THE INCLUSION OF STOCHASTIC, DENSITY INDEPENDENT

EVENTS IN BIOLOGIC AND BIOECONOMIC MODELS

by
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ABSTRACT

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Many population and bioeconomic models are determan-
istic.  As populations may suffer perturbations, affecting
their demographic variables (fecundity and survival) from
a number of different sources, determanistic models are
correspondingly inadequate.  In this thesis, a method is
developed whereby the effect of random events on demographic
variables can be included in bioeconomic models.

As natural populations produce a flow of products or
commodities over time, a capital use approach is used to obtain
optimal use rates.  In developing the capital use approach,
the procedure used is user cost, the reason being that user
cost explicitly conceptualizes the joint capital/commodity
nature of use dependent flow resources.  The thesis extends
user cost methodology in its handling of uncertainty--made
necessary by the use of stochastic density independent events.

The model is developed and quantified using red kangaroo
data.  To test the model's strength and predictive capability
and to examine simulated population response, outcome sensi-
tivity to variation in interest rates (.07, .11, .15), and

harvest proportions (.5, .75) are examined.  The results are found to be reasonable and consistent with observed harvest data.

# DEDICATION

To Mum.

## ACKNOWLEDGEMENTS

The writing of a thesis is a learning experience.
Hopefully, it also results in a product which has some value
beyond the exercise of researching and writing (fabrication?)
of the thesis. My wish for this thesis to be such a product
is not only for my own satisfaction, but, also to compliment
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It is standard practice to acknowledge the help of the
Committee separately. I am conforming to this practice, and
for good reason. It is these people in particular who have

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# CHAPTER I

## INTRODUCTION

This thesis develops and demonstrates a bioeconomic model for optimizing the economic yield from a natural population, when a natural population is defined as one to which little or no management control has been directed. Such a definition includes, for example, the fish populations of lakes Victoria and Michigan; the Mississippi, Don and Murray rivers; and most of the World's marine fisheries. It also includes most terrestrial wildlife populations such as deer, bison, elephants, and kangaroos. Indeed, the model is developed and quantified in terms of kangaroos. My use of kangaroos in this model arises from my chauvanist concern for Australian problems, and because red kangaroos (_Megaleia_ _rufa_) so amply demonstrate population response to density independent events.

Two lines of development are identifiable in the bio-economic literature. The first line of development, initiated by Gordon (1954), is concerned with identifying the common-property nature of the fishery, and the effect of common-property conditions on bioeconomic stability and resource rent. The problems are primarily long-run in nature, and examine the advantage of a regulated as against an unregulated fishery.

The second line of development, initiated with the papers of Beverton and Holt (1956), and Schaefer (1957), is short run, and more closely examines the interrelationship between biological properties and the economic allocative mechanism in effect than does the line of enquiry initiated by Gordon. Beverton and Holt's model was developed to describe the North Sea plaice fishery, and requires certain restrictive assumptions of the population being examined. Schaefer, working with the Inter-American Halibut Commission, was primarily concerned with halibut; his use, however, of the Verhulst-Pearl (1838; 1920) logistic function, has a wider application than that of Beverton and Holt's model.

My thesis is a continuation of the second line, and is concerned with extending the biological parameters in bio-economic models (and population models, for that matter); in particular, those parameters affected by density independent events. In attaining optimal use rates a capital use approach is used. In developing the capital use approach the procedure is user cost, the reason being that user cost explicitly describes the joint capital/commodity nature of use dependent flow resources. The thesis extends user cost methodology in its handling of uncertainty - made necessary by the use of stochastic density independent events. As the model contains dynamic state variables (for which present value is a function of the previous value) the model is run using simulation techniques.

The model is intended as a response to the need for understanding biological and economic relationships. In particular I am concerned with showing how proximate events through their influence on population numbers may affect harvest numbers over time. To examine these concerns a bioeconomic model is developed and quantified. To test the model's predictive capability, outcome sensitivity to variation in interest rates and harvest proportions is examined.

In developing the model, female members of a population only are included. The advantage of examining females is that in most populations, numbers are more sensitive to the removal of females than they are to the removal of males (especially for polygynous populations [like kangaroos]). If males were included productivity for males would be given by the rate of body growth, not by the rate of recruitment of offspring (male and female)--as it is with females. The model allows us to carry out a sensitivity analysis of population survival using different harvest and interest rates.

## Economic Framework

Crutchfield and Pontecorvo (1969) observed that "... given assumptions of economic growth, patterns of demand and costs and relative prices of substitutes and complimentary products, conservation of natural resources clearly is an aspect of capital theory involving optimal time rates of use of the

assets involved and optimal factor combinations at each use rate (pp. 3-4)." Hotelling (1931) and others (Ciriacy-Wantrup, 1968, 1971; Fisher and Krutilla, 1975; Scott, 1952; and Weinstein and Zeckhauser, 1974) have expressed concern over the rate of use of natural resources.

Given that the appropriate model with which to examine the use of natural resources is a capital use model, it does not follow that there is a single model appropriate to handle all such resources, especially as these resources vary in their response to management and use (Table 1).

## Biological Framework

Natural resources may be categorized as stock or flow resources according to the presence or absence of stock or flow characteristics (Ciriacy-Wantrup, 1968, pp. 35-37). A stock resource is one in which the amount of the resource does not change significantly in time; examples would include iron ore, oil and gas, limestone, and opals. Interestingly, these resources actaully may decrease in economic availability over time due to leakage and blow-off (oil and natural gas); and through oxidation and leaching (bauxite and phosphate), following the opening up of a deposit. A flow resource is defined as a resource such that different amounts of the resource become available for use in different periods. Examples in this case include sunlight, rainwater, Gulf of Carpentaria banana prawns and aardvarks.

TABLE 1

A CLASSIFICATION OF NATURAL RESOURCES
ACCORDING TO RESPONSE TO
HARVESTING (MANAGEMENT)

A. Stock Resources

Use independent,
   e. g., coal, iron, aluminum

Use dependent,
   e. g., oil, water

B. Flow Resources

|  | Entry of stock/ capital is independent of the manager | | Entry of stock/ capital is dependent on manager | |
|---|---|---|---|---|
|  | Rate of increase is independent of mgr. | Rate of increase is dependent on mgr. | Rate of increase is independent of mgr. | Rate of increase is dependent on mgr. |
| Use dependent | density independent populations, e. g., kangaroos | density dependent populations, e. g., deer | wine | trees |
| Use independent | rainfall sun & tides | | | |

The timing of entry and the rate of growth or change in
quality of a flow resource may, or may not, be a function
of manager control – thus they are dependent or independent
of the manager.

Based, in part, on Ciriacy-Wantrup (1968) and Gregory
(pers. comm.).

Wantrup differentiates between flow resources according to whether the flow is, or is not, affected by human action. It is observable, however, that the total of stock resource extractable under fixed economic and technological conditions can, for technological reasons, be affected by human actions. Even if, and in relation to this thesis, "human action" is confined to apply only to resource use; e.g., the total amount of oil available can be affected by historical and future rates of extraction. For this reason both stock and flow resources can be differentiated according to whether they are use dependent or use independent.

Considering the capital nature of natural resources, the effect of use rate on resource availability is to change the time pattern of revenues and costs and, very often, future rates of use. Depending on the required rate of return on capital, use dependent flow resources may be further sub-divided according "... to the existence or nonexistence of a critical zone in the decrease that may be caused, in rates of flow, by human action (Ciriacy-Wantrup, 1968)." A critical zone is a "... defined range of rates below which a decrease in flow cannot be reversed economically under present foreseeable conditions." This irriversability may be due to technical as well as economic constraints. For a natural population the zone of technical irreversibility may be referred to as the zone of depensation. Ignoring variation in population numbers due to age structure, depensation is exhibited when populations irreversably

continue to zero after numbers have fallen below some critical value; the "minimum viable population level" (Clarke, 1976, p. 16).

## Relevance of Optimization Models
## for Natural Populations

Reynolds (1971) proposed two tests of a model's usefulness--that of "realism" and that of "relevance." The former involves explanatory and predictive power while the latter involves the relationship of the model to high-priority policy issues (pp. 16-17)." I hope to answer the criterion of realism in the following chapters; here, however, the intention is to demonstrate the "relevance" of examining natural population use.

To ascertain whether an issue is of a sufficiently high priority to be relevant we can estimate the magnitude of the gains to be achieved through remedial action or refer to the explicit judgment of those responsible for economic policy. I here show that the value of natural populations is sufficient to warrant concern over optimizing their use.

### Natural Populations as a Source of Protein

"The developing countries share in the world's fish catch is now between 20 and 25 million tons annually out of a world total of around 65.0 million tons. By 1985 the developing countries could double their supplies of fish available for human consumption and this makes a significant contribution to increasing the high quality protein component in the diet of these peoples (F.A.O., 1974, p. 7) (Table 2

TABLE 2

WORLD CONSUMPTION OF MEAT

| | Consumption | Projected Demand | | | Total Increase | | Growth Rates | |
|---|---|---|---|---|---|---|---|---|
| | Million Metric Tons | | | | Percent | | Percent P. A. | Compound |
| | 69 to 71 | 1980 | 1985 | 1990 | 70 to 85 | 70 to 90 | 70 to 85 | 70 to 90 |
| Fish | 41 | 57 | 68 | 81 | 64.6 | 96.3 | 3.4 | 3.4 |
| Meat less fish | 107 | 144 | 168 | 197 | 51.3 | 84.7 | 3.1 | 3.1 |

Proportion = Fish/(Fish + Meat) = $\dfrac{41}{148}$ = 28% for 1969-71.

= $\dfrac{83.58}{281.4}$ = 30% for 1990.

CONSUMPTION OF MEAT FOR DEVELOPING MARKET ECONOMIES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fish | 12.3 | 19 | 24.3 | 31.4 | 98.7 | 155.9 | 4.7 | 4.8 |
| Meat less fish | 21.1 | 32.2 | 40.6 | 51.7 | 92.1 | 144.4 | 4.4 | 4.6 |

Proportion = Fish/(Fish + Meat) = 12.3/33.4 = 37% for 1969-71.

= 31.48/83.05 = 38% for 1990

supports this view)." Through 1969-71 fish made up 28 per cent of total world meat consumption (fish, beef and veal, mutton and lamb, and pig meat); by 1990 it is expected that this figure will increase to 30 per cent. For the developing countries, fish is an even more important source of meat, totalling 37 per cent of meat consumed in 1969-71, rising to 38 per cent by 1990. Because of the high protein content of fish, fish supplied 61.4 per cent of total meat protein consumed by the developing market economies (F.A.O., 1970).

These figures underrate the importance of natural populations as a source of food, as fish meat is an important input in pig and poultry production; while, for some countries, game supplies more than 50 per cent of total meat consumed. (The figure for Uganda is about 80 per cent [Proceedings III World Conference on Animal Production, 1975]). In addition, if we accept that diminishing marginal utility for meat consumption exists, and that the utility of meat can be assumed to be the same world wide, then a pound of meat has a higher marginal utility in the less developed countries.

The sectoral importance of fisheries for the less developed countries is further emphasized by the fact that over 64 per cent of the world's fishery potential lies off the coasts of the LDC's (Bell, 1977). In many cases these fisheries have not been fully developed, thus the standing crop (a "saving" or stock resource) and fishery yield over time (a flow) is an important source of initial and continuing development capital. Whether the potential rents are realized

will depend on the form of management instituted. Generally, the less developed countries have been more forthright in capturing the rents obtainable from fisheries through the use of license and extraction fees than the more developed countries, e.g., for South America: Brazil charges $1,215 per vessel per year; Mexico charges $18 per capacity ton; Ecuador charges $700 registration fee plus $60 per net registered ton for 50 days or one full load, whichever comes first; and Peru charges $500 registration fee per year, plus $20 per net registered ton for 100 days. Conversely, Public Law 94-265, which extends U. S. fisheries jurisdiction to 200 nautical miles, prohibits the collection of revenues from domestic fishermen (Bell, 1977).

Outline of Thesis

The following chapter (Chapter II) develops and presents a dynamic simulation model in which time, discrete age dependent fecundity, and survival are included, the demographic coefficients (fecundity and survival) being functions of density dependent and density independent events. The model is developed in terms of red kangaroos. As red kangaroos are reproductively "opportunistic," density dependent events fall out as an explanative variable affecting population numbers.

The third chapter presents a capital use model for use dependent flow resources. It is argued that because of the capital-commodity "jointness," of use dependent flow resources, user-cost, which explicitly conceptualizes this "jointness",

is a preferable tool. It is shown that the age at which a productive resource (female) will be "cashed in" is a function of the intrepreneur's (harvester's) perceived discounting rate (or, in the social welfare maximizing example used, the social discount rate) and the age dependent, climate dependent demographic variables.

The fourth chapter combines the biological and economic models and tests the possible effect of a profit maximizing harvester on the population. The strength of the model is tested by observing the outcome of different coefficient values. Policy considerations and application arising from the use of the model are discussed.

CHAPTER II

POPULATION SIMULATION MODEL

A population may be defined as the total number of a
given species in any one place at any time (Williamson, 1972).
In any period a number of events may act upon the demographic
variables (fecundity and survival) of a specified population.
The manner in which these factors affect fecundity and sur-
vival will depend upon the population numbers at that time,
and the type, timing and severity of the event. A factor
may act on a population directly (such as when a cold snap
causes losses in population numbers), or indirectly (such as
through the effect of rainfall on available feed, or through
the effect of variation on water temperature for marine life).
In addition, factors may act in isolation (such as with a
change in marine water temperature), or together (such as
when unseasonal cold weather and rainfall occur at the same
time so as to cause serious livestock losses).

In many cases, the intensity with which a factor may
effect fecundity and/or survival will depend upon population
numbers at that time. So important are population numbers
in explaining change in numbers, that most of the models
developed to mimick populations assume that proportional
change in numbers can be explained by differences in population
numbers alone. In many, or most cases, this may be a

satisfactory assumption, especially in stable or predictable habitats; however, under certain conditions, the assumption that change is primarily affected by numbers will not hold. Failure to meet this assumption is most likely true in unstable and unpredictable habitats (Low, 1976), such as we find in some arid areas where the timing and intensity of rainfall is uncertain (Noy-Meir, 1973; Low, 1978), and in fresh water (Watt, 1958) and marine environments (Bell, 1971). It is important, therefore, to develop a method by which the effect of events which are not wholly dependent on population numbers for their intensity can be included.

The model is quantified and tested using red kangaroo data. An important reason for using such data is that red kangaroos are rarely, if ever, affected by the number of animals in the population. By selecting a species which can be assumed to be independent of density dependent effects, the initial development of the model and the consequent manipulations are simplified. In spite of this, it is expected that the model will have a more general applicability. A method jointly representing density dependent and density independent effects is suggested.

The model developed in this chapter is used later to find optimal harvest strategy and population response to commercial harvesting--given certain economic and biological constraints and criteria.

## General Characteristics of Models

In constructing a population model it is necessary to decide how to best describe the population and what information is required from the model. We need to know which variables are necessary and how they change in time (Rosen, 1970).

### Deciding on Inputs

A precise dynamic simulation model may involve a large number of constraints and coefficients which are difficult to obtain. Simplifying assumptions are made so as to remove unimportant parameters. Often, complex relationships may be combined into a single overall measure. An example of such a simplification relevant to this study is the combining of temporal and spatial uncertainty into a single measure of uncertainty. The difficulty is in maintaining sufficient realism while keeping complexity to a minimum.

