ALASKA DEPARTMENT OF FISH AND GAME
JUNEAU, ALASKA

COMPUTERIZED POPULATION MODELS FOR USE IN CARIBOU MANAGEMENT PLANS

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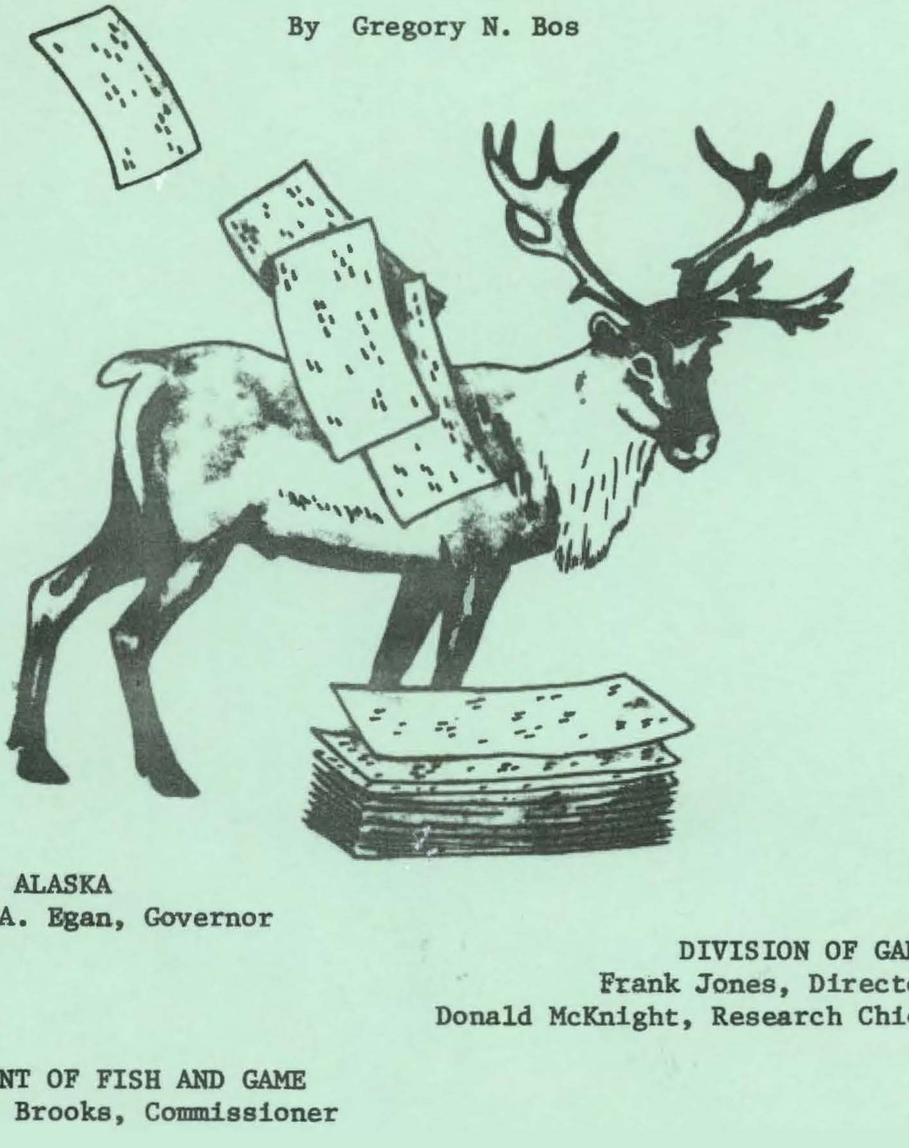

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Final Report
Federal Aid in Wildlife Restoration
Projects W-17-3, W-17-4 and W-17-5
Job 3.8R

(Printed September 1974)

FINAL REPORT (RESEARCH)

State: Alaska

Cooperator: Gregory N. Bos

Project Nos: W-17-3, W-17-4 and W-17-5

Project Title: Big Game Investigations

Job No: 3.8R

Job Title: Computerized Population Models For Use In Projected Caribou Management Plans

Period Covered: July 1, 1970 to June 30, 1973

SUMMARY

Specification of variables affecting population dynamics of the Nelchina caribou herd was used with the deterministic computer program POPSID to predict population and harvest trends for 20-year runs. For comparative purposes variations between runs were made with respect to mortality rates rather than reproductive rates. The relative influence of different calf mortality levels, different adult mortality levels and different harvest levels on rate of population increase, final population size and total yield was tested.

