COMPUTER SIMULATION MODELS OF THE PORCUPINE CARIBOU HERD: III. HARVEST

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Pacific and Yukon Region 1989
Canadian Wildlife Service

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ABSTRACT

The population dynamics of the Porcupine caribou herd are presented within the structure of a computer simulation model. Population parameters are updated on an annual basis while the dynamics within the model occur over five life cycle periods. The details and dynamics of community harvests on the herd are particularly stressed. The present model is one of three models, ENERGY, GROWTH and HARVEST, that were developed at the request of the Porcupine Caribou Technical Committee. The models run on IBM compatable microcomputers that have graphics capability. The supervisor program, Microsimcon, is incorporated into each model to assist in exercising the models.

RÉSUMÉ

La dynamique de la population du troupeau de caribous Porcupine est présentée a partir d'un modèle de simulation par ordinateur. Les paramètres de la population sont mis à jour annuellement, tandis que la dynamique à l'intérieur du modèle couvre 5 périodes du cycle vital. On met particulièrement l'accent sur les détails et la dynamique des récoltes de la communauté sur le troupeau. Ce modèle fait partie de trois modèles (ÉNERGIE, CROISSANCE et RÉCOLTE) qui ont été mis au point à la demande de Comité technique du caribou Porcupine. Les modèles sont utilisables sur les micro-ordinateurs ayant une compatibliité IBM et une capacité inforgraphique. Le programme superviseur, Microsimcon, est incorporé dans chaque modèle et facilite l'application et la vérification des modèles.

INTRODUCTION

Research and monitoring of the Porcupine caribou herd have been conducted almost continuously since the early 1970's. As more information is gathered it becomes increasingly difficult to integrate and apply that information to complex questions regarding effects on the herd from human activities and developments. The Porcupine Caribou Technical Committee, therefore, requested that individuals involved in research and management of the herd develop computer simulation models to aid in evaluating the present data, to help guide future research, and to provide some insights into the potential impact of alternate development scenarios. To this end the Canadian Wildlife Service contracted a group from the Faculty of Forestry, University of British Columbia, to help facilitate a number of workshops and to program the agreed upon models. From those discussions, three models were proposed. By order of increasing iteration time these models are: an ENERGY model which simulates the energetic relations of an individual and predicts the metabolizable energy intake (MEI) on a daily basis; a GROWTH model that incorporates the resultant MEI and projects the weight gain and loss throughout the year; and a HARVEST model that simulates the demographics of the herd over a number of years.

The models incorporate a simulation supervisor program that was adapted to microcomputers (Microsimcon), allowing efficient and user-friendly access while exercising the models. All coding is done in Basic using a "Quick Basic" compiler. All users of the models will require an IBM compatible computer with graphics capability.

This publication represents Version 1 of the models. Updates, executable files and other information on the model are available from D.E. Russell, Canadian Wildlife Service, Whitehorse.

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Caribou Harvest Model

PURPOSE

The HARVEST model is designed to examine effects of caribou migration patterns on the harvest and population dynamics of the Porcupine caribou herd (Fig. 1). Operation of the program is detailed in Appendix 1. The following is a description of the model's structure.

GENERAL DESCRIPTION

The HARVEST model deals primarily with harvest and its attendant effects on the annual dynamics of the caribou population under different caribou distribution patterns. Data on the historic distribution of the herd and the sex composition of the harvest are used to determine the number of caribou harvested by 10 native villages and 2 non-native groups in each of 5 different seasons (App. 1, Table A). Except for the distribution and harvest components, the model is a modified, simple Leslie Matrix. Effects of food quality and quantity on population dynamics are not explicitly coded in the model's structure. The model does, however, allow users to evaluate effects of both density dependent and independent population growth. The model also considers effects of predation on the herd by each of three principal caribou predators: wolves, grizzly bears, and golden eagles. In the model, predation is treated in one of two ways: 1) as a constant predation rate, or 2) as a constant number killed. The mortality component of the model is divided into three parts: 1) hunting mortality, 2) predation mortality, and 3) natural mortality (death due to old age, accidents, disease, etc). Unless directed not to, the model treats those sources of mortality as additive. The effects of compensatory mortality, where some specified proportion of the natural mortality is compensated by predation, can be evaluated directly by the model. Unlike the other two sources, mortality due to harvest is always treated as additive (Fig 2).

STEPPING THROUGH THE MODEL

Calculating the Survivorship Schedule

Each iteration of the model (i.e., year of simulation) begins by determining the proportion of the population in each sex/age class (i.e., survivorship schedule by sex and 13 age classes).

SX(SEX,AGE) = CAR(SEX,AGE) / POP(SEX) (1)

where SX(SEX,AGE) = survivorship (S) by age (X) and sex,
CAR(SEX,AGE) = number of caribou by age and sex, and
POP(SEX) = number of caribou by sex.