### Forms Which Variables May Assume

Model variables may take any one of three different forms (Kowall, 1972): input variables, non-dynamic state variables and dynamic state variables. Input variables originate outside of the model. Non-dynamic state variables are instantaneous and independent of their previous value. Dynamic state variables are dependent on their previous value. In the model being constructed, weather is the input variable, fecundity and survivorship rates for each age class constitute

the non-dynamic state variables and the number of females

in each age class is the dynamic state variable.

## Reproduction and Factors Affecting
## Red Kangaroo Populations

### Reproduction

The red kangaroo is capable of breeding continually

throughout the year, usually giving birth to a single

offspring.  As the gestation period is shorter than the

oestrus cycle (Sharman and Calaby, 1964; Sharman, 1970) the

female is capable of mating shortly after parturition.  At

birth, the embryonic young (Short, 1972) crawls into the

female's pouch, which it occupies for about 236 days

(Sharman, 1970).  The blastocyst, from the mating following

birth, remains quiescent until suckling diminishes or ceases

due to the premature loss of offspring in the pouch (joey),

at which time implantation may occur.  Suckling begins to

diminish after about 200 days of pouch life (Sharman, 1970).

The timing of the blastocyst's entry into the uterus and the

continuation of its development is such that the second joey

occupies the pouch within two days of the first joey's leaving

(Fig. 1).

The sex ratio for mature red kangaroos is 1:1 (Caughley

and Kean, 1964).  Although the probability of survival falls

with age, Frith and Sharman (1964) observed no variation in

fecundity with age; thus the female has a potential replace-

ment value of 0.75 per year.

REPRODUCTION CYCLE FOR FEMALE RED KANGAROO

# FIGURE 1.



MATING.    PARTURITION.

33 DAYS OESTRUS.

JOEY IN POUCH 235 DAYS.

YOUNG KANGAROO SUCKLED 130 DAYS.

GESTATION 35 DAYS.

BLASTOCYST DIAPAUSE 202 DAYS.

MATING.

2 DAYS.

BLASTOCYST IMPLANTS.
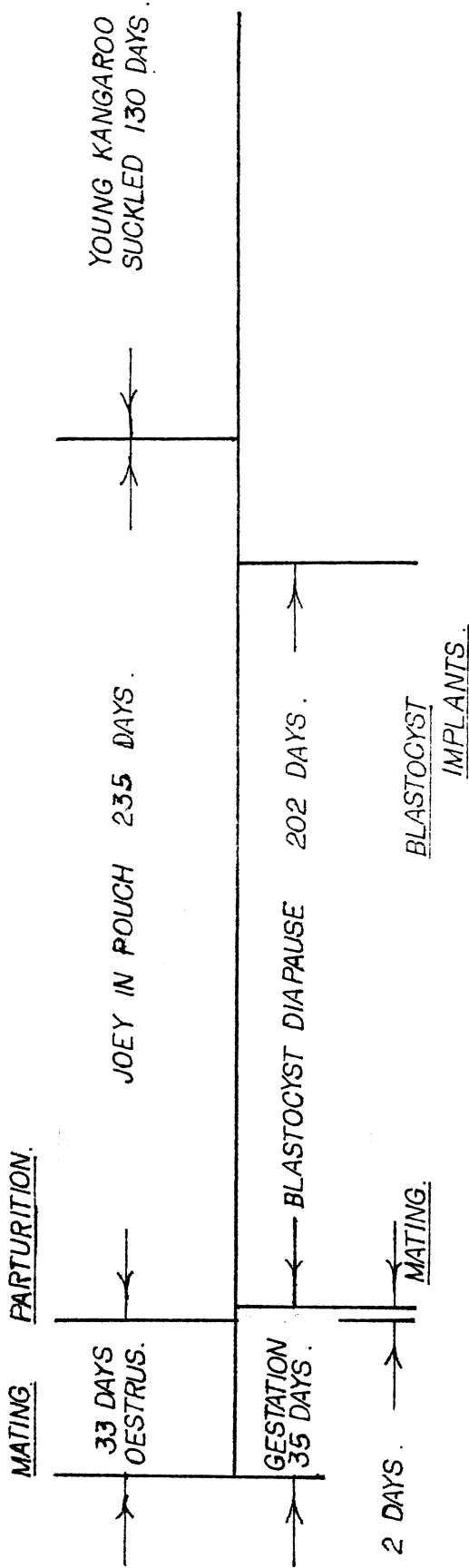
BASED ON SHORT (1972).

### Factors Affecting Reproduction

The potential replacement value is rarely achieved over long periods of time. Both Frith and Sharman (1964) and Newsome (1965) have found reproduction to be a function of weather, because proportion of females in breeding condition and the rate of development and survival of joeys were found to decrease as conditions became more arid. Also, older animals demonstrated a higher propensity to die in dry conditions than younger animals. Newsome (1965) concluded that density dependent events have little or no influence on population numbers either directly or indirectly through density independent events.

It is possible that under certain conditions density could affect population numbers; for example, if good conditions persist for long periods. Birch (1962) suggests that in certain environments there may be insufficient time during which conditions will be adequate to allow populations to build up to where density will affect population numbers. As rainfall is highly variable and uncertain in arid Australia (Low, 1978), Birch's explanation of insufficient time probably explains why we do not observe density dependent factors to be important for red kangaroos.

### Constructing a Representative System in Discrete Time

#### The System Variables

Although some members of a red kangaroo population respond to dry conditions by moving away (Campbell, 1978),

this model assumes that the net effect is not important.
Also, the model is constructed only for the female members of
a population. As we know little about the social system of
kangaroos, its effect on social structure (e.g., Russell,
1971), little information is lost in constructing a represen-
tative system for female members only.

The number of organisms in the next time period is a
function of the number of organisms now ($N_t$), their age class
structure ($Ac_t$), environmental conditions ($E_t$) and population
density or carrying capacity (K). That is

$$N_{t+1} = f(N_t, Ac_t, E_t, K). \qquad 2.1$$

For red kangaroos, density is not an important factor in
explaining change in numbers, and

$$N_{t+1} = f(N, Ac, E)_t. \qquad 2.2$$

If environmental variation is allowed to act through its
affect on age dependent demographic variables, then

$$N_{t+1} = f(N, E(Ac))_t. \qquad 2.3$$

Although reproduction in red kangaroos is continuous,
by assuming that it is discrete (that is, a certain number of
animals in each class die or reproduce through a given time
period), then change in population numbers between time
periods can be represented using difference equations:

$$N_{t+1} = \Sigma P_{i,t} N_{i,t} + \Sigma F_t N_{i,t}, \qquad 2.4$$

where $N_{i,t}$ is the average number of females in the $i^{th}$ age
class through time period t (i = 1, ..., n; t = 1, ..., k),
$P_{i,t}$ is the average survival coefficient for the $i^{th}$ age
class at time t and $F_t$ is the average fecundity coefficient in

time t. It will be noted that survival, $P_{i,t}$, and the total number of animals in the next time period, $N_{t+1}$, are a function of age class. While both these variables plus fecundity, $F_t$, may vary in time, for a mature animal, the probability of survival into the next age class decreases with both age and aridity. The number of females reproducing and the survival of young and older animals also decreases with aridity but not necessarily with age class.

The relationship 2.4 can be expanded into a set of difference equations, each equation representing population movement from one age class or group to another:

$$P_{1,t}N_{1,t} = N_{2,t+1}$$
$$F_t N_{2,t} + P_{2,t}N_{2,t} = N_{1,t+1} + N_{3,t+1}$$
$$F_t N_{3,t} + P_{3,t}N_{3,t} = N_{1,t+1} + N_{4,t+1}$$

$$\cdots\cdots \qquad\qquad \cdots\cdots \quad \cdots\cdots \qquad 2.5$$

$$F_t N_{n-1,t} + P_{n-1,t}N_{n-1,t} = N_{1,t+1} + N_{n,t+1}$$
$$F_t N_{n,t} + P_{n,t}N_{n,t} = N_{1,t+1}$$

For an indeterminate system, if the life table functions vary according to age class, a discrete dynamic system can be presented using a Lewis/Leslie (L/L) matrix format.

### Presenting the Model in a L/L Format

The format was first developed by Lewis (1943). Leslie (1945, 1948) later independently developed and extended the use of the format.

In the L/L format, the left hand, or operational, side of 2.5 consists of two matrices. The population structure is

represented by a nxl column vector containing the number of females in each age class. This is pre-multiplied by a nxn transformation matrix which contains the coefficients for fecundity and survival, and describes the transformation of a population from one age class to the next. This operation gives the population vector for the next time period. The fecundity values ($F \geq 0$) are along the top row of the transformation matrix where they give the transition, or proportional donation of offspring of each age class, to the first age class. The probability of survival ($0 \leq P \leq 1$) is given in the sub-diagonal, as there is a transition one step down the population column vector, into the next age class. All other values in the matrix are zero.

$$
\begin{bmatrix}
F_1 & F_2 & F_3 & \cdots & F_{n-1} & F_n \\
P_1 & 0 & 0 & \cdots & 0 & 0 \\
0 & P_2 & 0 & \cdots & 0 & 0 \\
0 & 0 & P_3 & \cdots & 0 & 0 \\
\cdot & \cdot & \cdot & \cdots & \cdot & \cdot \\
0 & 0 & 0 & \cdots & P_{n-1} & 0
\end{bmatrix}_t
\begin{bmatrix}
N_1 \\
N_2 \\
N_3 \\
N_4 \\
\\
N_n
\end{bmatrix}_t
\qquad 2.6
$$

In matrix notation this becomes:

$$
M_t N'_t = N'_{t+1}, \qquad 2.6'
$$

where M is the transition matrix and N' is the population vector.

Although each equation in the system is solved independently of the other equations and, therefore, no use is made of the matrix characteristics, it is still useful to represent the model using the L/L format. The use of this

format tidies up the presentation, is useful in writing out the computer program, and simplifies the possible inclusion of density dependent events.

To represent a population in an unstable environment it is necessary that the demographic coefficients are varied according to their likely response to change in environmental conditions. To represent this relationship, the possible outcomes in weather were divided into five discrete stages (quintiles) of equal (0.2) likelihood. For each of the five climatic conditions--very dry, dry, normal, wet, and a flood-- a representative transformation matrix was used. The age class dependent demographic coefficients for each climatic condition were calculated and used to specify the respective values in the transformation matrices. As climate is unpredictable, it enters the model by the use of random numbers, each matrix (climatic condition) is called forward depending on the value of the random number (see Appendix B).

Another reason for presenting the system of difference equations in a L/L matrix format is so that the methods for including density dependent effects, amply developed in the literature on the use of L/L formats, can readily be applied. One of the methods developed involves the multiplication of the transformation matrix by a variable which is adjusted in value according to the number of animals in the population (Leslie, 1948).

## Estimation of Coefficients

### Specification of the Mathematical Form of
### the Regression Equation/Equations

Two population relationships describing the survival

of mammals with age are the geometric function (concave to

the origin [Chapman and Robson, 1960]), and that described by

Caughley (1966) consisting of a juvenile stage with a high

mortality rate, and a mature stage having a low but increasing

mortality rate. Some workers, ignoring the juvenile stage,

have simply fitted Chapman's geometric function directly to

data for the mature animals (Wilson, 1975). Frith and Calaby

(1969, pp. 182-184) regressed the number of animals against

age using an exponential curve convex to the origin; such a

relationship predicts a high mortality rate for the juvenile

individuals and a lower and decreasing mortality rate for

mature individuals.

The work done by Frith (1964, 1969), Newsome (1965) and

others, indicates a low survival rate for immature red kang-

aroos, at least up until offspring are no longer dependent

on the doe. The age at which death rates level out varies from

year to year depending on the climatic conditions, although

for average conditions two years appears to be an acceptable

approximation (Newsome, 1963, 1965). In good conditions,

females will reach sexual maturity in 18 months, while, in

poor conditions they may be three years old.

On reaching maturity, the likelihood of death falls to

some value close to zero--this low rate continues until senility,

when the death rate increases again. A constant annual survival rate for animals four years and older was obtained by Wilson (1975) using data obtained from aged skulls of harvested animals by plotting age class frequency per 1,000 animals over age in years (Fig. 2). Although the data was obtained mainly from male skulls (personal observation of data), it is likely to be similar to that shown for females (Frith and Calaby, 1969), and some important trends can be observed. From Figure 7, survival rates do not appear to begin to fall off until eight years of age, and from four to eight years few animals appear to die. This appears to be consistent with Frith and Calaby's (1969) data (Fig. 3, Table 3).

It is apparent, then, that red kangaroo survival is best described as comprising three discrete stages: an immature or juvenile stage having a high mortality rate, a mature non-senile stage having a low mortality rate, and a senile stage over which survival is decreasing. Other populations also appear to fit this description: dall mountain sheep (Pianka, 1974; Caughley, 1966), hippopotamus, waterbuck (Pianka, 1974), man and Orkney vole (Caughley, 1966).

The mathematical form of the estimators giving the probability of survival with age may vary with each section; thus, the survival of individuals in such populations may be better represented using a series of regressions, or by Piece-wise Linear Regression (P.L.R.) of the form

## SURVIVORSHIP

Survivorship of adult red kangaroos and wallaroos collected during the winter of 1973.

FIGURE 2.



Red kangaroos:
 ○ Broken Hill;
 ■ Coonamble;
 △ Brewarrina;
 ▲ Collarenebri.
 ◆ Wallaroos from Uralla,
Deepwater and Tenterfield.
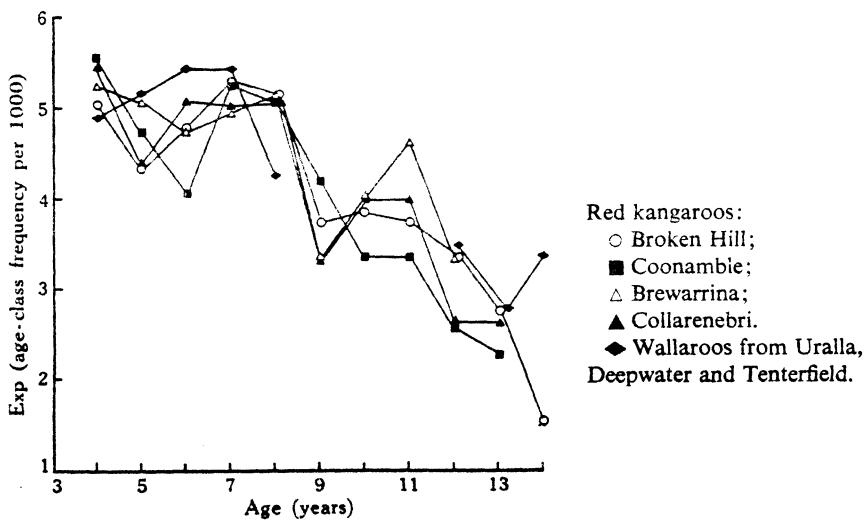
AFTER WILSON (1975)

SURVIVORSHIP CURVE FOR FEMALE RED KANGAROOS

# *FIGURE 3.*
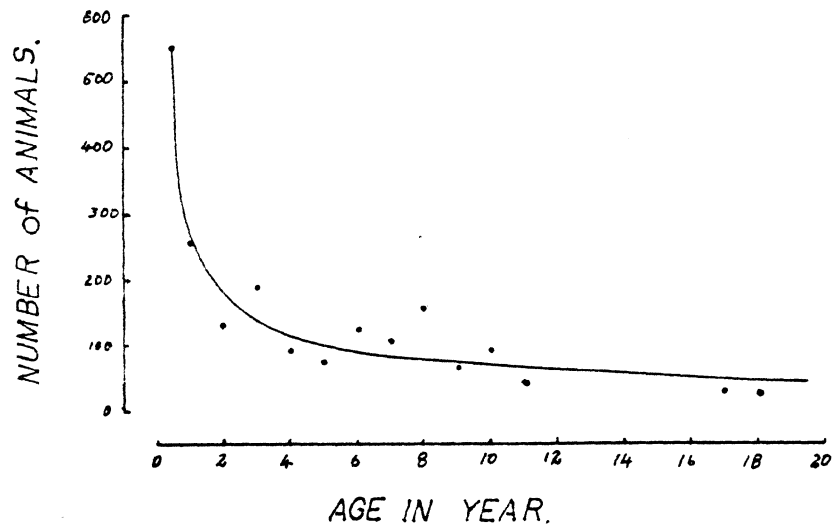


AFTER FRITH (1969).

