Aim

- Give you an idea about how a model can be built for an specific problem
- A simple single-species model was built to analyze the reasons for the wildebeest population decline in Africa grassland and to evaluate possible management action to reverse it

Content

- Background
- A modeling strategy
- Building the model
- Fitting the model to field data
- Exercising the model
- Some comments to modeling approach

Background

- Location: Game park in the central grassland in Africa
- Size: 500000 ha
- Grazing animals: Large herds of
  - Zebra (*Equus burchelli*)
  - Wildebeest (*Connochaetes taurinus*)
- Drought in decade of sixties leads to range overutilization
- Management action:
  - Crop zebra and wildebeest on the basis of data from annual aerial census of the park

Background

- In 1969, 14000 zebra and the same number of Wildebeest
- Wet years in 1972
- Cropping was discontinued
- Zebra population Ok
- Wildebeest population decline,
- In 1975, fewer than 7000 Wildebeest in Central grassland

Background

- Explanation: vegetation change, Tall grass was not a suitable habitat for wildebeest and their number had been reduced to a level where they were unable to maintain patches of short grass by their own grazing pressure.
- It was decided to build a model to analyze the reasons for the population decline and to evaluate possible management action to reverse it
- Controlling the principal predators, lion

A modeling strategy

- Objectives, (what should be included or excluded from the model).
- Objectives:

1. To help understand the decline in the Wildebeest population
2. To investigate how this decline might be reversed

A modeling strategy

- Simulating Wildebeest population
- Model should simulate the predators numbers (two way interactions)
- Wildebeest is not the only pray so the population dynamics of other prey species must be included
- Grass height affects the predator-prey interaction
- Grass height depends on rainfall and herbivore density
- The model must be a system model for entire park (system of interacting components)

Problem

- Lack of understanding about the relevant interactions in the system
- Time, money, efforts,…
- Managers needs to make a decision now

Solution

- Build a model that concentrates on and is defined by immediate problem management faces (declining in Wildebeest population).
- Wildebeest only variable and introduce other factors with first order effects only
  - The park system as a large painting
  - Our model show the wildebeest in some detail but go very fussy
  - Abstract as we move away from the wildebeest into the rest of the system

Modeling Strategy

- Our modeling strategy is thus to use the objectives of the model to isolate the essential variables

Building the model

- To build the model we need to know:
  1. What are the mechanisms that cause wildebeest numbers to change?
  2. How often do we need to calculate these changes?
  3. What level of details do we need to describe the wildebeest population?
     - (Do we need to differentiate between sexes and various age class?)

What are the mechanisms that cause wildebeest numbers to change?

- Central theme: wildebeest are dying faster than they are being born
- How they are born?
  - 2 years female starts to born calves
  - The fertility of 2 years female is lower than older females
  - Older female produce one calf a year
  - Calf birth’s are synchronized

What are the mechanisms that cause wildebeest numbers to change?

- How they die? Simple & confusing
  - Simple: lions are mostly responsible (the ratio 100 to 1 but in this park 10 to 1)
  - Confusing: When grazing condition are becoming poor, cows are week and do not have sufficient milk for their calves so they have many predators in these two weeks, then the lion become mostly responsible
  - How often do we need to calculate these changes?

    Once a year

What level of details do we need to describe the wildebeest population? genders

- Gender ratio at birth 50 : 50, at maturity female 70% and male 30%
- Filed data suggests, these ratio do not change from one year to the next
- Therefore we do not need to differentiate between the genders

What level of details do we need to describe the wildebeest population? ages

- Calf mortality is more complicated than adult mortality
  - Calves and yearlings do not breed
  - Fertility of two year olds is not the same as adult fertility
- Therefore we need to differentiate between the age classes
- Calves, Yearlings, 2 year olds and Adults

Notation

- Ct: the number of calves at a few weeks after calving season
- Yt: the number of yearlings (the calves that have survived from the previous year)
- Wt: the number of two year olds
- At: the number of adult wildebeest (three or more years of age)