Small differences in calf mortality levels maintained for 20 cycles resulted in relatively large differences in final population size. Maintenance of 0.05 proportional adult kill by hunters for 20 cycles for one run resulted in a larger final annual yield, a similar total yield, and a population size double that under the regime of 0.10 harvest.

CONTENTS

BACKGROUND

The application of computer simulation modeling to solve resource management problems has received increased attention in recent years. Complex ecological systems, involving multiple dependent and independent variables whose values may change in time and space with predictable or random frequency, are particularly amenable to computerization.

Simulation models have been designed for various levels of application, some dealing with specific local animal populations (Gross 1970), others with whole resource systems analysis (Walters and Bunnell 1971). Regardless of the scope, simulation models can have wide applicability provided the user can reconcile the assumptions upon which such models are based with the known characteristics of the specific situation he wishes to study. Discussions of applications of computer simulation modeling in resource management are available in the literature (Paulik 1969, Walters and Bunnel 1971, Halter et al. 1972 and Walters and Gross 1972).

Management of Alaskan game populations now requires comprehensive long-range planning to meet the demands engendered by growing human populations, increased resource utilization and changing patterns of land ownership. Computer models can provide information for improving perspectives in the decision-making level of sophisticated management.

Maintenance of caribou *(Rangifer tarandus)* populations in Alaska depends upon comprehensive management. The caribou is both a primary subsistence animal and an important source of recreation. It provides a substantial economic return to the State, and it has a great esthetic value as well. The caribou's dependence on a climax and wilderness environment make it vulnerable to land development programs and large scale construction projects such as the Trans-Alaska Oil Pipeline.

Some caribou populations in the state, accessible to human population centers and subjected to intensive hunting pressure, have experienced population declines in recent years. Although their management by the Department has been primarily by means of the hunting regulatory mechanism and to some extent through the management of predator populations, implementation of management alternatives has required consideration of environmental factors influencing the status of these caribou populations. The complexity of these interrelationships makes long-term predictions of the results of current management approaches difficult. Even with gross simplification of the causal relationships involved, the number of possible situations resulting from manipulation of the relevant variables is beyond the practical scope of the desk calculator. The use of a computer simulation model in this type of exercise provides immediate exposition of solutions where the variables can be changed at will. Although heuristic in nature, such representations have the advantages of: (1) testing the long-term effects of management alternatives before they are implemented, (2) focusing attention on those casual relationships most critical to management goals (thus providing guidance to research programs) and (3) using the knowledge of one part of a system to predict the behavior of another less well-known part of the system. If the simulation could approximate the real-world situation, the value of modeling to caribou management is apparent.

OBJECTIVE

To develop a long-term caribou management plan with the use of computerized population models.

PROCEDURES

This job was intended as a pilot study to examine the feasibility of modeling caribou populations for management applications. The priorities of concurrent projects, the turnover of project personnel and the level of funding and time allocation precluded an exhaustive study. The approach taken was that of literature review and the application of an existing computer population model program to the data available for the Nelchina caribou population. The deterministic program POPSID (Dean 1972) was used to gain familiarity with the difficulties of incorporating population data into a simulation and interpreting the results. The bulk of this report deals with the specification of input and the resultant predicted situations.

INPUT

Use of POPSID involves input of two series of variables: required (basic) input and supplementary input. Required input includes the initial statement of variables needed to complete a job. Examples of required variables are specification of the number of cycles desired in the job run, specification of the type and sequence of mortality, initial numbers of males and females, breeding age limits, number of young born per female, sex ratio at birth, and instructional input to change the application of mortality or reproduction patterns during the job. Supplementary input allows for specification of an initial age and sex distribution, specification of age - and sex-specific mortality rates and specification of reproductive and birth rate distributions.