Table 3.

Survivorship of Female Red Kangaroos

| Age Class | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Animals | 550 | 260 | 136 | 188 | 90 | 80 | 112 | 105 | 160 | 70 | 90 | 48 | / | / | / | / | / | 32 | 25 |

The number of female red kangaroos of different ages in samples collected near Wilcania, New South Wales, in the period October 1959 to January 1962. After Frith (1969).

$$Y_i = [\alpha_1 + \beta_1 (X_i)]D_1 + [\alpha_2 + \beta_2 (X_i)]$$

$$D_2 + [\alpha_3 + \beta_3 (X_i)]D_3 + e \qquad\qquad 2.8$$

where $D_i$ is a dummy variable whose value is 1 or 0 according

to

$$D_1 = \begin{cases} 1, & \text{if } X_0 \leq X_i \leq X_3, \\ 0, & \text{if } X_i > X_3 \end{cases}$$

(regresses the first 'piece' of the P.L.R. over immature

animals);

$$D_2 = \begin{cases} 0, & \text{if } X_i < X_3, \\ 1, & \text{if } X_3 \leq X_k \leq X_8, \\ 0, & \text{if } X_i > X_8 \end{cases}$$

(regresses the second 'piece' of the P.L.R. over mature

animals);

$$D_3 = \begin{cases} 0, & \text{if } X_i < X_8, \\ 1, & \text{if } X_8 \leq X_i \leq X_{18} \end{cases}$$

(regresses the third 'piece' of the P.L.R. over senile

animals). By using a P.L.R., a separate piece of the

regression is fitted over each life stage.*

---

*This approach could be further refined by placing
constraints on the intersects ($\alpha_i$) so that the function is
continuous or, by using a Spline Function (S.F.) (Suits, et.
al., 1977), so that the derivatives are continuous through-
out. As the population model is discrete, it is doubtful,
however, whether the use of a S.F. will be more discrimi-
nating (even if it is a refinement). In addition, as the
sections (0 to 3 years, 3 to 8 years, and 8 to 17 years) are
not of equal length, the fitting of a spline function is that
much more difficult.

## Estimation of Coefficients

The sample data upon which the functions were regressed
were collected by Frith and Calaby (1969, pp. 182-184)
(Fig. 3; Table 4) in Western N.S.W., Dr. A. E. Newsome
generously sent me the raw data from his most recent (1977)
and earlier work. Although this material would have been
preferable to what I ended up using, it was found to be
inadequate in its present form (see Appendix B).

A number of curves were regressed on Frith and Calaby's
(1969) data, including a geometric relationship concave to
the origin over the mature and senile stages, and log and
natural log functions. The most efficient predictor was found
to be the Piece-wise Linear Regression (P.L.R.) with separate
lines regressed through the mature age class, and through the
senile age class. As is explained later, the first 'piece'
of the regression, over the juvenile stage, is not included.
The P.L.R. predicting the number of animals as a function of
age becomes

$$\hat{Y}_i = (132.14 - 2.57X_i)D_2 + (92.86 - 10.85X_i)D_3 + e_i. \qquad 2.8'$$
$$(12.1) \quad (4.66) \qquad (14.79) \quad (6.2)$$
$$R_2^2 = .02 \qquad\qquad R_3^2 = .49.$$

This estimator is assumed to predict the number of animals
surviving in the respective year classes for a normal year.
Before proceeding further, there are several observations
pertinent to equation 2.8'. Although a good fit was obtained,
the first section (juvenile stage) has not been included in

the regression. The reason for this is that there is such a small number of points that it is unlikely that a line regressed through them would be a good predictor. Consequently, a recruitment value '$R_t$' giving the time dependent number of animals (males and females) into the third age class is used. An examination of the available literature (Caughly, 1967; Frith, 1964, 1969; Newsome, 1965, 1977) indicates that .2 may be a fair approximation of the mean value of recruitment. Other values were tried and the model was found to be locally stable about this value. In addition, the proportion of .2 (for males and females recruited) is less than the proportion indicated by 2.8' of .113 (for females only).

Because of the low $R_2^2$ (.02) and the related high standard error (4.66) for $\beta_2$ (2.57), little if any of the variation in the number of mature animals is explained by $\beta_2$. To see whether $a_2 > \hat{\bar{Y}}$, a one-tailed test was carried out on the P.L.R. 'piece' for mature animals. At (P < 0.25), the estimated mean value is less than the intercept. The low $R_2^2$ is, in addition to the large proportion of unexplained variation, most likely due to the regression line being close to the horizontal. There is some improvement in $R_3^2$ and the standard errors for the P.L.R. 'piece' for senile animals. Wilson's (1975) results (Fig. 2 ) do not appear to conflict with 2.8'.

The high unexplained variation is most likely due to climate dependent variation in age class numbers resulting in differential recruitment of offspring. The inclusion of

climatic variation would, then, give the model a better fit. However, there is insufficient data to run a regression for each climatic condition and, as discrete coefficient values are needed, inclusion of a random variable is unsatisfactory. If, therefore, we assume that amorphic (proportional) curves exist for each climatic condition and, the observed dependent variables are normally distributed about the regression curve (2.8'), then a series of harmonizing curves can be fitted.

Fitting the Harmonizing Curves

If the error term is primarily due to climatic variation and is normally distributed,* then the probability distribution can be divided into five discrete and equal sections (quintiles). Using the t statistic, an α (intersect) value was estimated for each quintile and a family of representative curves of equal slope were estimated for each quintile; thus giving the average age class survival for each climatic condition (Fig. $4_A$, $_B$).

Such curves are spaced according to the distance representing the appropriate probability level of occurrence, the climatic condition being represented, and the mean age dependent survival curve. Such curves, called harmonizing curves, have been used in forestry to quantify differences in site quality and are called 'site index' curves (Spurr, 1952; Bricknell, 1968). In this case the harmonizing curves represent differences in climatic condition and may be called 'climate index'

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*To check the distribution, the residuals of the dependent variable were examined. Considering the small number of examples they appear to be normally distributed.

# HARMONIZING CURVES
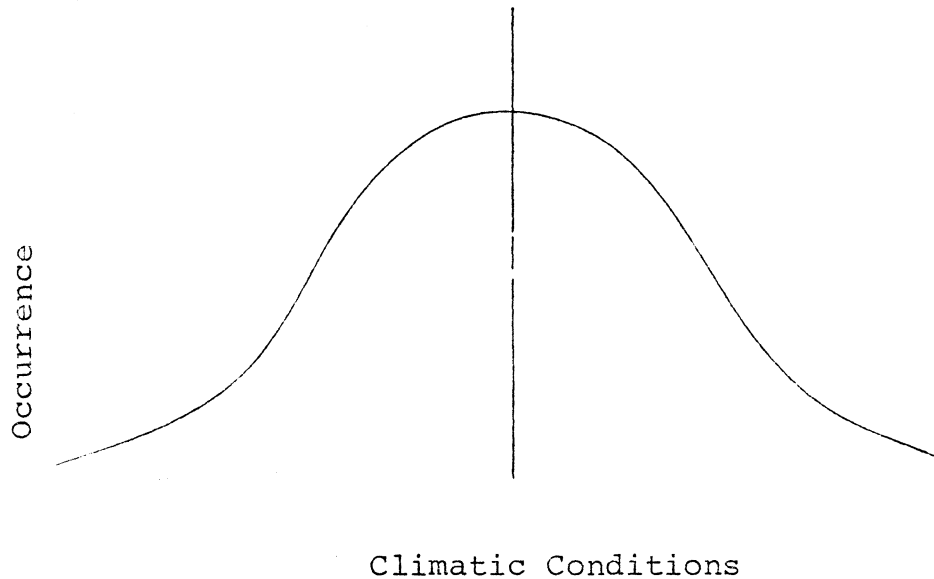


The area under the Gausian curve is divided so that each
climatic condition has an equal likelihood of occurring.

The set of curves give the relationship between the number of
animals recruited to the third age class and survival
with climatic conditions.

## FIGURE 4 A
## HARMONIZING CURVES.



REGRESSION INTERCEPT.
(Number of Animals)

114.    125·1.    131·86.    138·62.    149·72.

NORMAL CONDITIONS.

DRY CONDITIONS.

WET CONDITIONS.

A DROUGHT.

A FLOOD.

Z. VALUE          -·525.     -·253.    ·253.    ·525.

O

NOT TO PROPORTION.

20%.     20%.   10%.

## FIGURE 4 B



131·86.
138·62.
149·72.
125·1.
114.

NUMBER OF ANIMALS.
(Regression Intercept)

O     2    4    6    8    10    12    14    16    8    20.

AGE.
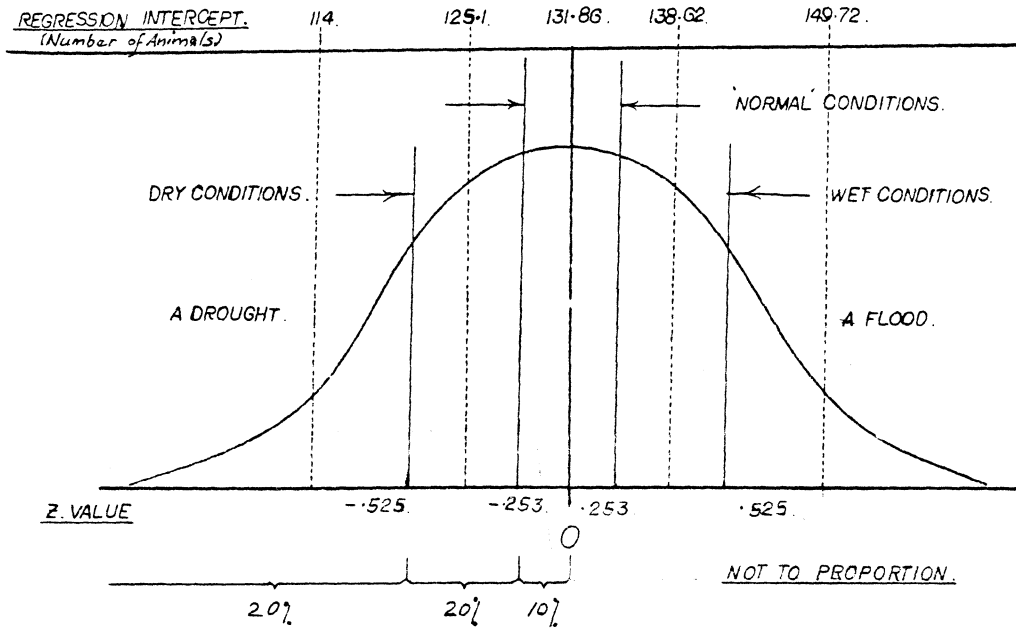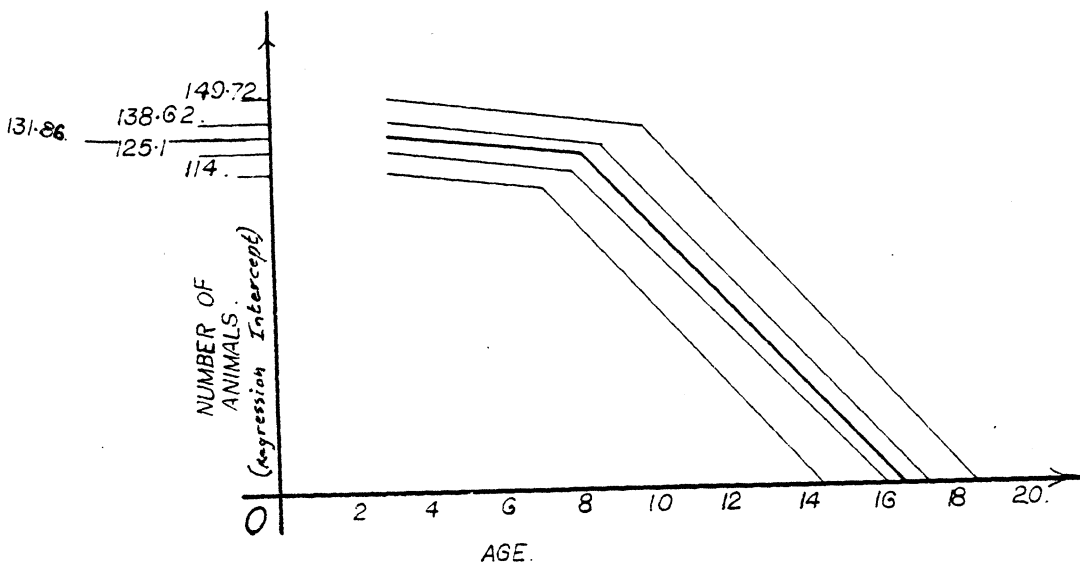
curves. The age dependent survival coefficients for each climatic condition is given by the differential survival between age classes. The values are given in the printout, Appendix C.

CHAPTER III

ECONOMIC MODEL

Introduction

If we accept that the distribution of wealth is socially satisfactory (Graaf, 1957, pp. 26-27, 59-61), and that market prices include all of the costs incurred in supplying a commodity, then, for the idealized competitive market, the allocation of resources between competing demands will be optimal (Bator, 1957). Such an analysis may be adequate in the static case, however, the nature of natural resources is such that they need to be allocated between competing uses over time.

Fisher (1930), in his classical treatise on interest, described allocation between time periods as a function of individual time preference ("impatience") and investment opportunity. In his exposition Fisher argues that "the rate of interest expresses a price in the exchange between present and future goods (1930, p. 60)." In a stable and perfectly competitive economy, the percentage interest rate, which gives the opportunity cost of investment, and the percentage time preference rate, giving the opportunity cost of foregoing present consumption, will be the same. Consequently, if "p" is the price received for resource "x" and "i" is the interest

rate, an individual will be indifferent between px now or
px(1 + i)$^t$ t years from now.

Anybody holding land or a factory expects a return on
his investment sufficient to compensate him for having fore-
gone either consumption or the opportunity of investing in
something else. So too does the holder of a biological
resource expect a return. If this return is not met, the
resource will be harvested and the income invested elsewhere.

