MODELING THE COMMON CRANE (Grus grus) POPULATION WINTERING IN IBERIA

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Abstract. A field study carried out during the last seven years on a wintering population of Common Cranes (Grus grus) in Spain allowed us to gather accurate field data on certain relevant demographic parameters: (a) the size of the Western Palearctic population of this species is estimated to be around 40000 birds, and (b) the age composition in autumn is estimated for 1979-85 to be around 13.5% young. These data enabled us to develop and test a population dynamics model which combines the density- and age-dependent effects on productivity and survival rates. The parameters of the productivity and survival functions were varied within biologically reasonable limits. From the series of possible combinations we selected those that fitted our field data on population size and age structure best. Each variable was then varied to study their influence on the model.

INTRODUCTION

One of the fields in which mathematical models have been increasingly applied during the last years is wildlife ecology and management (e.g. Miller and Botkin 1974, Miller 1978, Johnson 1982). The complexity of animal population dynamics and the difficulty in measuring the many parameters involved, such as productivity and mortality rates, longevity, age of reproductive maturity and the effects of population density and age on them, make it very difficult to obtain a series of data long enough to detect and analyse the effects of natural or man-induced events that affect these animal populations. Mathematical models help understand the structure and function of the latter. This is particularly interesting in the case of vertebrate species that are K-strategists, i.e. have long maximum longevities, delayed reproductive maturities, low rates of increase and long generation times and, therefore, low replacement rates. This paper presents a first attempt to develop a population dynamic model for one of these species, the Common Crane (Grus grus), similar to those produced for the Sandhill Crane (Grus canadensis) (Miller et al. 1972, Johnson 1979) and the Whooping Crane (Grus americana) (Miller et al. 1974).

DEMOGRAPHIC PARAMETERS OF THE CRANE POPULATION

While some of the demographic parameters of the Common Crane have been recorded quite accurately during the last years, others remain unknown, mainly due to the lack of individually marked birds.

Field data

Two of the parameters used were obtained by two of us (J.C.A., J.A.A.) during 1979-85 at Gallocanta, one of the most important wintering areas of the Western Common Crane population.

Population size. During the last decades some authors have tried to census the Western European Crane population. The results are diverse and confuse: some are only partial censuses in staging areas, reaching maximal figures between 25000 and 30000 birds (e.g. Keil 1970, Alerstam and Bauer 1973); others are estimations in more or less wide areas of the species'breeding range. Only recently has it been possible to count the migrants while leaving Iberia in spring, with a total of 31945 birds (Alonso et al. 1986). Assuming a certain error in minus, we estimate in around 40000 cranes the size of this population, which coincides with estimations recently made in Central Europe (Prange 1984, and in litt.).

Winter age composition. Only two age classes can be distinguished in the field by their plumage, here called adults and juveniles. In the "adult" category we included all cranes in nonjuvenile plumage, i.e. more than one year old. The birds less than one year old were included in the "juvenile" category. The adult:juvenile ratio was recorded at random, including unselectively all flocks as they were found in the field. This age-ratio is only valid and representative of the whole population if a large number of birds can be aged each season in the same area and time and under approximately equal conditions. The study area was surveyed regularly throughout the whole season. In total we aged over 125000 cranes, of which only the 105973 aged during autumn migration and early spring migration are used in this study. For a more detailed sample selection procedure see Alonso & Alonso (in press). The unweighted average for the seven years is 13.54% (Table 1).

Table 1. Age composition of the Western Common Crane population

Year	1979	1980	1981	1982	1983	1984	1985
% juveniles	12.48	12.95	14.17	12.12	11.67	12.34	19.02
No. cranes aged	5890	6508	20301	17991	20917	12898	21468

Data from other sources

Some of the data necessary to develop a population dynamics model are very poorly known or still unknown, like age of first breeding, longevity and mortality. It would be very time-consuming to significantly increase the accuracy of these data. Therefore, as some acceptable data for these parameters are available of other crane species of the same genus, we have used them in the model.

Age of first breeding. Common Cranes have been reported to lay eggs at an age of three years, but on the basis of recent literature revisions (Walkinshaw 1973, Johnsgard 1983) and captive breeding experiences (Archibald pers. comm.) we assumed that they reach sexual maturity at an age of four years.

Longevity and mortality. Although there are some literature records of several species of cranes living more than 40 years in captivity, authors generally estimate maximum longevities of 20-25 years for natural populations (Walkinshaw 1973, Johnsgard 1983), and Binkley & Miller (1980) recently utilized 24 age-classes. We also assumed the existence of 24 age-classes.
Most classic bird population studies assumed constant adult mortality rates (Deevey 1947, Lack 1966). However, these are not in accordance with longevity data for certain species for which nowadays enough recoveries of banded birds are available. It seems more reasonable to assume an age-dependent mortality effect (Miller et al. 1972, Botkin & Miller 1974). A density-dependent effect on mortality is also generally accepted, which affects birds of every age and reproductive condition. Common Cranes have not yet been banded, for which there are no reliable data on the magnitude and causes of mortality. Some data are available for the Sandhill Cranes (Johnsgard 1983) although such values are surely overestimated due to the effect of hunting. Therefore we have used the age-specific survivorship values estimated for the non-hunted population of Whooping Cranes by Binkley & Miller (1980). These are based on annual censuses and age compositions of that population conducted since 1938.

