Coyrab Version I

U.S. International Biological Program

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MODELS

COYRAB

VERSION 1

MODELLING REPORT SERIES NUMBER 3
THE PREPARATION OF THIS MODEL WAS WHOLLY SUPPORTED THROUGH THE US/IBP DESERT BIOME PROGRAM, UNDER GRANT # GB 15886 FROM THE NATIONAL SCIENCE FOUNDATION.
INTRODUCTION

Reports in this series are intended for internal use by Desert Biome collaborators. They are not to be quoted or referred to in formal publications. These reports have been produced by the Desert Biome Modelling Group, with the assistance of participants in the Desert Biome and other researchers.

The main function of the models, at this stage of their development, is to provide guidance in the research efforts of the Biome. Therefore, it will be noted that most of the information which they contain is fragmentary evidence, best available estimates, arbitrary assumptions or non-Biome supported research. The collection and incorporation of more accurate data will come after these models have been prepared in this form. Validation of the models will also come later.

Any use of the models must recognize the limitations imposed by their development at this early stage of research.

1. Biological interpretations must be performed with extreme caution. Output, for example, should be viewed in relation to system behavior (stability, general time relationships, relative magnitude of the variables, general responses to parameter modifications, etc.). These properties should be related to the processes incorporated in the model structure. No particular significance should be attached to the specific numbers given as output.

2. Data included in these models must not be used without explicit approval of the investigators who have supplied them to us. Please contact the Desert Biome Central Office for details.

3. The material contained in the models does not constitute publication. It is subject to revision. The modeling group requests that this material not be cited without their expressed permission.

As particular models are revised we will be re-issuing them in new versions. The versions will be numbered according to the general scheme:

Version 1. Models which have been developed by the modeling group in isolation from subject area specialists who have provided the question which has been modeled.

Version 2. Models revised to incorporate subject-areas specialist's criticisms.

Version 3. Models revised to incorporate finds of biome-sponsored research.
'Default' values of rabbit and coyote parameters are set.  2-5
'DATA1: GET DATA COPY' for over-riding the above default initializations for 5
a given set of runs.
Start of 'TEST' loop for multiple runs and 'DATA2: GET DATA COPY' for changing 6
parameter values from one run to the next.
Start year loop.  7
Determine rabbit litter regime as a function of 'weather' and begin 8
ten-day-interval loop.
Begin coyote procedure: advance young to adults at beginning of year. 9
Coyote reproduction and young/adult food demands per 30-day interval. 10
Determine food availability, compare intake with demand, and update 11
young/adult body weights.
Determine man-induced mortality rates for both young and adult coyotes 12
and compute total adult mortality.
Compute total young mortality and end coyote procedure. 13

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Begin rabbit procedure: determine vegetation consumed, advance young rabbits to adults in October, and adjust rabbit numbers due to coyote predation.

Rabbit disease.

Advance young cohorts, apply young mortality and start reproduction section.

Reproduction and adult mortality.

Output statements and end of program.
I* /RUN RABBIT RUN /

C0YRAB: PROC OPTIONS (MAIN):

ON ERROR PUT PAGE DATA:

******************************************************************************

/*

* ASU-EG1
*
* PROCEDURE COYRAB
*
* NORM SLADE AND CURTIS WILCOCK
*
* VERSION 1 APRIL 21, 1971
*
* PUNCH = 029
*
* PL/I 05/360
*
*
* THIS PROGRAM INCORPORATES THE MODEL OF STODDARD, WAGNER, AND CLARK DEVELOPED FOR COYOTE-JACKRABBIT INTERACTIONS IN CURLEW VALLEY, UTAH. IT WILL PRODUCE RABBIT POPULATION DATA WITH OR WITHOUT COYOTES IN THE MODEL. IN ADDITION A DISEASE EFFECT HAS BEEN INCLUDED TO CAUSE FLUCTUATIONS IN RABBIT POPULATIONS. RABBIT ALSO CALCULATES VEGETATION CONSUMED AND COULD BE USED TO ASSESS THE EFFECTS OF RABBITS AND COYOTES ON RANGE FORAGE.

******************************************************************************

/* THE FOLLOWING FOUR CARDS ARE USED FOR THE RANDOM NUMBER GENERATOR AND SHOULD BE VARIED AS NEEDED AT OTHER FACILITIES.

******************************************************************************

DCL RAND ENTRY (FLOAT,FLOAT) RETURNS (FLOAT);
DCL RANDSET ENTRY (FIXED BIN (31),FIXED BIN (31));
DCL LR FIXED BIN (31) INIT (5234789);
DCL ISEED FIXED BIN (31) INIT (2345521);

******************************************************************************

/* ENTER THE DEFAULT TEN-DAY INTERVALS WHEN RABBIT LITTERS WILL BE BORN. IN THIS CASE FIVE LITTERS WILL BE USED.

******************************************************************************

DCL LITTER_TIME (15) FIXED INIT (7,11,15,19,23);

******************************************************************************

/* ENTER THE DEFAULT FOR REDUCTION IN LATE RABBIT LITTERS DUE TO DROUGHT. IN THIS CASE THEY WILL BE 25% OF NORMAL.