Self-renewing flow resources, such as a natural popu-
lation, possess capital and commodity components. In broad
terms, the capital component is a stock which generates future
satisfaction (Hicks, 1973). In terms of this study, it is a
biological population capable of reproducing offspring and
undergoing growth. The commodity component is the flow of
goods and services obtained, or, the harvested offspring and
growth obtained from the population (capital stock).

Some goods possess capital and commodity components
"jointly" (Hicks, 1973); an example would be a car which
supplies a series of services over time. A population of
animals may also demonstrate "jointness," as it supplies a
series of services over time. An individual animal, though,
can not, as on becoming a commodity it is no longer a
population member and no longer a piece of capital. The
problem is to establish criteria by which to decide when an
individual organism should be harvested.

The earlier bioeconomic literature emphasized the need to maximize resource rent (Gordon, 1954; Turvey, 1964; Christy and Scott, 1965); where this is the "residue" return in excess of costs which accrues to the fixed factor (Mansfield, 1975, pp. 370-373). Scott (1967), using a user cost approach to examine output for the mine (a stock resource), showed that rent maximization is inadequate as it ignores the capital nature of the resource. Plourde (1970), Clarke (1973, 1976) and Pontecorvo, et al. (1977) have commented on the inadequacy of rent maximization due to its failure to include the capital component of the resource. A number of economic criteria are available which include maximizing:

a)  the internal rate of return,

b)  the present value of the enterprise, and

c)  the discounted net revenue (see Goundrey [1960] for

a discussion of these criteria and how they differ, in terms of forest management). The criteria that shall be used here is to maximize the present value of the enterprise using a user cost approach. As is shown, this approach is especially suited to self-renewing flow resources.

This evaluation assumes the existence of the hypothetical world of perfect competition in which all property right questions have been solved. As it is a partial analysis, questions of income distribution, balance of payments, changing input and output prices, the prices of close substitutes,

technological change, the entry and exit of producers and market equilibrium are not discussed: the affect of different discount rates on species extinction is.

The economic analysis is developed in five part. The assumptions in developing the first three parts are that future outcomes are predictable, and that the only costs incurred are initial capital costs and subsequent current expenses. In the first three parts user cost is discussed, optimal use is solved using a graphic analysis, and an initial mathematical analysis is developed. In the fourth part predictability is relaxed; while in the fifth part the effect of subsequent expenses of the capital type is examined.

## User Cost

User cost (Keynes, 1936) is a kind of opportunity cost, differing from it in that it includes only those net returns obtained from tangible assets owned by the entrepreneur: opportunity costs can include psychic as well as monetary income (Lutz and Lutz, 1951). Prime user cost is the difference between the asset's value after production and what that value would have been before production. It is applicable to three classes of factors:

a) durable equipment, such as buildings and machinery;

b) contract factors, such as for oil tankers, coal and wheat, and

c) inventory.

Individual members of a population appear to most closely resemble durable equipment.

## Diagrammatic Description

Figure 10a shows the total cost (T.C.) and total return (T.R.) functions for a generalized production process. The total cost function includes short-run maintenance costs as well as the opportunity cost of capital. Given this relationship, maximum current net revenue is where (TR - TC) is greatest. This is at output $X_a$ (Fig. 5A), ignoring time, this is equivalent to the rent maximization outcome given for the fishery (Gordon, 1954; Turvey, 1964).

To examine the whole range of possible outputs, including future output, it is necessary to include time. The total net return (N.R. [Fig. 5B]) function gives the net revenue obtained as a function of effort-output being a function of effort. The present output of a use-dependent flow resource will affect future output and future returns; it therefore has a user-cost, which is the present value of the future returns foregone due to present use. The present value of future net returns is obtained by discounting these returns back to the present. Function UC (Fig. 5B) is a possible user cost relationship.

At $Y_b$ (Fig. 5B), the marginal user cost is less than marginal net revenue. At output $X_B$, the rent maximization outcome, the slope of the user cost curve is greater than the slope of the total profit curve. At this point, therefore, an incremental increase in production will result in a decrease in the present value of the enterprise ( UC > TR).

## TOTAL COST AND TOTAL RETURN

functions for a generalized production process.

## TOTAL PROFIT AND USER COST

functions for a generalized production process.

FIGURE 5 A.

TOTAL COST.
TOTAL RETURN.

$.

O                    Y_a          X_a                    HARVEST EFFORT.

FIGURE 5 B.

USER COST.

$.

O          Y_b      J_b    X_b                  HARVEST EFFORT.
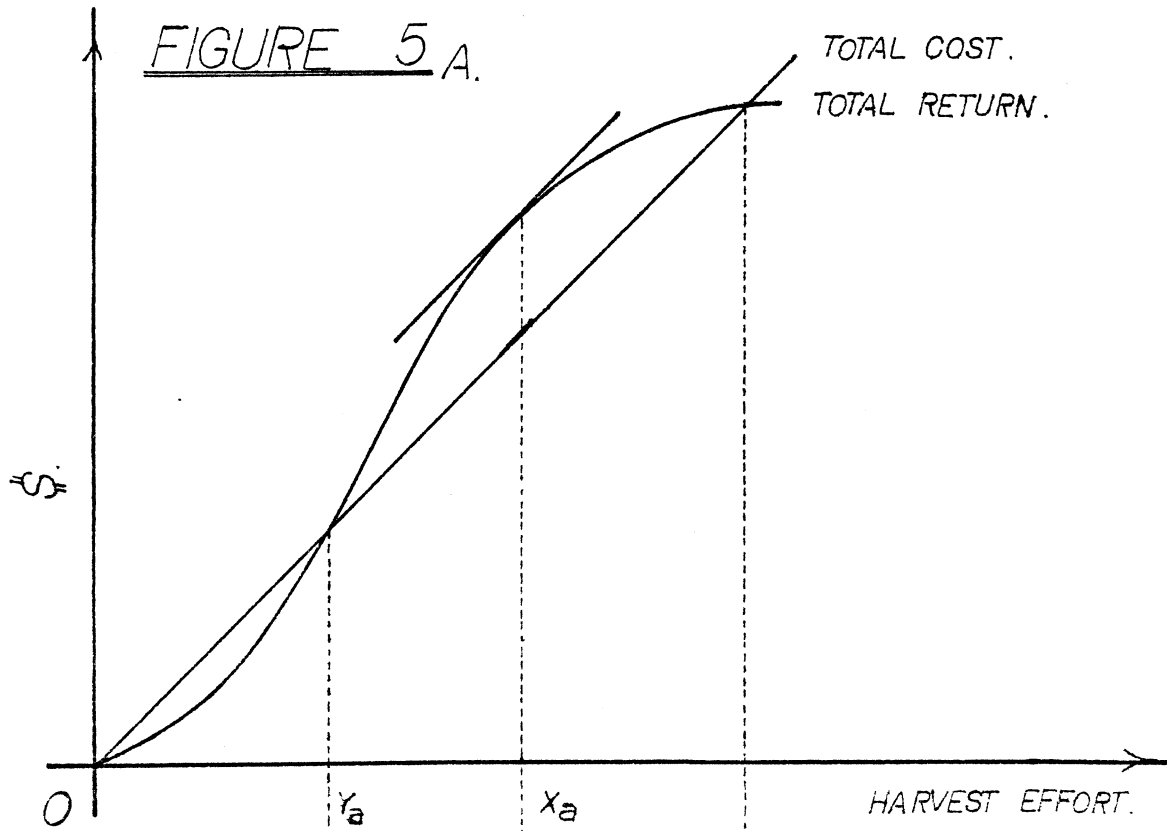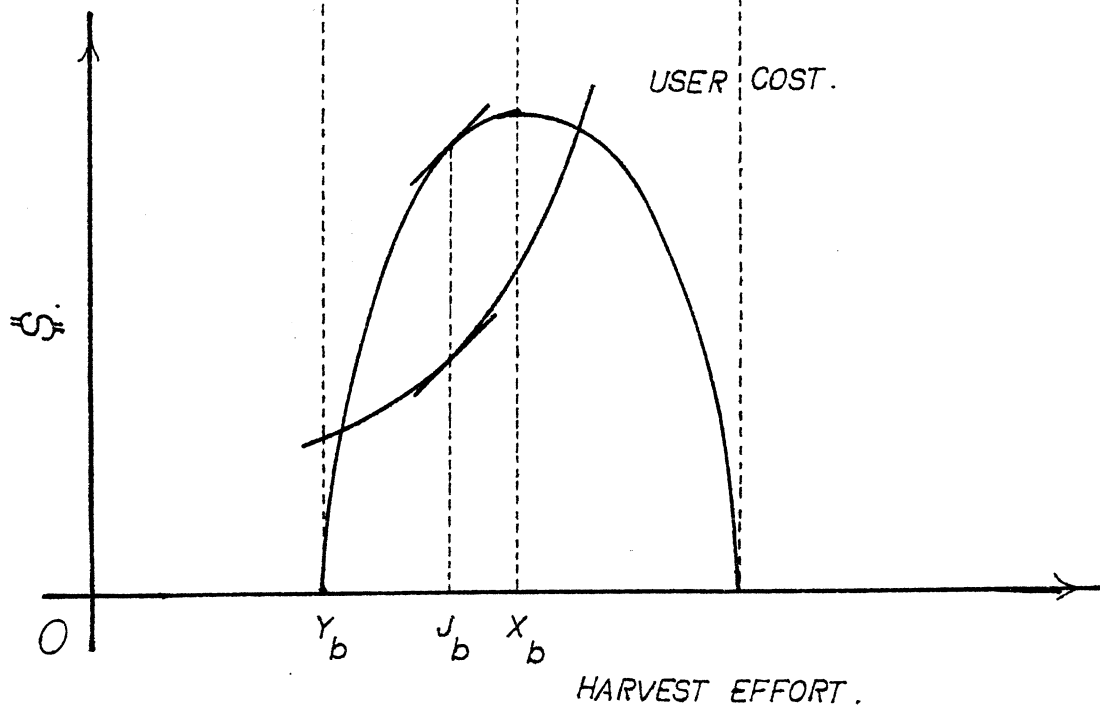
Note: In both 5_A & 5_B, the harvest effort scales are the same.

The present value is maximized at some level of production less than $X_b$, but greater than $Y_b (Y_b < PV < X_b)$. The $PV_{max.}$ outcome is achieved at output $5_b$. This point meets the necessary profit maximization conditions:

$$UC = TR;$$

at any level of output less than $P_b$

$$UC < TR; \text{ and}$$

at any level of output greater than $R_b$

$$UC > TR.$$

This outcome is different to that achieved using the rent maximization criteria; except when the discount rate is zero (Clarke, 1973a,b). With the functional relationship shown in 5A, B, present value is maximized at a level of output (level of effort) less than that obtained for rent maximization. Although the usual case may be one where user cost rises throughout (Scott, 1953), as in Figure 5B, it need not be so in all cases. As an example, where a non-homogeneous function would apply, Scott cites the thinning of timber so as to increase future production. The same result may occur with natural populations, especially when the population is highly responsive to density dependent events. In such cases, the removal of individuals will, depending on the competition for scarce resources, increase future production (Fig. 6 ). It need not, therefore, always hold that present production, in the $PV_{max.}$ case, will be less than the output for the rent maximization case.

## TOTAL PROFIT AND USER COST


functions for a density dependent flow resource.

# FIGURE 6



USER COST.

$

HARVEST EFFORT.

O
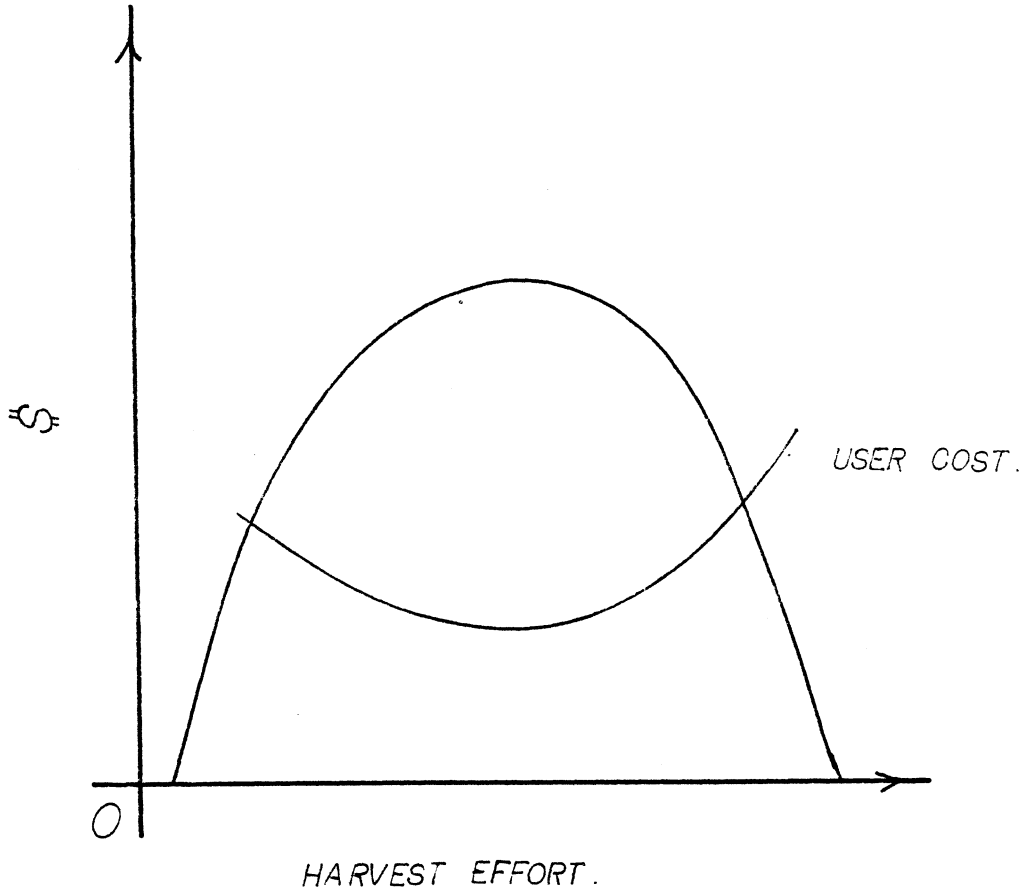
User Cost and Use Dependent Resources

As mentioned earlier, use dependent flow resources possess both commodity and capital components; user cost, more than most other approaches, conceptualizes this "jointness." The total profit function is the return received in excess of harvesting costs through the use of the resource as a commodity.  This profit accrues to the fixed factor (the fishery) as a rent.  The user cost function represents the present value of future benefits foregone through harvesting. These are benefits which would be obtained if the resource were left in its present form.

User Cost and Kangaroos; and Other Such Resources

Scott (1967) referred to flow resources as growing (or decaying) resources.  He asks "therefore the user cost curve of such growing resources will have a higher level than if it were merely an item in stock. ... The level of user cost leads us to inquire about the total condition:  is the rate of growth so great that the resource should be left unused in the present period?  That is, does the user cost curve lie above the profits curve?  If it does, the resource should be left unused " (p. 47).

Whether a red kangaroo should be harvested will depend on the relative rates of resource and social capital growth rates.  The question of how to maximize present value is equivalent to asking, what is the biological growth rate below which an animal should be harvested?  I shall here answer this question.