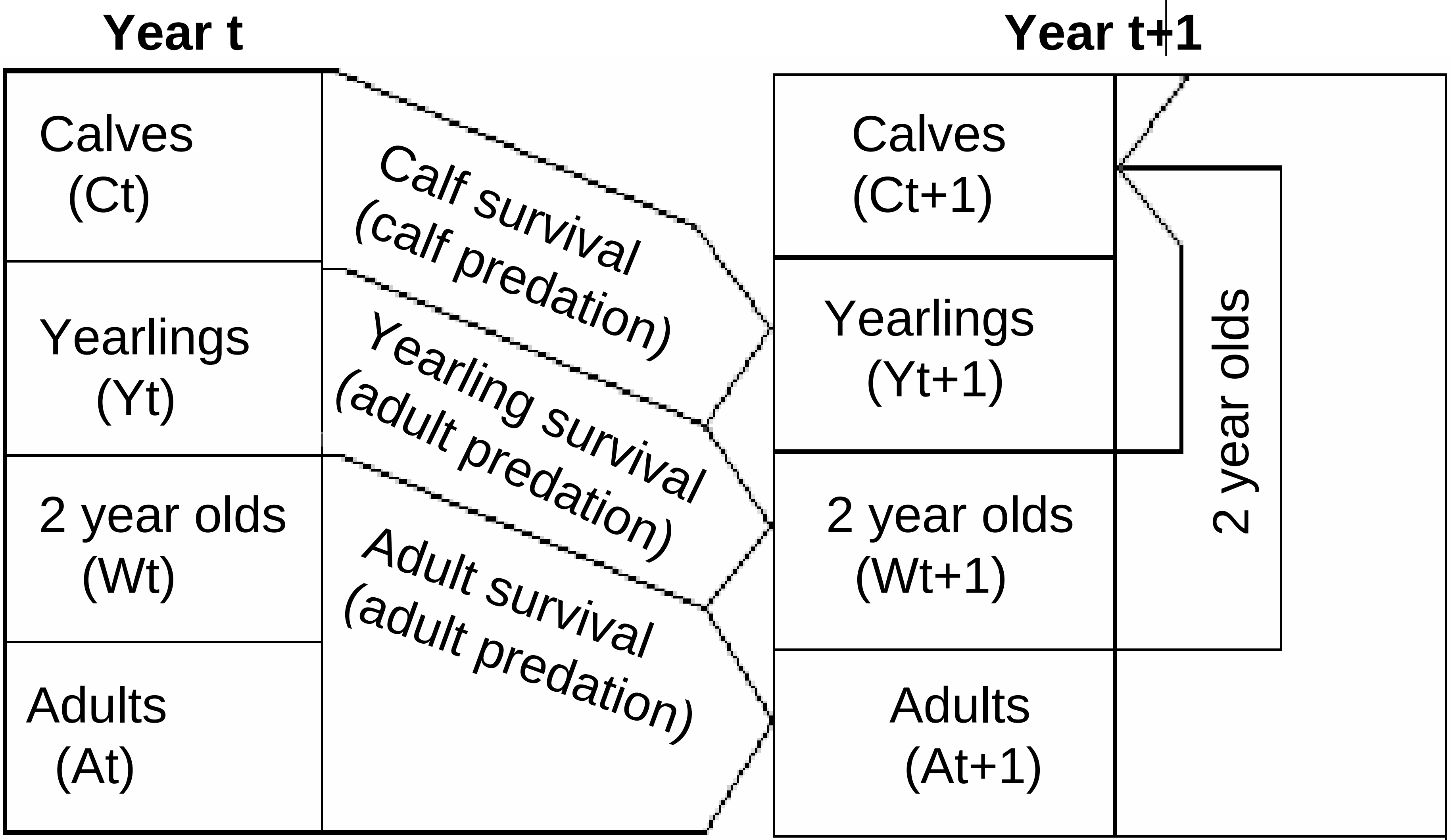
Model

- Predict population changes from one year to the next
- Given Ct,Yt, Wt and At, we must therefore develop equation that enable us to calculate Ct+1,yt+1, Wt+1 and At+1

Equation in words

- Ct+1= the number of calves born to those two year olds and adult females alive at the beginning of the calving season in year t+1
- Yt+1= Ct minus those calves that died during the year
- Wt+1= Yt minus those yearling that died the year
- At+1= Wt+At minus those two year olds and adults that died during the year