******************************************************************************

DCL LITTER_REDUCTION FLOAT INIT (.25);

******************************************************************************

/* PERCENT GRASS IN DIET REFERS TO THE PROPORTION OF VEGETATION CONSUMED BY RABBITS WHICH IS GRASS. THIS IS THOUGHT TO BE THE IMPORTANT IMPACT OF RABBITS ON CATTLE RANGE. THE SUBSCRIPT REFERS TO 10-DAY INTERVAL.

******************************************************************************

DCL PERCENT_GRASS_Diet (36) FLOAT DEC INIT (110.005,118.8,5847, .57,.461,.349,.235,.122,.025);
DATA DESCRIPTION:

**I* RUN RABBIT RUN

THE FOLLOWING DECLARATIONS ARE ONLY FOR VARIABLE TYPES AND DON'T SET INITIAL VALUES.

DCL COYOTE_DATA (2) CHAR(120) VAR;
DCL MOTHER_MUMP_DEMAND (12) FLOAT DEC INIT (1.1, 1.2, 1.3, 1.9, 1.0);
DCL WINTER_BIT (1)
DCL NEW_CASES FLOAT DEC INIT (0)
DCL DISEASE_BIT (1) INIT (0)
DCL EPIZOOTIC_BIT (1)
DCL EPIZOOTIC_DURATION FIXED INIT (6)
DCL SNOW_FALL, DRY_SUMMER BIT (1)
DCL ITEN_DAY INTERVAL, AGE, TEST, YEAR) FIXED BIN;
DCL (#RUNS, YEARS_PER_RUN) FIXED BIN

ENTER CONSUMPTION FIGURES IN GMS/RABBIT/10-DAYS BY AGE GROUP.
THE CONSUMPTION CURVE GENERATED BY THESE DATA FOLLOWS THE EQUATION OF
HASKELL & REYNOLDS (1947) & IS MODIFIED TO FIT DATA FROM
CURLEW VALLEY INCLUDING MASTAGE (CURRIE & GOODWIN, 1966).
THE FIRST 19 AGE GROUPS ARE YOUNG FROM 5 TO 185 DAYS OLD BY
TEN-DAY INTERVAL AND THE TWENTIETH CONTAINS ALL OLDER RABBITS

DCL (C(20) FLOAT DEC (4) INIT (0, 0, 20, 30, 70, 95, 95, 130, 1280, 1420, 1540, 1630, 1650, 1790, 1850, 1890, 1930, 1960, 1980, 1990, 2000));

ESTABLISH AN ARRAY OF 19 AGE GROUPS OF YOUNG RABBITS IN 10-DAY INTERVALS.

YOUNG_RABBITS (19) FLOAT DEC INIT (19) 0;

THERE ARE TWO SETS OF RABBIT LITTER SIZES FROM THE CURLEW DATA.
THE FIRST LINE IS LITTER SIZES OF 5 LITTERS UNDER WHAT WE
HAVE CALLED THE INFLUENCE OF DISEASE CARRY-OVER (EPIZOOTIC).
THE SECOND LINE OF 5 LITTERS IS THE LITTER SIZES OBSERVED
AFTER A DECLINE IS NEARLY OVER.

LITTER_SIZE (2, 5) FLOAT (3) INIT (1.0, 4.4, 5.4, 5.0, 0.0)
1.0, 5.2, 6.2, 3.3, 0.31;
/* RUN RABBIT RUN */

THE FOLLOWING ASSIGNMENT STATEMENTS ESTABLISH DEFAULT VALUES FOR ALL VARIABLE PARAMETERS IN THE PROGRAM. COMMENTS ARE INSERTED ONLY WHERE NAMES AREN'T SELF-EXPLANATORY.

ANNUAL_GRASS_LOSS = 0;
REPORT = 1;
#RUNS = 1;
YEARS_PER_RUN = 5;

PUT STRING (COYOTE_DATA(1)) EDIT ('TIME ADULT COYOTES YOUNG COYOTES', 'ES ADULT BODY WT YOUNG BODY WT RABBITS EATEN ALT PREY EATEN') (A);  

COYOTE ASSIGNMENTS

AVAILABILITY_MAX=0.2; /* RABBIT AVAILABILITY AT MAX DENSITY */
AVAILABILITY_MIN=0.2; /* RABBIT AVAILABILITY AT MIN DENSITY */
RABBIT_MAX=400; /* MAX RABBIT DENSITY (RAB/SQ.M) */
RABBIT_MIN=50; /* MIN RABBIT DENSITY (RAB/SQ.M) */
ALTERNATE_PREY_AVAILABILITY=0.10;
FOOD_SHARING_RATIO=1.12;
BASAL_RESPIRATION=21; /* RABBITS/COYOTE/30 DAYS */
BREED_MAX=4.8; /* MEAN FECUNDITY AT FULL BODY WEIGHT */
BREED_MIN=1.5; /* MEAN FECUNDITY AT MINIMUM BODY WEIGHT */
WEIGHT_MAX=16.0; /* KILOGRAMS */
WEIGHT_MIN=0.10; /* KILOGRAMS */
C=0.086; /* USE IN HUNTING DRIVE EQUATION */
HUNTING_DRIVE_MIN=0.8; /* USE IN HUNTING DRIVE EQUATION */
HUNTING_DRIVE=0.95; /* USE IN ADULT_MINIMUM_WEIGHT EQ */
F_ADULT=0.80; /* USE IN ADULT_MINIMUM_WEIGHT EQ */
F_YOUNG=0.90; /* USE IN YOUNG_MINIMUM_WEIGHT EQ */
ADULT_MAX_MORT_NATURAL=0.10; /* ALL MORTALITIES ARE RATIOS/30 DAYS */
ADULT_MIN_MORT_NATURAL=0.01;
YOUNG_MAX_MORT_NATURAL=0.15;
YOUNG_MIN_MORT_NATURAL=0.02;
AMORT_WINTER=0.091;
AMORT_SUMMER=0.06;
AMORT_WINTER=0.091;
AMORT_SUMMER=0.06;
ALTERNATE_PREY_INITIAL = 75; /* ALTERNATE PREY/SQUARE MILE */
RABBITS_EATEN = 0.0;

