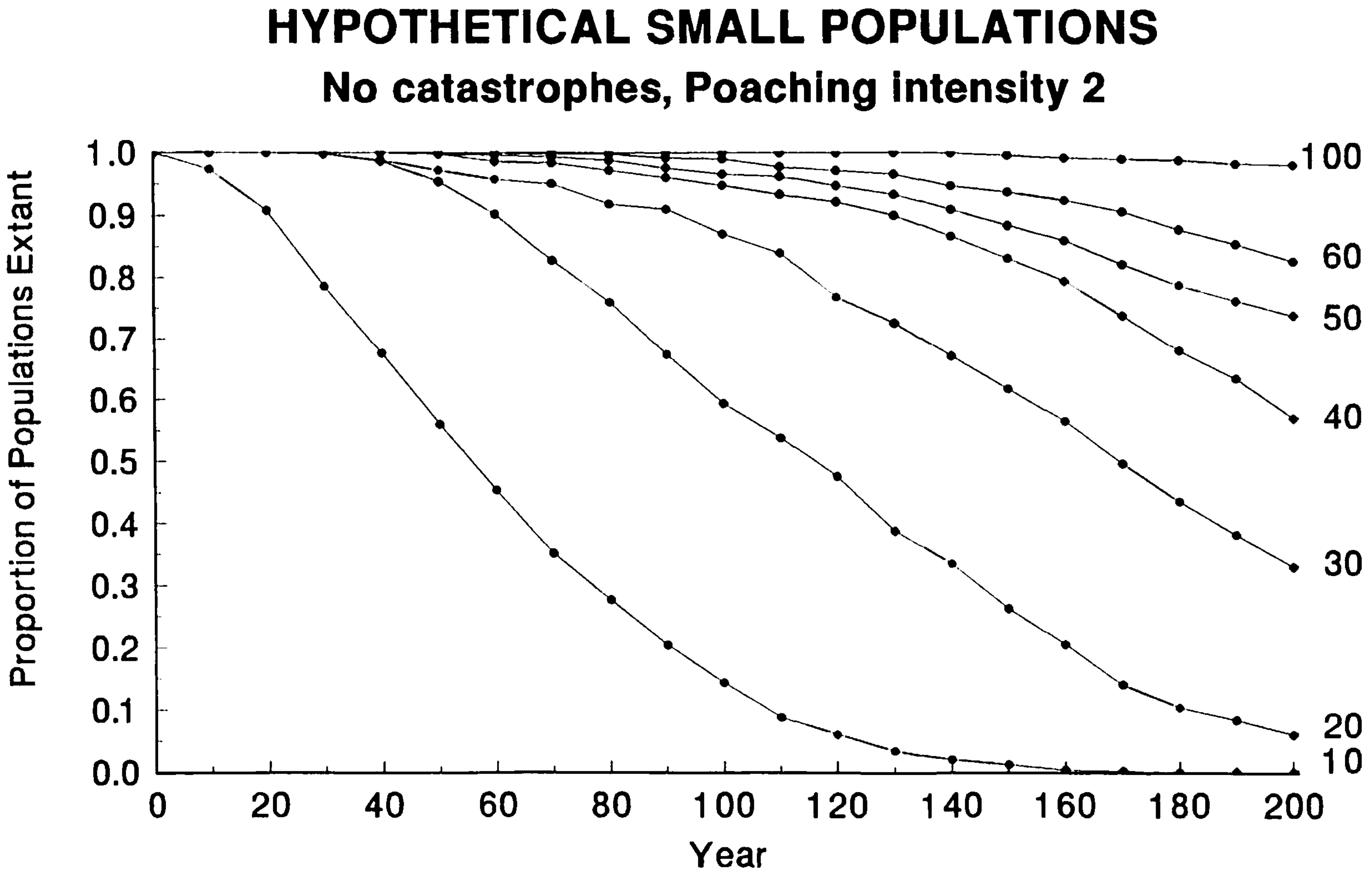

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, Poaching intensity 2
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
20
10

Figure 13b.

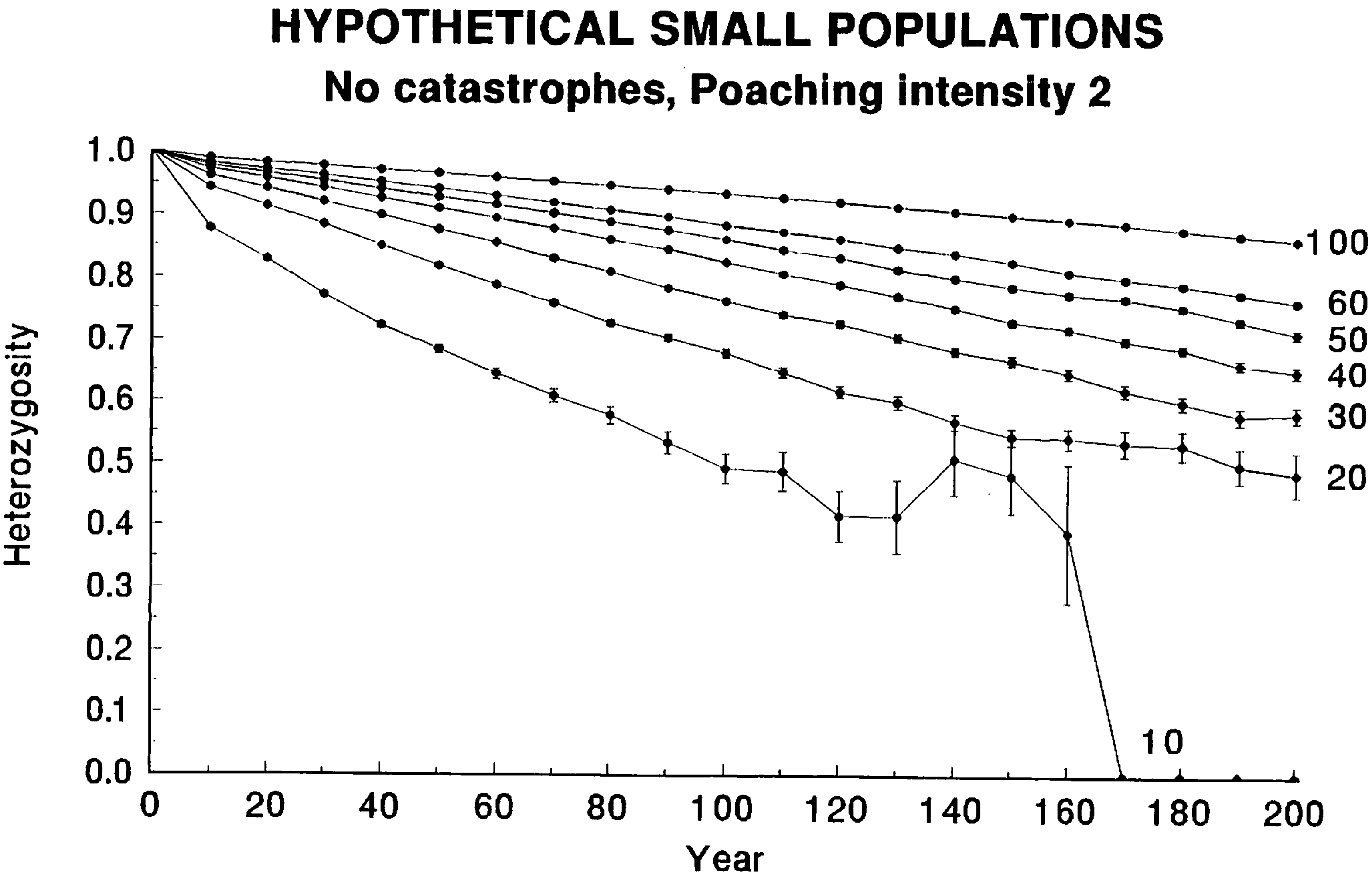
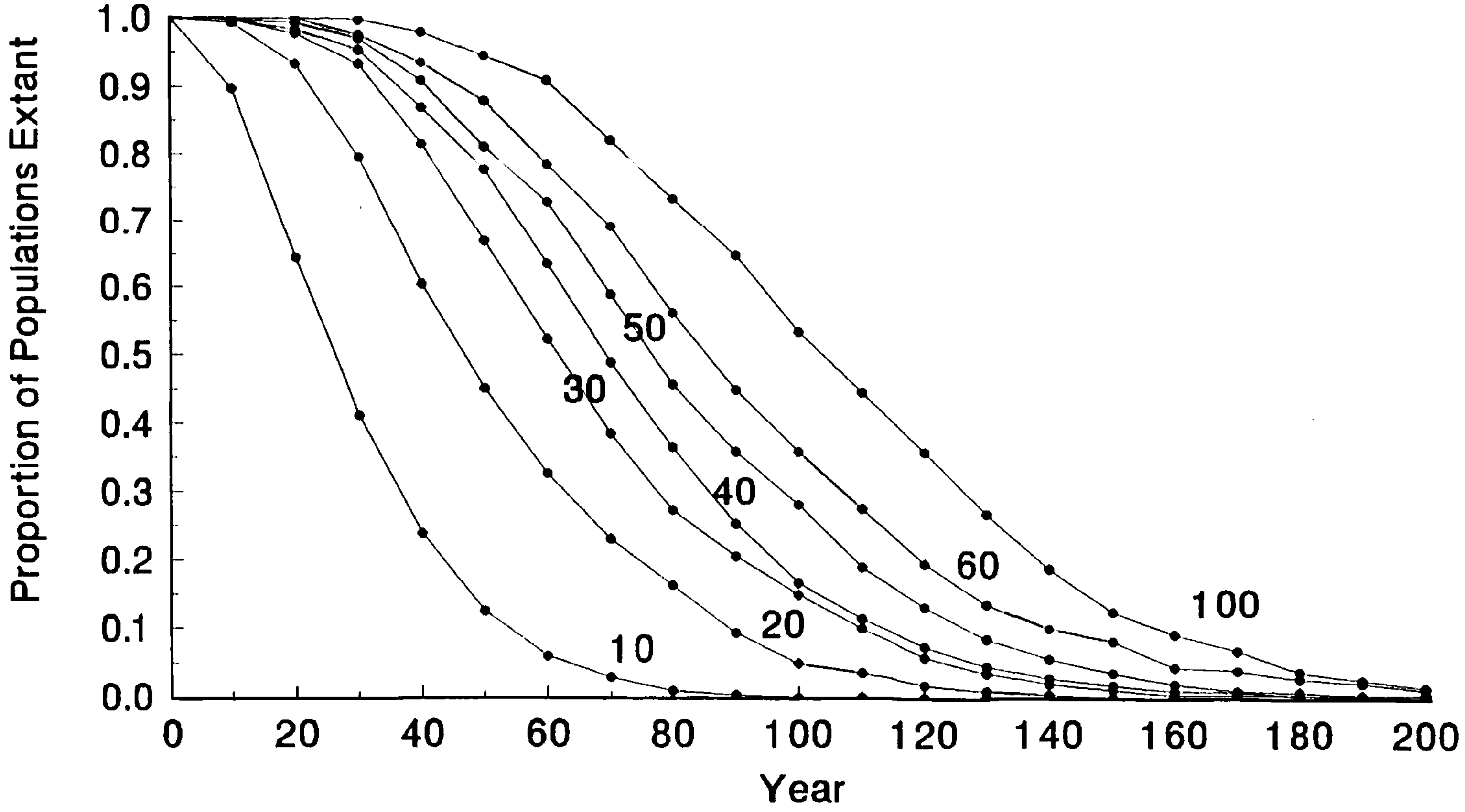

HYPOTHETICAL SMALL POPULATIONS
No catastrophes, Poaching intensity 2
Heterozygosity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
100
60
50
40
30
20
10

Figure 14a.