Changes in population



Replace words with mathematics

- C_{t+1}: Two year old and adult
- C_{t+1}: W_t+A_t but many of them died
- C_{t+1}: $W_{t+1}+A_{t+1}$
- p: represents the proportion of the adult population that is female
- C_{t+1}: $p(W_{t+1})+p(A_{t+1})$
- b: represent the fecundity of adult females and B the lower fecundity of 2 years old females
- pA_{t+1} adult female cows $\longrightarrow$ bpA_{t+1} calves
- pW_{t+1} two year old cows $\longrightarrow$ BpW_{t+1} calves
- $C_{t+1}=(BpW_{t+1})+(bpA_{t+1})$

- $Ct+1=(BpWt+1)+(bpAt+1)$
- We do not know the $Wt+1$ and $At+1$
- The equation for $Yt+1$ is very difficult to derive
  - So many factors affect the number of calves that die during a year
  - Our strategy will be to cut through the problem by introducing a factor ***qt*** which we will call the calf survival rate during year t
  - Calf survival is likely to change from one year to the next
- if we started with ***ct*** calves at the beginning of

  year t, only ***qt*** x ***ct*** will be left at the end of year t, so our equation for the yearlings becomes, $Yt+1=qtCt$

- Only complication in equations is for Two-year-olds and adults is, again, the number of yearlings, two-year-olds, and adults that die during the year. But here we have introduced a reasonable simplifying assumption-namely, that they are all killed by lions.
- How many lion?
- How many wildebeest will a lion kill each year?
- Do lions have a preference for yearlings, two-year-olds, or adults?

- There are ***Lt*** lions, that each of them eats, on average, ***st*** wildebeest and they do not differentiate between yearlings, adults and two years old.
- By manipulating the ***Lt*** and ***St*** we can then make use of any data we are able to find about the lions and their kill rate.
- Yt +Wt+At
- A total of Lt*St of them will be killed
- The numbers killed in each age class on a proportional basis:
  - LtStYt/ Yt+Wt+At yearling
  - LtSt (Wt+At)/ Yt+Wt+At Two years old and adult

Final two equations

Wt+1= Yt minus those yearling that died the year

At+1= Wt+At minus those two year olds and adults that died during the year

$$w_{t+1} = y_t - \frac{l_t s_t y_t}{y_t + w_t + a_t}$$

$$a_{t+1} = a_t + w_t - \frac{l_t s_t (w_t + a_t)}{y_t + w_t + a_t}$$

- To implement these equations, we need an initial population structure at year 1, estimates of the parameters *b, p,* and p, and estimates of qt, Lt and St separately

FITTING THE MODEL TO FIELD DATA

- abstract relationships leading to the equations that describe our population model.
- The process of fitting the model to the field data is thus rather like detective work: We have facts, clues, and hypotheses, and from these we must attempt to construct a convincing case.

FITTING THE MODEL TO FIELD DATA

- P (the proportion of adults that are female) =0.7
- Adult fecundity b is close to 1.0, while *B* is approximately 0.3.
- Rangers tell 400 to 600 lions
- Each lion eat two to four cows a year
- Calf survival rate vary roughly 0.1 to 0.6
- Total cows estimates from aerial censuses
- Rough estimates of proportion of calves and yearlings is available from road counts.

FITTING THE MODEL TO FIELD DATA

Given this information, our strategy will be to take successive guesses at the calf survival rate and see whether, using values for the number of lions and the lion kill-rate that are reasonable, we can relate results from the model to the aerial census and road-count data. Specifically, we will try to reproduce six years of field data using the model. (We use the census data for the first year as the starting point of our computation.)

additional complication

Wildebeest were cropped during four of the six years, and obviously we must take account of this in our model. Accurate records were kept of the total number, let us call it gt, cropped during year *t,* we can model the cropping process merely by replacing the product ltst wherever it appears in our equations with the