MODEL DESCRIPTION

The model we have developed is a very simple one that describes the population dynamics of the species. The program was written in Basic Apple Soft and has been operated successfully by one of us (M.Q.) on an Apple II computer. Figure 1 presents a simplified causal diagram which accounts for the density-dependent effects of the population size on annual recruitment and survival rates. Figure 2 shows the complete flowchart of the model, including (a) the assumed 24 age-classes (see above, "Demographic parameters"), (b) the distinction between the first three nonreproductive age-classes and the rest of sexually mature cranes, and (c) the type of curves (=reverse logistic functions) that govern the density-dependent effects on recruitment and survival rates.
The crane population of level 1 (G00, see Appendix) is determined by the following two equations:

$$NAC = GTER * PRD$$

where NAC = number of births; GTER = number of sexually

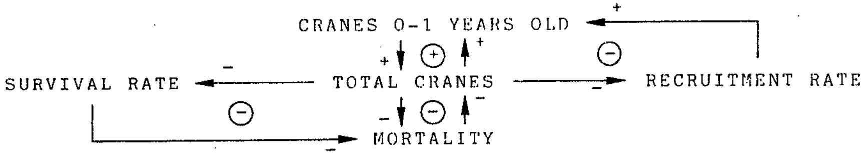

Figure 1. Simplified causal population model for the Common Crane.

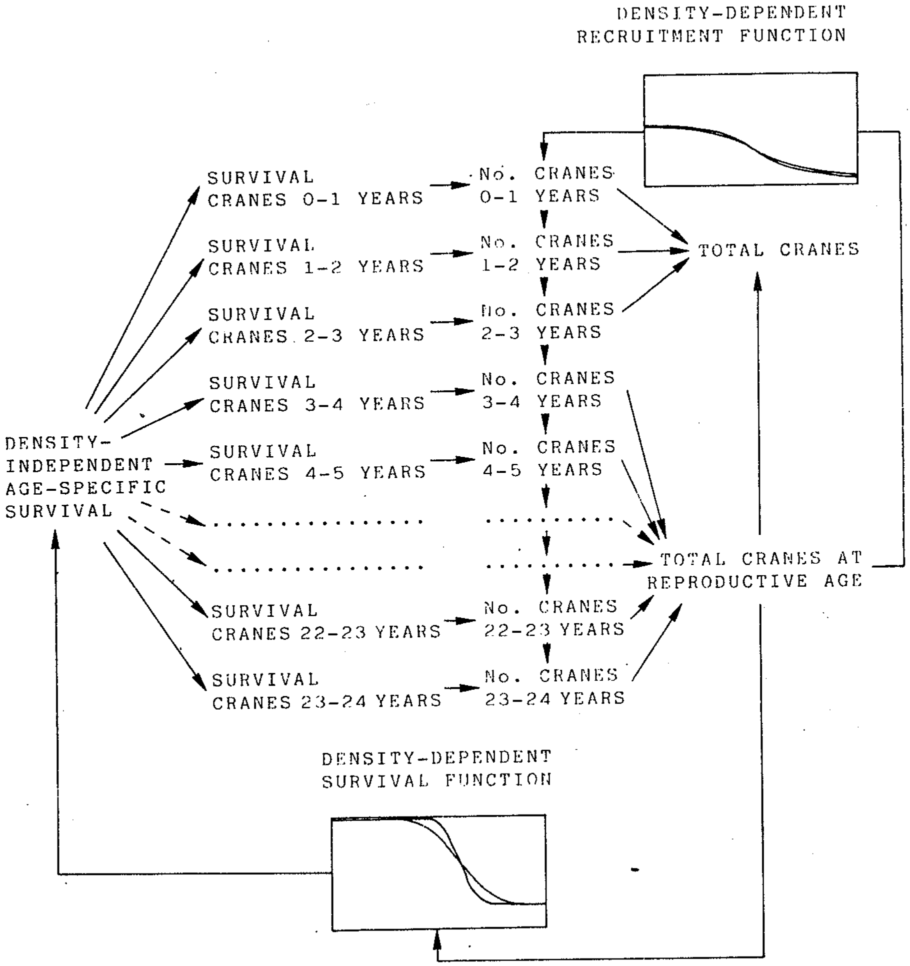

Figure 2. Flowchart of the Common Crane population model.

mature cranes; and PRD = productivity, or annual recruitment rate.