MAX_DURATION IS THE TIME LIMIT IN YEARS FOR THE EPIZOOTIC EFFECT ON LITTER SIZE. BECAUSE THE TEST STATEMENT USES <, A VALUE OF 6 GIVES A DURATION OF 5 YEARS.

MAX_DURATION = 6;
P_SNOW_FALL = .1 ;
P_DRY_SUMMER = .5 ;
P_DISEASE = .5 ;

DISEASE_TIME = 20 ;

RATE_OF_SPREAD = .998 ;
#LITTERS = 5 ;
MATURATION_DATE = 30 ;

PERCENT_FOR_E = .25 ;

DATA1: GET DATA COPY ;
The following declarations are used for the graphing routine:
- Each year, for a run of any length, this output is preferably to the standard table. To get a table one must put REPORT=2 in the first data field of the first data card along with #RUNS.

DCL ROUNDS (4) INIT (3,0,400,0), DIVE2 FLOAT, NDIVE2 (2) INIT, ALINE(701) CHAR(1), SYMRF(2) CHAR(1) INIT('C', 'R');
DCL YLABELS (2) CHAR (10) INIT ('COYOTES', 'RABBITS');

TEST is a loop for varying parameters from run to run.

THE DEFAULT VALUES FOR NEW CASES OF DISEASE, ADULT RABBITS, COYOTES, & YOUNG RABBITS ARE ESTABLISHED AND BOTH DISEASE & EPIZOOTIC ARE MADE FALSE.

NEW_CASES = 0;

INITIALIZE COYOTE PROCEDURE VARIABLES:

ADULT_COYOTES=61; /* ADULT COYOTES/SQUARE MILE */
ADULT_BODY_WEIGHT=15.0; /* KILOGRAMS */
YOUNG_COYOTES=2.21; /* YOUNG COYOTES/SQUARE MILE */
YOUNG_BODY_WEIGHT=16.0; /* KILOGRAMS */
ADULT_RABBITS=255; /* RABBITS/SQUARE MILE */
YOUNG_RABBITS(1) = 0;
EPIZOOTIC_DURATION = MAX_DURATION;
DISEASE = "O";
IF TEST = 1 THEN PUT SKIP(2); ELSE PUT PAGE;

DATA2 allows modification of any of the parameters from one run to the next. If no modifications are desired enter a blank & a semicolon on the data card. All deviations from default are used. All values initialized or assigned before the first GET DATA and changed in a run must be reset to default on the next. If one wishes to run coyotes alone set total rabbits = 0 for each run desired; if rabbits alone, set adult coyotes = 0.
/* RUN RABBIT RUN */

/* PRINT REPORT-2 GRAPH HEADINGS */

IF REPORT = 2 THEN DO:
  PUT PAGE EDIT ("GRAPH OF COYOTE AND RABBIT NUMBERS AT THE END", (COL(31), A));
  PUT SKIP EDIT ("MINIMUM", "MAXIMUM", "GRAPHING", (COL(31), A), (COL(59), A, COL(92), A));
  DO I = 1 TO Z;
    J = 2 * I;
    DIV(J, (BOUNDS(J-1)-BOUNDS(J+1))/70;
    PUT SKIP EDIT (YEAR, LABELS(I), (BOUNDS(J), A, COL(149), A, COL(61), A, COL(71), A, COL(90), A, COL(117), A));
  ENDO;
END:
END:

/* PRIME RANDOM NUMBER GENERATOR */

CALL RANDSET(IR, ISeed):

/* THERE ARE 19 AGE CLASSES OF YOUNG RABBITS BUT ONLY PART OF THE */
/* ARRAY MAY HAVE DATA AT ANY ONE TIME, NB & NE ARE THE */
/* LIMITS OF THE PART OF THE YOUNG RABBIT ARRAY WHICH HOLDS DATA */
/* BECAUSE NE MIGHT BE INTERPRETED AS NOT EQUAL, THE DO */
/* CHARACTER OPTION MUST BE SPECIFIED WHEN RUNNING. */

NB = 1; NE = 1;

/* COMPUTE COYOTE EQUATION PARAMETERS */

ADULT_MAXIMUM_HEIGHT = WEIGHT_MAXIMUM;
ADULT_MAXIMUM_WEIGHT = F_4 * ADULT_MAXIMUM_HEIGHT;
ADULT_MAXIMUM_WEIGHT = ADULT_MAXIMUM_WEIGHT;
OPTIMUM_GROWTH_RATE = (WEIGHT_MAXIMUM - BIRTH_WEIGHT)/8;
C = BIRTH_MAX - 4 * WEIGHT_MAXIMUM;
D1 = RABBIT_MX * AVAILABILITY_MIN / RABBIT_MAX - RABBIT_MIN;
O2 = (AVAILABILITY_MAX - AVAILABILITY_MIN) / (RABBIT_MAX - RABBIT_MIN);