HYPOTHETICAL SMALL POPULATIONS

Disease, Drought, Poaching Intensity 2

Figure 14b.

## HYPOTHETICAL SMALL POPULATIONS

### Disease, Droughts, Poaching intensity 2

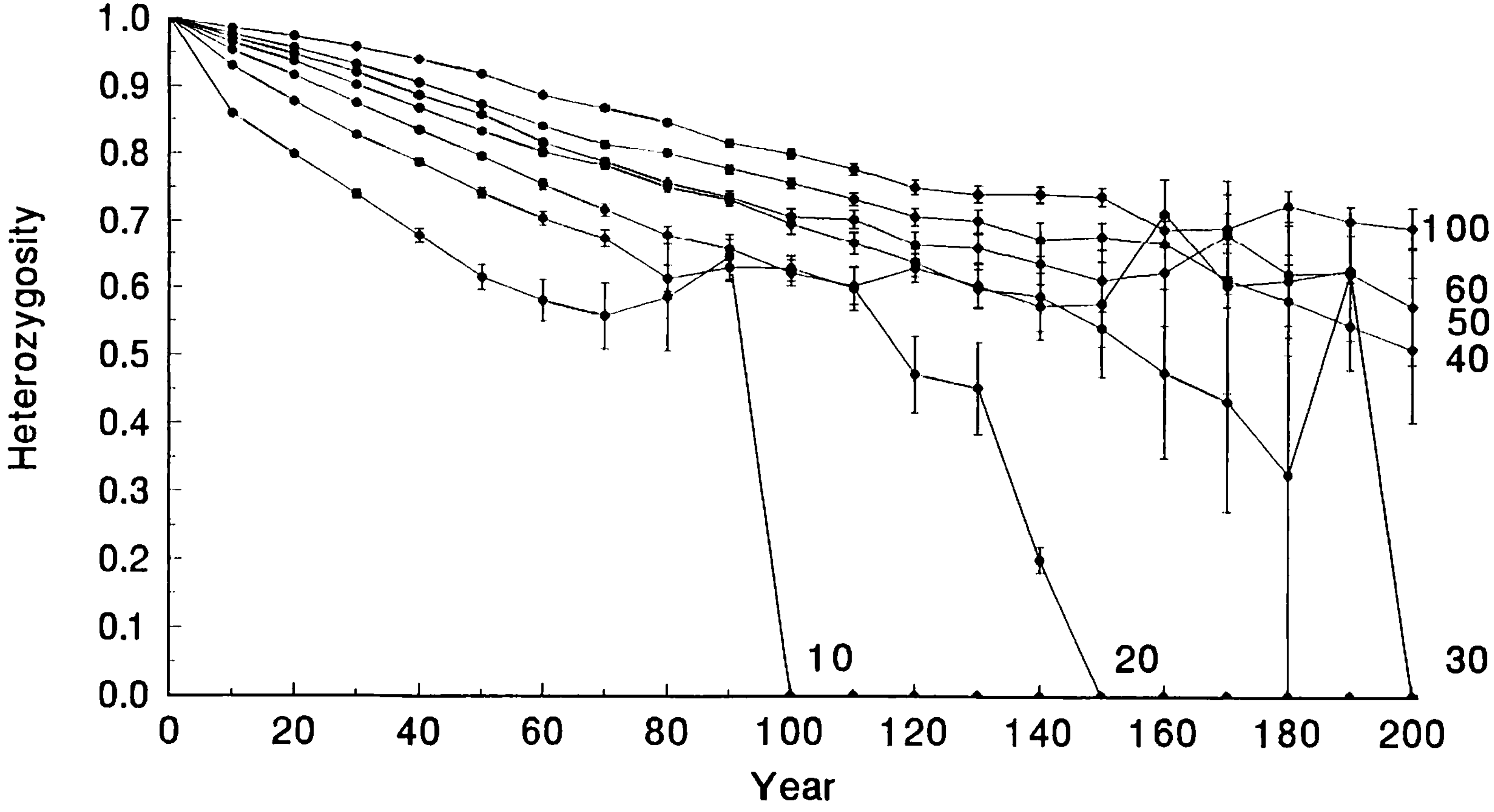
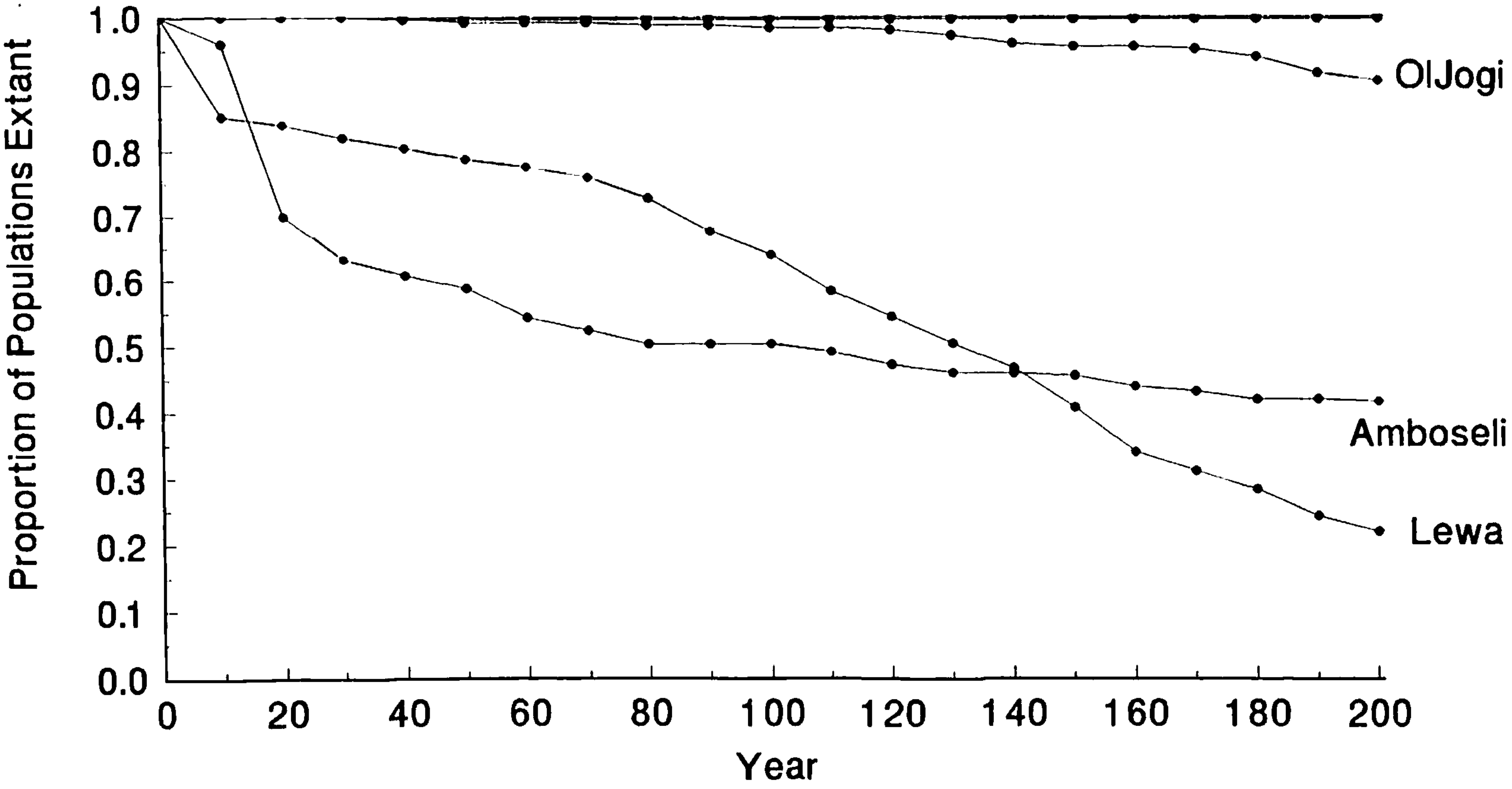


Figure 15a.



KENYA RHINO SANCTUARIES

No catastrophes, No founder adjustment, No migration

Figure 15b.