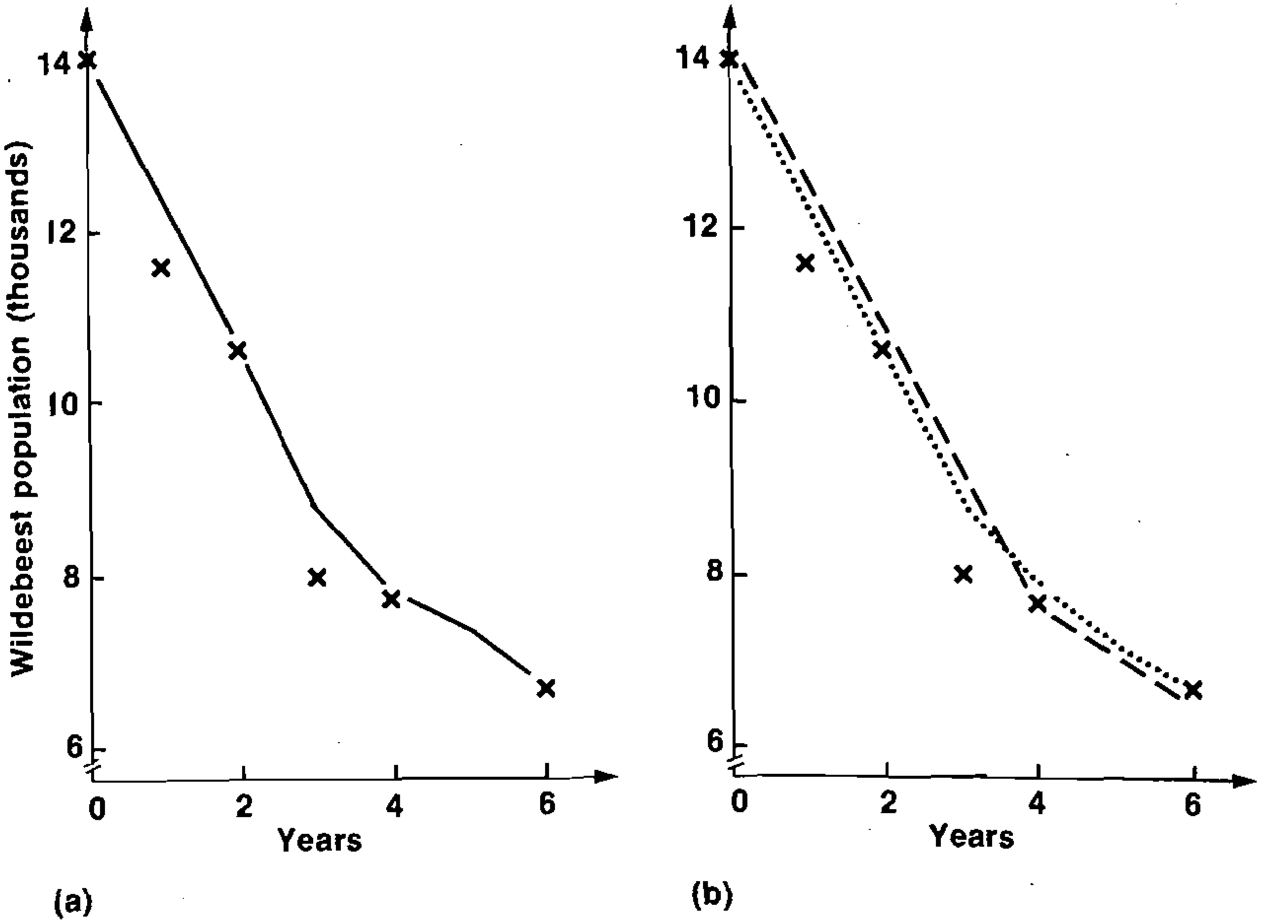
expression ltst + gt.