Nelchina caribou population parameters selected for input into POPSID are described below in the order in which they entered the program.

Test value for small populations: POPTST

POPTST is a threshold value which determines what mortality fraction of a whole animal is considered as a mortality loss of that animal. A value smaller than POPTST retains the animal in the population.

POPTST = 0.5 was selected on all runs.

Male breeding age limits: MINM AND MAXM.
Female breeding age limits: MINF AND MAXF.

Jones (1966) reported a minimum breeding age of 17 months for caribou transplanted to Adak Island as calves. In natural populations the minimum breeding age for males is probably greater. Bergerud (1961) determined that some males breed at 29 months and that females sometimes breed at 17 months. Skoog (1968) felt that breeding in yearlings was quite limited and that first breeding usually occurred at 29-30 months of age. MINM = 2 MINF = 1 were originally assumed for the purposes of this exercise. However, MINF was later altered through the use of the supplementary reproductive distribution input.

I could find no data on maximum breeding age recorded. Bergerud (1961) found pregnant females over 10 years of age. For purposes of this exercise breeding until death was assumed: MAXM and MAXF = NAGE = 15.

Frequency of female's breeding: KCYC

KCYC is expressed as the number of times a given female breeds each cycle. In this exercise, one cycle equalled one year. Therefore KCYC = 1.

Number of cycles desired on the job run: NFOR

All jobs were run for 20 cycles (20 years). NFOR = 20.

Maximum age attainable: NAGE

The maximum age attainable by Nelchina caribou under wild conditions was assumed to be 15 years. Only 4 of 1,710 Nelchina caribou aged by the cementum annuli method during 1969-1971 were over 15 years of age. None were found to be older than 17 years. NAGE = 15 years.

Type and sequence of mortality: MORGO

POPSID enables mortality rates to be applied as proportional mortality, density-dependent mortality, and density-independent mortality, separately or in combination.

MORGO offers the following options:

1. No mortality or only density-independent mortality.
2. Proportional mortality only.
3. Density-dependent mortality only.
4. Proportional followed by density-dependent mortality.
5. Density-dependent followed by proportional mortality.
6. Proportional, then density-independent and then density-dependent mortality.
7. Density-dependent, then density-independent and then proportional mortality.

Because no information is available on density-dependent relationships of natural mortality factors operating on the Nelchina herd, all natural mortality was lumped and treated as proportional mortality.

In this exercise it was desirable to simulate harvest levels in some job runs by use of the density-independent mode. In terms of the program mechanics, when density-independent mortality is considered in combination with other mortality types the sequence of calculations in the program requires calculation of density-independent mortality after other mortality calculations have been completed. However, with the early fall hunting season now in effect, mortality due to hunting occurs before the winter period when I think much of the natural mortality on animals older than calves occurs.

One way to circumvent this problem was to use MORGO = 7 where density-dependent mortality is followed by density-independent and then by proportional mortality. By setting density-dependent mortality at 0, the desired combination and sequence were attained.

Density-dependent mortality was also used in a proportional mortality mode where combinations of two proportional mortality rates were used. This was the case when hunting mortality was expressed as a proportion and was then followed by natural mortality, also expressed as a proportion. In POPSID, density-dependent mortality is expressed by the equation $Y = dX + BX^2$. The constants d and B are under the user's control. X is the number of animals to which the mortality applied. Thus by setting B = 0, the density function is eliminated and Y = dX becomes proportional mortality. Mortality option MORGO = 5 was selected for those job runs where density-dependent mortality (used as proportional mortality) was to be followed by proportional mortality.

Some job runs in this exercise treated all mortality as proportional mortality only.

Initial number of males: XM (MINM)

In POPSID, XM is the number of males assumed to be at least at the minimum breeding age. This entry is overridden by specification of the supplementary starting age and sex distribution input. I used XM (MINM) = 1,410, assuming a starting total population of 10,000. Derivation of this value is explained under Initial age and sex distribution.

Initial number of females: XF (MINF)

As above. XF = 6,150.

Maximum number of females one male can breed each breeding period: HAREM

Bergerud (1961) suggested one male could breed 7 females per breeding season. This was the ratio used for most of the job runs. On some jobs, HAREM size was reduced to 4 to measure effects, if any, on population parameters. HAREM = 7, 4.