The survivorship schedule is used later in the model to apportion the

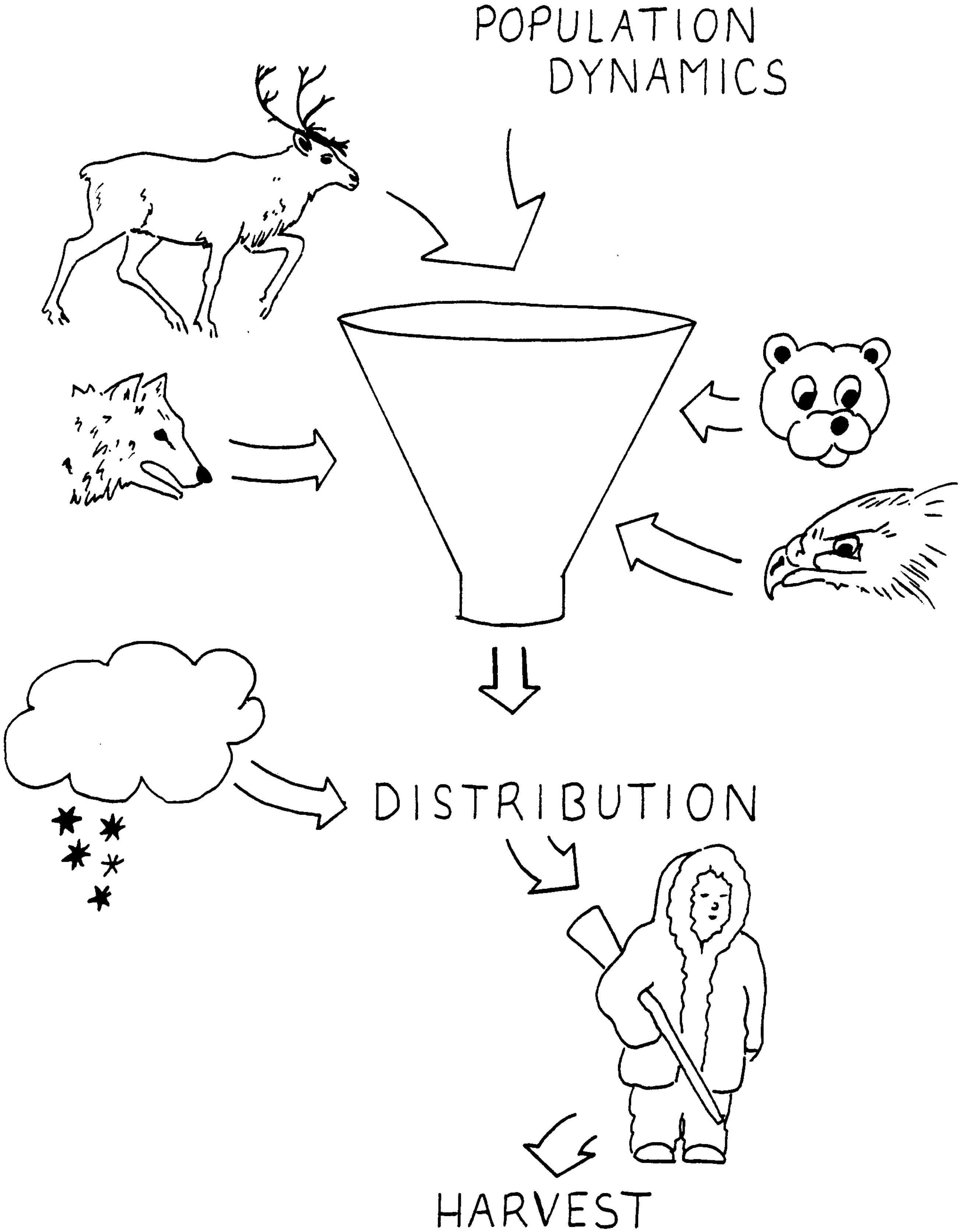

Figure 1. Generalized flowchart of the HARVEST model.

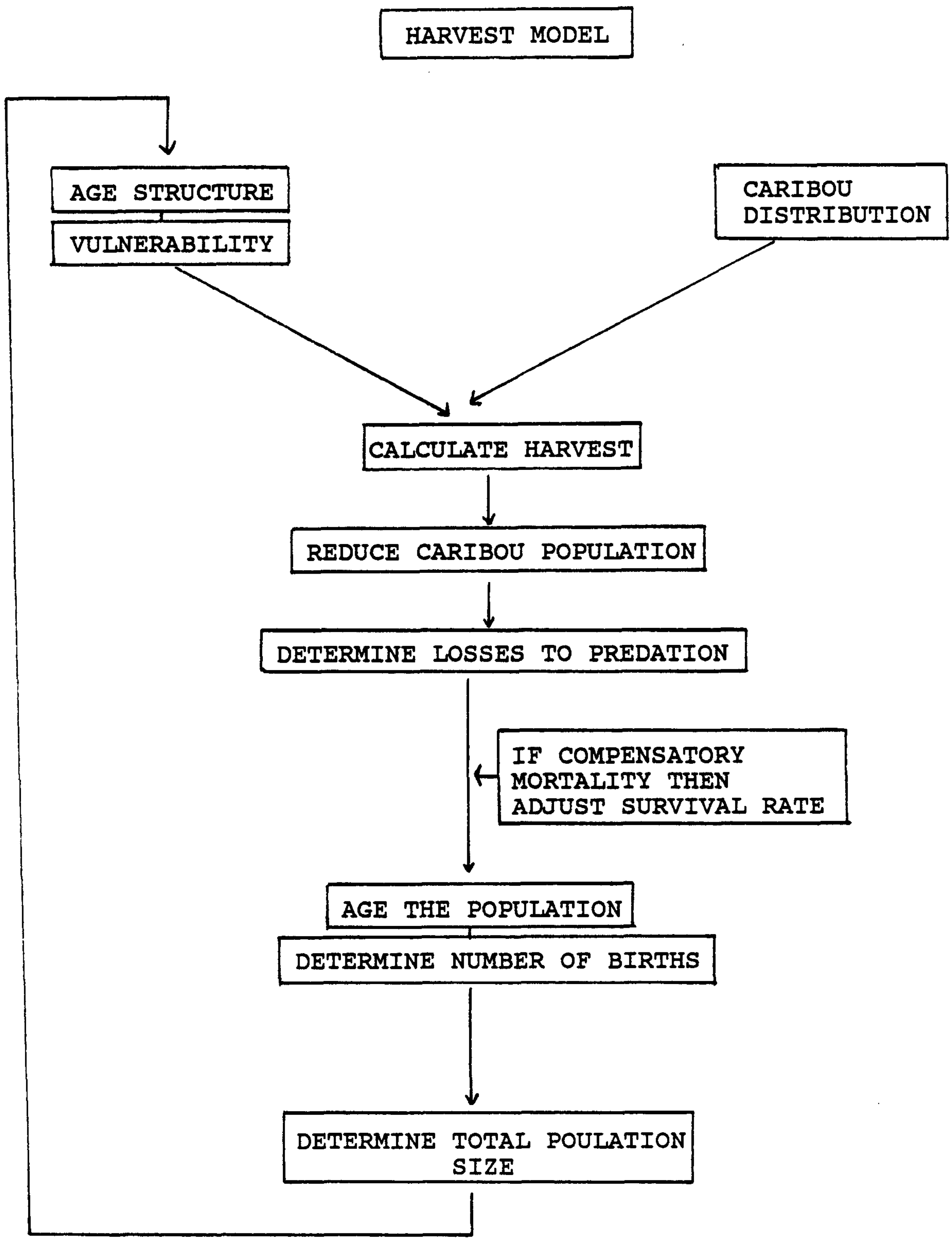

Figure 1. Flowchart of the HARVEST model

harvest by age and sex. With most barren ground caribou populations, not all age classes are equally vulnerable to harvest. For example, calves are usually killed less frequently than are adult females. In the fall, hunters concentrate on adult bulls, often ignoring cows. In other seasons, they treat the sexes equally. To account for the differences in sex/age and season-specific vulnerability, the model applies a user-defined vulnerability coefficient (see VULNER; App. 1) to the survivorship schedule. A vulnerability coefficient of 2, for example, would indicate that the proportion of that sex/age class making up the harvest is twice as large as the proportion making up the total population (i.e., survivorship). Because the sex/age-specific vulnerability coefficient adjusts the survivorship schedule, the schedule no longer sums to 1. To correct that problem, the model normalizes the product of the survivorship schedule and the vulnerability coefficient by dividing each product by the sum of all the products. The model calculates the sum of the products when it determines the survivorship schedule; normalization occurs later in the program.

SXTOTAL(SEX) = SUM(SX(SEX,AGE) * VULNER(1 OR 2)) (2)

where SXTOTAL(SEX) = sum of the products of SX and VULNER by sex.

<u>Selecting the Distribution Scenario</u>

The model's next step is to allow selection of a caribou distribution scenario that reflects historical caribou migration patterns (Table 1.). Distribution scenarios are specified for five seasons:

1) Calving: two distribution scenarios are possible - calving in the foothills or calving within the core "1002" calving area. Historical evidence suggests that caribou will attempt to calve in the core area unless late snowmelt either hinders movement or precludes use.