## KENYA RHINO SANCTUARIES

No catastrophes, No founder adjustment, No migration

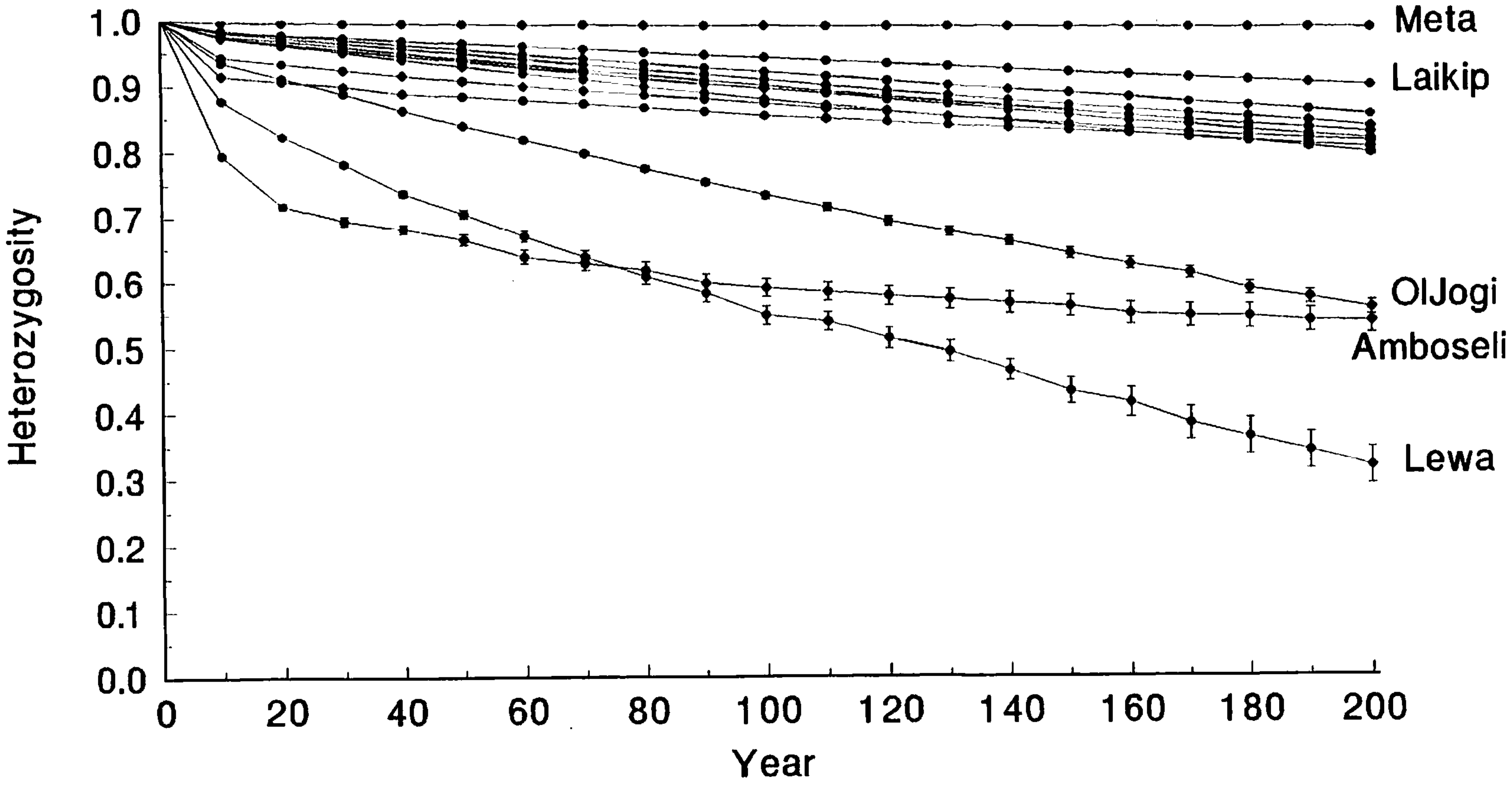


Figure 16a.

## KENYA RHINO SANCTUARIES

### Catastrophes, No founder adjustment, No migration

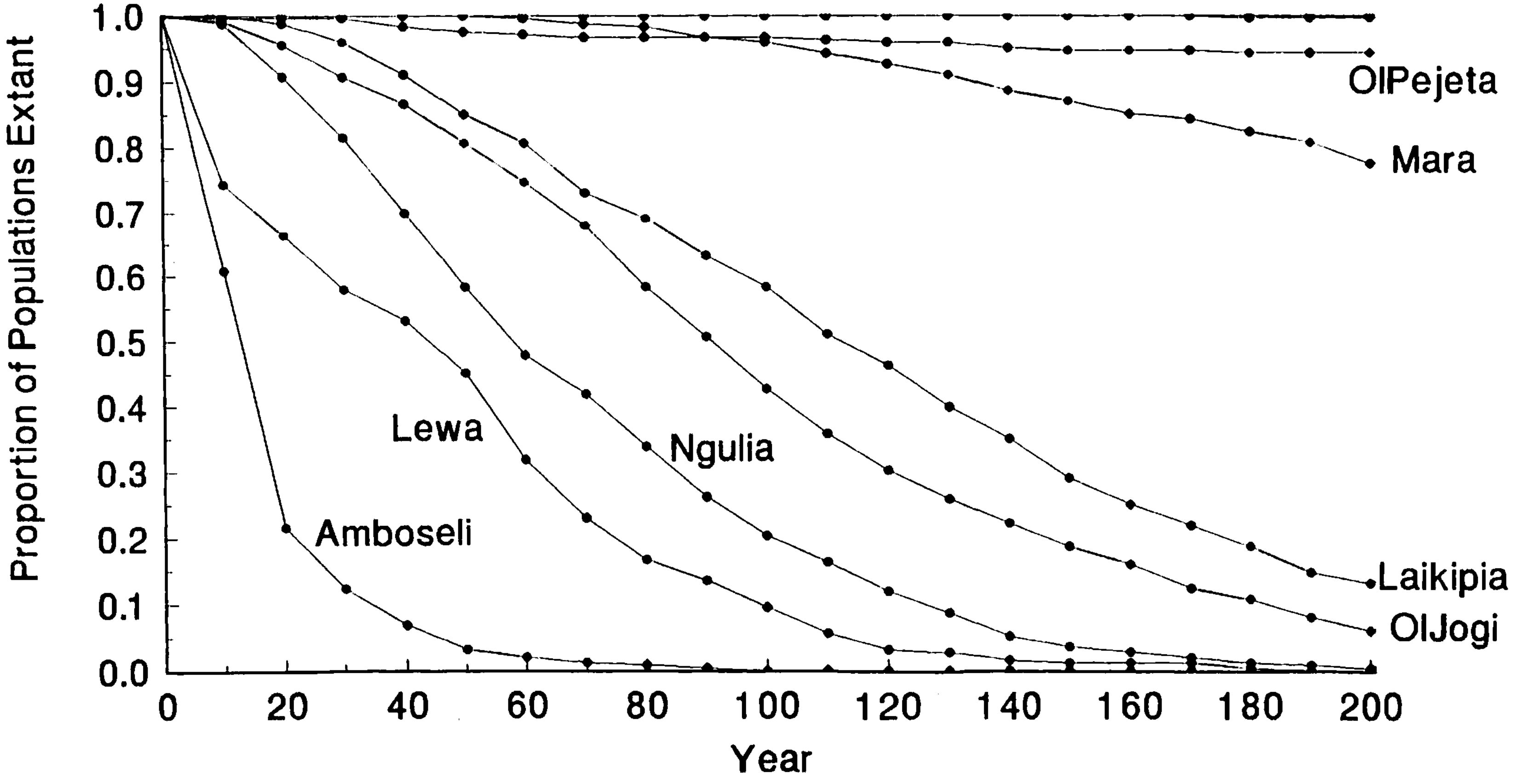
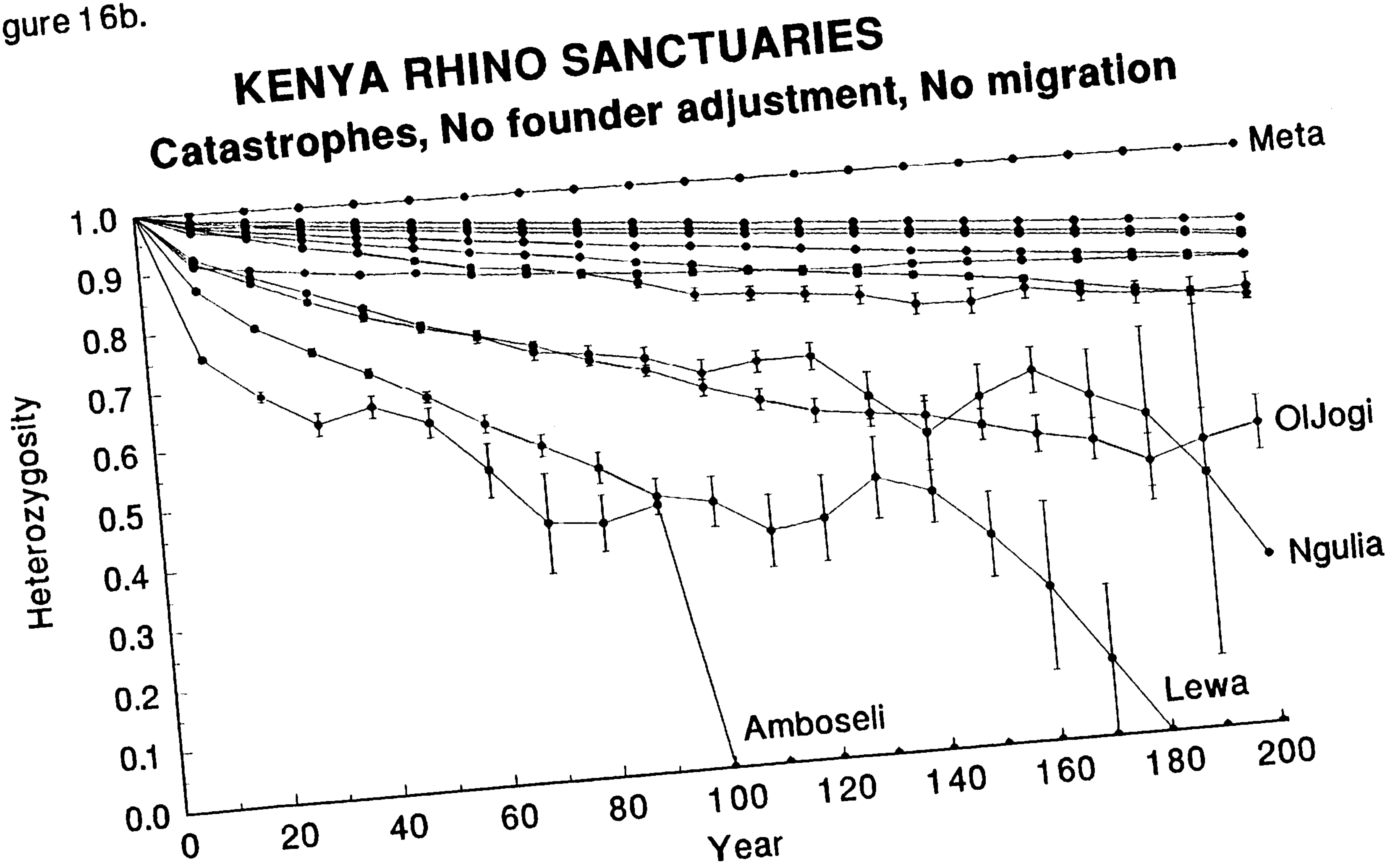


Figure 16b.