Number of young born to each breeding female each breeding period: BRATE

BRATE = 0.785. This value was derived as a weighted average of values described under Birth rate distribution.

Proportion of young born that is female: RATIO

Skoog (1968) reported secondary sex ratios for the Nelchina herd and two other Alaskan herds ranging from 0.500 females to 0.483 females, and averaging 0.488 females (n = 260). He assumed the Nelchina ratio to be 0.49 females. This value was used in this exercise. RATIO = 0.49.

Starting age and sex distribution options: MODOP

A "1" specifies that a distribution is desired. A "2" specifies no distribution is desired.

Initial age and sex distribution

POPSID provides an option for specifying the initial age and sex distribution of the simulated population. One of two distributions was specified in most runs. A basic age and sex structure was derived from data gathered in field classifications of Nelchina caribou in 1972, and from age class proportions determined from age samples of the kill for the years 1963 through 1971. The basic age and sex structure was similar to that originally prepared and later revised as part of a partial Nelchina population status evaluation (Bos, in press). For use in the simulation model, the basic age and sex structure was assumed to apply to a June 1 population. In addition, it was modified to reflect different sex ratios in calf, yearling, and 2-year-old age classes (Table 1). Two initial age and sex distributions differing with respect to the sex ratios of the first three age classes were used. Sex ratios for these age classes were specified as:

Calves	51 males: 49 females		54 males: 46 females
Yearlings	50 males: 50 females	OR	55 males: 45 females
2-year-olds	45 males: 55 females		50 males: 50 females

I had intended to specify two initial age and sex distributions as above except for the calf sex ratio of 54 males:46 females which should have been 51 males:49 females, giving then the two distributions based on the sex ratios:

Calves	51 males: 49 females		51 males: 49 females
Yearlings	50 males: 50 females	OR	55 males: 45 females
2-year-olds	45 males: 55 females		50 males: 50 females

Also, I had intended that these distributions be "paired off" with the corresponding proportional mortality rate distributions (see <u>Proportional mortality</u> below), which were determined in part on the assumption of the above sex ratios for the first three age classes. Through an oversight these conditions were not programmed. However, I feel the effect on the results of the affected runs was minor because these differences are equivalent to small differences in absolute numbers in the initial age and sex distributions. In addition, as each job was run, the initial specified distribution was rapidly replaced by new cohorts that were generated according to the parameters influencing reproduction and mortality.

No initial age and sex distribution was specified in five additional runs.

Proportional mortality

Age - and sex-specific proportional mortality rates were applied to the simulated population in all job runs. Proportional mortality was used in some runs (Table 6) to represent <u>all</u> mortality operating on the population. In other runs proportional mortality represented all non-hunting mortality, while hunting mortality was represented by density-independent mortality input or by density-dependent input (converted to proportional, as explained under <u>Density-dependent mortality</u>). Proportional mortality rates were determined by a life-table analysis of mortality or were arbitrarily specified.

Although Nelchina caribou mortality statistics do not meet the assumptions required for life table analysis, use of the life table approach probably gives a useful approximation of age - and sex-specific

Table 1. Initial age and sex distributions specified in application of POPSID to Nelchina caribou.

Age Class	Males*	Males**	Females*	Females**
0 (calves)***	920	970	880	830
1	640	780	640	640
2	420	520	510	510
3	360	280	982	978
4	164	128	740	737
5	142	110	536	534
6	140	109	415	413
7	64	50	393	391
8	48	37	483	481
9	34	26	476	474
10	14	11	408	406
11	14	11	211	210
12	6	5	128	128
13	2	2	113	114
14	1	1	92	91
15	1	0	23	23

*	**
calf sex ratio - 51 males: 49 females	54 males: 46 females
yearling sex ratio - 50 males: 50 females	55 males: 45 females
2-year-old sex ratio - 45 males: 55 females	50 males: 50 females