/* START YEAR */

DO YEAR = 1 TO YEARS_PER_RUN:

*/

*_ALTERNATE_PREY = _ALTERNATE_PREY_INITIAL;
I* *I
/* PUT HEADINGS FOR THE YEAR AT TOP OF PAGE */
I* *I
I********************************************I
IF REPORT=1 THEN
  IF YEAR = 1 THEN PUT SKIP(2) DATA (TEST,YEAR);
  ELSE PUT PAGE DATA (TEST,YEAR);
IF TOTAL_RABBITS <= 0 THEN GO TO TOI;
EPIZOOTIC_DURATIUN = EPIZOOTIC_DURATIUN + 1 ;
IF ~ DISEASE THEN FATALITIES = 0.0;
I********************************************I
* SELECT RANDOM NUMBERS FOR DETERMINING RABBIT LITTER SIZES FOR THE *
* YEAR. RAND IS A FUNCTION SUBROUTINE THAT RETURNS A RANDOM *
* NUMBER BETWEEN ZERO & ONE. *
I********************************************I
X = RAND;
SNOW_FALL = X < P_SNOW_FALL ;
X = RAND;
DRY SUMMER= X < P_DRY SUMMER ;
I********************************************I
IF EPIZOOTIC THEN LITTER_REGIME = 1;
ELSE LITTER_REGIME = 2 ;
IF REPORT=1 THEN DO;
  PUT EDIT ('FORAGE LOSS') (COL=97, A); put ;
  PUT SKIP EDIT ('TIME', , 19 AGE CLASSES OF YOUNG RABBIT', , 'ADULTS', 'CASES', 'TOTAL', 'GAESS') (A(4), X(22), A(11), X(22)
  , A(0), X(2), A(5), X(2), A(5), X(5), A(5));
END;
I********************************************I
* CYCLE THROUGH YEAR BY TEN DAY INTERVALS *
I********************************************I
TOI: DO TEN_DAY_INTERVAL = 1 TO 36;
/* RU~ RARBIT RUN */

/* COYOTE PROCEDURE */

COYOTE: IF MOD(TEN_DAY_INTERVAL+2,3)=0 & ADULT_COYOTES>0 THEN CC;

IF TEN_DAY_INTERVAL = 1 THEN DO;

125 JJ=2;

127 COYOTE: IF MOD(TEN_DAY_INTERVAL+2,3)=0 & ADULT_COYOTES>0 THEN CC;

129 JJ=2;

130 /* ADVANCE YOUNG TO ADULTS AND SET APPROPRIATE VARIABLES TO ZERO */

ADULT_MAXIMUM_WEIGHT=(ADULT_MAXIMUM_WEIGHT*ADULT_COYOTES+YOUNG_MAXIMUM_WEIGHT*YOUNG_COYOTES)/ADULT_COYOTES;

ADULT_MINIMUM_WEIGHT=ADULT_MINIMUM_WEIGHT*ADULT_COYOTES;

YOUNG_COYOTES=YOUNG_COYOTES+0.;

YOUNG_BODY_WEIGHT=YOUNG_BODY_WEIGHT+0.;

YOUNG_MAXIMUM_WEIGHT=0.;

YOUNG_MINIMUM_WEIGHT=0.;

YOUNG_RESPIRATION=0.;

YOUNG_DEMAND=0.;

TOTAL_YOUNG_FOOD_DEMAND=0.;

TOTAL_RABBITS_EATEN=0.;

END;
RUN RABBIT RUN

/* RUN RABBIT RUN */

/*****************************************************************************/
/** AA AND BA ARE USED IN THE ADULT COYOTE NATURAL MORTALITY EQUATION **/
/*****************************************************************************/
141 ADULT_MINIMUM_RESPIRATION = BASAL_RESPIRATION * ADULT_MINIMUM_WEIGHT / WEIGHT_MAXIMUM;
142 AA = (ADULT_MIN_MORT_NATURAL - ADULT_MAX_MORT_NATURAL) / (ADULT_MAXIMUM_WEIGHT - ADULT_MINIMUM_WEIGHT);
143 BA = ADULT_MIN_MORT_NATURAL - AA * ADULT_MAXIMUM_WEIGHT;

/*****************************************************************************/
/** SEE IF IT IS WINTER **/
/*****************************************************************************/
144 WINTER = (TEN_DAY_INTERVAL <= 6 I TEN_DAY_INTERVAL >= 31);

/*****************************************************************************/
/** COYOTE REPRODUCTION **/
/*****************************************************************************/
145 IF TEN_DAY_INTERVAL = 10 THEN DO;
146 COYOTE_MEAN_FECUNDITY = MAX(0, 0.4 * ADULT_BODY_WEIGHT + 5);
147 YOUNG_COYOTES = 0.5 * ADULT_COYOTES * COYOTE_MEAN_FECUNDITY;
148 YOUNG_BODY_WEIGHT = BIRTH_WEIGHT;
149 END;