2) Summer: three distribution scenarios can be generalized from historical records. The selection of any of these scenarios has implications to certain communities. The three scenarios are: early dispersal south of treeline, dispersal from summer aggregations north of treeline, and dispersal north of treeline into the Northwest Territories via the Richardson Mountains.

3-5) Fall, Winter, and Spring: We have assumed that the route chosen during fall migrations dictates the winter distribution as well as the routes taken during spring migration. Although spring migration routes chosen can vary from a given winter distribution, for the purpose of tracking harvest, the variations are not important. Table 1 details the nine potential distributions considered during fall, winter and spring.

These distribution scenarios allocate total caribou harvest to 12 native villages and other groups. Each village's level of harvest is calculated relative to high harvest values which would be observed if animals were always available (COMP.DAT file; App. 1). Harvest levels can only decrease from the inputted high values (DISTDAT.S__ files; App. 1).

The user can control the selection of distribution scenarios in two ways: 1) by directing the model to select the scenarios at random, or 2) by directing the model to select scenarios following a pattern specified by the user. If the user chooses random selection, the model will select certain distribution scenarios more frequently than it does others. This bias ensures that the selected caribou distribution scenarios reflect historical patterns. The probability of a particular pattern being selected is shown in Table 2.

Table 1. Fall,winter and spring distribution scenarios of the Porcupine caribou herd considered in the model.

Scenarios	Fall migration route	winter distribution	spring migration route	frequency
1	O[a]	P	O	3/17
2	O/R	P/R	O/R	1/17
3	O/C	P/A	O/C	4/17
4	O/R/C	P/R/A	O/R/C	3/17
5	O/N	P/N	O/N	1/17
6	O/C	A/K	O/C	1/17
7	O/R/C/E/N	E	O/R/C/E/N	1/17
8	O/R/C/N	P/R/A/N	O/R/C/N	1/17
9	C/N	N/A	C/N	2/17

[a]Fall/Spring Codes: C= Chandelar
E= Exceptional routes - Tatonduk, Chalkyitsik
N= North of Porcupine river
O= Ogilvie
R= Richardson
K= Keele range
A= Arctic village
P= Peel Olgilvie

Table 2. Probability of selecting a distribution scenario

Season	Distribution Scenario[a/] 1	2	3	4	5	6	7	8	9
1	.40[b]	.60							
2	.25	.42	.33						
3	.18	.06	.24	.18	.06	.06	.06	.06	.10
4	.18	.06	.24	.18	.06	.06	.06	.06	.10
5	.18	.06	.24	.18	.06	.06	.06	.06	.10

a/ see Table 1 and Appendix 1 for description of scenario types.
b/ probabilities calculated from data on historical migration patterns (Rick Farnell, pers. comm.).

The model stores the selected distribution scenario in the variable:

SCENARIO(1 to 3,TIME) (3)

where 1 to 3 refer to seasons 1, 2, and 3-5, respectively, and TIME refers to the year of the simulation.

Reflecting the number of distribution choices, SCENARIO can have the following values: 1 or 2 in season 1, 1 to 3 in season 2, and 1 to 9 in seasons 3 to 5. To reduce the number of variables in computer memory, the value of SCENARIO is stored in the temporary variable J. Thus, J identifies the selected distribution scenario for a particular village and season.

Calculating the Harvest

Each of the distribution scenarios noted above identify a specific pattern of harvest levels. These harvest levels are defined as H (high), M (medium), L (low), or X (none) and are stored for each scenario, village, and season in the variable:

DISTRIB$(J,SEASON,VILLAGE) (4)

The user can control the magnitude of each harvest level by assigning values to the set file variable, DISTF (App. 1).

Where:

DISTF(1) adjusts the number harvested to a low level, (5)
DISTF(2) adjusts the number harvested to an average level (6)
DISTF(3) adjusts the number harvested to a maximum level (7)
(values other than L, M, and H are assumed to be equal to 0)

The DISTF factor is applied to the variable containing the total number of caribou harvested by each village in each season (App. 1),

COMPO(SEX,SEASON,VILLAGE) (8)

The result of that multiplication is the adjusted harvest number, RICK.

RICK = COMPO(SEX,SEASON,VILLAGE) * DISTF (9)

An example of selecting distribution scenarios, harvest levels, and adjusting the total number of caribou harvested follows:

If

SEASON = 1,
VILLAGE = 1,
SEX = FEMALE,
SCENARIO(1,TIME) = 2 (i.e., pattern 2 was selected in season 1); therefore, J = 2,
DISTRIB$(2,1,1) = M,
DISTF(1)=.3, DISTF(2)=.7, DISTF(3) = 1.0, and
COMPO(FEMALE,1,1) = 100

then the total number of cows harvested by Old Crow hunters (Village 1) from June 1 to July 15 (Season 1) would be multiplied by 0.7 producing an adjusted harvest (RICK) of 70 female caribou. That calculation yields a level of harvest 30% less than the value supplied by the user.

To account for effects of native population growth on the caribou harvest, the number harvested is further adjusted by multiplying it by a village-specific native population growth rate (NATPOP(VILLAGE)).

RICK(SEX,SEASON,VILLAGE)=RICK(SEX,SEASON,VILLAGE) * NATPOP(VILLAGE) (10)

The adjusted harvest is then apportioned by age according to the survivorship schedule and the sex- and age-specific vulnerability coefficient. This sex- and age-specific harvest is stored in the variable HARVNUM.

HARVNUM(SEX,AGE) = RICK(SEX,SEASON,VILLAGE) * SX(SEX,AGE) * VULNER(1 OR 2) / SXTOTAL(SEX) (11)

Presently, the model considers only two vulnerability coefficients, one for calves (1) and the other for adult bulls (2). The vulnerability coefficient for calves is applied in all seasons, while the one for bulls is applied only in the fall season (i.e., season 3). The model treats vulnerability of females as being equal to 1. That is, female harvest is apportioned by age according to the survivorship schedule.

The model also applies a season- and village-specific wounding rate to HARVNUM to account for additional kills due to crippling.

HARVNUM(SEX,AGE) = HARVNUM(SEX,AGE) * (1 + CRIPP(SEASON,VILLAGE)) (12)

where CRIPP(SEASON,VILLAGE) = harvest wounding rate

The number of caribou in each sex/age class is then subtracted from its portion of the population.

CAR(SEX,AGE) = CAR(SEX,AGE) - HARVNUM(SEX,AGE) (13)

<u>Calculating Survival and Predation</u>

Depending on the chosen scenario, the model then calculates the natural survival rate of the calves from either a density dependent or density independent relationship. If the user chooses density dependent population growth, the model adjusts calf survival rate by multiplying it by a density dependent factor (DENSITY) that is calculated as follows:

DENSITY = 1 - (POP(MALE) + POP(FEMALE)) / POPK (14)

where: POP(MALE or FEMALE) is total caribou population by sex
POPK is the carrying capacity is set by user (App. 1)

SURVRATE(1,SEX) = SURVRATE(1,SEX) * DENSITY (15)

where: SURVRATE(1,SEX) = survival rate of calves by sex.