*** values for calves (age class 0) are not entered in program (see POPSID).

mortality rates. Table 2 presents the frequency distribution of 1,710 Nelchina caribou of known sex aged by the cementum annuli method during 1969-71. The data for calves and yearlings, and to some extent, for 2-year-old males, were biased by hunter selectivity and possibly by collection procedures. For these age classes, mortality rates were determined as follows:

Calves--Mortality of calves from all causes during the first year of life was estimated by taking the difference between observed calf:cow ratios in April and the assumed calf:cow ratio of 60:100 (estimated natality) of the preceding June (Skoog 1968). For the years 1955-62, Skoog determined an average mortality of calves of 0.40 (Skoog 1968). Calf counts conducted in the late winters of 1970, 71 and 72 yielded mortality estimates of 0.55, 0.48 and 0.76 respectively, for an average mortality of 0.60. Using these values as a range, three calf mortality levels were assigned: 0.40, 0.50 and 0.60 mortality.

Arbitrary specification of sex ratios at one year of age (i.e., 0.50 males or 0.55 males), when combined with the assigned calf mortality rates of 0.40, 0.50 and 0.60, resulted in six possible different pairs of sex-specific calf mortality rates of which four were used (Table 3).

Yearlings--The mortality rate of yearling females was taken to be 0.202. This value, which represents an average mortality rate for females 2-years-old and older, was obtained through the survival estimation procedure presented by Robson and Chapman (1961). The frequency distribution for females 2-years-old or older in Table 2 was used in the calculation. By applying the mortality rate of 0.202 to the female yearling age class and then setting the number of 2-year-old males to conform to arbitrary 2-year-old sex ratios, the mortality rate of male yearlings was calculated to be 0.347.

Two-year-olds--The mortality rate for 2-year-old females was calculated from the frequency distribution in Table 2. For 2-year-old males, the same procedure was used as for yearling females, above, except that for males, only animals 3-years-old or older were used to avoid bias due to hunter selection. The average mortality rate for males 3-years-old or older was calculated at 0.337 and was used for the 2-year-old males.

Three-year-olds or older--Mortality rates for all animals older than 3 years were calculated from the frequency distribution in Table 2.

The above described age-specific mortality rates were applied to the simulated population in five runs where the only mortality was the specified proportional mortality.

An alternative mortality schedule was used in five additional runs where an estimated average mortality rate was calculated for each sex. Calculations followed the procedure used by Robson and Chapman (1961). The rates of 0.337 for males and 0.202 for females (used above for 2-year-old males and yearling females, respectively) were applied to all

Table 2. Sex and age frequency distribution of Nelchina kill sample 1969-71.

Age Class	Males	Females
0-1	74	54
1-2	71	59
2-3	145	149
3-4	180	130
4-5	82	98
5-6	71	71
6-7	70	55
7-8	32	52
8-9	24	64
9-10	17	63
10-11	7	54
11-12	7	28
12-13	3	17
13-14	0	15
14-15	1	11
15-16	-	2
16-17	-	2
17-18	1	1
	785	925

Table 3. Proportional mortality distribution by age and sex used in POPSID Nelchina caribou.

	Mortality Rates							
	Males				Females			
Age Class	A	B	C	D	A	B	C	D
0	0.412	0.510	0.460	0.608	0.388	0.490	0.541	0.592
1	0.347				0.202			
2	0.337				0.184			
3	0.364				0.196			
4	0.260				0.184			
5	0.305				0.164			
6	0.432				0.152			
7	0.348				0.169			
8	0.400				0.250			
9	0.472				0.328			
10	0.368				0.419			
11	0.583				0.373			
12	0.600				0.362			
13	0.500				0.500			
14	0.500				0.733			
15	1.000				1.000			

A	B	C	D
0.40 calf mortality	0.50 calf mortality	0.50 calf mortality	0.60 calf mortality
0.51 male at birth	0.51 male at birth	0.51 male at birth	0.51 male at birth
0.50 male at 1 year	0.50 male at 1 year	0.55 male at 1 year	0.50 male at 1 year
0.45 male at 2 year	0.45 male at 2 year	0.50 male at 2 year	0.45 male at 2 year

Note: Mortality rates for age classes older than calves were the same for distributions A-D.

age classes older than calves. For the calf age class, the rates indicated in Table 3 were used.