/*****************************************************************************/
/** COMPUTE YOUNG COYOTE FOOD DEMAND **/
/*****************************************************************************/
150 IF YOUNG_COYOTES ~= 0 THEN DO;
151 YOUNG_MAXIMUM_WEIGHT = MIN(ADULT_MAXIMUM_WEIGHT, YOUNG_BODY_WEIGHT + OPTIMUM_GROWTH_RATE);
152 YOUNG_MINIMUM_WEIGHT = YOUNG_MIN_MORT_NATURAL - AA * YOUNG_MAXIMUM_WEIGHT;
153 YOUNG_RESPIRATION = BASAL_RESPIRATION * 0.5 * YOUNG_BODY_WEIGHT + YOUNG_MAXIMUM_WEIGHT / WEIGHT_MAXIMUM;
154 YOUNG_DEMAND = YOUNG_RESPIRATION * YOUNG_MAX_MORT_NATURAL-YOUNG_MIN_MORT_NATURAL / YOUNG_MAXIMUM_WEIGHT;
155 TOTAL_YOUNG_FOOD_DEMAND = YOUNG_DEMAND * YOUNG_COYOTES;
156 END;

/*****************************************************************************/
/** COMPUTE ADULT COYOTE FOOD DEMAND **/
/*****************************************************************************/
157 ADULT_RESPIRATION = BASAL_RESPIRATION * ADULT_BODY_WEIGHT / WEIGHT_MAXIMUM + MOTHERHOOD_DEMAND * (TEN_DAY_INTERVAL + 21 / 3);
158 ADULT_DEMAND = ADULT_RESPIRATION * ADULT_MAXIMUM_WEIGHT / ADULT_MINIMUM_WEIGHT;
159 TOTAL_ADULT_FOOD_DEMAND = ADULT_DEMAND * ADULT_COYOTES;
160 TOTAL_FOOD_DEMAND = TOTAL_ADULT_FOOD_DEMAND + TOTAL_YOUNG_FOOD_DEMAND;
/* RUN RABBIT RUN */

#define TOTAL_AVAILABLE_FOOD /*
#define ALTERNATE_FOOD_SOURCE /*
#define RABBIT_AVAILABILITY /*
#define PREDATION_RATE /*
#define HUNTING_DRIVE_MIN /*
#define HUNTING_DRIVE_MAX /*
#define TOTAL_RABBITS /*
#define ALTERNATE_Prey /*
#define TOTAL_ALTERNATE_FOOD SOURCE /*
#define TOTAL_FOOD_OEAND /*
#define TOTAL_FOOD_DEMAND /*
#define ADULT_MAXIMUM_WEIGHT /*
#define ADULT_MINIMUM_WEIGHT /*
#define TOTAL_AVAI_ABLE_FOOD /*
#define ADULT_BUDY_WEIGHT /*
#define ADULT_RESPIRATION /*
#define YOUNG_BODY_WEIGHT /*
#define YOUNG_RESPIRATION /*

OPTIMUM_HUNTING_WEIGHT = HUNTING_DRIVE * ADULT_MAXIMUM_WEIGHT;
HUNTING_DRIVE = MAX(HUNTING_DRIVE_MIN, 1.0 - 3.5 * (TOTAL_RABBITS) * (TOTAL_FOOD_DEMAND) / TOTAL_FOOD_OEAND);

IF RABBIT_AVAILABILITY > AVAILABILITY_MAX THEN
  RABBIT_AVAILABILITY = AVAILABILITY_MAX;
ELSE IF RABBIT_AVAILABILITY < AVAILABILITY_MIN THEN
  RABBIT_AVAILABILITY = AVAILABILITY_MIN;

AVAILABLE_RABBITS = RABBIT_AVAILABILITY * TOTAL_RABBITS;
POTENTIAL_RABBIT_CATCH = AVAILABLE_RABBITS * HUNTING_DRIVE;

ALTERNATE_FOOD_SOURCE = ALTERNATE_Prey * ALTERNATE_FOOD_SOURCE;
TOTAL_AVAILABLE_FOOD = TOTAL_AVAILABLE_FOOD + POTENTIAL_RABBIT_CATCH + ALTERNATE_FOOD_SOURCE;

COMPAR E TOTAL_FOOD_OEAND WITH TOTAL_AVAILABLE_FOOD AND SEE

IF SOME COYOTES GO HUNGRY

IF TOTAL_AVAILABLE_FOOD < TOTAL_FOOD_OEAND THEN DO;
  COYOTE_DATA(JJ) = 'SOME COYOTES GO HUNGRY';
  JJ = JJ + 1;
END;

ADULT_INTAKE = MIN(TOTAL_ADULT_FOOD_DEMAND, 
  FODD_SHARING_RATI0 * (TOTAL_ADULT_FOOD_DEMAND / TOTAL_FOOD_OEAND) / TOTAL_AVAILABLE_FOOD, 
  TOTAL_FOOD_OEAND - TOTAL_FOOD_OEAND);

YOUNG_INTAKE = MIN(TOTAL_AVAILABLE_FOOD - ADULT_INTAKE, 
  TOTAL_YOUNG_FOOD_OEAND);

TOTAL_PREY_EATEN = YOUNG_INTAKE + ADULT_INTAKE;

RABBITS_EATEN = MIN(POTENTIAL_RABBIT_CATCH, TOTAL_PREY_EATEN);

ALTERNATE_PREY_EATEN = TOTAL_PREY_EATEN - RABBITS_EATEN;

TOTAL_RABBITS_EATEN = TOTAL_RABBITS_EATEN + RABBITS_EATEN;

#_ALTERNATE_PREY = #_ALTERNATE_PREY - ALTERNATE_PREY_EATEN;