$$GOO = NAC$$

where GOO = number of cranes between 0 and 1 year old.
So, reproduction is simplified in the present model to a single process that depends only on the breeding population and their productivity expressed as recruitment of young birds to the winter population. The model ignores hatching and fledging success, for which no data are available.
The subsequent age-classes or levels are calculated as follows:

For I = 2 to 24, $$G(I) = G(I-1) * S(I-1)$$

where I = age-class, or level; G(I) = number of cranes of age I; and S(I) = survival rate of cranes at age I.
These density-independent survival rates are assumed to be different for each age-class considered (see above, "Demographic parameters") and each age-specific value is also affected by a reverse logistic function that accounts for the effect of population density on it: the survival rate declines at high population levels:

$$S(I) = PTMM * (1-TM(I)) + \frac{(1 - TM(I)) * (1 - PTMM)}{1 + e^{(A * (GTOTAL - GPIX)/1000)}}$$

where S(I) = survival rate of cranes at age I; PTMM = proportion between minimal and maximal assumed survival rates, i.e. lower and upper asymptotes of the logistic function; TM (I) = density-independent mortality at age I, or natural rate of deaths due to accidents, predation, etc.; A = parameter that regulates the rate of decline of the logistic curve; GTOTAL = total number of cranes in the population; and GPIX = number of cranes at the inflection point of the curve.
Recruitment rates are also assumed to be density-dependent, varying from high values at low population densities to low values as the population grows:

$$PRD = \frac{TMP}{1 + e^{(B * (GTOTAL - GPIX)/1000)}}$$

where PRD = recruitment rate of the population; TMP = maximal theoretical recruitment rate (see above, "Demographic parameters"); B = parameter that regulates the rate of decline; and GTOTAL and GPIX as in the preceeding equation.
This recruitment rate was applied only to sexually mature birds, i. e. $\geqslant$ 4 years old.
Each simulation was started with an initial population of 20000 cranes. This initial population was assumed to have an age-distribution identical to that calculated for the Whooping Crane by Binkley & Miller (1983). The model was then run for 50 years.
The initial values of the parameters A and B were estimated from the figures and equations given by Johnson (1979). Later, combinations of both parameters between 0.01 and 0.5 were tested. As these parameters govern the form of the logistic curve, it is virtually impossible to determine exactly their values with the data available at present.
PTMM regulates the effect of population density on survival: high values of this parameter indicate low density-dependence

of survivorship. We tested values of 0.5 to 0.9.
For GPIX, various values around the real size of the crane population have been considered (35000-60000), assuming that the latter is stable.
The values for TMP were estimated by four different ways:
(a) If we assume that each mature bird pairs in spring and each pair produces 2 chicks that would survive until their first winter, then from 100 cranes, 63.7 birds would be ⩾ 4 years old (following Binkley & Miller 1983) and could produce a maximum of 63.7 young, that would represent 39.1% of the next winter population.
(b) If instead of 2 young per reproductive pair we consider our field average of 1.35 young per pair, the maximum possible percentage of juveniles would be 30.1 %, also assuming that all mature birds breed.
(c) One may also assume that the annual recruitment observed for the Whooping Crane represents a maximal value, provided that the small population of this endangered species (18 birds in 1938, increasing up to 78 in 1980) should stay at the left extreme of the density-dependent inverse logistic function of recruitment. The average for these 43 years (1938-80) and this species is 14.5 % juveniles in the winter population.
(d) We could also consider the maximal percentage of juveniles observed for the Whooping Crane, which was 31.8 % in 1939.
We think, however, that possibility (d) may be influenced by the stochastic nature of the breeding process and should be therefore considered as an exceptionally high value, not representative for TMP in our deterministic model. Possibility (a) is also hardly representative, as it does not account for natural, density-independent losses of eggs and young up to the first winter, moment of the simulation start. Therefore, we have used as the most realistic values for TMP those comprised between 0.15 and 0.30.

RESULTS

We have tried a total of 221 combinations of the parameters of the survival and recruitment functions, and have selected those that yield (a) stabilized populations between 35000 and 45000 cranes, and (b) with percentages of juveniles of 13.54 ± 2.27 (= mean of the seven annual values measured in the field ± 95% confidence interval) (Table 2).

DISCUSSION

The model developed may seem mathematically too simple. This simplicity is mainly a consequence of the scarce data available on the demography of crane populations, particularly of the Common Crane. We are thus unable to narrow the variation margins of the multitude of possible combinations of these parameters sufficiently. Therefore, we must consider a relatively large series of plausible combinations of survival and recruitment curves that are consistent with the initially accepted conditions of population size and percentage of juveniles ((a) and (b), see Results).
A further limitation of the model is its deterministic nature.

Table 2. Values of the model variables that yield stabilized population sizes and age ratios similar to those observed in the field.