KENYA RHINO SANCTUARIES
Catastrophes, No founder adjustment, No migration

Figure 17a.

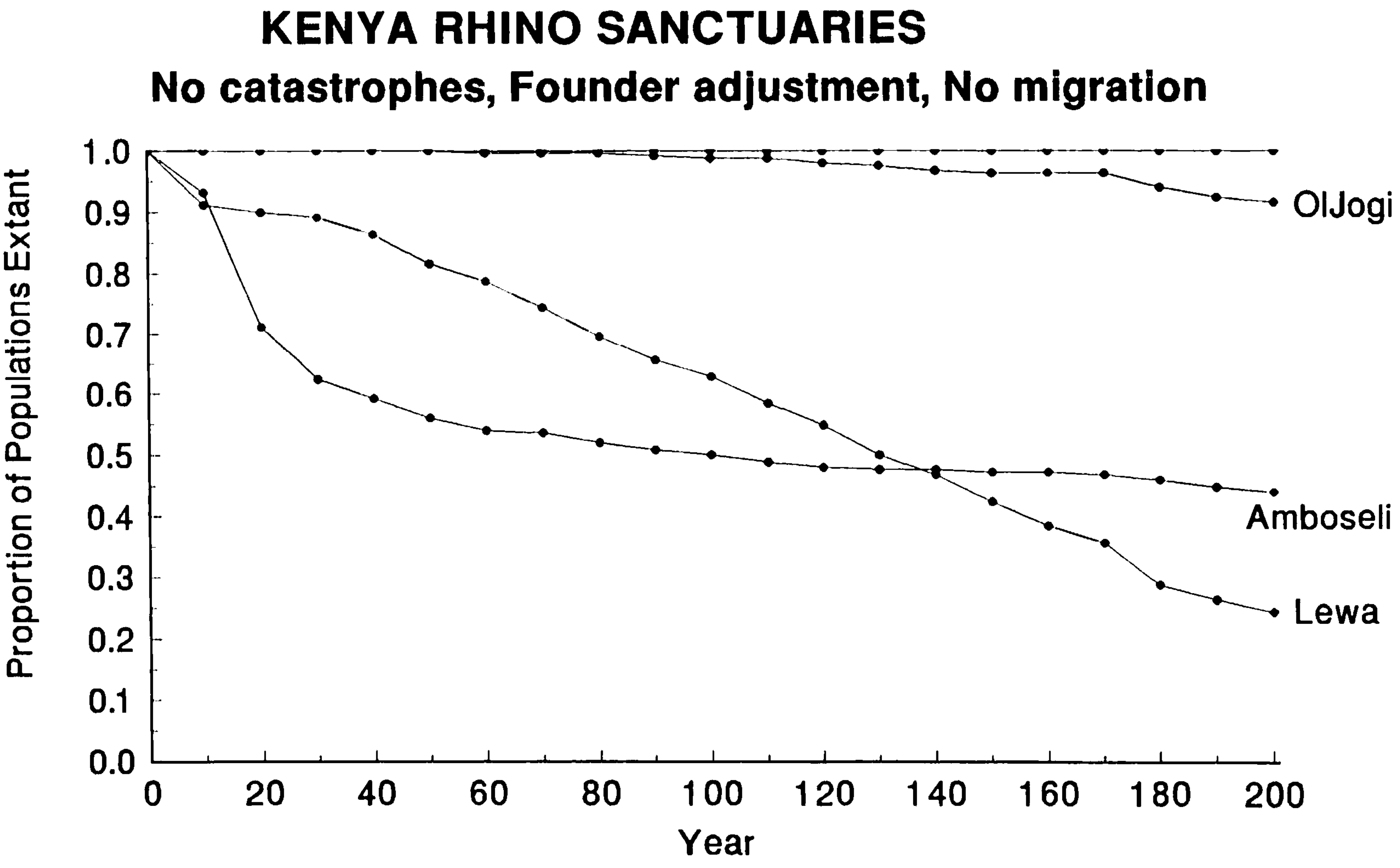

KENYA RHINO SANCTUARIES
No catastrophes, Founder adjustment, No migration
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
OlJogi
Amboseli
Lewa

Figure 17b.

**KENYA RHINO SANCTUARIES**

**No catastrophes, Founder adjustment, No migration**

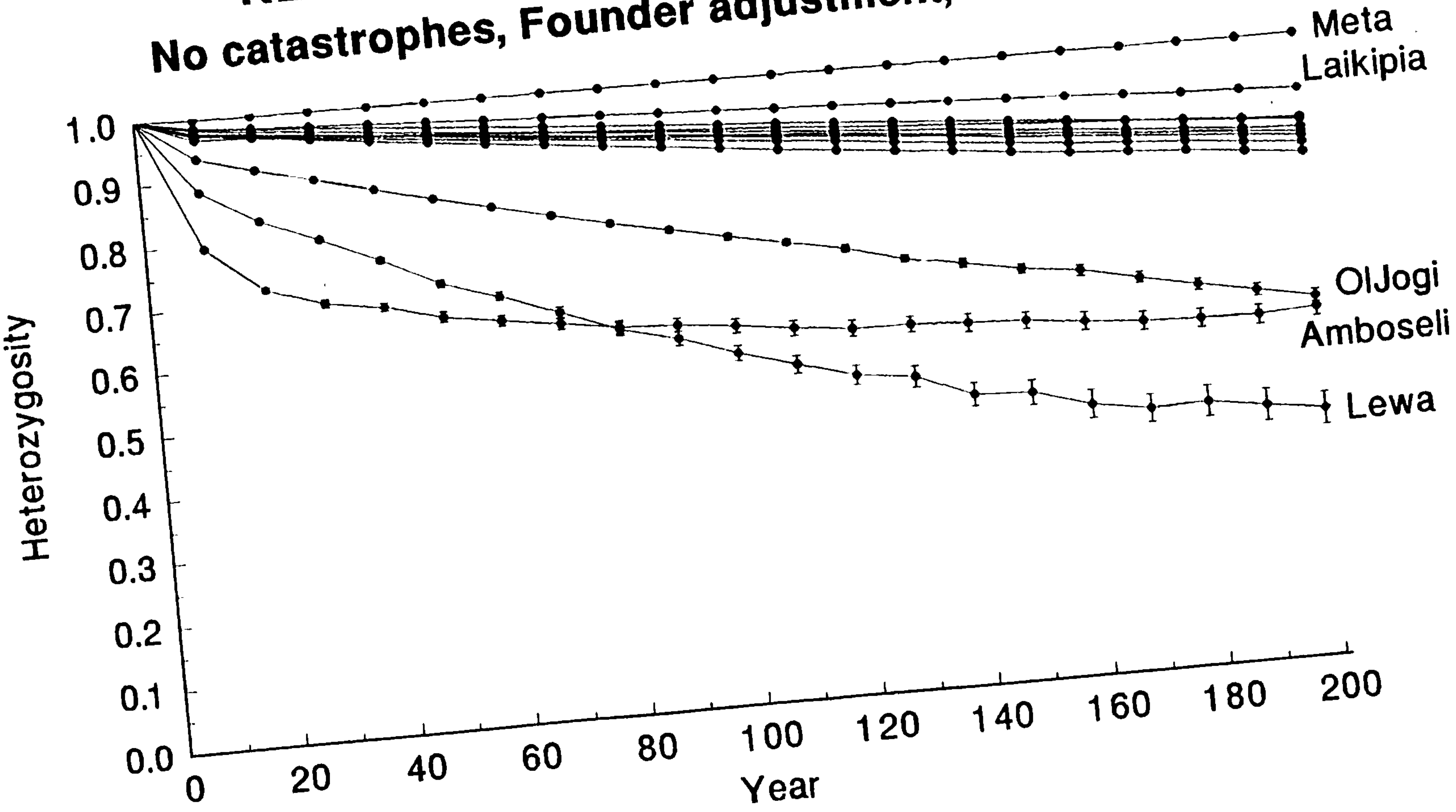
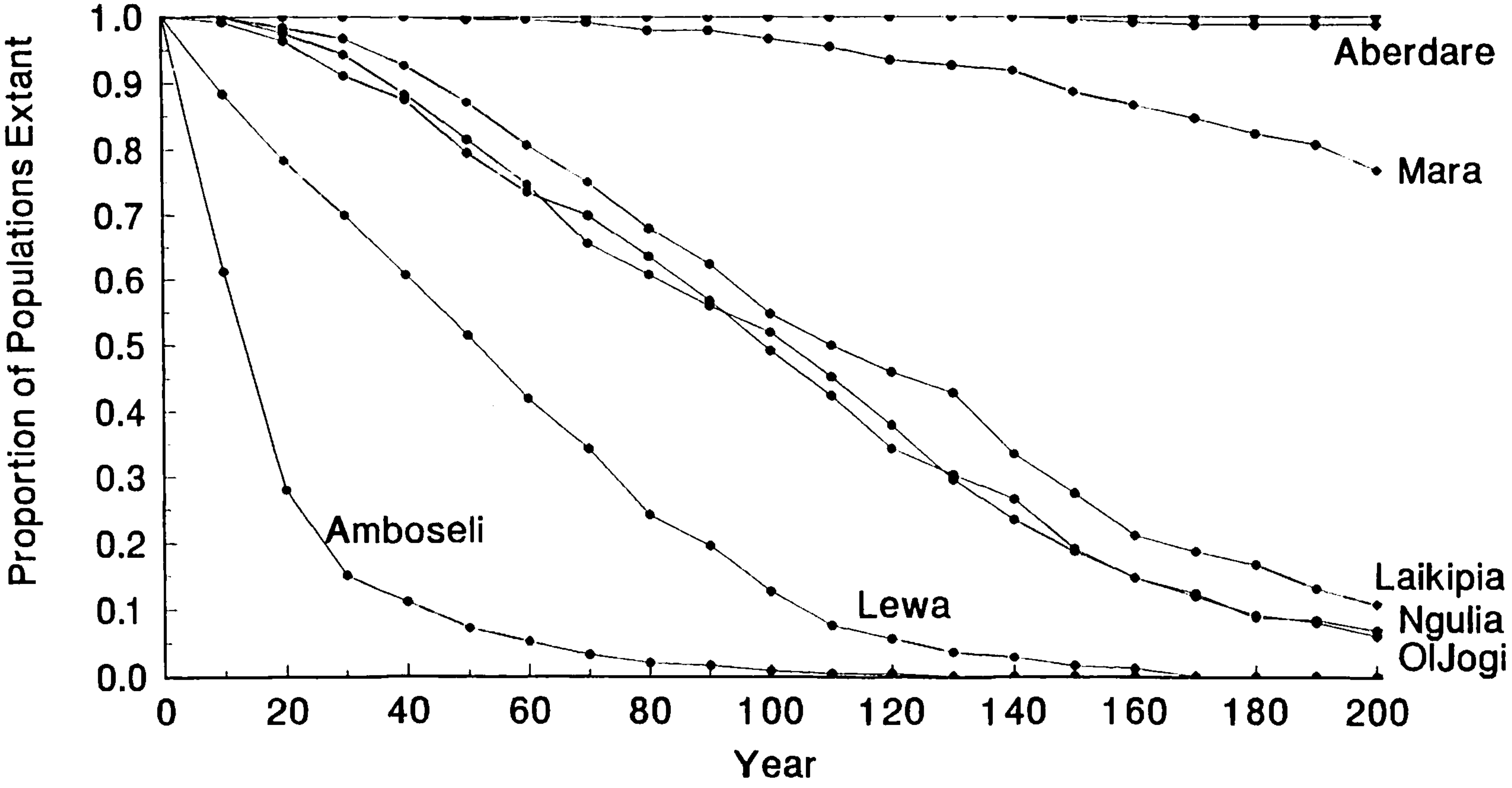