If the population of caribou is small, DENSITY will be close to 1 and the survival rate will not change from that supplied by the user (i.e., same result as the density independent case). If the population is at carrying capacity, however, DENSITY will equal zero (1 - 1) causing the calf survival rate to equal zero. Survival rates for the other age classes follow those set by the user (see SURVRATE; App. 1).

The number of caribou killed in each sex/age class by each of the three predators (wolves, grizzly bears, and golden eagles) is then determined by one of the two methods noted earlier (i.e., constant rate or constant number killed). If the model has been directed to use constant predation rates, it multiples the predator-, season-, and caribou age- specific rate (PREDSRATE(PREDATOR,SEASON,AGE)) by the number of caribou and accumulates the result in the variable (TOTKILL(SEX,AGE)).

TOTKILL(SEX,AGE) = TOTKILL (SEX,AGE) * PREDSRATE(PREDATOR,SEASON,AGE) * CAR(SEX,AGE) (16)

If the user wants predation to be a constant number, the model simply adds the number of caribou in each age class killed by each predator in each season to TOTKILL(SEX,AGE). The user is required to set numbers killed instead of predation rates in the PRED.DAT data file (App. 1).

The model adjusts the total survival rate (i.e., combined effects of natural mortality and predation) to compensate for effects of predation according to a percentage specified by the user (COMPEN (%)). If no compensation is requested, COMPEN equals zero and no adjustment is made. If compensation is requested, however, the model assumes that the predators kill animals that would have died that year from some other cause; it then adjusts the survival rate. The total predation rate (PREDSRATE) (summed across predators) for each sex/age class is calculated as

PREDSRATE(SEX,AGE) = TOTKILL(SEX,AGE) / CAR(SEX,AGE) (17)

where: TOTKILL(SEX,AGE) = the number of caribou in each sex/age class killed by predators.

That result is then subtracted from 1 to give the survival rate due to predation

PREDSRATE(SEX,AGE) = 1 - PREDSRATE(SEX,AGE) (18)

The model then compares that rate to the age-specific natural survival rate (SURVRATE) and selects the smallest one (MINSURV). Next, the model calculates the product of SURVRATE and PREDSRATE and stores it in the variable SURVIVAL. Thus, SURVIVAL describes the potential survival rate due to natural mortality and predation. That rate is adjusted for compensatory mortality as follows:

SURVIVAL(SEX,AGE) = SURVIVAL(SEX,AGE) + (MINSURV-SURVIVAL) / 100 * COMPEN (19)

This rate is then applied to its specific sex/age class to determine the proportion of caribou that survive natural mortality and predation (note that harvest has already been accounted for; see Eq. (13)).

CAR(SEX,AGE) = CAR(SEX,AGE) * SURVIVAL(SEX,AGE) (20)

Calculating Recruitment

The number of calves produced in the spring season (i.e, season 1) is calculated by multiplying the number of females in each age class by the age-specific fecundity schedule supplied by the user (Fecundity; App. 1). If density dependence is requested, the model will adjust the fecundity schedule of each female age class in exactly the same manner as it adjusted the calf survival rate described earlier

$$CAR(1,SEX) = CAR(FEMALE,AGE) * FECUNDITY(AGE) \tag{21}$$

The final step in any iteration of the model is to sum the numbers of caribou in each sex/age class to determine the total population of the herd by sex (POP(SEX)) and record the plot variables (Z).

WEAKNESSES

Like any model, the HARVEST model has weaknesses. A few of the more notable ones follow.

The model does not explicitly consider effects of hunter behaviour on the harvest. For example, socio-economic factors such as increased financial income were not modelled. These factors probably affect the success (through better transportation methods to hunting areas, better hunting equipment, more ammunition, etc.) and desire (increased opportunities to do other things besides hunting) of individual hunters and thus the magnitude of the caribou harvest.

The survival and fecundity schedules of the caribou are not linked to their food resources and abiotic environmental conditions. The model does allow for density dependent growth, but the method it uses is coarse.

Predation is modelled, but only as either a constant rate or a constant number. At present, the total predation rate is not linked to caribou density as a functional response. Also, the model does not consider effects of caribou distribution on predation rates, which may affect the total harvest.

If directed to, the model will allow for compensatory mortality due to predation. The compensation mechanism, however, is applied equally to all age and size classes. This application may be biologically unrealistic.

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Hovey, F.W. 1988. PC Simulator, version 2.0. Canadian Wildlife Service Report. 10pp.

APPENDIX 1

Operation

The following is a description of the operation of the harvest model. All the variables used in the model are described in Appendix 2. Interactive graphics will not be discussed; that part of the program is detailed in PC_SIMULATOR (Hovey 1988). Like the other two caribou models, the harvest model requires set and data files to operate. Specifically, it requires 1 set file and up to 6 data files. The set file contains the following 11 statements:

Statement	Description
VULNER(1-2)	This array determines the vulnerability of calves(1) and adult bulls(2) to harvest. The vulnerability for calves is applied in all seasons; the value for bulls is applied only in the fall.
DISTF(1-3)	DISTF or "distribution factor" determines the amount the harvest is to be adjusted by when either a low (1), average (2), or high (3) harvest level has been selected.
COMP(1-7)	The initial number of caribou in the first 7 age classes.
COMP(8-13)	The initial number of caribou in the last 6 age classes.
SURVRATE(1-7)	Natural survival rates for the first 7 age classes.
SURVRATE(8-13)	Natural survival rates for the last 6 age classes.
FECUNDITY(1-7)	The number of calves per female for the first 7 age classes.
FECUNDITY(8-13)	The number of calves per female for the last 6 age classes.
CARRYING CAPACITY (POPK)	Caribou population carrying capacity used when density dependent growth is requested.
NATIVE POPULATION GROWTH RATE (NATPOP(VILLAGE))	Native population growth rate for each of the native villages and other groups (%).
TIMESTOP (default is 0)	The iteration at which the simulation is to be interrupted.

The age composition (COMP) and survival schedules (SURVRATE) described above are the same for each sex.