For the remainder of the job runs, where proportional mortality was used by itself in combination with density-dependent or density-independent mortality, arbitrary proportional mortality rates of 0.050, 0.075, 0.100, 0.150 and 0.200 were used to represent natural mortality only.

Density-Dependent Mortality

Quantification of density-dependent mortality was not attempted. Elimination of the density function from the density-dependent mode allowed its use as a proportional mortality input in runs where the assigned kill by hunters was expressed either as proportional or density independent mortality, and it was used in combination with the program proportional mortality (nonhunting mortality).

Reproductive Distribution

Specification of a reproductive distribution is a supplementary input which overrides information in MINF, MAXF, and KCYC. The distribution is expressed as the proportion of females in each age class that will breed if males are available.

In all runs where initial age and sex distribution were specified, the following reproductive distribution, based on data from Skoog (1968), was specified:

Calves: 0.0 pregnant
Yearlings: 0.13 pregnant
2-year-olds: 0.61 pregnant
3 years +: 0.89 pregnant

Birth Rate Distribution

Supplementary input on age-specific birth rate for females that are bred overrides BRATE. Entry of a reproductive distribution makes a simultaneous birth rate distribution entry mandatory. In all cases where a birth rate distribuion was used, all females that were bred were given a birth rate of 1.0

Density-Independent Mortality

Density-independent mortality was used to arbitrarily specify the number of individuals in each age and sex class killed by hunters. Data in Table 2 and information from harvest statistics for the Nelchina herd for the years 1955-72 were used to develop a density-independent mortality scale. In years when the either-sex caribou kill was less than 4,000 an average of 0.68 of the kill was reported to be males. In years with a kill of 4,000 caribou or more, an average of 0.54 of the kill was males. By applying these sex ratios to a specified kill level and then using the age specific percentages in the kill from data in Table 2, the density-independent hunter kill levels (Table 4) were prepared.

Table 4. Kill levels used in POPSID Nelchina caribou density-independent mortality.

Age- and sex-specific losses for each 1000 animals in kill.

Age Class	Kill less than 4000 = 68% male		Kill greater than 4000 = 54% male	
	Male	Female	Male	Female
1	62	20	48	30
2	126	52	100	74
3	156	46	124	64
4	72	34	56	48
5	62	24	48	30
6	60	20	48	30
7	28	18	22	26
8	20	22	16	32
9	14	22	12	32
10	6	18	4	26
11	6	10	4	14
12	2	6	2	8
13	1	6	1	8
14	1	4	1	6
15	1	1	1	1
Subtotals	680	320	540	460
Totals	1000		1000	

As mentioned previously, all runs were 20 cycles in length. Density-independent mortality levels had to be specified for each cycle. Table 5 is a schedule of the mortality levels of Table 4 for the 20-cycle treatments. In runs where density-independent mortality rates brought about extinction of some age-sex classes, abnormal termination of the runs resulted. Tests of schedules coded as 3, 4 and 5 were not run pending adjustments in POPSID to prevent the malfunction.

Use of Parameters

All the above parameters and the runs in which they were used are summarized in Table 6. For comparative purposes, variations between runs were made with respect to mortality rates rather than reproductive rates because:

1. Fewer data are available on mortality rates than on reproductive rates of Nelchina caribou.
2. Mortality rates are probably less constant from year to year than reproductive rates.
3. The overall mortality rate can be significantly affected by management controls on hunting.

FINDINGS

The results of imposing specific regimes of reproductive and mortality parameters on the runs are expressed here in terms of population size and trend and in addition, where indicated, in terms of size of the hunter kill. Since application of mortality was basically separated into calf mortality and adult (older than calves) mortality, comparisons between runs were made with respect to these two variables where one variable was held constant while the second was changed. Rather than review all of the runs and duplicate much material, only some of the runs are used to illustrate the basic differences in results obtained. The results are indicated in Appendices 1-6. Each Appendix identifies the major variables represented therein.

At the outset it should be made clear that these simulations approached the real world situation only to the extent that the values entered for the variables and the performance of the program itself reflected actual conditions. Further, only a few of the variables were changed and these changes were made between runs rather than within runs. The number of possible combinations of factors considered on a cycle-by-cycle basis is enormous. Consideration of these on the limited trial basis of this project was not feasible.