Figure 18a.



**KENYA RHINO SANCTUARIES**

**Catastrophes, Founder adjustment, No migration**

Figure 18b.

KENYA RHINO SANCTUARIES

Catastrophes, Founder adjustment, No migration

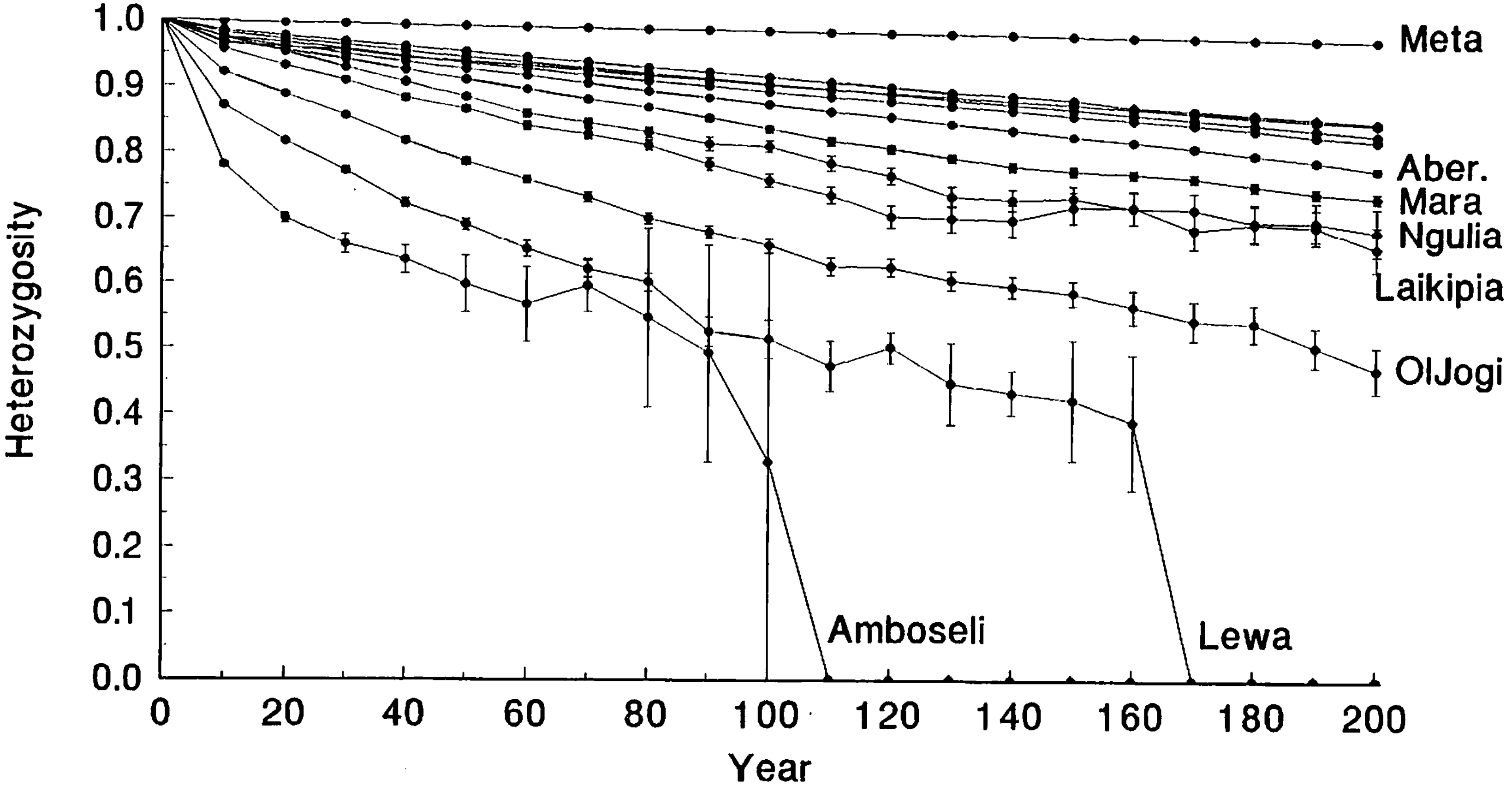


Figure 19a.

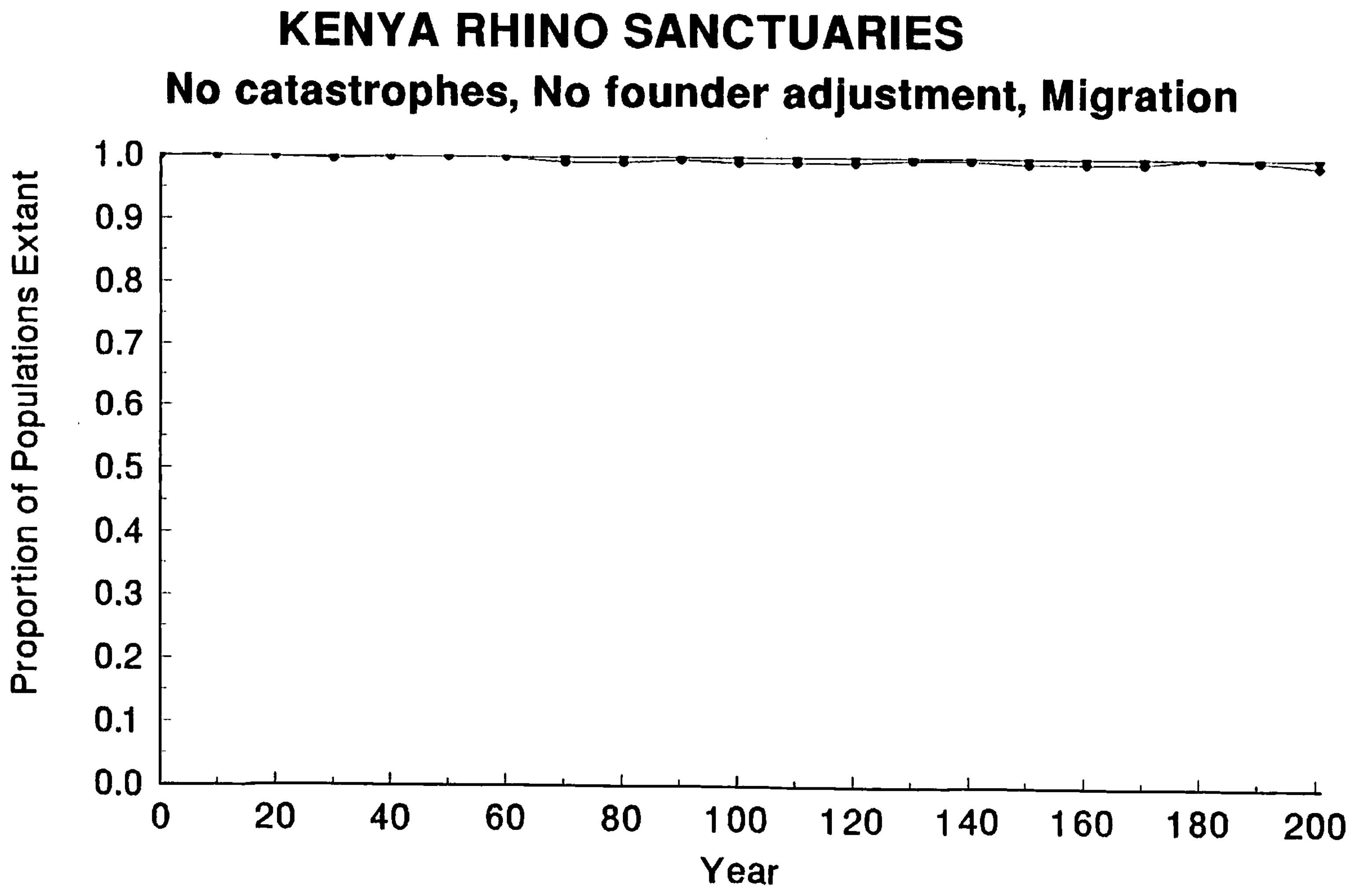

KENYA RHINO SANCTUARIES
No catastrophes, No founder adjustment, Migration
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year

Figure 19b.