COMPUTE NEW BODY WEIGHTS FOR ADULTS AND YOUNG ON THE BASIS OF

ADULT_NEW_WEIGHT = ADULT_BUDY_WEIGHT + RABBIT_CONVERSION_WEIGHT * (ADULT_INTAKE / ADULT_CCYOTES * ADULT_RESPIRATION);

IF YOUNG_CCYOTES = 0 THEN
  YOUNG_NEW_WEIGHT = YOUNG_BUDY_WEIGHT + RABBIT_CONVERSION_WEIGHT * (YOUNG_INTAKE / YOUNG_CCYOTES * YOUNG_RESPIRATION);

PAGE 11
RUN RABBIT RUN

---

191

IF WINTER THEN DO:
193     ADULT_MORTALITY_MAN=AMORT_WINTER;
194     IF YOUNG_COYOTES ^= 0 THEN
195         YOUNG_MORTALITY_MAN=YMORT_WINTER;
196 ENDO;
197 ELSE DO:
198     ADULT_MORTALITY_MAN=AMORT_SUMMER;
199     IF YOUNG_COYOTES ^= 0 THEN
200         YOUNG_MORTALITY_MAN=YMORT_SUMMER;
201 ENDO;

---

202 IF ADULT_NEW_WEIGHT >= ADULT_MINIMUM_WEIGHT THEN DO:
204     ADULT_BODY_WEIGHT=ADULT_NEW_WEIGHT;
205     ADULT_MORTALITY_NATURAL=AA*ADULT_BODY_WEIGHT+BA;
206 ENDO;
207 ELSE DO:
208     AVERAGE_ADULT_RESPIRATION=0.5*ADULT_RESPIRATION+
209         ADULT_MINIMUM_RESPIRATION;
210     ADULT_MAX_NUMBERS=MIN(AADULT_COYOTES,ADULT_INTAKE+
211         ADULT_BODY_WEIGHT-ADULT_MINIMUM_WEIGHT)/
212         RABBIT_CONVERSION_WEIGHT/AVERAGE_ADULT_RESPIRATION;
213     ADULT_BODY_WEIGHT=ADULT_MINIMUM_WEIGHT;
214     ADULT_MORTALITY_NATURAL=ADULT_MORTALITY_NATURAL+
215         ADULT_REDUCTION/ADULT_MORTALITY_NATURAL;
216     COYOTE_DATA(J J-11)=COYOTE_DATA(J J-11)+1';
217     ADULT_DIE_OFF;
218 ENDO;
219 IF ADULT_MORTALITY=ADULT_MORTALITY_NATURAL+ADULT_MORTALITY_MAN-
220         ADULT_MORTALITY_NATURAL+ADULT_MORTALITY_MAN;
221 END;
/* RUN RABBIT RUN */

/*************************************************************************/
/* SIMILAR CALCULATIONS FOR THE YOUNG COYOTES */
/*************************************************************************/

223 IF YOUNG_COYOTES =< 0 THEN DO;
225 IF YOUNG_NEW_WEIGHT >= YOUNG_MINIMUM_WEIGHT THEN DU:
227 YOUNG_BODY_WEIGHT = YOUNG_NEW_WEIGHT;
228 YOUNG_MORTALITY_NATURAL = A Y * YOUNG_BODY_WEIGHT * BYC;
229 END;
230 ELSE DU:
231 YOUNG_MINIMUM_RESPIRATION = BASAL_RESPIRATION * 0.5 *
232 (YOUNG_BODY_WEIGHT + YOUNG_MINIMUM_WEIGHT) /
233 WEIGHT_MAXIMUM;
234 YOUNG_MAX_NUMBERS = MIN(YOUNG_COYOTES, YOUNG_INTAKE /
235 (YOUNG_MINIMUM_RESPIRATION + (YOUNG_MINIMUM_WEIGHT -
236 YOUNG_BODY_WEIGHT) / RABBIT_CONVERSION_WEIGHT));
237 YOUNG_BODY_WEIGHT = YOUNG_MINIMUM_WEIGHT;
238 YOUNG_MORTALITY_NATURAL = A Y * YOUNG_BODY_WEIGHT * BYC;
239 IF YOUNG_MAX_NUMBERS < YOUNG_COYOTES THEN DU:
240 YOUNG_REDUCTION = (YOUNG_COYOTES - YOUNG_MAX_NUMBERS) /
241 YOUNG_COYOTES;
242 YOUNG_MORTALITY_NATURAL = YOUNG_MORTALITY_NATURAL * YOUNG_REDUCTION;
243 YOUNG_COYOTES = YOUNG_COYOTES * (1.0 - YOUNG_MORTALITY_NATURAL);

/*************************************************************************/
/* CHECK TO SEE IF YOUNG_COYOTES ARE EXTINCT */
/*************************************************************************/

244 IF YOUNG_COYOTES < .001 THEN YOUNG_COYOTES = 0;
246 END;
247 IF REPORT = 1 THEN
248 PUT STRING (COYOTE_DATA(JJ)) EDIT (TEN_DAY_INTERVAL, ADULT_COYOTES, YOUNG_COYOTES, ADULT_BODY_WEIGHT, YOUNG_BODY_WEIGHT, RABBITS_EATEN, ALTERNATE_PREY_EATEN) IF (2) 2 (X(8), F(6, 3)), 2 (X(12), F(14, 1)), X(10), F(6), X(10), F(6));
249 JJ = JJ + 1;
250 END;