The harvest model also uses the following 6 data files:

Data File Name	Description
COMPOSIT.DAT	Contains the number of caribou of each sex harvested by each village during each season (COMPO(SEX,SEASON,VILLAGE); Table A)
CRIPPLE.DAT	Contains the wounding rates for caribou by village and season (CRIPP(SEASON,VILLAGE; Table B)
DISTDAT.S12	Contains data on the distribution of caribou by village for seasons 1 and 2 (DISTRIB$(SCENARIO, VILLAGE, 1 or 2); Table C). The file contains 2 potential distribution patterns that can be selected for season 1 and 3 patterns for season 2.
DISTDAT.S35	Contains data on the distribution of caribou by village for seasons 3, 4, and 5 (DISTRIB$(SCENARIO, VILLAGE, 3 to 5); Table C). This file provides 9 distribution patterns to choose from. The pattern used in season 3 is also the one used in seasons 4 and 5.
PRED.DAT	Depending on what the user desires, this file contains either the predation rate or the number of caribou killed by bears, golden eagles, or wolves. Values are organized by predator and age of caribou. Only the first three age classes (i.e., calves, yearlings, and adults) are used. Values for the third age class are also applied to the older age classes (PREDSRATE(PREDATOR,SEASON,AGE); Table D).
SELECT.DAT	Contains data on which caribou distribution pattern is to be selected from the DISTDAT.S__ files (SCENARIO(SEASON,YEAR). For each year, selections for each season (i.e., 1, 2, and 3 (which combines 3, 4, & 5)) must be on 1 line and separated by commas.

The above file names are the default names used by the program; they are not mandatory. The user can give the data or set files any valid DOS file name.

Normally, the program requires only the first 5 data files to operate. The SELECT.DAT file is needed only when the user wishes to control the distribution scenarios.

In addition to the set and data files described above, the model also requires input data that it prompts for when the program is started. For example, the model will ask the user for the names of the set and data files and the following 4 questions:

following 4 questions:

1) "Are the predation data recorded as rates (DEFAULT = YES)?"

If the user answers yes (generated in this case simply by pressing the return key) to this question the model assumes that the numbers in the file are constant rates of predation. If the answer is "NO", the model assumes that the data are numbers of caribou killed by predators.

2) "Do you want density dependence (DEFAULT = NO)?"

The answer to this question determines whether population growth rate of the caribou is density dependent or independent. If the answer is yes, then the caribou carrying capacity value must be properly defined in the set file.

3) "What % of predation mortality is compensatory (DEFAULT=0)?"

The response to this question determines the amount the total survival rate is adjusted to account for the effects of compensatory predation.

4) "Do you want random scenario selection (DEFAULT = YES)?"

A yes answer indicates that the user wants the caribou distribution patterns, given in the DISTDAT.S__ data files, to be selected at random. The model will also prompt the user for a number that will start the random number generator. The same number will produce the same random pattern each time it is used. To get a different random pattern on subsequent runs of the model, different numbers must be used to "seed" the random number generator. If a "NO" answer is given to question 3, the model assumes that the user wishes to control the caribou distribution pattern. It will then prompt the user for the name of the data file (default is SELECT.DAT) containing the selections.

Table A. Composition data

	Seasons[1]									
	Calving		Summer		Fall migration		Winter		Spring migration	
	M[2]	F[3]	M	F	M	F	M	F	M	F
Old Crow	50,	0,	125,	25,	300,	50,	0,	100,	0,	400
Aklavik	100,	0,	75,	25,	0,	0,	300,	1200,	0,	0
Ft. MacPherson	0,	0,	0,	0,	500,	500,	0,	500,	100,	900
Southern Yukon Natives	0,	0,	0,	0,	250,	500,	0,	0,	0,	0
Southern Yukon Whites	0,	0,	0,	0,	500,	100,	50,	0,	0,	0
Fly in U.S.	0,	0,	100,	25,	50,	10,	0,	0,	0,	0
Kaktovik	0,	25,	25,	25,	0,	0,	0,	0,	0,	25
Arctic Village	0,	0,	50,	25,	150,	50,	100,	300,	50,	250
Venetie	0,	0,	0,	0,	0,	0,	50,	100,	50,	50
Chalkyitsik	0,	0,	0,	0,	0,	0,	50,	50,	20,	30
Ft. Yukon	0,	0,	50,	20,	50,	20,	0,	0,	0,	0
Eagle	0,	0,	0,	0,	30,	20,	10,	20,	20,	10

1/ Seasons: Calving= June 1 - July 15
Summer= July 16 - Sept 7
Fall migration= Sept 8 - Oct 31
Winter= Nov 1 - Mar 31
Spring migration= April 1 - May 31

2/ M = Males
3/ F = Females

Table B. Cripple Loss Data

	Seasons[1]				
	1	2	3	4	5
Villages:					
Old Crow	.05[1],	.20,	.20,	.05,	.05
Aklavik	.00,	.20,	.00,	.05,	.05
Ft. MacPherson	.20,	.20,	.20,	.00,	.00
Southern Yukon Natives	.15,	.00,	.00,	.00,	.00
Southern Yukon Whites	.05,	.05,	.00,	.00,	.00
Fly in U.S.	.10,	.00,	.00,	.00,	.10
Arctic Village	.20,	.00,	.00,	.00,	.20
Kaktovik	.00,	.00,	.05,	.20,	.20
Venetie	.00,	.20,	.20,	.00,	.00
Chalkyitsik	.00,	.20,	.20,	.00,	.00
Ft. Yukon	.05,	.00,	.00,	.00,	.05
Eagle	.10,	.20,	.20,	.00,	.00

[1]Seasons: 1=June 1 - July 15
2=July 16 - Sept 7
3=Sept 8 - Oct 31
4=Nov 1 - Mar 31
5=Apr 1 - May 31

[2] Cripple loss as percent of harvest

Table C. Example of distribution data

Scenario		1 2 3 4 5 6 7 8 9
Season 1	Old Crow	H,H,X[1]
June 1-	Aklavik	H,H,X
July 15	Ft. MacPherson	X,X,X
	Southern Yukon Natives	X,X,X
	Southern Yukon Whites	X,X,X
	Fly-in U.S.	X,X,X
	Kaktovik	H,M,X
	Arctic Village	X,X,X
	Venetie	X,X,X
	Chalkyitsik	X,X,X
	Ft. Yukon	X,X,X
	Eagle	X,X,X
Season 2	Old Crow	H,L,L
July 16-	Aklavik	L,H,X
Sept 7	Ft. MacPherson	X,X,X
	Southern Yukon Natives	X,X,X
	Southern Yukon Whites	X,X,X
	Fly-in U.S.	H,H,H
	Kaktovik	H,H,H
	Arctic Village	H,L,L
	Venetie	X,X,X
	Chalkyitsik	X,X,X
	Ft. Yukon	H,L,L
	Eagle	X,X,X
Season 3	Old Crow	H,H,H,H,H,H,M,M,L
Sept 8-	Aklavik	X,X,X,X,X,X,X,X,X
Oct 31	Ft. MacPherson	X,H,X,H,M,X,X,H,X
	Southern Yukon Natives	X,X,X,X,X,X,X,X,X
	Southern Yukon Whites	H,H,H,H,H,X,H,M,X
	Fly-in U.S.	X,X,X,X,X,X,X,X,X
	Kaktovik	X,X,X,X,X,X,X,X,X
	Arctic Village	X,X,H,H,X,X,H,M,H
	Venetie	X,X,X,X,X,X,X,X,X
	Chalkyitsik	X,X,X,X,X,X,X,X,X
	Ft. Yukon	M,X,H,H,X,X,H,M,L
	Eagle	L,L,L,L,L,X,H,X,X
Season 4	Old Crow	X,X,X,X,L,H,M,L,L
Nov 1-	Aklavik	X,X,X,X,H,X,M,M,H
Mar 31	Ft. MacPherson	X,H,X,H,L,X,M,H,L
	Southern Yukon Natives	X,X,X,X,X,X,X,X,X
	Southern Yukon Whites	X,X,X,X,X,X,X,X,X
	Fly-in U.S.	X,X,X,X,X,X,X,X,X
	Kaktovik	X,X,X,X,X,X,X,X,X
	Arctic Village	X,X,H,H,X,X,H,M,H
	Venetie	X,X,M,M,X,X,H,M,H