## KENYA RHINO SANCTUARIES

### No catastrophes, No founder adjustment, Migration

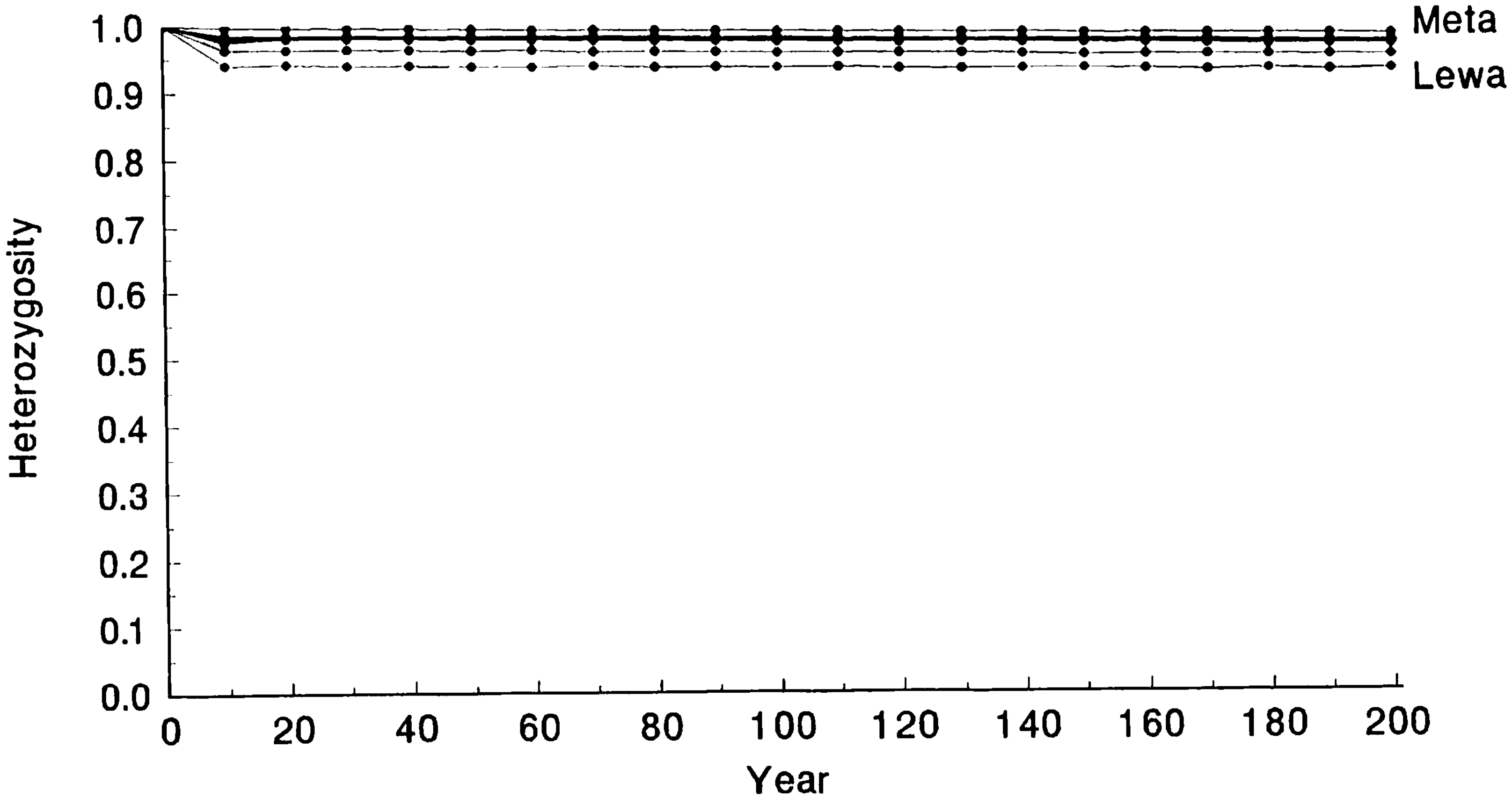


Figure 20a.

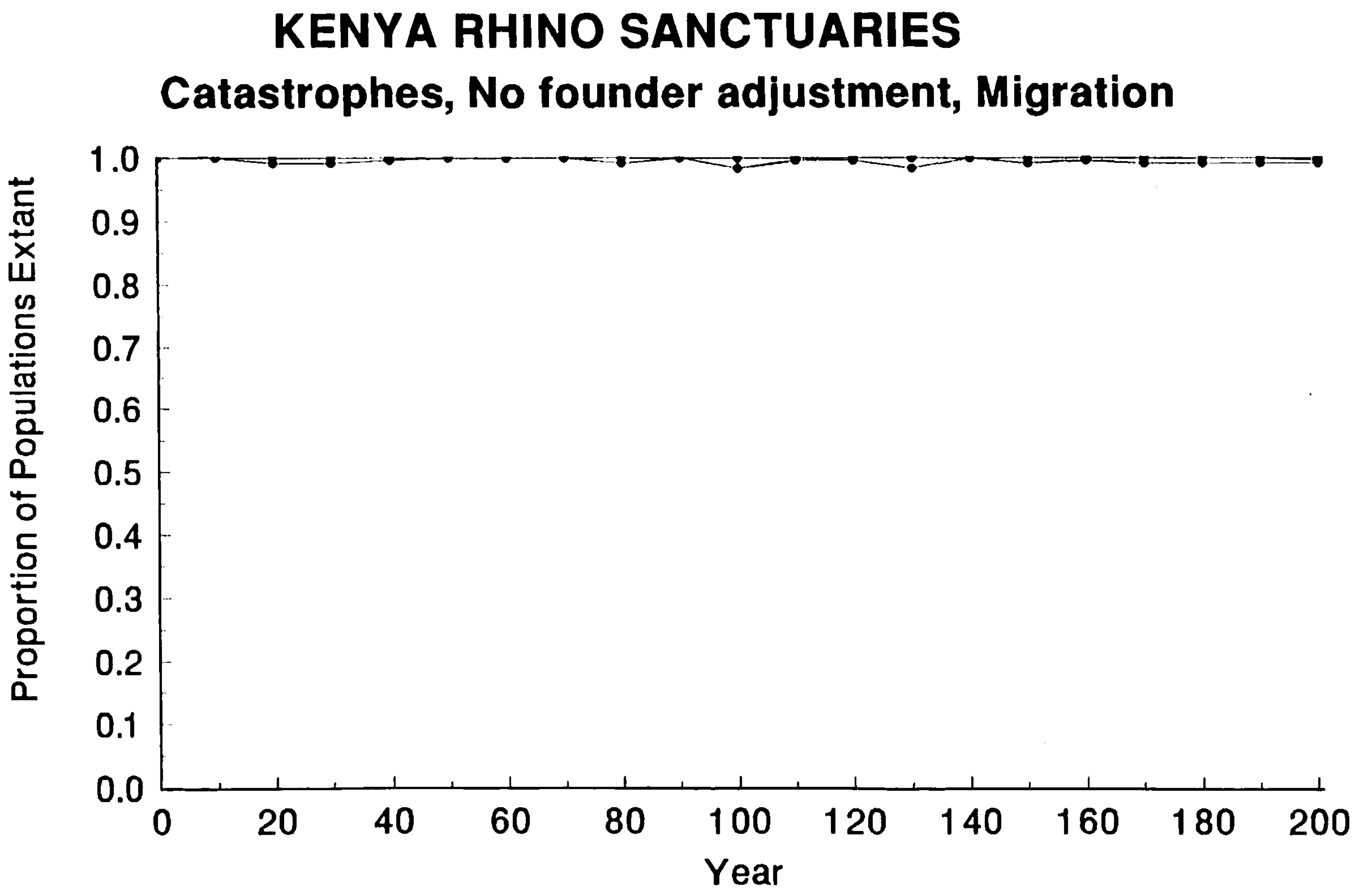

KENYA RHINO SANCTUARIES
Catastrophes, No founder adjustment, Migration
Proportion of Populations Extant
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year

Figure 20b.