/*************************************************************************/
/* END OF COYOTE PROCEDURE */
/*************************************************************************/
/* RUN RABBIT RUN */

IF TOTAL_RABBITS <= 0 THEN GO TO Q2;

DECLARE VEGETATION CONSUMED;

CONSUMPTION = 0.0;
DO AGE = 0 TO NE;
    CONSUMPTION = CONSUMPTION + ARAGE) * YOUNG_RABBITS(AGE);
END;

CONSUMPTION = CONSUMPTION + ADULT_RABBITS;
IF TFN_DAY_INTERVAL = 10 THEN ANNUAL_GRASS_LOSS = 0;
GRASS_LOSS_RABBIT = CONSUMPTION * PERCENT_GRASS_DIETIEN_DAY_INTERVAL;
ANNUAL_GRASS_LOSS = ANNUAL_GRASS_LOSS + GRASS_LOSS_RABBIT;

DECLARE OLDEST JUVENILES TO ADULTS AFTER OCTOBER;
DECLARE CHANGE THE SUM OF ALL RABBITS > 30 DAYS OLD;
DECLARE ADJUST RABBIT SURVIVAL FOR RABBITS EATEN BY COYOTES;

TOTAL_RABBITS = ADULT_RABBITS;
DO AGE = 4 TO NE;
    TOTAL_RABBITS = TOTAL_RABBITS + YOUNG_RABBITS(AGE);
END;

RABBIT_SURVIVAL = 0.97 - (1 - (RABBITS_EATEN/3)/TOTAL_RABBITS);
YOUNG_RABBIT_SURVIVAL = 0.981 - 0.000138 * TOTAL_RABBITS;
IF MOD(TEN_DAY_INTERVAL,3) = 0 THEN RABBITS_EATEN = 0;
I* *I
ONLY TEST FOR THE START OF A DISEASE IF A DISEASE IS NOT STILL
IN PROGRESS OR ITS EFFECTS BEING FELT IN REPRODUCTION.

IF TEN_DAY_INTERVAL = DISEASE_TIME & ~ DISEASE & ~ EPIZOOTIC
THEN DO:

X = RAND;
IF X < P_DISEASE THEN DO:

START THE DISEASE

IF REPORT=1 THEN

PUT SKIP IT ('DISEASE STRIKES') (A);
SUSCEPTIBLES = TOTAL_RABBITS;
NEW_CASES = 1.0;
DISEASE = 'I'
END;

IF DISEASE THEN DO:

THE EQUATIONS FOR NEW CASES OF DISEASE ARE FROM REED & FROST AS
REPORTED BY ABBEY (1952).

NEW_CASES = TOTAL_RABBITS*(1-RATE_OF_SPREAD)**NEW_CASES;

IF A DISEASE KILLS 10 OUT OF 100 THEN THE SUBSEQUENT SURVIVAL IS
ONLY NINE-TENTHS OF ITS FORMER SELF.

RABBIT_SURVIVAL = RABBIT_SURVIVAL * (1-NEW_CASES/TOTAL_RABBITS);
YOUNG_RABBIT_SURVIVAL = YOUNG_RABBIT_SURVIVAL * (1-
NEW_CASES/TOTAL_RABBITS);

FATALITIES = FATALITIES + NEW_CASES :
IF NEW_CASES < 1 THEN NEW_CASES = 0 :
DISEASE = NEW_CASES > 0 ;
/* RUN RABBIT RUN */

/* WHEN DISEASE HITS > X % OF POPULATION, DECLARE AN EPIZOOTIC */

***/

EPIZOOTIC: FATALITIES > PERCENT_FOR_E * SUSCEPTIBLES:

IF EPIZOOTIC & EPIZOOTIC_DURATION >= MAX_DURATION THEN DO:

EPIZOOTIC_DURATION = 0.0;

IF REPORT = 1 THEN

PUT SKIP EDIT ('EPIZOOTIC') (A); END;

END:

*****************************************************************************/

/* ADVANCE LOOP LIMITS FOR CALCULATIONS INVOLVING JUVENILES */

IF TEN_DAY_INTERVAL > LITTER_TIME(1) THEN DO:

NB = NB + 1;

IF NE < 19 THEN NE = NE + 1;

END;

*****************************************************************************/

IF TEN_DAY_INTERVAL > LITTER_TIME(1) THEN DO:

NB = NB + 1;

IF NE < 19 THEN NE = NE + 1;

END:

*****************************************************************************/

MAKE YOUNG RABBITS OLDER & WISER (SOME DIE)

/* AFTER OCTOBER APPLY ADULT MORTALITY */

IF TEN_DAY_INTERVAL > 30 THEN DO AGl = NETO NB BY -1

WHILE (AGE > 1):

YOUNG_RABBITS(AGE) = YOUNG_RABBITS(AGE - 1) * RABBIT_SURVIVAL;

YOUNG_RABBITS(AGE - 1) = 0.0;

END;

*****************************************************************************/

ELSE DO AGl = NETO NB BY -1 WHILE (AGE > 1):

YOUNG_RABBITS(AGE) = (YOUNG_RABBITS(AGE) +

YOUNG_RABBITS(AGE - 1)) * RABBIT_SURVIVAL;

YOUNG_RABBITS(AGE - 1) = 0.0;