	Chalkyitsik	M,X,H,H,X,X,H,M,L
	Ft. Yukon	X,X,X,X,X,X,X,X,X
	Eagle	L,L,L,L,L,X,H,X,X
Season 5 April 1- May 31	Old Crow	H,H,H,H,H,H,M,M,X
	Aklavik	X,X,X,X,X,X,X,X,X
	Ft. MacPherson	X,H,X,H,L,X,M,M,L
	Southern Yukon Natives	X,X,X,X,X,X,X,X,X
	Southern Yukon Whites	X,X,X,X,X,X,X,X,X
	Fly-in U.S.	X,X,X,X,X,X,X,X,X
	Kaktovik	L,L,L,L,L,L,L,L,L
	Arctic Village	X,X,H,H,X,X,H,M,H
	Venetie	X,X,M,M,X,X,M,L,H
	Chalkyitsik	X,X,L,L,X,X,H,L,L
	Ft. Yukon	X,X,X,X,X,X,X,X,X
	Eagle	L,L,L,L,L,X,H,X,X

[1] H=HIGH CARIBOU HARVEST
M=MEDIUM CARIBOU HARVEST
L=LOW CARIBOU HARVEST
X=NO CARIBOU HARVEST

Table D. Example of predation rates

Seasons[1]	1			2			3			4			5		
Predators[2]	B	E	W	B	E	W	B	E	W	B	E	W	B	E	W
AGE CLASSES[3]															
1	0,	0,	0,	0,	0,	0,	.067,	.067,	.067,	0,	0,	.06,	.06,	0,	.06
2	.015,	0,	.015,	0,	0,	0,	.02,	0,	.02,	0,	0,	.04,	.03,	0,	.03
3	.01,	0,	.01,	0,	0,	0,	.01,	0,	.01,	0,	0,	.02,	.015,	0,	.015

[1]Seasons: 1=June 1 - July 15
2=July 16 - Sept 7
3=Sept 8 - Oct 31
4=Nov 1 - Mar 31
5=Apr 1 - May 31

[2]Predators: B=Bears
E=Eagles
W=Wolves

[3]Age classe: 1= calves
2= yearlings
3= adults

Appendix 2

List of Variables

Variable	Description
AGE	Identifies caribou age class (years).
AGEDIM	Parameter indicating the number of caribou age classes used in the model.
BEAR	Identifies predator type as bear.
BIRTHS	Number of caribou births.
CAR(2,13)	Number of caribou in each sex/age class.
CRIPP(5,12)	Proportion of caribou harvest lost to crippling and wounding for each village during each season.
COMPEN	Amount of compensatory mortality due to predation (%).
COMP(13)	The initial number of caribou in each age class.
COMPO(2,5,12)	Proportion of caribou harvest by sex, season and village.
DDEP$	Logical variable monitoring whether density dependent growth has been requested (YES or NO).
DENSITY	Number of caribou relative to population carrying capacity.
DISTRIB$(9,5,12)	Array storing data on up to 9 distribution scenarios by 5 seasons and 12 villages.
DISTF(4)	DISTF or "distribution factor" determines the amount the harvest is to be adjusted by when either a low (1), average (2), high (3), or 0 (4) harvest level has been selected.
EAGLES	Identifies predator type is golden eagle.
FECUNDITY(12)	Fecundity schedule of each age class. Array contains the number of calves per female.
FEMALE	Identifies female sex class
FREQUENCY	Random number generated to select distribution scenario.
HARVEST(2)	Total numbers harvested in each sex class

HARVNUM	Number of caribou harvested and lost to crippling for each village
HIGH	Identifies high caribou numbers in the areas specified by a scenario
LOW	Identifies low caribou numbers in the area specified by a scenario
MALES	Identifies male sex class
MEDIUM	Identifies average numbers of caribou in the area specified by a scenario
MINSURV	Minimum survival rate given a comparison between predation and natural mortality.
NATPOP(12)	Annual native population growth for each village (%).
POP(2)	Total number of male (1) and female (2) caribou summed over all age classes
POPK	Caribou population carrying capacity.
PREDATOR	Predator selected: 1=bears, 2=eagles, 3=wolves
PREDKILL(3)	Number of caribou killed by predators index by PREDATOR type.
PREDRATE(3,5,13)	Array contain predation rate or the number of caribou killed by each predator for each season and caribou age class
PREDSRATE	The survival rate of caribou due to predation.
RAND$	Logical variable that monitors whether user wants random selection of distribution scenarios (YES or NO).
RICK	Age- and sex-specific caribou for a particular village during a specific-season.
SCENDIM	Parameter indicating the maximum number of scenarios.
SCENARIO(3,TIME%)	Scenario determining caribou population distribution. Array is indexed by season and year (TIME%).
SEASDIM	Parameter indicating the number of seasons.
SEASON	Variable indicating season type.

SURVIVE	Number of caribou surviving natural mortality.
SURVRATE(2,13)	Array containing survival rates of caribou for two sexes and thirteen age classes.
SX(2,13)	Proportion of caribou in each age class, for each sex. This array is the caribou survivorship schedule.
SXTOTAL(2)	The sum of the survivorship schedule by sex (male=1 and female = 2) and corrected for differential vulnerabilities to hunting.
TOTAGE(2)	The sum of the product of the number of caribou in each age class and age by sex.
TOTKILL	Number of caribou killed by predators in each age class and sex during a specific-season.
VILLAGE	Indicates village type.
VILLDIM	Parameter indicating the number of villages.
VULNER(2)	Factor determining the vulnerability of calves (1) and adult bulls to harvest.
WOLF	Identifies predator type is a wolf.
Z(TIME%,NUM.OF.VAR)	Array used to store simulation results for plotting.
ZN$(NUM.OF.VAR)	Labels for plot variables.

PC SIMULATOR

Version 2.0

by

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Background

PC_Simulator (PC_SIM) is a program that makes simulation models easy to use. Among its many useful features is the ability to plot, display, or print the values of key variables at any stage of the simulation. The program was developed at U.B.C. by the author for use with BASIC language compilers. It has its origins with Dr. C.J. Walter's (U.B.C.; Zoology) MICROSIMCON program that was developed in the late seventies for use with Apple micro-computers and INTERPRETATIVE BASIC. In 1985, D. J. Vales (U.B.C.; Forestry) modified MICROSIMCON to make it compatible with IBM PCs. Among the features Vales added were an online help menu and the ability to display plot variable names and data. Those features have been retained and enhanced in PC_SIM.