## KENYA RHINO SANCTUARIES

### Catastrophes, No founder adjustment, Migration

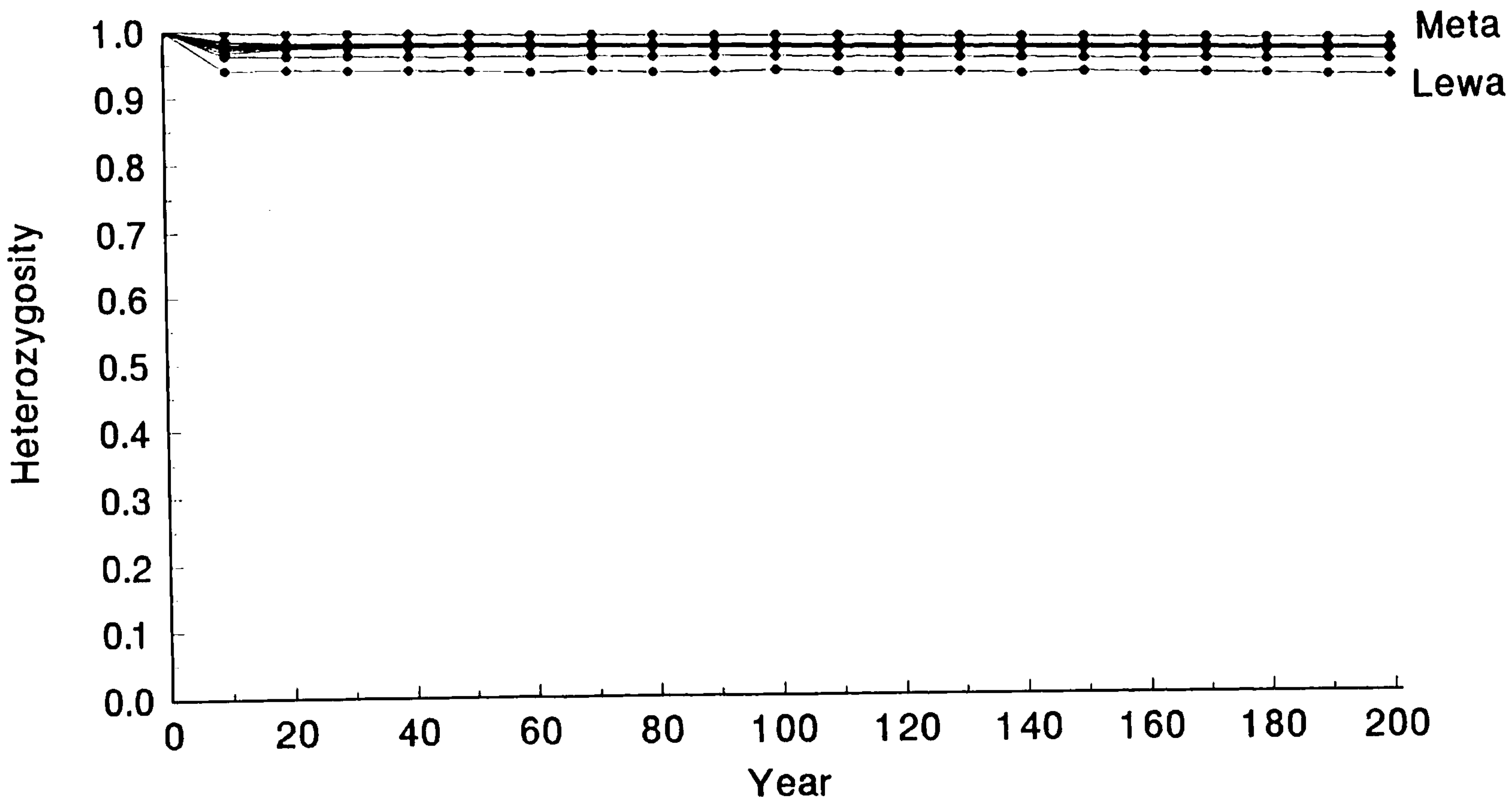
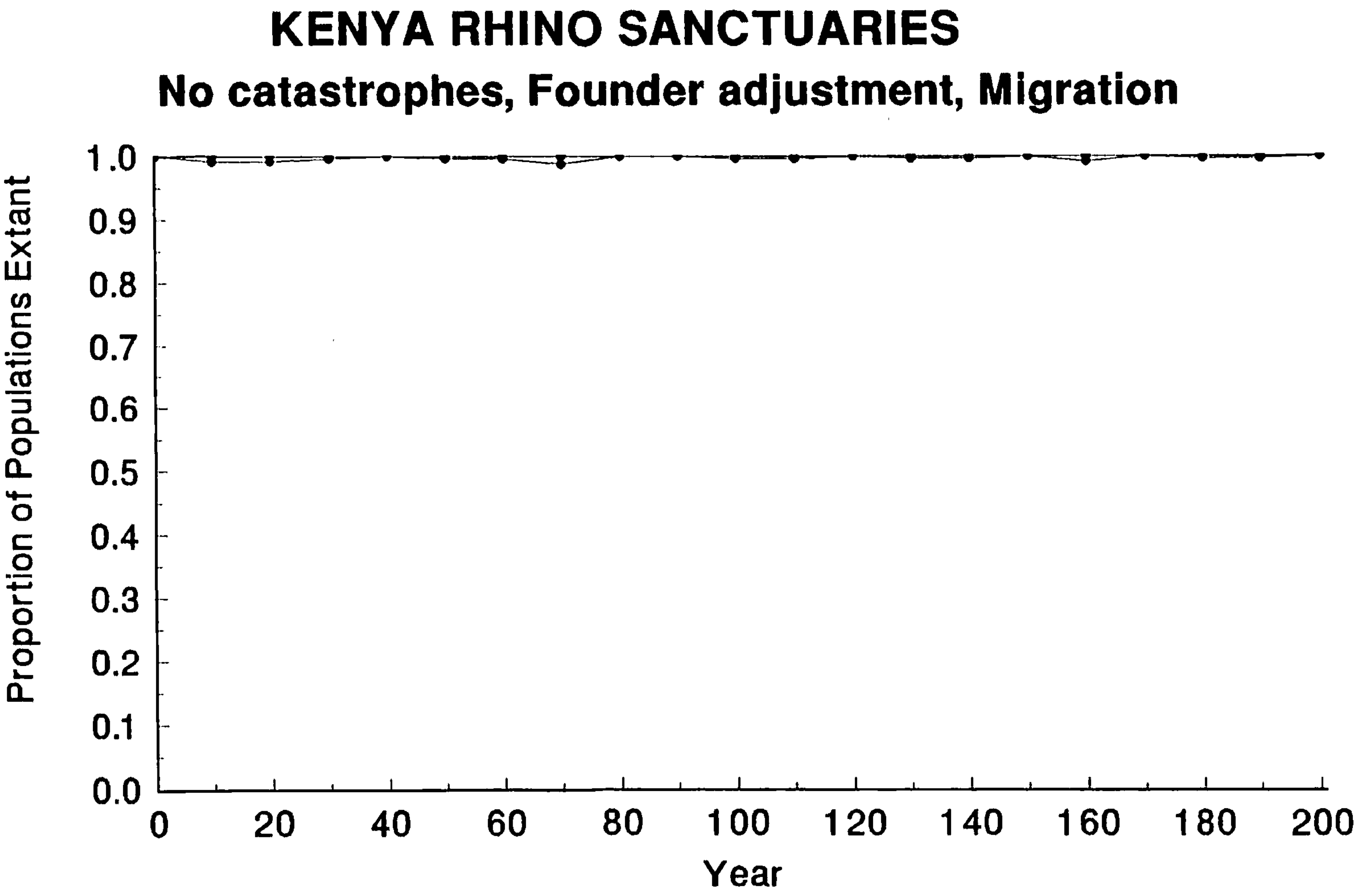


Figure 21a.



KENYA RHINO SANCTUARIES

No catastrophes, Founder adjustment, Migration

Figure 21 b.

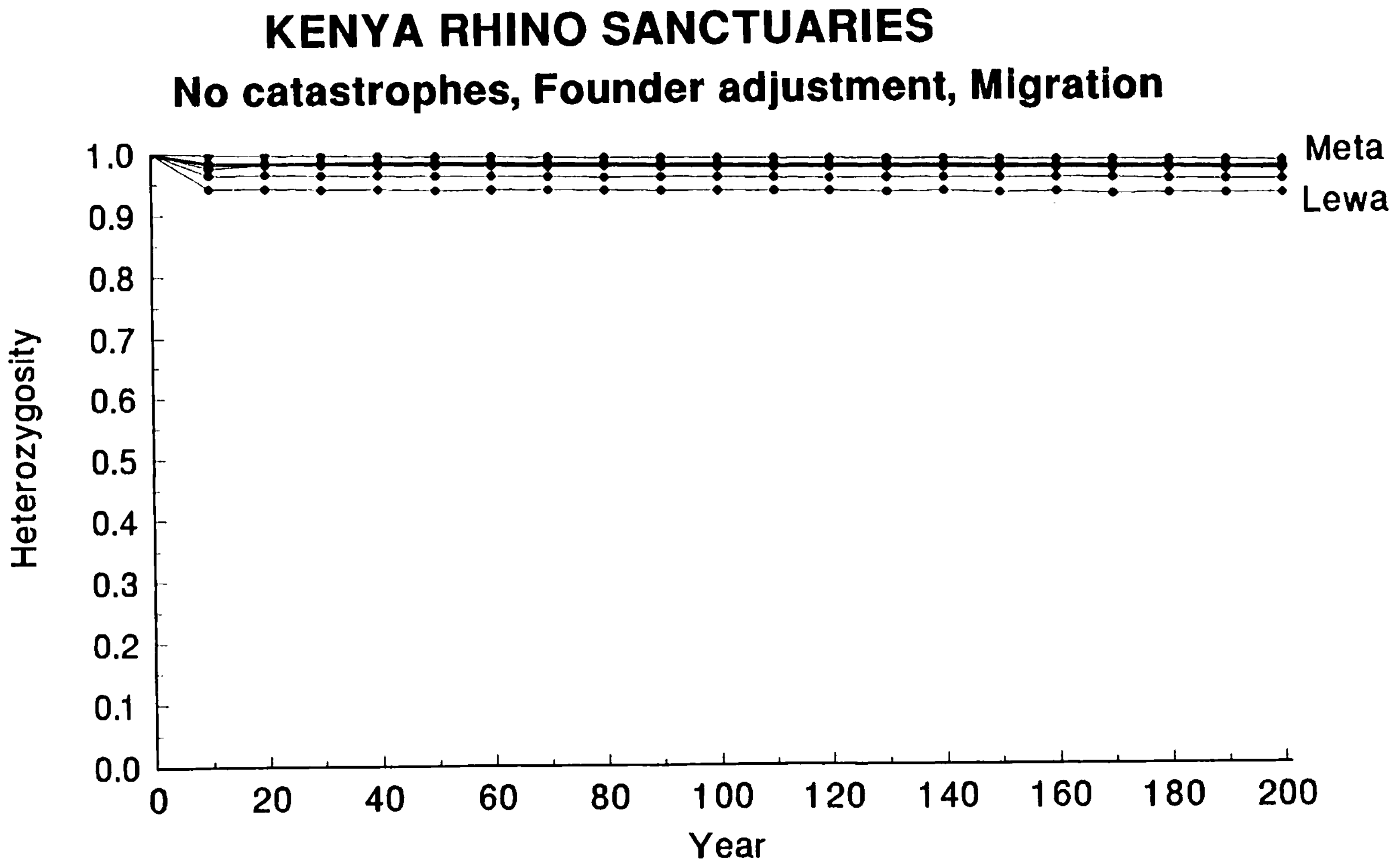

KENYA RHINO SANCTUARIES
No catastrophes, Founder adjustment, Migration
Heterozygosity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
Year
Meta
Lewa

Figure 22a.