Information currently available on the Nelchina herd does not allow specification of mortality rates by sex and age class except for a rough approximation by life table analysis. Runs 1, 3, and 5, represented in Appendix 1(a and b), used such estimated sex - and age-specific mortality rates (Table 3) for adults paired with calf mortality rates of 0.40, 0.50, and 0.60, respectively. All three simulated populations declined.

Table 5. Schedule of density-independent mortality levels used in POPSID Nelchina caribou.

Cycle (Year)	Schedule Code 1*	2*	3	4	5
1	500	500	500	500	500
2	1000	1000	1000	1000	1000
3	↓	↓	↓	↓	↓
4	↓	↓	↓	2000	2000
5	↓	2000	2000	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	3000	3000
8	↓	↓	↓	↓	↓
9	↓	↓	↓	↓	↓
10	2000	3000	4000	4000	4000
11	↓	↓	↓	↓	↓
12	↓	↓	↓	↓	↓
13	↓	↓	↓	6000	↓
14	↓	↓	↓	↓	8000
15	↓	4000	8000	↓	↓
16	↓	↓	↓	8000	↓
17	↓	↓	↓	↓	↓
18	↓	↓	↓	↓	16000
19	↓	↓	↓	10000	↓
20	↓	↓	↓	↓	↓

* Schedule Codes 1 and 2 were the only codes tested due to malfunction of POPSID.

Table 6. Parameters used in POPSID Nelchina caribou.

Required input	Used in runs numbered:
POPTST = 0.5 MINM = 2 MAXM = 15 MINF = 1 MAXF = 15 KCYC = 1 NFOR = 20 NAGE = 15	1-47
MORGO = 2	1-18
= 5	19-42
= 7	43-47
XM (MINM) = 1410	1-47
XF (MINF) = 6150	1-47
HAREM = 7	1, 3-6, 8-12, 14-20, 22-28, 30-36, 38-47
= 4	2, 7, 13, 21, 29, 37
BRATE = 0.785	1-47
RATIO = 0.49	1-47
MODOP = 1	1-8, 10-14, 16-22, 24-30, 32-38, 40-47
= 2	9, 15, 23, 31, 39

Supplementary input			Used in runs numbered:
<u>Initial age and sex distribution</u> (distributions presented in Table 1) - Based on sex ratios:			
<u>Calves</u>	<u>Yearlings</u>	<u>2 year olds</u>	
51M:49F	50M:50F	45M:55F	1-3, 5-9, 11-15, 17-23, 25-31, 33-39, 41-45, 47
54M:46F	55M:45F	50M:50F	4, 10, 16, 24, 32, 40, 46

Table 6. (continued)

Supplementary input		Used in runs numbered:
Proportional mortality		
Calf mortality rates	0.40	1, 6, 12, 20, 28, 36, 44
	0.50	2-47-11, 13-16, 18, 19, 21-24, 26, 27, 29-32, 34, 35, 37-40, 42, 43, 45, 46
	0.60	5, 17, 25, 33, 41, 47
Life table mortality rates on adults (see Table 3 for age and sex distribution of mortality rates)		
Based on yearling sex ratios:	0.50 M	1-3, 5
	0.55 M	4
Estimated average mortality rates on adults:		
M males = 0.337	M females = 0.202	6-10
Assigned proportional mortality rates:		
0.050		19, 27, 35, 43-47
0.075		20-25, 28-33, 36-40
0.100		11, 26, 34, 42
0.150		12-17
0.200		18
Density-dependent mortality		
$y - dX + Bx^2$		
Mortality rate set to 0 (d = 0 B = 0)		43-47
mortality used as proportional mode where B = 0.0		
d = 0.050		19-26
d = 0.075		27-34
d = 0.100		35-42

Table 6. (continued)