MICROSIMCON was designed to run in INTERPRETATIVE BASIC; consequently, it is slow. To take advantage of the speed, compactness, and portability of programs generated by compilers I greatly modified MICROSIMCON's code. The program is now structured and modularized. In addition, many new features and error-handling routines that improve the use of simulation models on micros have been added. Those features and changes are detailed in Appendix I.

Operation

PC_SIM begins by asking the user how many iterations (e.g., years or days) the model is to cycle before entering graphics mode (Fig. 1). The user can input any value up to a maximum of 32,737 ($2^{15}-1$). The program then asks for the names of the data files needed to run the simulation model. In each case, the program provides a default file name that can be chosen simply by pressing the carriage return key, ENTER (indicated as <CR>).

The starting values of certain variables used in the simulation can be set via a special data file called the "set file". That file, like all other data files used by PC_SIM, is external to the program; hence any editor can be used to create or change it. Each line of the set file contains the name and initial value of the variable that is to be set by the program. For example,

caribou weight =,100

would initialize the variable representing caribou weight to a value of 100. In all cases, a comma <u>must</u> appear after, but not before the equals sign ("="). To set the initial values for variable arrays, the numbers must be separated by commas. For example,

caribou numbers (age 1 to 5) =,1000,800,600,500,300

YEAR = 0

Simulation begins at Year: 0
Finish Simulation at Year:? 100

What is the name of the set file (DEFAULT = HARVEST.SET)?

Figure 1. The initial PC_SIM screen. In this example the user has instructed the program to execute the model for 100 iterations (i.e., years).

sets the first element of an array containing the age-specific population of caribou to 1000 and the last element to 300.

Once the data and initial conditions are loaded, the program begins cycling through the model. You can interrupt the progress of the simulation at the end of any cycle or iteration, by pressing any key on the keyboard or by setting the variable "TIMESTOP" in the set file to the desired stop point. This feature is useful for monitoring the progress of the simulation and for changing any of the set or data files. When the program has been interrupted, it asks the user whether they wish to continue the simulation (Fig. 2). Any response (including <CR>) other than a character string beginning with "N"[1] or "n" signifies a yes answer (this command format is common throughout PC_SIM). A NO answer terminates execution of the program. If the user wishes to continue the simulation, the program will ask whether it should enter graphics mode to allow viewing the status of key variables. A NO answer indicates that the user wishes to change the data before continuing the simulation. If the latter answer is chosen the program will ask the user if they wish to change the data in the set file (Fig. 3). A "Y" or "y" will generate the prompt: "Do you wish to read another set file". If the answer is affirmative, the user has the option of changing the set data either by reading another file ("Y" or "y" answer) or by changing the data interactively (<CR>). Before continuing, the program will also ask the user whether to change the other data files used in the simulation.

After an interruption, program execution begins with the iteration following the one at which the model was stopped. To restart the program, the user must enter the number of iterations at which the simulation is to terminate or press enter to take the default value. By repeating the above procedures the user can interrupt the program, view model's output, or alter the data and set files as often as desired.

Graphics

When the program reaches the specified number of iterations, it enters graphics mode (Fig. 4) and allows the user to, among other things, plot the simulation variables. One of the more useful commands in this mode of PC_SIM is the "H" or "HELP" command that generates the help menu. The following is a more detailed description of that menu.

COMMAND	DESCRIPTION
1. Clear	clears the screen and removes any minimum or maximum scaling factors set with either a min or m# command.
2. Quit	clears the screen and terminates program execution.
3. Help	prints the help menu on the screen.

1/ Throughout PC_SIM command language, only the first letter of a command needs to be entered. That letter can be in either upper or lower case format.

YEAR = 5

Simulation begins at Year: 0
Finish Simulation at Year:? 100

PRESS ANY KEY TO INTERRUPT PROGRAM
Do you want to continue program execution (<CR> or No)?

Do you want to plot the current results (Yes or <CR>)?

Figure 2. The PC_SIM screen after the program has been interrupted. In this example the user has interrupted the simulation at year 5 and instructed the program to continue execution. The program now asks the user whether to plot the results of the simulation from years 1 through 5.

```
CURRENTLY YEAR = 5


DO YOU WANT TO START OVER (Yes OR <CR>)?
DO YOU WANT TO CHANGE THE VARIABLES IN THE SET FILE (Yes OR <CR>)? y
DO YOU WANT TO READ ANOTHER SET FILE (Yes OR <CR>)?




What is the vulnerability of yearling males (Default = 2)
```

Figure 3. Interactively altering the data during an interruption in program execution. This screen is generated if the user answers no to the last question shown in Fig. 2.