END;

*****************************************************************************/

IF REPRODUCTIVE SEASON SEE IF IT'S TIME FOR A LITTER */

ELSE DO AGl = NETO NB BY -1 WHILE (AGE > 1):

YOUNG_RABBITS(AGE) = (YOUNG_RABBITS(AGE) +

YOUNG_RABBITS(AGE - 1)) * RABBIT_SURVIVAL;

YOUNG_RABBITS(AGE - 1) = 0.0;

END;

*****************************************************************************/

DO I = 1 TO #LITTERS ;

IF TEN_DAY_INTERVAL = LITTER_TIME(I) THEN GOTO REPRO;

END;

GO TO Q4 ;
/* RUN RABBIT RUN */

/* */

/* IF THE SNOWFALL IN LATE WINTER IS TOO HEAVY ( A FREQUENCY OF 1 IN */
/* 10 IN OUR EXAMPLE) THEN THE FIRST LITTER IS CALLED OFF. */

/* */

/* IF THE SUMMER IS DRY THE LAST TWO LITTERS ARE MADE A FRACTION OF */
/* THEIR FORMER SIZE. */

/* */

/* IF TEN_DAY_INTERVAL > LITTER_TIME(3) & DRY_SUMMER THEN */

/* YOUNG_RABBITS(1) = YOUNG_RABBITS(1) * LITTER_REDUCTION; */

/* */

/* SOME ADULTS DIE */

/* */

/* Q4: ADULT_RABBITS = ADULT_RABBITS * RABBIT_SURVIVAL : */

/* IF REPORT=1 THEN */

/* PUT EDIT (TEN_DAY_INTERVAL,YOUNG_RABBITS,ADULT_RABBITS, */
/* NEW_CASES,CONSUMPTION,GRASS_LOSS_RABBIT)(SKIP,F12),19 F(4), */
/* 2 F(6),1 F(10)); */

/* Q2: END ; /* END OF TEN_DAY_INTERVAL LOOP */

/* */

/* MAKE ALL JUVENILES ADULTS */

/* */

/* */

/* DO AGE= NB TO NE : */

/* ADULT_RABBITS = ADULT_RABBITS + YOUNG_RABBITS(AGE); */

/* NE = 1; */

/* NF = 1; */
I* RUN RABBIT RUN

I* THE FOLLOWING STATEMENTS ARE ONLY FOR THE DATA OUTPUT AND CLOSING #
I* THE LOOPS FOR RUNS AND YEARS.
I* #
I* #
I* *********************************************
I* I* I*
I* # THE FOLLOWING STATEMENTS ARE ONLY FOR THE DATA OUTPUT AND CLOSING #
I* # THE LOOPS FOR RUNS AND YEARS.
I* #
I* #
I* *********************************************
I* I* I*

IF REPORT=1 THEN DO;
  PUT SKIP(2);
  DU I=1 TO JJ = 1 ;
  PUT EDIT (COYOTE_DATA(I)) (SKIP,A);
  END;
  PUT SKIP EDIT (**END OF YEAR *** TOTAL RABBITS EATEN=' ,
  TOTAL_RABBITS_EATEN (A,F(5)));
  PUT DATA (ANNUAL_GRASS_LOSS);
  ENO;
END;

IF REPORT=2 THEN DO;
  TOTAL_COYOTES=ADULT_COYOTES+YOUNG_COYOTES;
  ALINE(*' = 1 ;
  ALINE(1),ALINE(10)=1;
  NOIV(1)=(TOTAL_COYOTES-BOUNDS(2))/DIV(1)*.5;
  NOIV(2)=(ADULT_RABBITS-BOUNDS(4))/DIV(2)**.5;
  DO I = 1 TO 2;
    IF NOIV(I) < 1 THEN NOIV(I) = 1;
    ELSE IF NOIV(I) > 70 THEN NOIV(I) = 70;
    ALINE(NDIV(I)) = SYMB(I);
  END;
  PUT SKIP EDIT (YEAR,TOTAL_COYOTES,ADULT_RABBITS)
  (F(7),GUL(17),E(11,4),GCL(311),70 A,GCL(105),E(11,4));
END;

IF TOTAL_RABBITS = 0 THEN GO TO SILLY;
END ; /* END OF YEAR LOOP */

SILLY: PUT SKIP(2) EDIT (**YOU RAN OUT OF RABBITS, TRY AGAIN!');
GOTO Q3;

Q3: END ; /* END OF RUN LOOP */

END COYRAB;
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********* JJ

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********* LITTER_REGIME

19  LITTER_SIZE

8  LITTER_TIME

********* MATURATION_DATE

MAX

********* MAX_DURATION

MIN

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12  MOTHERHOOD_DEMAND

********* NB

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**RUN RABBIT RUN**

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END IF YEAR *** TOTAL PAR_ITS ENTE= 284  ANNUAL_GRASS_LOSS=1.44422E+06;

TEST COMPLETED, CONGRATULATIONS

YEARS_PSR_RUN=50,
REPORT=71
Graph of Coyote and Rabbit Numbers at the End of the Year

Year: 1-30

Minimum Coyotes
0.0000E+00
0.0000E+00

Minimum Rabbits
1.8018E+02
2.0423E+02

Maximum Coyotes
3.0000E+02
4.0000E+02

Maximum Rabbits
1.5016E+02
2.0423E+02

Test Completed, Congratulations