## Mathematical Response

This response is developed in two stages. In the first, the argument is developed in much the same manner as it has been in much of the earlier literature. That is, where the harvesting decision is made over an assumed homogeneous and continuous function. In the second stage I show that this development is inadequate and develop the response accordingly.

### I. With Certainty

Conditions: price (p) and cost (c) are given and fixed so that the profit (rent [R]) for a given animal is

$$p-c = R$$

$$(p-c) = Z, \text{ and} \qquad\qquad 3.1$$

$$Z = R.$$

Each animal is considered in isolation (in reality this is likely to be each age class) so that Q, the quantity harvested, will always be equal to 1. The object being to maximize the present value of

$$QZ-r^t Q(Z)^{-at}, \qquad\qquad 3.2$$

where r is the observed rate of increase (Caughley and Birch, 1972).

Solution: for a continuous differentiable function, the derivative of (2) is set equal to zero,

$$dPV/dQ = Z-r^t(Z)^{-at} = 0; \qquad\qquad 3.3$$

therefore

$$z = r^t(Z)^{-at},$$

which tells us, that on the margin, for the present value maximizing case, the marginal return from harvesting will equal the marginal return from foregoing harvest. To obtain this result, it is necessary that

$$r = \alpha.$$

If

$$dPV'/d'Q < Q,$$

then PV is maximized by foregoing harvest as long as $r > \alpha$. Harvest will occur for $r \leq \alpha$.

When $r = 1$, growth is zero; when $(r-1) > 0$, biological growth is occurring. As $\alpha$ is $(I+1)$, then $\alpha - 1$ equals I-- which was earlier defined as the market interest rate given as a percentage. Therefore when biological growth for an individual animal given as a percentage, is equal to or less than the market interest rate, the animal should, all else being equal, be harvested.

Graphic Response

The approach is similar to that used by Fisher (1930, pp. 162-163), which was demonstrated for harvesting timber; the graphic representation is that of Lutz (1968, p. 90) and Gregory (1972, pp. 283-286).

In Figure 7, the amount of investment, in number of years, is measured along the x axis, the rate of return over cost (growth) and the market rate of interest are measured along the y axis. The growth curve represents the marginal rate of return for a single "representative" (where this is a statistical entity) female kangaroo. The interest line represents the market rate of interest.

COMPARISON OF BIOLOGICAL AND ECONOMIC RATES

# FIGURE 7.



RATE of RETURN and MARKET INTEREST RATE.

GROWTH CURVE.

INTEREST RATE.

INVESTMENT TIME in YEARS.

A
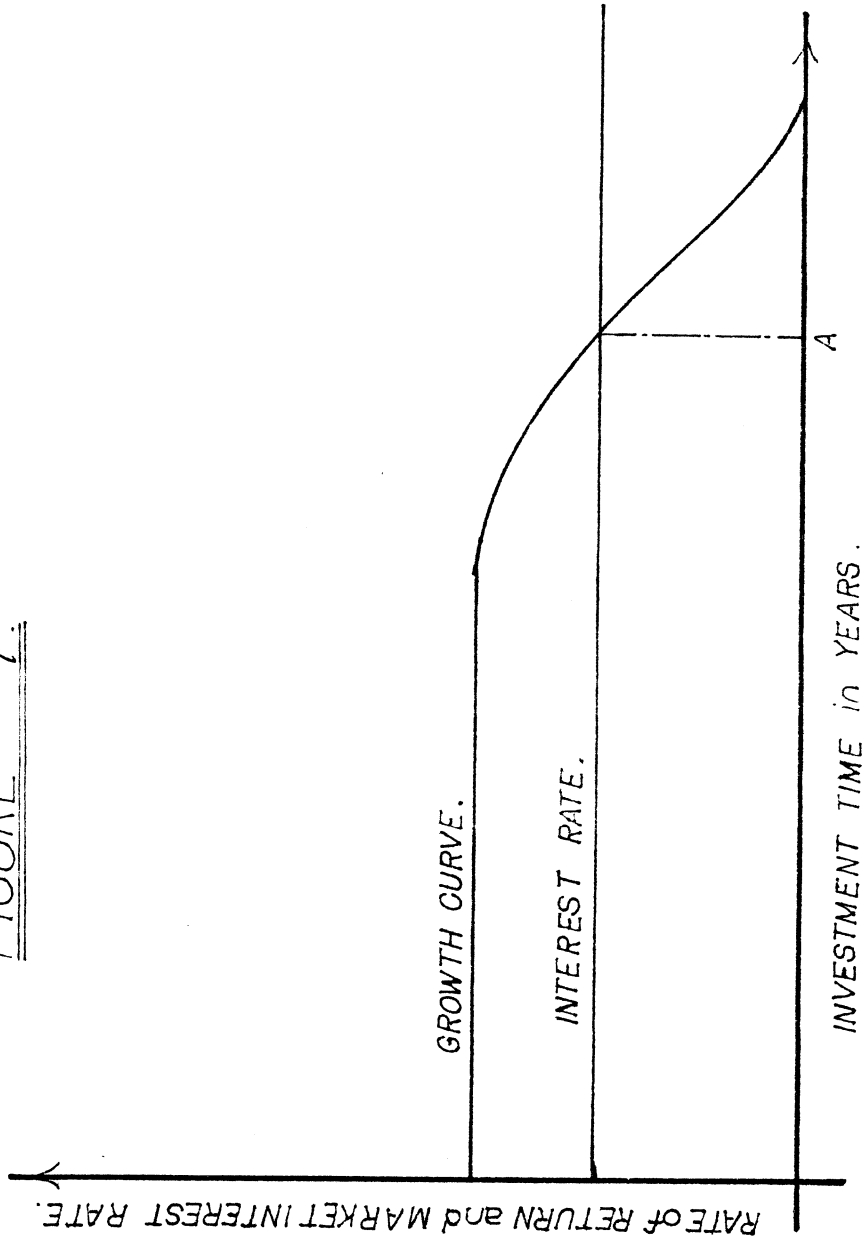
As shown earlier, the harvester will allow the female to continue to reproduce as long as the marginal rate of return (biological growth) exceeds the cost of investment (interest rate). At age A, though, the marginal rate of return equals the interest rate and the animal will be harvested. As reproduction and survival are likely to vary (Chapter III), the optimal age of harvest (A) also is likely to vary over time.

## II.  Including Uncertainty

As already observed, a capital good supplies a flow of services over time. For a red kangaroo this flow of services (offspring) varies according to climatic conditions. To the harvester, unable to predict future climatic conditions, the future rate of pay-off is approximated by the mean value $\bar{R}$ (= .2). The probability that the capital unit (female) will supply the flow of resources into the next time period is given by the age and time dependent rate of survival $(P_{n,t})$ so that the compounded biological rate of return (growth) of foregoing harvest is $P_{n,t}\bar{R}$. For simplicity of exposition $P_{n,t}\bar{R}$ is set equal to $r_H$.

To transform the model into a form whereby variation in doe survival is included, variable $r_H$ is substituted for $r$ in (3) giving

$$Z - r_H^t(Z)^{-\alpha t} = 0, \qquad\qquad 3.4$$

so that PV is maximized by foregoing harvest as long as $r_H \geq \alpha$ and harvesting when $r_H < \alpha$. Everything else follows as developed in the first stage.

## Inclusion of Subsequent Expenses

Following the initial capital costs, consequent expenses incurred in obtaining a flow of services from a piece of capital may be of two types: capital (maintenance) expenses when the effect of the expense is spread over a sequence of short periods (as in the replacement of a part) or, of the current expense type when the effect of the expenditure is exhausted in a single period (Lutz and Lutz, 1951). Up to this point, we have assumed that there are no expenses of the 'capital expense' type. The intention now is to examine how the relaxing of this assumption may affect our analysis for the harvesting of natural populations. Interestingly we find that the outcome varies according to the characteristics of the population being examined.

Under the assumptions in this thesis, whether costs of the 'capital expense' type occur or not is dependent on population response to harvesting. It is helpful, therefore, to refer back to Table 1. The timing of entry of stock/capital is independent of the manager (and of the harvest rate). While the total number of organisms available in the next time period is independent of the manager, the rate at which the population increases may or may not be dependent. Whether the rate of increase is or is not dependent on the manager will depend on whether the population is or is not density dependent. For a density independent population the rate is independent of harvest. For a density dependent population the rate of increase is dependent on harvest

history and harvest is, therefore, adjusted not only to effect present harvest, but also so as to effect future harvest. In this way on-going costs may have capital type expenses and current type expenses, jointly.

The proportion of capital/current expenses incurred depends on the previous harvest history and the population response to this previous history. For a density dependent population, harvest rate and the rate of increase will, over time, become constant and equal and eventually harvest rate will no longer be important in affecting change in future harvest rates. The real difficulty arises when a single population is affected by both density independent and density dependent events. For such a situation harvest rate and the rate of increase are unlikely to approach constant and equal rates, and future rates of increase will continue to be dependent on present harvest rates according to the population involved and the previous history of events. In such cases, this form of analysis can only be an approximation.

For this analysis, red kangaroos can be referred to as being density independent and we need not be concerned with subsequent capital expenditure type costs.

CHAPTER IV

THE MODEL

## Introduction

This chapter divides into two sections. In the first section the two lines of development (biologic and economic) are brought together; the criteria for testing simulation models and the experimental design is presented, the model is run and the outcomes are examined. In the second section the model is discussed, including possible uses.

## Unifying the Biological and Economic Components

There are two biological rates relevant to the bioeconomic model. The first of these, the age and time dependent observed rate of increase ('r'), is developed in the biological model and is obtained by multiplying the time dependent recruitment value ('R') by the age and time dependent survival rate ('P'). The second, the rate of biological increase expected by the harvester ('$r_H$'), is developed in the economic model and is obtained by multiplying the expected (mean) recruitment value ('$\bar{R}$') by the survival value. In addition the new population vector ('$N_{t+1}$') is generated within the biological model; while the interest rate ('I') is exogenous.

48

Under the $PV_{max.}$ criteria, developed in Chapter III, to test whether an animal should be harvested, the harvester needs to compare $r_H$ with the interest rate, so that

$$r_H = I \begin{cases} r_H \geq I, \text{ do not harvest,} \\ \\ r_H < I, \text{ harvest.} \end{cases}$$

## Criterian for Testing Simulation Models

The testing of a simulation model, to see whether it is an adequate representation of the system it is supposed to mimick, can be separated into two parts. The first involves a questioning of the assumptions whereby constants and coefficients are included, and, in the case of dynamic state variables, how they change in time. This is because the way model variables interract may be as important as the variables themselves. The second part relates to the predictive adequacy of the model, and requires a comparison of the distribution of the values generated against either those values observed (requiring a second data set), or those values generated by some other predictive model.

The questions relating to the adequacy of the model's static structure and the processes involved have been responded to in Chapters II and III. As a second data set is not available, it is not possible to run a statistical comparison of the models results against an observed set of outcomes. In spite of this, by running the model using

different coefficient values (treatments) it is possible to test outcome adequacy and to obtain a qualitative response to how closely the model maps the real system.

As this procedure tests the sensitivity of dynamic state variables to changes in input values, it is referred to as a sensitivity analysis. In carrying out the sensitivity analysis each set of coefficient values constitutes a separate treatment.

## Experimental Design

The model was originally run using a pseudorandom number generator (Fox, 1977) to simulate weather. As a consequence, the testing of the model's sensitivity to different coefficient values was confounded by differences in climatic conditions between runs. To overcome this difficulty a single set of fifty random numbers is used over all treatments (App. B).

To test the model's sensitivity to variation in coefficient values the design is partitioned according to interest rate (.07, .11, and .15) and harvest rate (.5 and .75) giving six treatments.

## Results

The maximum number generated in any itteration, the total number generated, the total harvested, and the final count are given in Table 4. Looking at the marginal change in final count according to interest rate we observe that the count falls with increasing interest rate, while the standard

TABLE

RESULTS

|  |  | Discount Rate | | | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
|  |  | .07 | .11 | .15 |  |  |
| .5 | G. Tot. | 58,144 | 56,31 | 47,145 |  |  |
|  | Harvest | 271 | 560 | 1,375 | 735 | 572 |
|  | Fi. Cnt | 818 | 730 | 475 | 674 | 178 |
| .75 | G. Tot. | 57,681 | 54,712 | 43,693 |  |  |
|  | Harvest | 381 | 808 | 1,649 | 946 | 645 |
|  | Fi. Cnt | 798 | 651 | 386 | 612 | 209 |
|  | Har. Mean | 326 | 684 | 1,512 |  |  |
|  | Har. Standard Deviation | 78 | 175 | 194 |  |  |
|  | F.C. Mean | 808 | 690 | 430 |  |  |
|  | F.C. Standard Deviation | 14 | 55.86 | 63 |  |  |

Harvest Rate

G. Tot. is the grand total, and Fi. Cnt is the final count

deviation increases. Over the treatments examined, it is apparent that interest rate has a greater affect on outcomes than harvest rate. The final count is less than 1,000 (the initial number) in all cases, which is not unexpected considering the sequence of climatic conditions used. The final count does not become unreasonably low, however, until we get to the .15 interest rate. It is interesting to note that there is little difference in final counts between Int. = .07, Har. = .75 and Int. = .11, Har. = .5 (798 v's 560), while there is an appreciable difference in harvest (380 v's 560). Maximum yield over the sequence used is 724 and is obtained at Int. = .15, Har. = .75.

## Discussion

The outcomes from the simulation model appear reasonable. In its present form, the model indicates that, at the .07 interest rate, harvest need not threaten the biological survival of red kangaroos. The low proportion of females harvested is consistent with the observed harvest data from New South Wales.

The harvesting question is more complicated than the model indicates; whether harvest occurs will depend on how the harvester handles risk and uncertainty, and whether the average and marginal cost curves intersect above or below the demand curve--which is a function of population density and the price of substitutes such as beef and mutton. Interestingly, the price of substitutes are likely to be highest

when harvest is most likely to occur, that is, during
drought periods.

Although kangaroo harvest has only a marginal affect on
total GNP, harvesting can be important in some regions.
This is especially so as the harvest rate will tend to
increase during dry periods when other regional sources of
income are falling. As labor is the major input, money
brought in by the harvesting industry will tend to have a
higher regional multiplier than money obtained from agri-
culture which is likely to require exogenous inputs such as
seed, chemicals and machinery.

## Discussion on the Use of
## the General Model

This discussion has three components: economic, bio-
logical and the interaction of these. To help clarify the
discussion these components shall be separated. However,
they are interrelated in their effects, so the division will
at times appear arbitrary.

### Economic

There is a need to differentiate between the user cost
curve likely to be perceived by the harvester and the social
user cost curve, as, under certain conditions, these two
functions will diverge. This divergence will arise due to
the existance of externalities--which may be of two types:
dynamic externality (from 'imperfect' foresight), resulting
in temporal misallocation; and static externality (from

imperfect possession), resulting in misallocation between inputs and outputs.