Detailed input and output for the cows model

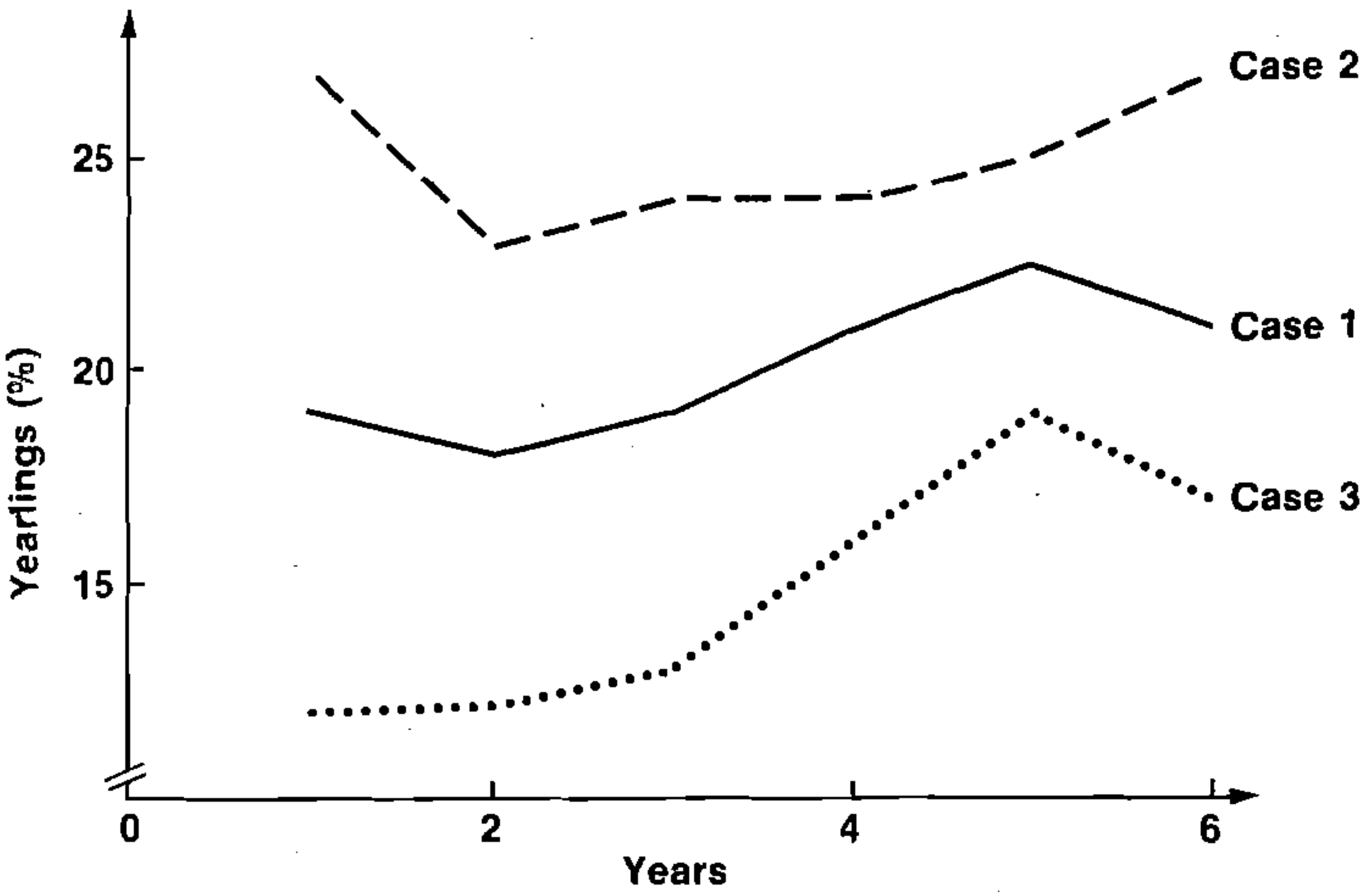
	Input parameters				Computer results					
Year (t)	Lions (l_t)	Kill rate (s_t)	No. cropped (g_t)	Calf survival rate (q_t)	Calves (c_{t+1})	Yearlings (y_{t+1})	Two-year-olds (w_{t+1})	Adults (a_{t+1})	Total	Census total
0					3640	2240	1680	6440	14,000	14,000
1	500	4.5	572	0.35	2903	1820	1630	5908	12,261	11,800
2	500	4.5	550	0.35	2569	1451	1275	5283	10,578	10,600
3	500	4.5	302	0.35	2160	1285	989	4468	8,902	8,000
4	500	3.8	78	0.42	1872	1296	908	3856	7,932	7,700
5	500	3.3	0	0.48	1702	1284	943	3467	7,396	—
6	500	3.3	0	0.48	1546	1167	912	3132	6,757	6,700