Trial No.	PTMM	A	GPIX x1000	TMP	B	GTOTAL	% JUV
1	0.5	0.2	50	0.2	0.2	37200	13.20
2	0.5	0.2	50	0.2	0.15	36400	12.75
3	0.7	0.15	50	0.2	0.15	35875	12.86
4	0.7	0.15	50	0.2	0.2	36850	13.27
5	0.7	0.15	50	0.2	0.3	37780	13.72
6	0.7	0.2	50	0.2	0.15	38440	12.39
7	0.7	0.2	50	0.2	0.2	39400	12.87
8	0.7	0.2	50	0.2	0.3	40380	13.43
9	0.8	0.15	50	0.2	0.15	38000	12.50
10	0.8	0.15	50	0.2	0.2	39100	12.91
11	0.8	0.15	50	0.2	0.3	40380	13.43
12	0.8	0.2	50	0.2	0.15	39900	12.06
13	0.9	0.15	50	0.2	0.15	40900	11.79

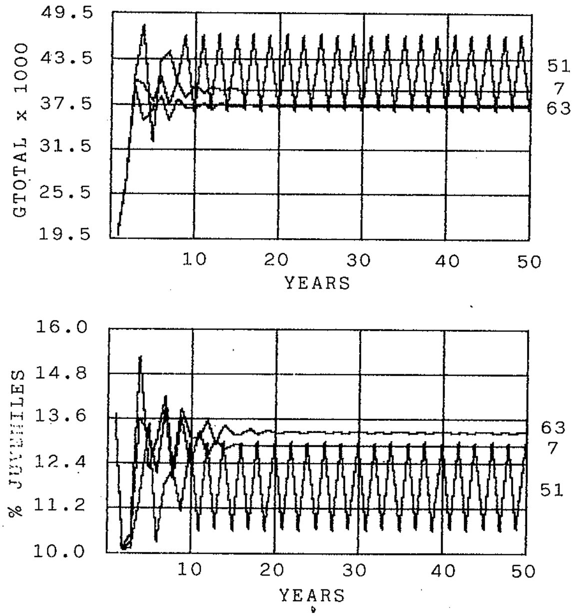

Fig. 3. Examples of simulations (trial number at right side of the diagrams) showing the effect of changing parameter PTMM from 0.7 (trial no. 7, accepted as one of the best simulations tested, see Table 2) to 0.5 (trial no. 63) or (trial no. 51) in the size of the crane population (left diagram), and the percentage of juveniles (right diagram).

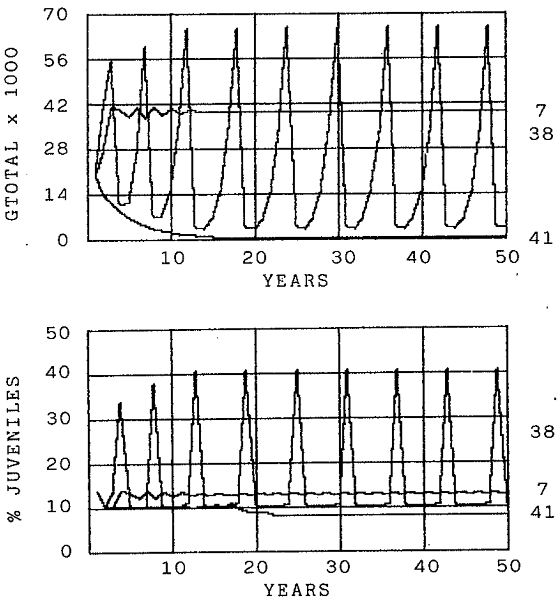

Fig. 4. As in Fig. 3, examples showing the effect of changing parameter TMP from 0.2 (trial no. 7) to 0.1 (trial no. 41) or 0.3 (trial no. 38).

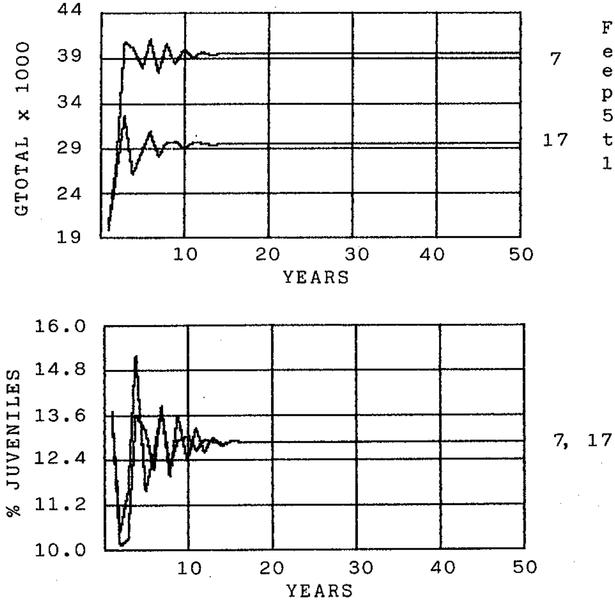

Fig. 5. As in Fig. 3, examples showing the effect of changing parameter GPIX from 50000 (trial no. 7) to 40000 (trial no. 17).