Imperfect foresight may arise due to difference in risk and risk perception, uncertainty and imperfect possession. If a specific event (such as a number of drought years) occurs, so that the harvester goes out of business, then he is dealing with uncertainty as such a case lacks the necessary high number of simular occurrences. For society, having a number of such harvesters and other industries, we are only interested in the probability of such an event occurring and thus risk. The discount rate will, therefore, differ, and therefore so too will the user cost curves. Imperfect possession may arise from insecurity of ownership (common access), monopoly or through external economies. A possible external economy may arise where population numbers are so high as to constitute a pest (such as for rabbits in Australia); harvest in this case will result in a benefit to the harvester (price received) and to the grazier in the form of increased carrying capacity. As is discussed later, taxes can be applied so as to mitigate the divergence between the social and private outcomes.

Depending on the form that taxes take, so they will effect the slope and magnitude of the profit and user cost functions. Such instruments can be used to bring social and private user cost functions closer together. Wilson and Anderson (1977, p. 199) observed that the choice of the fee (instrument) used should enhance the overall objectives of

the fishery (population). They list several factors worth
considering, including the behavior of the harvester to fee
induced uncertainty (of course, such taxes can be used to
convert what is uncertainty at the individual level to risk).

A survey of the affect of some of the possible instru-
ments on the industry and the individual harvester follows.

Profit tax:  under a static interpretation of the conditions
established in this thesis profit taxes will merely serve as
a means of reallocating resource rents--harvester behaviour
remaining unchanged.  Thus the marginal harvester (firm) and
the marginal animal harvested will be the same with a profit
tax as it will be without the tax.  In the more dynamic case
though, where a harvester is likely to receive profits one
year and losses the next, a profit tax discriminates against
those firms and industries which are more likely to suffer
such fluctuations.  In such a case, a profit tax will result
in a contraction of the industry.

Licence fee:  this can be a once only or an annual payment
which may be levied at an administratively fixed rate, or
through bidding.  It is a means whereby some of the future
rents can be obtained from the harvester--where the licence
fee is established by bidding, and resale is allowed, har-
vesters will be willing to pay up to the present value of
future rents.  A set licence fee can be used to control
total effort in the industry by making the marginal firm
unprofitable.  Depending on how the fee is established and
applied, it may or may not cause distortion between inputs.

Royalty payments:  these are paid at a given amount per animal harvested.  Such payments are likely to decrease marginal harvester effort.

Subsidy:  a subsidy may be paid per animal harvested, in which case it is called a bounty, or it may be in the form of a tax break or direct subsidy on capital equipment--such as when fishermen receive subsidies for new boats.  It is likely that such subsidies will expand harvester effort, though not necessarily yield.  A bounty has the advantage over the other forms of subsidy in being more flexible.  For instance, red kangaroos may not be a pest unles they exceed a certain number, and a bounty per animal harvested could be applied when populations exceed this number; in which case the bounty becomes a density dependent variable.

Subsidy and profit tax:  these instruments could be used in conjunction so as to level out the harvester's future stream of income.  This would remove the harvester from a state of high risk and uncertainty, bringing his discount rate more in line with the social discount rate; thus affecting the length of time that harvesters will forego harvest in bad years, and the rate of harvest in good years.

It is worth emphasizing at this point that, for the policy maker interested in maximizing total public welfare, the user cost analysis is only concerned with the future stream of commodity resources obtainable from a resource.

## Biological

One of the reasons for using red kangaroos to develop and quantify the model was so as to concentrate on the means whereby density independent events can be included. After much in-house bickering, biologists have come to accept that both density dependent and density independent events may affect population numbers--although their relative importance may vary between species and populations, over time. This acceptance has particularly been apparent since MacArthur and Wilson's (1967) paper on "r" and "K" selection (density dependent and density independent selection). In spite of this general acceptance, some population biologists still remain somewhat hesitant. This hesitancy is particularly noticeable of researchers at the University of York, where so much of the work on the use of Lewis/Leslie matrices has been done. In light of this hesitancy by some population biologists, it is not surprising that there is a paucity of papers in bioeconomics which include density independent events (Bell's 1972 paper is a notable exception).

The reader will note that the usual necessary condition for stability

$$dN/dt = F(N)-h = 0,$$

is unlikely to be obtained. Economists will recognize the problem of obtaining stability as being similar to that for the Domar growth model, and arises due to the linearity of the formulation. The inclusion of non-linear relationships

will maintain some stability in the model. Non-linearity may enter due to density dependent responses by the population and/or by the harvester.

In this model we are primarily concerned with proximate events. Harvesting, however, is a new selective factor affecting population membership and reproductive value. As larger and faster growing animals are more likely to be harvested, a selective regime against genotypes for these characteristics is established. Therefore, ultimately, harvesting can change the genetic composition of the population in a manner detrimental to the harvester.

A criticism levied by some conservationists against the use of natural populations as an economic resource is that this use may result in the extinction of the resource. The model developed here and the above discussion argues that this need not necessarily be so. The problem involves the optimal allocation of resources between uses over time. As long as the rate of growth exceeds the discount rate, there is nothing implicit in meeting the demands of the economic problem which will result in the destruction of the resource. That the resource may be destroyed, is not denied, but that this does occur is for reasons (such as the distribution and form of property rights) other than the use of the population.

Interaction of Biological and Economic Factors

Population density is an important variable affecting economic and biological variables through its

i. being an indicator of the total number of females (the reproductive units);

ii. influence on reproduction because of its effect on

(a) the probability of survival for the individual animal,

(b) the survival of offspring, weight increase, and age of sexual maturity; and

iii. its effect on marginal harvest costs.

Depending on the aggregate of i. through iii., the user cost function may or may not be homogeneous and increasing throughout. The use of the logistic function in the earlier bioeconomic literature implies that the user cost function is downward sloping at higher population levels. That is, at higher population levels, the removal of population members will result in increased future benefits. Beyond a given population level, the user cost will be upward sloping and the question confronting the harvester is whether the marginal profit from harvesting that animal is greater than the marginal discounted future benefits foregone in harvesting that animal. As long as the $NR > UC$ (Fig. $10_b$) harvest should continue. Obviously the weight given to future benefits is represented in the discounting rate used.

For an individual that is primarily affected by density independent events, the expected shape of the user cost function will be homogeneous throughout. Whether the function rises, falls, or is horizontal will depend on the expected productivity relevant to the individual at the time of

examination. The expected productivity will vary between individuals according to whether fecundity is age dependent, and the time and age dependent survival value relevant to that individual at that time.

## Discussion

A criticism I have against many population models is that they are deterministic in nature. Even complex models, examining the passage of population numbers over time, examine this movement to either a stable equilibrium, or over a constant cycle or rate. Yet natural populations may suffer a number of perturbations which are capable of affecting present and future demographic coefficients and values. Even if central tendencies do exist, these tendencies may only be observable over long periods of time, and for a resource manager, harvester, or what-have-you, these tendencies may be irrelevant or of minor importance.

The benefit of the model developed here, then, is that it shows how the affect of destabilizing density independent events may be included. It is worth noting that the demands of this model on the mathematical skills of the user are less than that required by many of the more deterministic models.

The important consequence of the ideas developed in this thesis is that the range of circumstances to which population models can be applied is extended; by so doing, such models will be more responsive to proximate variables. By making

such models more responsive to proximate events, the models become more useful to those individuals concerned with managing natural populations.

APPENDIX A

APPENDIX A

TERMS USED AND THEIR USE

Biological

As the thesis uses biological and economic terms and
concepts, and as it is directed at both biologists and
economists, there may be some confusion over terms and their
use. In the hope of at least mitigating, if not preventing,
this confusion, some of the terms used are here defined and
discussed.

Logistic Equation: the logistic equation is an important
conceptual and predictive tool which may be used in the model
in a dynamic form to include density dependent factors. In
addition, its use in the biological (Pielou, 1969; Watt,
1968; Williamson, 1972) and bioeconomic (Scott, 1955; Smith,
1968, 1969) literature is extensive. Economists, also, are
familiar with it as it relates to the Law of Diminishing
Marginal Productivity. This is only to be expected as, in
both cases, we are describing the marginal product received
from incremental increases of a single variable with all
other variables fixed. Formally the "Law" reads ". . . if
the input of one resource [population numbers] is increased
by equal increments per unit of time while the inputs of
other resources [observed as fixed carrying capacity] are
held constant, total product output will increase, but

beyond some point the resulting output increase will become

smaller and smaller (Leftwich, 1966, pp. 99-100)."

The first mathematical formulation of population growth

using the logistic equation was by Verhulst (1838; Kormondy,

1965, pp. 64-67). Letting "p" represent the population and

"m" a constant (commonly known as the intrinsic rate of

increase "r" [Birch, 1948]), he obtained

$$\frac{dp}{dt} = mp - \quad (p).$$  1.

The function " " gives the retarding relationship (resistance)

to population growth as an inverse function of population

numbers. Verhulst's contribution went unnoticed until

Pearl and Reed (1920) independently derived the same relation-

ship.

The function " " can be represented using a number of

relationships including $np^2$ (Verhulst, 1838) where "n" is a

constant. A more common formulation for " " is $\frac{K - N}{K}$ (MacFadyen,

1963, p. 207) where "N" is the number of organisms in the

population (our variable input) and "K" is the environmental

carrying capacity (the fixed input). The complete formulation

becomes

$$\frac{dN}{dt} = rN \frac{K - N}{K}$$  2.

which in much of the bioeconomic literature (Smith, 1968;

Clarke, 1976) is simplified to

$$\frac{dN}{dE} = F(N)$$

Relationship 2 can be represented by Fig. 1A, 1B. The graphs show change in population numbers as a function of time, and population growth as a function of population numbers, respectively. The values $\underline{N}$ and $\bar{N}$ are the levels at which the minimum and maximum self-sustaining growth is obtained.

A number of observations concerning the harvesting of natural populations arise from the use of $l_A$ and $l_B$: (1) any sustained harvest rate greater than the maximum sustainable yield $h_m$ will result in the extinction of the resource; (2) any harvest rate less than $h_m$, such as h', will have two equilibria, $N_1$ and $N_2$, of which only $N_2$ is stable. As long as population numbers are greater than $N_1$, and harvest remains at h', h' < N and population numbers will approach $N_2$, which is a stable equilibrium where h=N. For population levels below $N_1$, h' > N, and numbers will decrease; (3) maximum sustained yield is not obtained where population numbers are maximized (N=K), but at some value less--where F(N) is symmetric this is at K/2. Clarke (1976) discusses this model including the occurence of depensation.

The model shown here (Fig. 8A, B) is a static model for which the major assumption is that populations tend to remain in balance; that is, over any long period of time losses are balanced by recruitment. In this model, harvesting by man ("h") is included as an additional source of predation which is met by a compensatory increase in the rate of population renewal. A necessary condition for stability is

$$\frac{dx}{dt} = F(N) - h = 0$$

# VERHULST-PEARL LOGISTIC EQUATION

$1_A$.

    N is population numbers;

    K is maximum carrying capacity;

    T is time;

    $N_1$ and $N_2$ are the two population levels at which

       harvest rate h' can be sustained.

$1_B$.

    $\underline{N}$ and $\bar{N}$ are the minimum and maximum self sustaining

       populations;

    $N^o$ is the population level producing the largest

       sustainable yield;

    N is the rate of change over time, or $\dfrac{dN}{dE}$

    h is harvest;

    $h_m$ is the largest sustainable harvest.

FIGURE 8

A
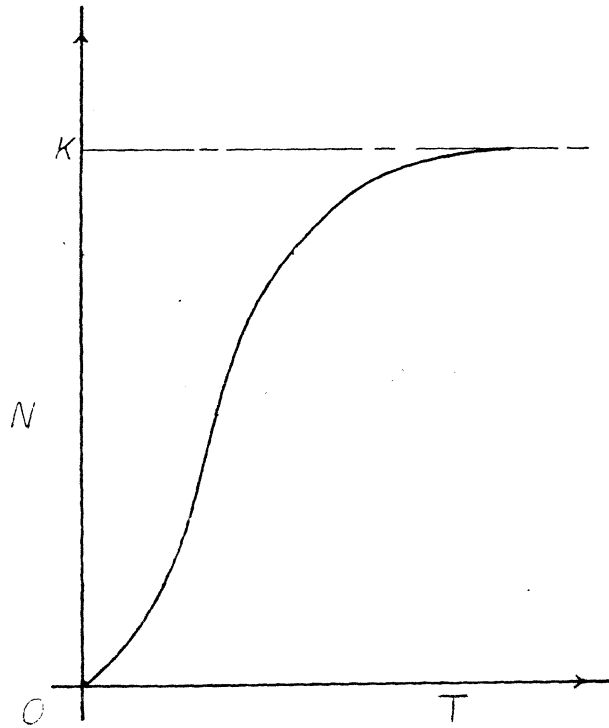
B
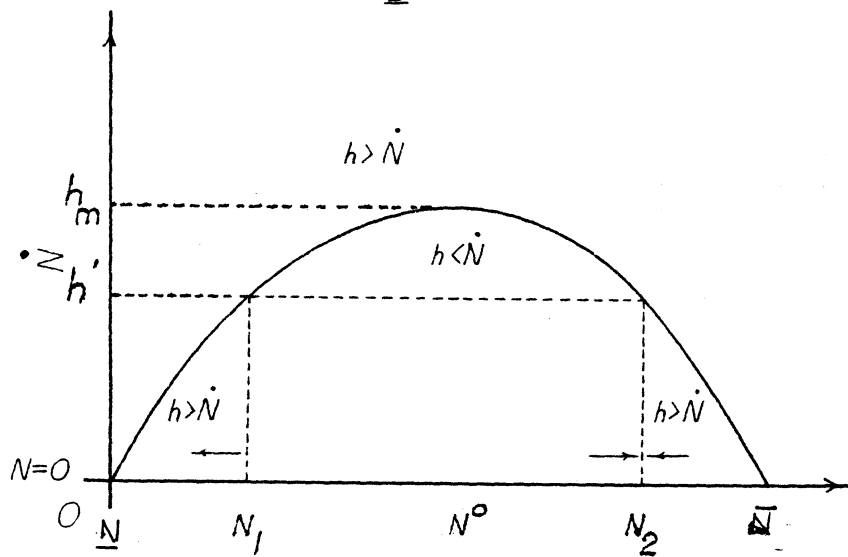
When this condition is met, population growth balances the loss from harvest. This relationship also works in the opposite direction: a balance can only be achieved as long as harvest does not exceed the long run capacity of the population to compensate for that loss.

Productivity (Yield): "The total mass of organic food that can be manufactured in a particular area for a certain period of time. . . . It is the net yield of the producer and consumer elements of a food series and as a consequence, it will govern the amount of living matter that may reside in a particular area (standing crop) (Knight, 1965, p. 189)." The term is a measure of "flow" in units weight of organic matter per unit time.

Standing Crop: is ". . . the total quantity of organic matter available at a given time and place" (Knight, 1965, p. 190). In this case the term is a measure of "stock" in units weight of organic matter.

Biomass: is a measure of the weight of organic matter; it can be a measure of standing crop (stock) as, for example, a yield of 50 tons of fish on the 24th of September; or it can be a measure of productivity (yield) as in 300 tons of fish per year since 1943.

Proximate and Ultimate Factors: these factors differ in the time frame or "level" of inquiry to which they refer. Ultimate factors respond to long-term consistent patterns of environmental change and fit into an evolutionary or geological time frame. Proximate factors, though, are more

immediate or "now" and refer to functional responses of the organism to variation in the environment (Williams, 1966; Pianka, 1974). Within an economic time frame, ultimate factors will rarely be important (although harvesting will apply a selective bias on a population), therefore, this thesis is intended to function within a proximate time frame. Biologists have been known to get these two terms confused (see Williamson, 1972, p. 29).