Validating Model

Three different fits of the cows model to the census data

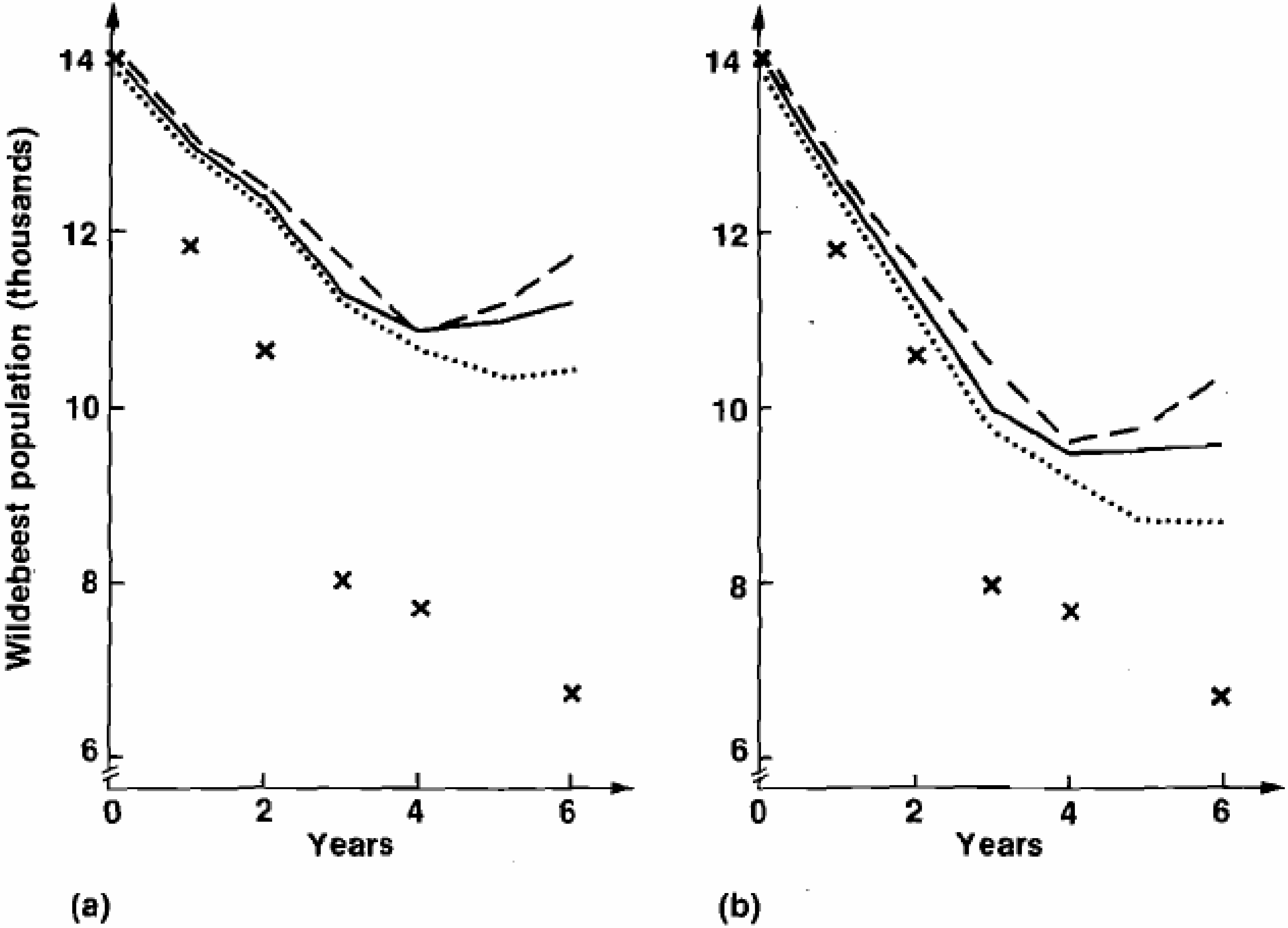


The percentage of yearling in the population for each of the three cases in previous slide