As claimed by Miller et al. (1972) and Johnson (1979), stochastic variability of biological processes related with crane demography cannot be modeled due to the lack of information on causal intercorrelations between environmental and populational variables.

Nevertheless, the model remains interesting and valid as a description of the population dynamics of this potentially threatened species, provided the difficulty of significantly improving the accuracy of most demographic parameters in a near future. It helps, as well, discover the kind of data that need further study most urgently, in order to try to manage the species properly. Although a sensitivity analysis remains to be done, the study of varying the model parameters already suggests some interesting preliminary conclusions. The value given to parameter PTMM, that governs the density-dependence effect on survival, depends entirely on the author criterion. So, the models of Miller et al. (1972) and Johnson (1979) differ in the relative importance of this parameter. In our model, as the value of PTMM increases, the population (GTOTAL) and the % juveniles present higher oscillations, the first around higher than normal values and the second around lower values (Fig. 3). Thus, a decrease in the relative importance of the density-dependence (= increase of PTMM) reduces, as expected, the self-regulating ability of the population. The best value of PTMM is 0.7 (Table 2 and Fig. 3), and 20% changes around this value determine changes of only approximately 5% in the size of the population and 3% in the percentage of juveniles.

Values of TMP lower than 0.10 determine the extintion of the population in less than 20 years, for every numerical combination of the other four parameters (Fig. 4). On the contrary, values higher than 0.20 determine high oscillations of the population size and percentage of juveniles. It is interesting to observe tha all values of annual recruitment measured in the field in the crane population and the most realistic values inferred from our species as well as from other crane species fall within these limits. This suggests similar demographic structures in the various crane species for which populational data are available. Also interestingly, the annual recruitment values measured are closer to the lower limit than to the higher of those inferred, perhaps suggesting a conservative behaviour of the crane population in the selection of the optimal productivity rate.

The parameter GPIX directly affects the stabilization level of the population size. Changes in the parameter between 40000 and 50000 change GTOTAL in the same sense and by identical magnitudes, but do not alter the % juveniles (Fig. 5). Higher values of GPIX determine very high oscillations of GTOTAL and % juveniles. Although we have used the same GPIX for both survival and recruitment functions, if different points are used in the same simulation, the results are different.

Changes in parameters A and B change GTOTAL and % juveniles in the same sense, although by lower magnitude.

CONCLUSIONS

We have developed a simple model that serves as an appropriate instrument for the description of the Common Crane population dynamics. The series of curves obtained do not exclude the possibility that other combinations exist. This model may be considered as a first attempt, with only preliminary results. The main limitations derive from the difficulty of obtainingcertain demographic parameters. The main advantage is the possibility of generating hypothesis and undertaking "natural experiments" on this basic model (determination of optimal population size depending on carrying capacity of breeding and wintering areas, predicting future trends of the population, etc.) and readjusting it to new data. A sensitivity analysis is necessary to determine the relative importance of the parameters used. The possibility remains of future incorporation of submodels that account for the stochastic variability due to natural events or human activities. The model presented could provide a basis for future research as well as guidelines for the management and conservation of the Common Crane in W-Europe.