Density Dependent and Density Independent (Facultative and Catastrophic) Factors: a good deal of discussion exists in the biological literature over the use of these two terms. In some cases the confusion has arisen over the author's failure to establish whether they are talking about the long-run (ultimate factors), or the short-run (proximate factors). Pianka (1974) gives a good description of these two classes of factors: "Various factors can influence populations in two fundamentally different ways. If their effects on a population do not vary with population density, but the same proportion of organisms are affected at any density, factors are said to be density-independent. Climatic factors often, though by no means always, affect populations in this manner. If, on the other hand, a factor's effects vary with population density, so that the proportion of organisms influenced actually changes with density, that factor is said to be density-dependent" (p. 87). The use of these terms is also discussed in MacFadyen (1963, pp. 152-157).

Economic

<u>Externality</u>: which may be positive or negative, is a
form of "market failure" resulting in divergence between
private profit and social benefits (Scitovsky, 1954). Meade
(1952) has defined an externality as " . . . where what is
done in one industry reacts upon the conditions of pro-
duction in the other industry in some way other than through
the possible effect upon the price of the product or of the
factors in that other industry"(p. 56). Externalities may
occur due to a number of causes including the common
property nature of the resource (see Mishan, 1971, for a fuller
discussion).

<u>Common Property Resources</u>: are those for which the
" . . . physical circumstances of their occurrence made it
difficult, if not impossible, to assign private property
rights to clearly identifiable portions of them under pre-
vailing social institutions." Thus, ". . . private property
and market exchange have but little applicability to their
allocation, development and conservation" (Kneese and Bower,
1972, pp. 3-4). The term "common property" is an ambiguous
term as in a legal sense a resource is not property unless
it is owned, thus Crutchfield (1969, p. 11) prefers the term
"open access resource." Also, it has been suggested that the
distinguishing feature of such a resource is its ability to
transmit influences from one economic agent to another; if
this is the case, private ownership is not precluded from
such resources (Dorfman, 1974, p. 7).

Stock, Flow: these two terms are analogous to the biological "standing crop" and "productivity"; examples include savings, inventory and capital; and income, interest and earnings, respectively.

Rent: Mishan (1959, 1971) describes two categories of rent. "One conceives of rent as a payment in excess of that necessary to maintain a factor in its current occupation. The other would describe it as the difference between the factor's current earnings and its 'transfer earnings'--the latter term denoting its earnings in the next highly paid use" (1971, p. 339). I am here concerned with "a payment in excess of that necessary to maintain a factor in its current occupation" or Ricardian rent.

APPENDIX B

APPENDIX B

NEWSOME'S DATA

Introduction

Dr. A. E. Newsome kindly forwarded to me the red
kangaroo population data he had collected near Alice Springs
during the early 1960s (1977); I did not use this data. As
it contains the date at which it was collected, the number of
females in each age-class and the aridity index during
collection, it would appear to be preferable to the data I
have used. My handling of this data and the reason for not
using it are, therefore, explained here.

Problem:

To obtain age-aridity specific death rates.

Method:

a. Using the tooth class age table (Newsome, 1977),
the number of animals in each age-class for each sample were
obtained;

b. The number in each age-class was calculated as a
percentage of each sample;

c. This figure was then multiplied by ten to give the
age-class frequency per 1,000 animals;

d. The expected number of animals in the next age-
class sample period was calculated using

$$N_{t+1,\ i+1} = \partial N_{t,i} + N_{tm\ i+1} - \partial N_{t,i+1} - Q_{t-(t+1)} + e_{i,t};$$

where N is the number of animals, t is the time period, i is the age-class, $\partial$ is a weight obtained by dividing the number of weeks between collections by 53, Q is the number of animals lost through death and e is the sample error term.

e. Assuming $e_{i,t} = 0$, the value $Q_{t-(t-1)}$ is expected to be greater than zero. The value was obtained by observing the difference between the predicted and observed values in each age-class.

<div align="center">Result:</div>

a. To test $(Q_{t-(t-i)} + e_t) > 0$, a one-way t test (Rothman, 1977, p. 46) was used;

b. The Null Hypothesis ($H_0$: $(Q_{t-(t+1)} + e_t \leq 0$) was accepted (Table 6).

c. As it is not possible for $Q_{t-(t-1)} \leq 0$, then $|e_t| > 0$.

Newsome's (1977) paper was re-examined. It was found that although most of the animals were collected randomly, an additional 20 per cent of those collected were selected on the criteria that they were older animals. This would account for the non-expected results.

TABLE 5

Newsome's Data

$H_0$:  $T \leq 0$

$H_1$:  $T > 0$  $\bar{d}$

Test Statistic  $T = S_d^2/N$  (Rothman, 1977, p. 46)

$\sigma = .1$  d.f. $= 13 - 1$

$\bar{d}$ is the difference between predicted
and observed values.

| Age Class | T | $\bar{d}$ | $S_d$ |
|---|---|---|---|
| 3 | -0.69 | -12.49 | 65.1 |
| 4 | 0.87 | 10.16 | 42.26 |
| 5 | 0.38 | 5.44 | 51.07 |
| 6 | 2.24 | 17.62 | 28.31 |
| 7 | -0.39 | -6.75 | 63.15 |
| 8 | -0.62 | -5.15 | 30.16 |
| 9-10 | 0.44 | 7.53 | 61.96 |
| 11-12 | 1.25 | 13.15 | 38.04 |
| 13 | 0.73 | 17.20 | 85.26 |
| 14 | -0.25 | -7.28 | 103.90 |

$t_{.90,12} = -1.356$

APPENDIX C

# APPENDIX C

# Bioeconomic Simulation Program

```
          C        *****BIOECONOMIC SIMULATION MODEL FOR HARVESTING*****
          C        *****NATURAL POPULATIONS. THE MODEL INCLUDES AGE *****
          C        *****AND CLIMATE DEPENDENT SURVIVAL AND           *****
          C        *****RECRUITMENT COEFFICIENTS.                    *****
0001               REAL INT
          C        .....ENTER CLIMATE AND AGE DEPENDENT COEFFICIENTS.....
          C        .....AND NUMBER OF ANIMALS BY AGE CLASS           .....
          C        CATA DIMENSIONS
0002               DIMENSION EMI(20,20), EMII(20,20), EMIII(20,20), EMIV(20,20),
                  +EMV(20,20), EN(20), ENT(20), HARV(20), A(100),EM(20,20)
0003               DATA ENT/20*0./, HARV/20*0./
0004               K=17
0005               L=17
0006               INTEGER A
          C        REAC IN CATA
0007               READ(5,11) ((EMI(I,J),J=1,L),I=1,K), ((EMII(I,J) ,J=1,L),I=1,K),
                  +((EMIII(I,J),J=1,L),I=1,K), ((EMIV(I,J),J=1,L),I=1,K),
                  +((EMV(I,J),J=1,L),I=1,K), (EN(I), I=1,K), (A(I),I=1,50)
0008           11  FORMAT(85(17F3.0/),17F3.0/,25I2/25I2)
0009               WRITE(6,12)((EMI(I,J),J=1,L),I=1,K), ((EMII(I,J) ,J=1,L),I=1,K),
                  +((EMIII(I,J),J=1,L),I=1,K), ((EMIV(I,J),J=1,L),I=1,K),
                  +((EMV(I,J),J=1,L),I=1,K), (EN(I), I=1,K), (A(I),I=1,50)
0010           12  FORMAT ('COEFFICIENTS FOR VERY DRY CONDITIONS'/17(17F3.2/)//
                  +'COEFFICINTS FOR DRY CONDITIONS' /17(17F3.2/)//
                  +'COEFFICIENTS FOR NORMAL CONDITIONS' /17(17F3.2/)//
                  +'COEFFICIENTS FOR MOIST CONDITIONS'/17(17F3.2/)//
                  +'COEFFICIENTS FOR A BLOODY FLOOD' /17(17F3.2/)//
                  +'INITIAL AGE CLASS MEMBERS'/10X17F4.0//
                  +'RANDOM CLIMATIC CONDITIONS'/4X2(25I2))
0011               DO 200 K=1,50
0012               DO 55 I=1,17
0013               DO 55 J=1,17
          C            SELECT DEMOGRAPHIC MATRIX ACCORDING TO VALUE
          C            OF RANDOM NUMBER
          C            SET VALUE OF DEMOGRAPHIC MATRIX
0014               IF(A(K).LE.1) GO TO 70
0015               IF(A(K).LE.2) GO TO 71
0016               IF(A(K).LE.3) GO TO 72
0017               IF(A(K).LE.4) GO TO 73
0018               GO TO 74
0019           70  EM(I,J) =EMI(I,J)
0020               GO TO 55
0021           71  EM(I,J)=EMII(I,J)
0022               GO TO 55
0023           72  EM(I,J)=EMIII(I,J)
0024               GO TO 55
0025           73  EM(I,J)=EMIV(I,J)
0026               GO TO 55
0027           74  EM(I,J)=EMV(I,J)
0028           55  CONTINUE
0029               WRITE (6,85) (EN(I),I=1,17)
0030           85  FORMAT (' EN VALUE'/17F6.0/)
          C        *****GENERATE NEW POPULATION VECTOR              *****
          C            ONE. MULTIPLY RECRUITMENT VALUE BY AGE CLASS
0031               DO50 I=1,17
```

```
0032        50  ENT(1)=ENT(1)+E1(1,1)*EN(1)
        C           TWO. MULTIPLY POPULATION VECTOR BY SURVIVAL
        C           COEFFICIENTS
0033            DO 60 I=2,17
0034            DO 60 J=1,17
0035        60  ENT(I)=ENT(I)+EM(I,J)*EN(I-1)
0036            WRITE (6,13) (ENT(I),I=1,17)
1037        13  FORMAT (15X'NUMBER OF ANIMALS BY AGE CLASS'/22X17F6.2/)
        C       .....TEST THE BIOLOGICAL RATE AGAINST THE          .....
        C       .....INTEREST RATE                                 .....
        C           SET INTEREST RATE
0038            INT=.07
        C       ESTABLISH BIOLOGICAL RATE BY MULTIPLYING
        C       RECRUITMENT VALUE BY SURVIVAL VALUE
0039            DO 77 J=4,16
0040            DO 76 I=1,1
0041            IF((.20+EM(J+1,J)).LT.INT)GO TO 76
0042        78  CONTINUE
0043        77  CONTINUE
        C       .....HARVEST THOSE AGE GROUPS FOR WHICH            .....
        C       .....BIOLOGICAL RATE IS LESS THAN INTEREST RATE    .....
0044        76  DO 80 I=3,17
0045            HARV(I)=ENT(I)*.75
0046        80  CONTINUE
0047            WRITE (6,81) (HARV(I),I=1,17)
0048        81  FORMAT(' ANIMALS TO BE HARVESTED BY AGE CLASS'/1X17F5.0//)
0049            DO 91 I=1,17
0050            EN(I)=0.
0051        91  CONTINUE
        C       .....SET NEW POPULATION VECTOR                    .....
0052            DO 40 I=1,17
0053            EN(I)=ENT(I)-HARV(I)
0054        40  CONTINUE
        C       ....REMOVE MALES ....
0055            EN(1) =EN(1)*.5
0056            DO 82 I=1,17
0057            HARV(I)=0.
0058            ENT(I)=0.
0059        82  CONTINUE
0060       200  CONTINUE
0061            STOP
0062            END
     *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NUMAP
     *OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =        57
     *STATISTICS*   SOURCE STATEMENTS =      62,PROGRAM SIZE =    13810
     *STATISTICS*   NO DIAGNOSTICS GENERATED
 NO ERRORS IN MAIN
```

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$RUN -LOAD
EXECUTION BEGINS   13:32:08
COEFFICIENTS FOR VERY DRY CONDITIONS
.04.04.04.04.04.04.04.04.04.04.04.04.04.0 .0 .0
.98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.) .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
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.0 .0 .0 .0 .88.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .87.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .85.0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .82.0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .78.0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .72.0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .61.0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .36.0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
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COEFFICINTS FOR DRY CONDITIONS

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.12.12.12.12.12.12.12.12.12.12.12.12.12.12.0 .0 .0
.98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .93.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .91.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .81.0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .80.0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .78.0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .75.0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .68.0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .65.0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .54.0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .29.0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
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COEFFICIENTS FOR NORMAL CONDITIONS

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.20.20.20.20.20.20.20.20.20.20.20.20.20.20.20.0 .0
.98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .96.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .83.0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .87.0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .85.0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .82.0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .78.0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .72.0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .61.0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .36.0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
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COEFFICIENTS FOR MOIST CONDITIONS

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.28.28.28.28.28.28.28.28.28.28.28.28.28.28.0 .0
.98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .

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.0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .93.0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .94.0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .92.0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .89.0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .85.0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .79.0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .63.0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .43.0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0

COEFFICIENTS FOR A BLOODY FLOOD
.36.36.36.36.36.36.36.36.36.36.36.36.36.36.36.36.0
.98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .98.0 .0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .88.0 .0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .87.0 .0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .85.0 .0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .82.0 .0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .78.0 .0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .72.0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .61.0 .0
.0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .36.0

INITIAL AGE CLASS MEMBERS
          231.122.122. 28. 54. 75. 75. 20. 14.  8. 20. 82. 54. 15. 36. 44.  0.

RANDOM CLIMATIC CONDITIONS
    5 5 3 1 3 3 1 2 3 4 4 5 4 5 5 3 5 4 2 3 2 2 1 5 2 1 5 5 4 3 2 3 2 4 5 1 2 5 1 1 3 3 3 5 2 3 2 5 3 2
EN VALUE
 231.  122.  122.   28.   54.   75.   75.   20.   14.    8.   20.   82.   54.   15.   36.   44.    0.

               NUMBER OF ANIMALS BY AGE CLASS
                          360.00  226.38  119.56  119.56   27.44   52.92   73.50   73.50   19.60   12.32    6.96   17.00   67.24
   42.12   10.30   21.55   15.84

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  16.  12.

EN VALUE
 180.  226.  120.  120.   27.   53.   74.   74.   20.   12.    7.   17.   67.   42.   11.    5.    4.