## KENYA RHINO SANCTUARIES

### Catastrophes, Founder adjustment, Migration

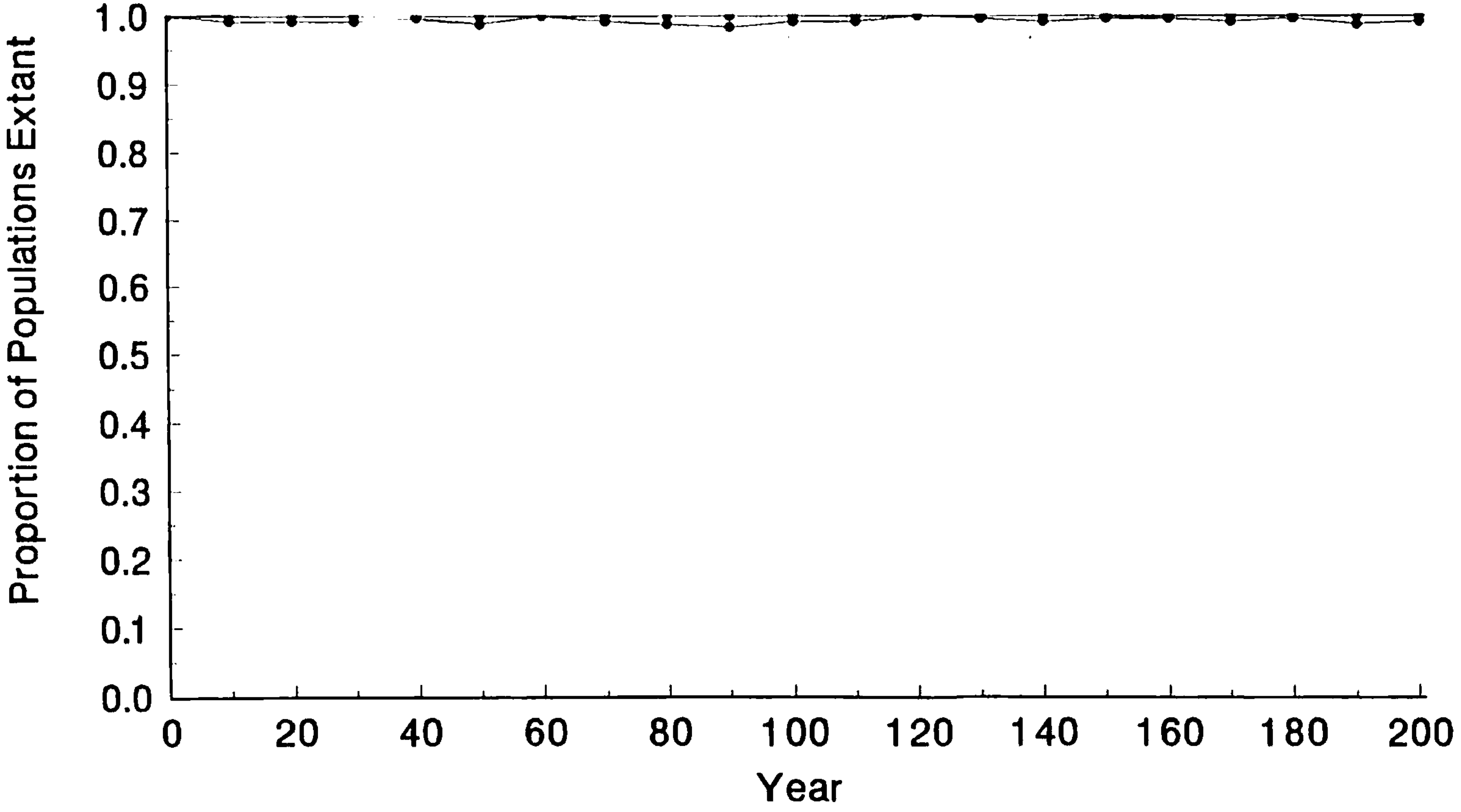
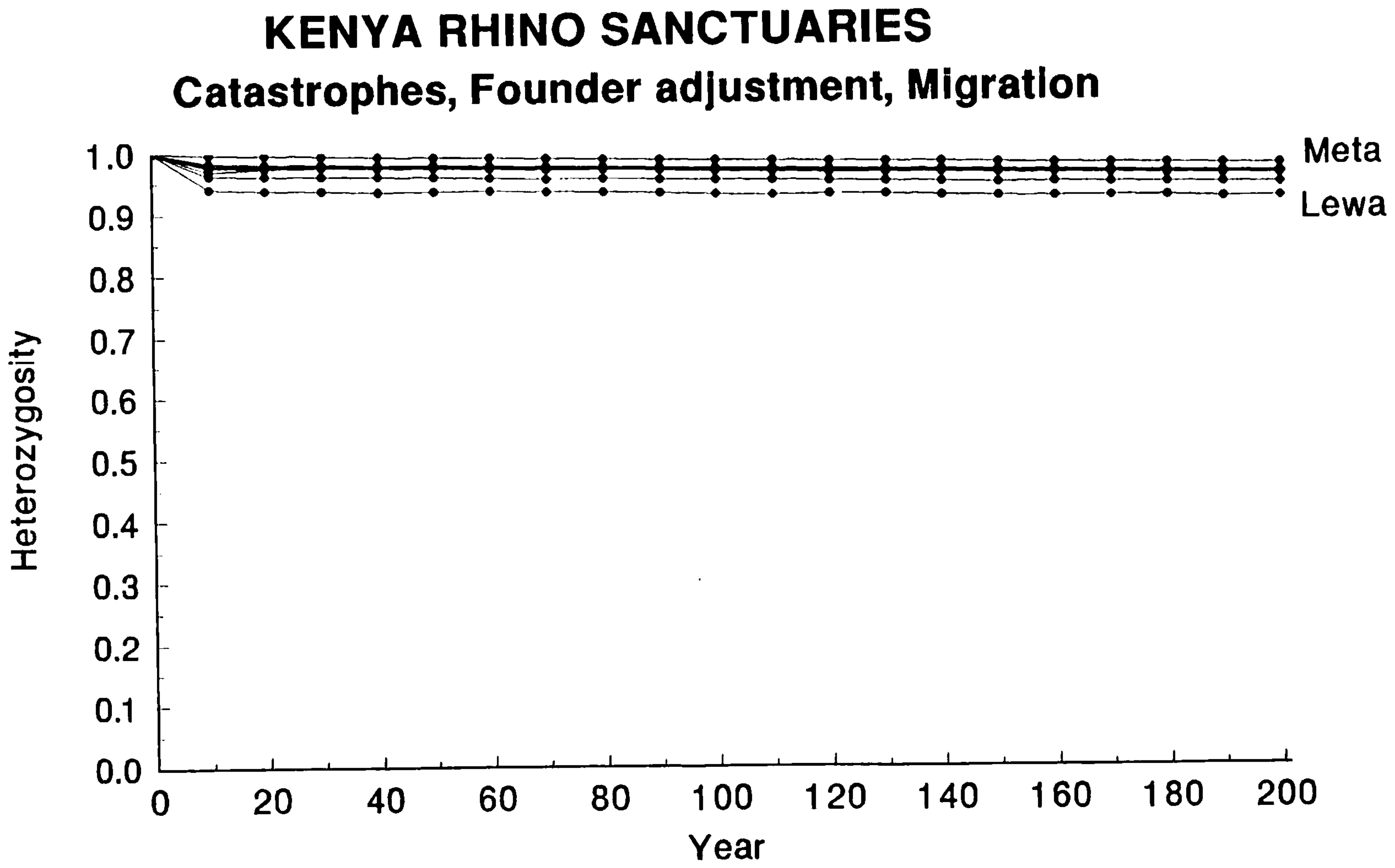


Figure 22b.



KENYA RHINO SANCTUARIES

Catastrophes, Founder adjustment, Migration

Figure 23a. (Smaller Lewa Version.)

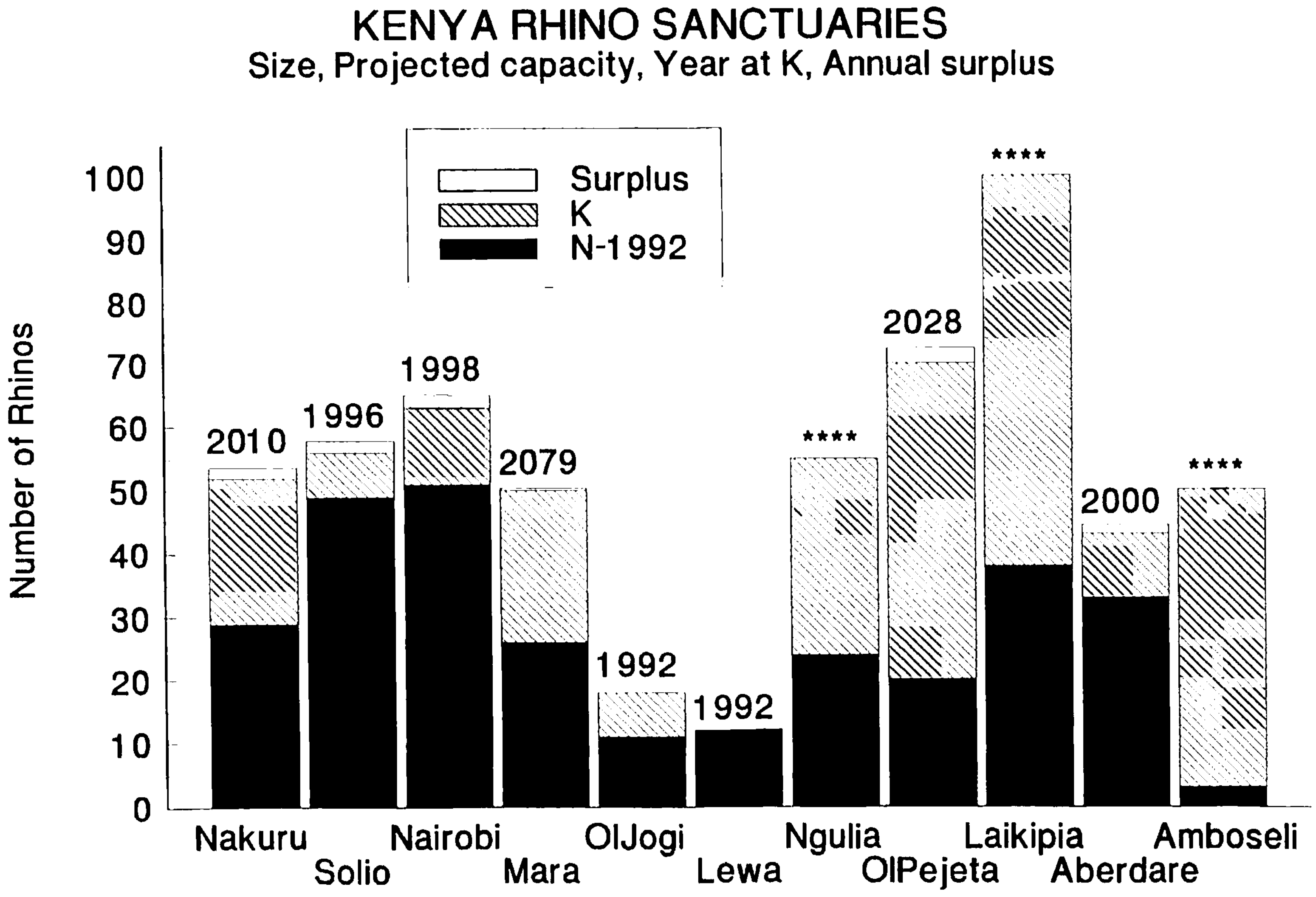


Figure 23b. (Larger Lewa Version.)