ACKNOWLEDGEMENTS

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APPENDIX I. PROGRAM

```
5000  REM   ***MODELO GRULLAS-5***
5010  REM
5020  REM ***CODIGO DE VARIABLES***
5030  REM
5040  REM  G00=NUMERO DE GRULLAS ENTRE 0 Y 1 ANO(INDIVIDUOS),N,#01
5050  REM  G01=NUMERO DE GRULLAS ENTRE 1 Y 2 ANOS(INDIVIDUOS),N,#02
5060  REM  G02=NUMERO DE GRULLAS ENTRE 2 Y 3 ANOS(INDIVIDUOS),N,#03
5070  REM  G03=NUMERO DE GRULLAS ENTRE 3 Y 4 ANOS(INDIVIDUOS),N,#04
5080  REM  G04=NUMERO DE GRULLAS ENTRE 4 Y 5 ANOS(INDIVIDUOS),N,#05
5090  REM  G05=NUMERO DE GRULLAS ENTRE 5 Y 6 ANOS(INDIVIDUOS),N,#06
5100  REM  G06=NUMERO DE GRULLAS ENTRE 6 Y 7 ANOS(INDIVIDUOS),N,#07
5110  REM  G07=NUMERO DE GRULLAS ENTRE 7 Y 8 ANOS(INDIVIDUOS),N,#08
5120  REM  G08=NUMERO DE GRULLAS ENTRE 8 Y 9 ANOS(INDIVIDUOS),N,#09
5130  REM  G09=NUMERO DE GRULLAS ENTRE 9 Y 10 ANOS(INDIVIDUOS),N,#10
5140  REM  G10=NUMERO DE GRULLAS ENTRE 10 Y 11 ANOS(INDIVIDUOS),N,#11
5150  REM  G11=NUMERO DE GRULLAS ENTRE 11 Y 12 ANOS(INDIVIDUOS),N,#12
5160  REM  G12=NUMERO DE GRULLAS ENTRE 12 Y 13 ANOS(INDIVIDUOS),N,#13
5170  REM  G13=NUMERO DE GRULLAS ENTRE 13 Y 14 ANOS(INDIVIDUOS),N,#14
5180  REM  G14=NUMERO DE GRULLAS ENTRE 14 Y 15 ANOS(INDIVIDUOS),N,#15
5190  REM  G15=NUMERO DE GRULLAS ENTRE 15 Y 16 ANOS(INDIVIDUOS),N,#16
5200  REM  G16=NUMERO DE GRULLAS ENTRE 16 Y 17 ANOS(INDIVIDUOS),N,#17
5210  REM  G17=NUMERO DE GRULLAS ENTRE 17 Y 18 ANOS(INDIVIDUOS),N,#18
5220  REM  G18=NUMERO DE GRULLAS ENTRE 18 Y 19 ANOS(INDIVIDUOS),N,#19
5230  REM  G19=NUMERO DE GRULLAS ENTRE 19 Y 20 ANOS(INDIVIDUOS),N,#20
5240  REM  G20=NUMERO DE GRULLAS ENTRE 20 Y 21 ANOS(INDIVIDUOS),N,#21
5250  REM  G21=NUMERO DE GRULLAS ENTRE 21 Y 22 ANOS(INDIVIDUOS),N,#22
5260  REM  G22=NUMERO DE GRULLAS ENTRE 22 Y 23 ANOS(INDIVIDUOS),N,#23
5270  REM  G23=NUMERO DE GRULLAS ENTRE 23 Y 24 ANOS(INDIVIDUOS),N,#24
5280  REM  S00=TASA DE SUPERVIVENCIA DE G00(TANTO POR 1),F,#25
5290  REM  S01=TASA DE SUPERVIVENCIA DE G01(TANTO POR 1),F,#26
5300  REM  S02=TASA DE SUPERVIVENCIA DE G02(TANTO POR 1),F,#27
5310  REM  S03=TASA DE SUPERVIVENCIA DE G03(TANTO POR 1),F,#28
5320  REM  S04=TASA DE SUPERVIVENCIA DE G04(TANTO POR 1),F,#29
5330  REM  S05=TASA DE SUPERVIVENCIA DE G05(TANTO POR 1),F,#30
5340  REM  S06=TASA DE SUPERVIVENCIA DE G06(TANTO POR 1),F,#31
5350  REM  S07=TASA DE SUPERVIVENCIA DE G07(TANTO POR 1),F,#32
5360  REM  S08=TASA DE SUPERVIVENCIA DE G08(TANTO POR 1),F,#33
5370  REM  S09=TASA DE SUPERVIVENCIA DE G09(TANTO POR 1),F,#34
5380  REM  S10=TASA DE SUPERVIVENCIA DE G10(TANTO POR 1),F,#35
5390  REM  S11=TASA DE SUPERVIVENCIA DE G11(TANTO POR 1),F,#36
5400  REM  S12=TASA DE SUPERVIVENCIA DE G12(TANTO POR 1),F,#37
5410  REM  S13=TASA DE SUPERVIVENCIA DE G13(TANTO POR 1),F,#38
5420  REM  S14=TASA DE SUPERVIVENCIA DE G14(TANTO POR 1),F,#39
5430  REM  S15=TASA DE SUPERVIVENCIA DE G15(TANTO POR 1),F,#40
5440  REM  S16=TASA DE SUPERVIVENCIA DE G16(TANTO POR 1),F,#41
5450  REM  S17=TASA DE SUPERVIVENCIA DE G17(TANTO POR 1),F,#42
5460  REM  S18=TASA DE SUPERVIVENCIA DE G18(TANTO POR 1),F,#43
5470  REM  S19=TASA DE SUPERVIVENCIA DE G19(TANTO POR 1),F,#44
5480  REM  S20=TASA DE SUPERVIVENCIA DE G20(TANTO POR 1),F,#45
5490  REM  S21=TASA DE SUPERVIVENCIA DE G21(TANTO POR 1),F,#46
5500  REM  S22=TASA DE SUPERVIVENCIA DE G22(TANTO POR 1),F,#47
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5510  REM  !LA TASA DE SUPERVIVENCIA DE G23 ES 0!
5520  REM  GTER=TOTAL DE GRULLAS EN EDAD DE REPRODUCIRSE(INDIVIDUOS),A,#4