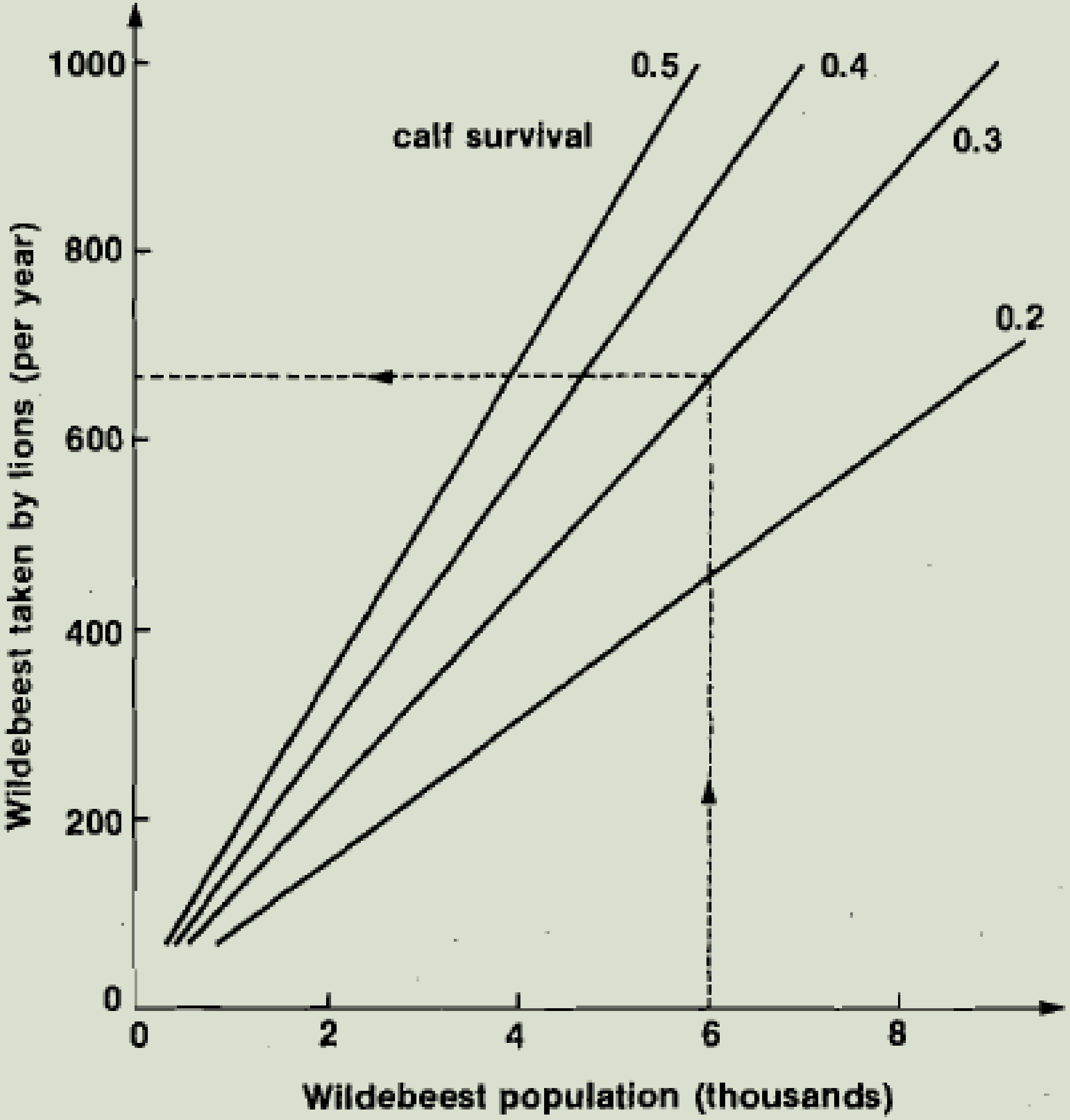


Scenario Analysis

- What might have happened if there had been no cropping of the Wildebeest during year I through 4