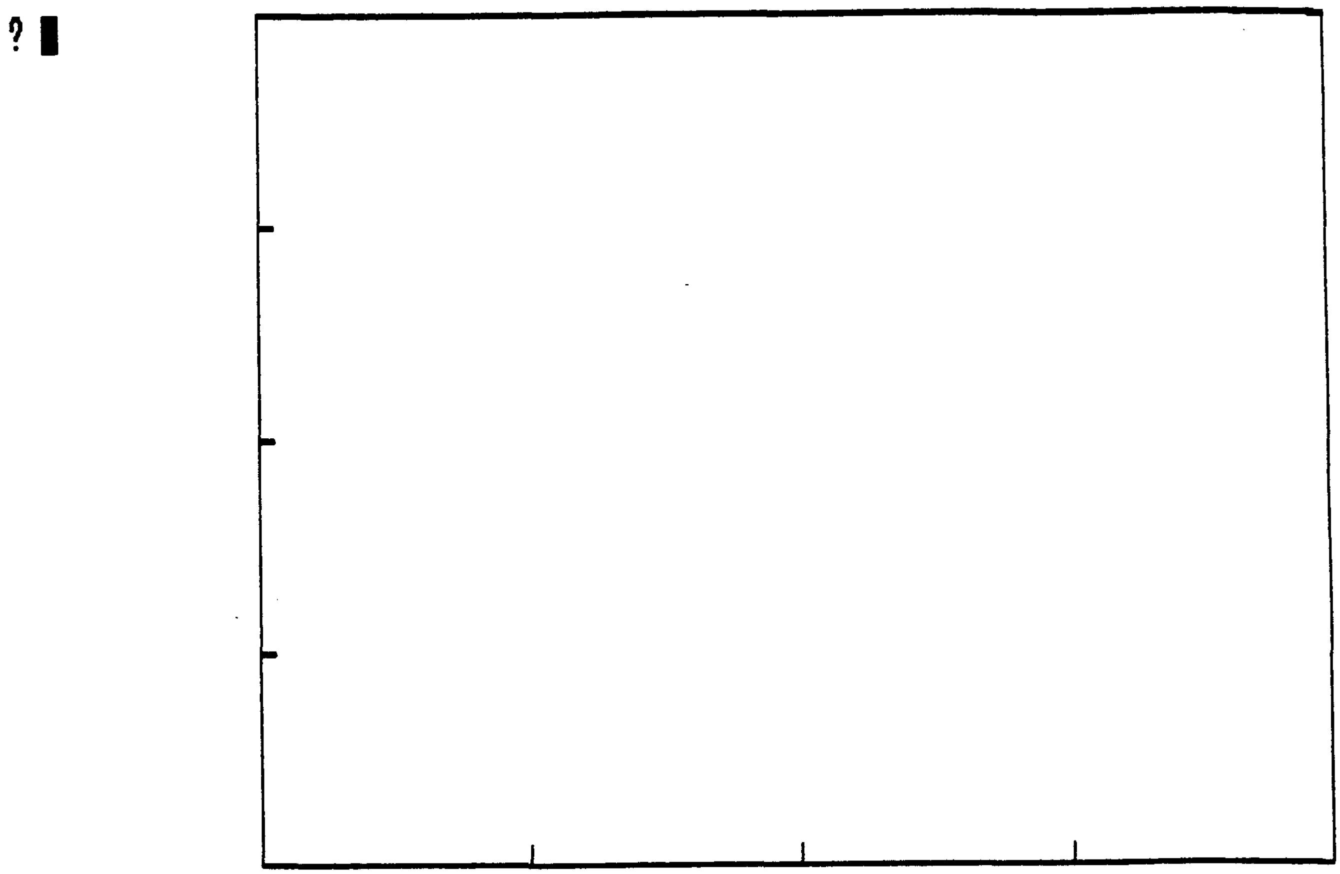

Figure 4. The PC_SIM screen after the program has entered graphics mode

4. Variable list — prints a list of all the variable names and their associated plotting numbers on to the screen.

5. Saves filename — saves the plot exactly as it appears on the screen onto a floppy or hard disk. The plot will be stored in the file specified by filename. That name must follow DOS conventions. If the three letter file extension is not specified, the program appends .BAS to the filename.

   e.g., S a:plotl saves screen onto a floppy disk located in drive A with the name plotl.bas.

6. Restore filename — erases the current screen and then restores the plot from hard memory that has been saved with an "S" command. The program allows additional plotting over the restored plot. With an "S" or "R" command, if the filename is not specified the program will trap the error and allow the user to enter DOS, quit the program, enter a new filename, or cancel the command. Experienced users of PC_SIM will take advantage of this feature when they wish to enter DOS without terminating program execution.

7. Display# — displays the values and associated iteration number for plot variable specified by #.

   e.g., D5 displays values for variable number 5

8. Maximum# — scales all subsequent plots to the maximum specified by #. This scaling factor applies only to those variables that have maximum values less than #.

   e.g., M1000 scales all subsequent plots to a maximum of 1000. This command stays in effect until a C command is issued.

9. MIN — scales all subsequent plots to the minimum value of the plot variable.

10. Write# filename — writes the values for variable # and their corresponding iteration numbers to the file specified by filename.

11. <cr> or Null line — restarts program for another simulation period.

12. # — plots variable # versus time

e.g., 5 plots variable number 5

13. #p — plots variable # with unconnected points (scatter plot)

14. 1 vs 2 or
    1   2 — plots variable 1 versus variable 2 (i.e., 1 on Y axis, 2 on X axis)

15. 1/30 vs 2/100 — plots variable 1 versus variable 2 with Y axis scaled to a maximum of 30 and the X axis scaled to a maximum of 100. Note that the "/" overrides any maximums set with the "M#" command (see point 8).

16. 1/30 vs 2p/100 — same result as in the preceding example, except a scatter plot is generated instead of a line plot.

See Appendix I for a description of the other features of PC_SIM not included in the help menu.

Appendix I

Changes to MICROSIMCON:

1. The framework for reading data and set files has now been established. In addition to this new feature, for each required data set, the program offers the user the choice of taking a default file name (by simply pressing the return key) or specifying a different one.

2. Without terminating the simulation, the program now identifies and allows the user to correct such inevitable errors as:

   i) specifying an incorrect or non-existent file directory, file name, or DOS path.

   ii) specifying files in which the format of the data is incorrect.

   iii) writing plot or data files to protected disks or to disks with insufficient memory availability.

   iv) hardware or disk problems that prevent proper I/O operations.

3. On detecting an error or during plotting, the program now allows the user to access DOS without terminating simulation execution. Thus, the user now has the ability to edit incorrect data files, examine the file directories, change the default DOS path, etc., or issue any DOS command he wishes (this includes running other programs!) without re-starting the often time consuming simulation.

4. Simulations can now be interrupted at any point either by setting a special variable in the set file to a specified stop time or by pressing any key at the desired moment.

5. Interrupted simulations can be continued or terminated at the discretion of the user. If the user wishes to continue the simulation he can either enter graphics mode to plot the status of selected variables or change any of the data used in the simulation. Set data can be changed either interactively or by requesting a new set file.

6. The value determining the end of the simulation period can be changed before an interrupted simulation is continued.

7. The program now detects the kind of graphics card you are using automatically and then configures graphics arrays accordingly.

8. The labeling of all graphs has been made more readable; variable names, maximums, and minimums are now printed under all plotting situations. In addition, the bug where Y-axis labels containing exponents overwrote the screen during plotting has been corrected.

9. Negative numbers can now be plotted.

10. For variables containing both negative and positive values, the program now draws a "zero" line across the screen.

11. The program now allows the user to set a plot maximum so that all subsequent plots are on the same scale until either a clear command is entered or a new maximum is specified.

12. A bug has been corrected so that the user can now scale any variable independent of the rest to a maximum equal to or greater than the variable's actual maximum. This corrected feature also works when one variable is plotted against the other or when a plot maximum command has been issued.

13. The program now allows the user to set the minimum to which the program scales plots. By default all plots containing positive numbers are scaled from 0 to the maximum value of the data. When the "min" command is issued or when plots contain negative numbers, the program scales the axes from the smallest number to the largest or to the number set by "max" or "/" commands.

14. Values of selected variables indexed by corresponding day or year can now be displayed (100 at a time) for any simulation length (i.e., periods > 100).

15. The printing of variable names is no longer restricted to one screen.

16. More efficient programing structure and variable use has resulted in a saving of approximately 20% of the memory used in plotting.

17. A <u>single</u> simulation period can now extend to 32,767 (2^{15}-1) iterations.

18. After the user has finished plotting, the program now allows one the choice of either terminating the program or continuing the simulation. If the user decides to continue the simulation, he can either start over (i.e., re-initialize) or continue with the values the simulation terminated with. If the latter choice is exercised repeatedly, the user can theoretically simulate the chosen conditions for periods limited only by his patience. As with interrupted simulations, simulations following graphics mode also allow the user the option of changing any of the data or set files. If the user does not exercise the option of changing the end time, the simulation will, by default, finish after the same number of iterations as the previous simulation.