     8
5530  REM  PRD=PRODUCTIVIDAD,A,#49
5540  REM  GTOTAL=NUMERO TOTAL DE GRULLAS(INDIVIDUOS),A,#50
5550  REM  J%=PORCENTAJE DE GRULLAS JOVENES(TANTO POR 1),A,#51
5560  REM
5570  REM ***CODIGO DE PARAMETROS O TASAS***
5580  REM
5590  REM  PTMM=PROPORCION DE LA FUNCION DE SUPERVIVENCIA,#01
5600  REM  A=PARAMETRO DE LA FUNCION DE SUPERVIVENCIA(..),#02
5610  REM  GPIX=TAMANO DE LA POBLACION EN EL PUNTO DE INFLEXION(INDIVIDUO
     S),#03
5620  REM  TMP=TASA MAXIMA DE PRODUCTIVIDAD(TANTO POR 1),#04
5630  REM  B=PARAMETRO DE LA FUNCION DE PRODUCTIVIDAD(..),#05
5640  REM  TM00=TASA DE MORTALIDAD DE G00(TANTO POR 1),#06
5650  REM  TM01=TASA DE MORTALIDAD DE G01(TANTO POR 1),#07
5660  REM  TM02=TASA DE MORTALIDAD DE G02(TANTO POR 1),#08
5670  REM  TM03=TASA DE MORTALIDAD DE G03(TANTO POR 1),#09
5680  REM  TM04=TASA DE MORTALIDAD DE G04(TANTO POR 1),#10
5690  REM  TM05=TASA DE MORTALIDAD DE G05(TANTO POR 1),#11
5700  REM  TM06=TASA DE MORTALIDAD DE G06(TANTO POR 1),#12
5710  REM  TM07=TASA DE MORTALIDAD DE G07(TANTO POR 1),#13
5720  REM  TM08=TASA DE MORTALIDAD DE G08(TANTO POR 1),#14
5730  REM  TM09=TASA DE MORTALIDAD DE G09(TANTO POR 1),#15
5740  REM  TM10=TASA DE MORTALIDAD DE G10(TANTO POR 1),#16
5750  REM  TM11=TASA DE MORTALIDAD DE G11(TANTO POR 1),#17
5760  REM  TM12=TASA DE MORTALIDAD DE G12(TANTO POR 1),#18
5770  REM  TM13=TASA DE MORTALIDAD DE G13(TANTO POR 1),#19
5780  REM  TM14=TASA DE MORTALIDAD DE G14(TANTO POR 1),#20
5790  REM  TM15=TASA DE MORTALIDAD DE G15(TANTO POR 1),#21
5800  REM  TM16=TASA DE MORTALIDAD DE G16(TANTO POR 1),#22
5810  REM  TM17=TASA DE MORTALIDAD DE G17(TANTO POR 1),#23
5820  REM  TM18=TASA DE MORTALIDAD DE G18(TANTO POR 1),#24
5830  REM  TM19=TASA DE MORTALIDAD DE G19(TANTO POR 1),#25
5840  REM  TM20=TASA DE MORTALIDAD DE G20(TANTO POR 1),#26
5850  REM  TM21=TASA DE MORTALIDAD DE G21(TANTO POR 1),#27
5860  REM  TM22=TASA DE MORTALIDAD DE G22(TANTO POR 1),#28
5870  REM
5880  REM ***SISTEMA DE ECUACIONES ANALITICAS***
5890  REM
5900  REM  G00=GTER*PRD
5910  REM  G01=G00*S00
5920  REM  G02=G01*S01
5930  REM  G03=G02*S02
5940  REM  G04=G03*S03
5950  REM  G05=G04*S04
5960  REM  G06=G05*S05
5970  REM  G07=G06*S06
5980  REM  G08=G07*S07
5990  REM  G09=G08*S08
6000  REM  G10=G09*S09
6010  REM  G11=G10*S10
6020  REM  G12=G11*S11
6030  REM  G13=G12*S12
6040  REM  G14=G13*S13
6050  REM  G15=G14*S14
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```
6060  REM  G16=G15*S15
6070  REM  G17=G16*S16
6080  REM  G18=G17*S17
6090  REM  G19=G18*S18
6100  REM  G20=G19*S19
6110  REM  G21=G20*S20
6120  REM  G22=G21*S21
6130  REM  G23=G22*S22
6140  REM   S00=PTMM*(1-TM00)+((1-TM00)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6150  REM   S01=PTMM*(1-TM01)+((1-TM01)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6160  REM   S02=PTMM*(1-TM02)+((1-TM02)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6170  REM   S03=PTMM*(1-TM03)+((1-TM03)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6180  REM   S04=PTMM*(1-TM04)+((1-TM04)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6190  REM   S05=PTMM*(1-TM05)+((1-TM05)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6200  REM   S06=PTMM*(1-TM06)+((1-TM06)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6210  REM   S07=PTMM*(1-TM07)+((1-TM07)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6220  REM   S08=PTMM*(1-TM08)+((1-TM08)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6230  