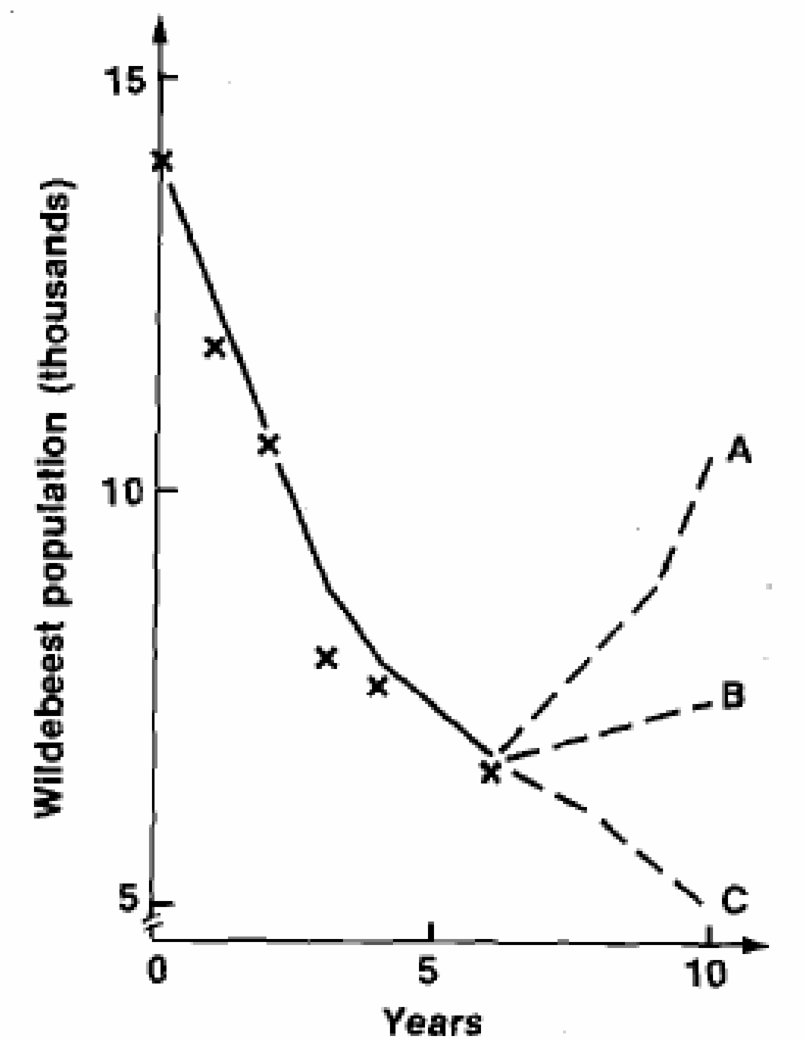
What the wildebeest model predicts might have happened if (a) no wildebeest had been cropped and (b) predators were cropped as well as wildebeest. [The three cases are shown as solid, dashed, and dotted lines respectively, and the crosses (X) are the original census data.]



Predation thresholds. (For example, if the wildebeest population is 6000 and the calf survival is 0.3, the population will remain constant if the lions kill 666 wildebeest per year but will decline if predation is any higher.)

Predicting what will happen

If the number of lions decrease to (A) 200, (B) 300, and (C) 400



Model in Retrospect

Perhaps the most important contribution of the modeling exercise was the fact that it focused attention on wildebeest births and wildebeest deaths. The field biologists knew that they had a declining wildebeest population, but their explanations for it were varied and vague. Building a model forced them to establish a mechanism, and that mechanism turned out to be predation. Exercising the model and comparing it with census data provided a plausible explanation for the decline, one that could be interpreted in a way that was consistent with both the available data and peripheral field observations.

Some comments on the Modeling Approach

- Resolution, Specific to ask of a model. The model shows what combination of calf survival and number of adult wildebeest killed by lions per year will stabilize the wildebeest population, but it does not ***and cannot*** suggest specific ways of engineering these conditions. It only encourage to think how to double the calf survival.
- Extracting part of a system and modeling it.