               NUMBER OF ANIMALS BY AGE CLASS
                          379.58  176.40  221.85  117.17  117.17   26.89   51.86   72.03   72.03   17.25   10.72    5.92   13.94
   52.45   30.33    6.59    1.98

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   5.   1.
```

EN VALUE
150. 176. 222. 117. 117. 27. 52. 72. 72. 17. 11. 6. 14. 52. 30. 2. 0.
NUMBER OF ANIMALS BY AGE CLASS
233.16 183.93 172.07 62.67 61.23 14.14 8.36 4.26
3.90 18.98 0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 14. 0. 0.

EN VALUE
116. 180. 173. 217. 115. 115. 28. 46. 63. 61. 14. 8. 4. 9. 5. 0. 0.
NUMBER OF ANIMALS BY AGE CLASS
46.19 115.23 182.27 109.41 213.07 101.05 99.90 22.40 31.42 48.88 44.08 8.63 3.01
0.0 0.0 0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 2. 0. 0. 0.

EN VALUE
23. 115. 142. 103. 213. 101. 100. 22. 37. 49. 44. 9. 1. 0. 0. 0. 0.
NUMBER OF ANIMALS BY AGE CLASS
213.24 22.63 112.92 176.63 166.03 206.01 99.03 87.91 19.49 31.81 40.08 34.38 6.21
0.0 0.0 0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EN VALUE
107. 23. 113. 175. 160. 205. 99. 86. 19. 32. 40. 34. 6. 0. 0. 0. 0.
NUMBER OF ANIMALS BY AGE CLASS
223.00 104.49 22.18 110.66 175.00 162.71 204.63 87.14 16.57 26.08 31.26 24.76
3.19 0.17 0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EN VALUE
112. 104. 22. 111. 175. 163. 205. 87. 76. 17. 26. 31. 25. 4. 0. 0. 0.
NUMBER OF ANIMALS BY AGE CLASS
40.29 109.27 192.90 21.74 108.45 154.05 141.55 173.94 71.40 55.66 11.93 15.91 11.25
0.0 0.0 0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EN VALUE
23. 109. 102. 22. 108. 154. 142. 174. 71. 60. 12. 16. 3. 0. 0. 0. 0.
NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EQ VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EQ VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EQ VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EQ VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE
161. 190. 155. 125. 88. 54. 21. 51. 87. 132.13 120.92 84.13 52.55 55. 50. 3. 0. 0.
            NUMBER OF ANIMALS BY AGE CLASS
   42.10   35.92   1.57   0.0   472.95   103.24   103.51   0.   0.   0.   0.   0.   0.   1.   0.   1240   03.01   84.69

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   0.   15.13   16.56   0.

EN VALUE
225. 185. 190. 155. 121. 84. 55. 20. 55. 20. 10. 04. 65. 43. 30. 0. 0.
            NUMBER OF ANIMALS BY AGE CLASS
   30.30   21.51   0.14   472.95   210.51   155.98   182.15   130.08   116.50   02.45   51.89   19.09   03.48   66.01   13.37   52.38

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   0.   0.   0.   16.   0.   0.   0.   374   1

EN VALUE
240. 219. 160. 106. 130. 116. 82. 52. 20. 67. 13. 52. 50. 51. 5. 0.
            NUMBER OF ANIMALS BY AGE CLASS
   31.15   16.17   0.0   501.00   243.07   214.14   156.70   170.55   141.47   116.13   12.56   45.15   10.74   68.45   51.56   5.62

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   0.   0.   14.   0.   0.   14   1512

EN VALUE
151. 243. 214. 157. 175. 121. 116. 73. 45. 11. 52. 10. 22. 5. 0. 0.
            NUMBER OF ANIMALS BY AGE CLASS
   3.67   11.50   0.0   291.53   147.82   238.15   205.06   153.04   174.90   124.53   102.19   63.13   30.38   13.13   55.39   31.41

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   5.   0.   0.   9   1475

EN VALUE
159. 148. 230. 210. 175. 175. 102. 63. 14. 55. 31. 0. 0. 2. 0. 0.
            NUMBER OF ANIMALS BY AGE CLASS
   25.44   6.52   0.0   427.24   145.01   174.00   233.41   205.00   150.57   171.40   122.43   96.00   50.08   34.15   11.67   42.18

ANIMALS TO BE HARVESTED BY AGE CLASS
   0.   0.   0.   0.   0.   2.   0.   0.   7   1514

EN VALUE
212. 140. 195. 255. 200. 151. 171. 122. 56. 50. 12. 42. 25. 1. 0. 0.   1654

NUMBER OF ANIMALS BY AGE CLASS
190.47  207.88  142.90  141.91  220.74  201.55  151.02  130.90  91.94  74.53  43.56  25.23  1.58
22.18  7.58  1955

ANIMALS TO BE HARVESTED BY AGE CLASS
0.  0.  0.  0.  0.  0.  17.  6.  0.  0.  2.3

EV VALUE
52.  203.  143.  142.  227.  202.  137.  155.  93.  75.  44.  25.  8.  6.  2.  0.  0.  1555
310.55  91.25  203.72  140.04  159.13  224.17  191.52  120.57  160.84  83.25  61.44  33.91  16.72
7.63  2.05  0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0.  0.  0.  0.  0.  0.  0.  0.  2.  0.  0.  2

EV VALUE
155.  57.  204.  140.  155.  224.  195.  121.  121.  83.  61.  34.  17.  5.  1.  0.  0.  1680
151.03  152.19  95.31  199.65  131.24  136.35  203.59  159.59  56.46  94.26  41.18  22.08
3.63  1.59  0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0.  0.  0.  0.  0.  0.  0.  7.  1.  0.  0.  8

EV VALUE
50.  152.  55.  200.  157.  155.  204.  100.  56.  94.  62.  42.  22.  2.  0.  0.  0.  1498
179.55  93.99  149.15  93.40  195.05  134.49  124.07  165.24  15.24
11.92  0.55  0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0.  0.  0.  0.  0.  9.  0.  0.  0.  0.  9

EV VALUE
50.  54.  149.  55.  150.  157.  124.  165.  128.  75.  11.  42.  27.  3.  0.  0.  0.  1841
55.10  80.19  92.11  140.16  91.05  172.18  117.01  105.46  133.45  99.83  54.17  43.12  15.28

ANIMALS TO BE HARVESTED BY AGE CLASS
0.  0.  0.  0.  0.  11.  5.  43.  4.  0.  11

EV VALUE
28.  88.  72.  166.  52.  172.  117.  105.  155.  100.  54.  43.  4.  0.  0.  0.  0.  1176
425.16  21.23  90.43  145.24  30.21  108.73  114.61  103.55  119.23  86.83  46.05  35.36
2.28  0.0  0.0

ANIMALS TO BE HARVESTED BY AGE CLASS

84

EN VALUE
212. 21. 30. 90. 145. 90. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

NUMBER OF ANIMALS BY AGE CLASS
199.12 207.01 26.15 0.0  136.12 207.01  91.14  90.62  89.43  59.00  29.93

1225

ANIMALS TO BE HARVESTED BY AGE CLASS
17.09 0.86 0.0 0.0 0.0 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EN VALUE
80. 200. 21. 65. 80. 140. 92. 157. 92. 59. 30. 5. 0. 0. 0. 0. 0.

NUMBER OF ANIMALS BY AGE CLASS
48.05 71.57 203.46 26.21 83.01 11.85 122.13 09.38 112.07 11.55 28.04 34.55 21.26

1205

ANIMALS TO BE HARVESTED BY AGE CLASS
0.0 0.0 0.0 0. 0. 14. 1. 0. 0. 0. 0.

15

EN VALUE
20. 10. 203. 20. 83. 78. 122. 69. 112. 72. 50. 25. 5. 0. 0. 0. 0.

NUMBER OF ANIMALS BY AGE CLASS
357.00 23.55 10.41 155.39 25.69 81.35 76.29 119.60 68.00 94.62 62.25 47.44 44.73

1145

ANIMALS TO BE HARVESTED BY AGE CLASS
4.15 0.0 0. 0. 16. 0. 0. 0. 0. 0. 0.

16

EN VALUE
117. 27. 10. 155. 20. 81. 10. 120. 60. 99. 62. 47. 45. 4. 0. 0. 0.

NUMBER OF ANIMALS BY AGE CLASS
390.40 175.05 23.07 74.03 195.40 25.11 79.12 117.29 74.77 59.04 55.00 152.51 40.40

1106

ANIMALS TO BE HARVESTED BY AGE CLASS
2.29 0.0 0. 0. 0. 0. 0. 0. 0. 0.

8

EN VALUE
155. 170. 23. 15. 155. 25. 30. 15. 117. 60. 80. 53. 40. 35. 4. 0. 0.

NUMBER OF ANIMALS BY AGE CLASS
217.28 195.25 110.00 22.61 13.58 191.49 24.07 78.13 10.28 107.91 23.25 12.55 71.60

1240

ANIMALS TO BE HARVESTED BY AGE CLASS
21.51 15.00 0. 0. 0. 11. 0. 0.

11

EN VALUE
11. 155. 170. 25. 15. 191. 25. 15. 10. 100. 53. 13. 42. 20. 4. 0. 0.

1107

NUMBER OF ANIMALS BY AGE CLASS
25.50   9.90   204.90   170.17   191.34   160.91   22.16   71.92   101.60   21.71   01.91   59.74   00.48   41.54   52.51

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   1.   0.   0.   0.   0.   7   1201

EN VALUE
151.   170.   171.   157.   22.   108.   22.   08.   00.   00.   42.   53.   25.   2.   0.   0.

NUMBER OF ANIMALS BY AGE CLASS
155.00   128.03   166.76   101.52   103.03   21.72   65.44   152.01   17.51   53.02   44.80   60.11   27.00

ANIMALS TO BE HARVESTED BY AGE CLASS
26.36   1.59   0.0   0.0   0.   0.   0.   0.   0.   0.   0.   21.   6.   0.   0.   27   1175

EN VALUE
10.   128.   107.   166.   164.   22.   65.   152.   17.   23.   45.   60.   27.   1.   0.   0.

NUMBER OF ANIMALS BY AGE CLASS
234.07   76.34   125.52   103.43   103.16   100.36   21.26   57.59   132.25   14.76   43.47   34.95   43.32

ANIMALS TO BE HARVESTED BY AGE CLASS
10.17   2.55   0.0   0.   0.   0.   0.   0.   0.   0.   2.   0.   0.   2   1410

EN VALUE
117.   10.   128.   103.   104.   100.   21.   58.   132.   43.   35.   43.   16.   1.   0.   0.

NUMBER OF ANIMALS BY AGE CLASS
142.51   115.03   74.82   123.01   100.16   100.09   145.93   11.24   46.01   103.15   11.07   25.56   22.12

ANIMALS TO BE HARVESTED BY AGE CLASS
25.55   4.78   0.0   0.   0.   0.   0.   0.   0.   10.   4.   0.   0.   22   1107

EN VALUE
41.   115.   15.   123.   100.   100.   140.   17.   70.   103.   11.   50.   23.   1.   0.   0.

NUMBER OF ANIMALS BY AGE CLASS
310.07   70.03   112.75   75.32   120.55   150.96   176.49   143.01   10.21   42.39   91.81   9.41   23.35

ANIMALS TO BE HARVESTED BY AGE CLASS
1.55   2.55   0.0   0.   0.   0.   0.   0.   0.   2.   0.   0.   0.   2   1206

EN VALUE
155.   10.   115.   160.   151.   170.   16.   42.   92.   9.   25.   15.   1.   0.   0.

NUMBER OF ANIMALS BY AGE CLASS
43.07   151.94   110.53   11.85   110.17   153.62   172.50   140.15   14.26   32.08   18.04   1.72

ANIMALS TO BE HARVESTED BY AGE CLASS
10.22   11.12   0.58   0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EV VALUE
217. 152. 69. 111. 72. 116. 154. 173. 140. 51. 73. 0. 0. 0. 0. 0.
0.0 0.0 59.92 211.59 148.50 61.25 100.32 83.23 102.16 130.74 141.83 109.31 0. 1772 10.27 22.49 28.09

NUMBER OF ANIMALS BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 21. 0. 0. 0. 2|

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EV VALUE
21. 213. 143. 67. 108. 63. 103. 131. 142. 105. 10. 22. 7. 0. 0. 1151
3.75 0.0 130.28 20.00 200.0 143.92 65.91 100.15 51.57 83.25 104.60 110.02 61.95 6.98 14.62

NUMBER OF ANIMALS BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 3. 0. 0. 0. 3

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EV VALUE
67. 21. 209. 140. 66. 106. 58. 83. 105. 111. 82. 7. 15. 1. 0. 1035
11.40 0.08 309.90 67.16 204.55 27.13 143.00 67.59 104.03 56.39 61.59 92.04 96.24 65.69 5.73

NUMBER OF ANIMALS BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 11.

EV VALUE
155. 63. 26. 205. 143. 65. 104. 56. 82. 92. 90. 19. 0. 0. 1. 1220
0.0 0.0 48.72 191.05 66.40 25.01 200.75 122.04 200.19 66.45 40.24 63.64 66.27 58.11 25.09

NUMBER OF ANIMALS BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 19. 0. 0. 0. 19

ANIMALS TO BE HARVESTED BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

EV VALUE
24. 191. 60. 28. 263. 126. 56. 88. 46. 84. 66. 59. 10. 0. 0. 1012
0.0 0.0 40.78 23.01 197.25 65.07 105.48 47.11 12.51 36.07 45.02 40.43 21.13

NUMBER OF ANIMALS BY AGE CLASS
0. 0. 0. 0. 0. 0. 0. 0. 16. 0. 0. 0. 16

ANIMALS TO BE HARVESTED BY AGE CLASS

EV VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

NUMBER OF ANIMALS BY AGE CLASS

ANIMALS TO BE HARVESTED BY AGE CLASS

EN VALUE

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   0.   0.1

EN VALUE
85.   56.  149.  82.  80.   77.   18.  18.  122.  41.   13.  68.  30.  10.  14.63  14.11  54.93  0.   0.
16.35   2.33   0.0

NUMBER OF ANIMALS BY AGE CLASS
101.75  82.94  54.56  145.75  0.0

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   12.   2.   0.   0.14

EN VALUE
81.   83.   55.  149.   80.   79.  79.  15.   14.  95.  31.   5.  44.  4.   1.   0.   0.
34.55   2.95   0.03   0.0

NUMBER OF ANIMALS BY AGE CLASS
215.28  49.67  51.28  53.47  142.88  78.51  77.14  68.96  14.34  12.41  82.58  26.02  7.41

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   6

EN VALUE
140.  50.   81.   53.  143.   79.   77.  69.   14.  12.  83.  26.  7.  35.  3.   0.   0.
4.52   12.44   0.0   0.0

NUMBER OF ANIMALS BY AGE CLASS
174.40  136.85  40.88  79.65  52.40  140.02  76.94  67.88  59.99  12.13  10.18  64.42  18.73

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   5.   0.   0.   9

EN VALUE
87.  137.   49.   80.   52.  140.   77.  68.   60.  12.  10.  64.  19.  5.   3.   0.   0.
10.12   1.31   0.0   0.0

NUMBER OF ANIMALS BY AGE CLASS
103.18  85.46  134.11  78.06  51.35  121.42  62.32  54.31  46.79  9.14  6.92  41.87

ANIMALS TO BE HARVESTED BY AGE CLASS
0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   1.   0.   0.   9

EXECUTION TERMINATED   18:32:11   T=.58   RC=0   1.41

$SIGNOFF

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POSTSCRIPT

WHAT ARE WE

FOOLS TO BE

CLIMBING UP

THIS SHEET OF GLASS

THE WORLD

FOR WHICH TO SEE

WHEN WE CAN

STAND HERE BELOW AND

BEHOLD ALL WE WISH

TO KNOW.


AND WHEN THE NIGHT IS OVER

AND WHEN THE DAY IS DONE

SHALL OUR SILENT PASSING

BE NOTED BY A LOVED ONE

OR SHALL ALL OUR YEARNING

TO BETTER BE

PASS AWAY WITH HISTORY

ALONG WITH YOU AND ME.


SHALL THE KNOWLEDGE WE HAVE GATHERED

AND THE SKILLS WE HAVE POSSESSED

GIVE US PEACE AND HAPPINESS

WHEN WE ARE LAID TO REST.

-David Campbell-

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