REM   S09=PTMM*(1-TM09)+((1+TM09)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6240  REM   S10=PTMM*(1-TM10)+((1-TM10)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6250  REM   S11=PTMM*(1-TM11)+((1-TM11)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6260  REM   S12=PTMM*(1-TM12)+((1-TM12)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6270  REM   S13=PTMM*(1-TM13)+((1-TM13)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6280  REM   S14=PTMM*(1-TM14)+((1-TM14)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6290  REM   S15=PTMM*(1-TM15)+((1-TM15)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6300  REM   S16=PTMM*(1-TM16)+((1-TM16)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6310  REM   S17=PTMM*(1-TM17)+((1-TM17)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6320  REM   S18=PTMM*(1-TM18)+((1-TM18)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6330  REM   S19=PTMM*(1-TM19)+((1-TM19)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6340  REM   S20=PTMM*(1-TM20)+((1-TM20)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6350  REM   S21=PTMM*(1-TM21)+((1-TM21)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
6360  REM   S22=PTMM*(1-TM22)+((1-TM22)*(1-PTMM)/(1+EXP(A*(GTOTAL-GPIX)/1
     000)))
```

```
6370  REM   PRD=(TMP/(1+EXP(B*(GTOTAL-GPIX)/1000)))
6380  REM  GTOTAL=GTER+G00+G01+G02
6390  REM
7000  REM ***SISTEMA DE ECUACIONES MDS***
7010  IF T <  > TI THEN 7030
7020  GOTO 7070
7030 VN(1) =  INT (VN(48) * VN(49) + .5)
7040  FOR I = 1 TO 23
7050 VN(I + 1) =  INT (VN(I) * VN(24 + I) + .5)
7060  NEXT I
7070 VN(48) = 0
7080  FOR I = 4 TO 24
7090 VN(48) = VN(48) + VN(I)
7100  NEXT
7105 VN(50) = VN(48) + VN(1) + VN(2) + VN(3)
7110  FOR I = 1 TO 23
7120 VN(I + 24) = TA(1) * (1 - TA(I + 5)) + (1 - TA(I + 5)) * (1 - TA(1))
      / (1 +  EXP (TA(2) * ((VN(50) - TA(3)) / 1000)))
7130  NEXT I
7140 VN(49) = TA(4) / (1 +  EXP (TA(5) * ((VN(50) - TA(3)) / 1000)))
7160 VN(51) =  INT ((VN(1) / VN(50) + .00005) * 10000) / 100
8000  RETURN
30000  REM
30010  REM ***DATOS ESTRUCTURALES***
30020  REM
30030  DATA  0001,0050,1,1
30040  DATA   24,28,51
30050  REM
30060  REM ***CONDICIONES INICIALES***
30070  REM
30080  DATA  2700,1620,1520,1420
30090  DATA  1340,1240,1160,1080
30100  DATA  1000,0920,0840,0760
30110  DATA  0680,0620,0540,0480
30120  DATA  0420,0360,0300,0240
30130  DATA   0200,0140,0092,0044
30140  REM
30150  REM ***VALORES DE PARAMETROS O TASAS***
30160  REM
30170  DATA  .7
30180  DATA   .2
30190  DATA   40000
30200  DATA   .20
30210  DATA   .2
30220  DATA  .3750,.0183,.0210,.0238
30230  DATA  .0222,.0347,.0344,.0376
30240  DATA  .0416,.0464,.0517,.0576
30250  DATA  .0647,.0725,.0826,.0939
30260  DATA  .1090,.1270,.1510,.1860
30270  DATA  .2370,.3220,.4910
```

```
31000  REM
31010  REM ***SIMBOLOS DE VARIABLES***
31020  REM
31030  DATA  G00,G01,G02,G03,G04
31040  DATA  G05,G06,G07,G08,G09
31050  DATA  G10,G11,G12,G13,G14
31060  DATA  G15,G16,G17,G18,G19
31070  DATA  G20,G21,G22,G23
31080  DATA  S00,S01,S02,S03,S04
31090  DATA  S05,S06,S07,S08,S09
31100  DATA  S10,S11,S12,S13,S14
31110  DATA  S15,S16,S17,S18,S19
31120  DATA  S20,S21,S22
31130  DATA   GTER,PRD,GTOTAL
31135  DATA   J%
31140  DATA  PTMM,A,GPIX,TMP,B
31150  DATA  TM00,TM01,TM02,TM03,TM04
31160  DATA  TM05,TM06,TM07,TM08,TM09
31170  DATA  TM10,TM11,TM12,TM13,TM14
31180  DATA  TM15,TM16,TM17,TM18,TM19
31190  DATA  TM20,TM21,TM22
```