Supplementary input	Used in runs numbered:
<u>Reproductive distribution</u>	
Cycles 1-20	
Calves 0.0 pregnant	1-8, 10-14, 16-22, 24-30 32-38, 40-47
Yearlings 0.13 pregnant	
2 year olds 0.61 pregnant	
3 years + 0.89 pregnant	
Cycle 1	9, 15, 23, 31, 39
Calves 0.0 pregnant	
Older than calves 0.79 pregnant	
Cycle 2	
Calves 0.0 pregnant	
Yearlings 0.13 pregnant	
Older than yearlings 0.86 pregnant	
Cycles 3-20	
Calves 0.0 pregnant	
Yearlings 0.13 pregnant	
2 year olds 0.61 pregnant	
3 years + 0.89 pregnant	
<u>Birth rate distribution</u>	
1.0 for all females bred	1-47
<u>Density-independent mortality</u>	
Schedule 1	43
Schedule 2 (see Table 5)	44-47

The population in run 1 with 0.40 calf mortality was not quite able to sustain itself. Runs 3 and 5 declined more rapidly. If calf mortality actually averages close to 0.40 or 0.50, the results of these runs suggest the estimated sex - and age-specific mortality rates are a little high. Simulations using estimated sex-specific mortality rates derived also from life table analysis produced results similar to runs 1, 3 and 5.

Except for those simulations utilizing estimated sex - and age-specific mortality rates (Runs 1-10) all other runs used one or another designated proportional mortality rates for all adult sex and age classes. In some runs (Runs 19-42) two proportional mortality rates were used in each run, one rate for hunting mortality, and one rate for all other mortality. Finally, in Runs 43-47, hunting mortality was expressed as an integer (density-independent mortality) while all other mortality was expressed as proportional.

Except for runs 43-47, where numerical losses of adults to hunting were specified by sex and age class, the effect of using a proportional rate on all adult sex and age classes was to progress initial specified age-specific sex ratios through the population. Since the yearling sex ratio was set at 0.50 males (some runs at 0.55 males) for all cycles, this ratio progressed through the population with each cohort. By the 14th year in the simulations, all adult age classes in the population had 0.50 males (some runs 0.55 males). Observed natural proportions of adult males in Alaskan caribou populations have been less than 0.50. In the heavily-hunted Nelchina herd, males constitute only 0.25 of the adults. Therefore, population sizes and rates of increase in runs 11-42 should be recognized as somewhat below expected values.

The influence of the "balancing effect" of proportional mortality rates on sex ratios can be seen in the population trend curves (for example Appendices 2b and 3b). Initial specified sex ratios for adult age classes resulted in greater rates of increase in the early cycles of the run. When proportional mortality effected more equal adult sex ratios rates of increase decreased. In Run 18 (Appendix 2b), maintenance of the initial sex ratio structure throughout the run would have produced an increasing population rather than a declining population.

Examination of Runs 11, 14, 16 and 18 reveals the effects of applying 0.50 mortality to calves and mortality rates of 0.10, 0.15, 0.15, and 0.20, respectively, to all adult sex and age classes. Runs 11, 14 and 18 differed from run 16 in that the sex ratio of yearlings was 0.50 males in the former and 0.55 males in the latter. The results (Appendix 2[a and b]) indicate that for runs 11, 14, and 18, successive increases of 50 percent and 30 percent in the adult mortality rate decreased the final population by 62 percent and 64 percent, respectively. A final population of 45,352 was reduced to 6,335 by raising the adult mortality rate from 0.10 to 0.20. Population trends indicated in Appendix 2b suggest that at a calf mortality level of 0.50, an adult mortality rate between 0.15 and 0.20 would stabilize the population.

The effect of increasing the proportion of yearling males from 0.50 to 0.55 was to reduce the final population by 21 percent from 17,418 to 13,728. While the real effect of changing the yearling male sex ratio is masked by the influence of proportional mortality, as discussed above, comparison of Runs 14 and 16 suggests that relatively small differences in sex ratios of yearlings (and other young age classes) can have significant effects on long-term population trends. The need for more precise information on these ratios may thus be indicated.

Runs 13,14 and 15 applied an adult mortality rate of 0.15 and calf mortality rates of 0.40, 0.50, and 0.60, respectively. The results of these runs (Appendix 3[a and b]) indicate relatively wide divergences in final populations. With calf mortality at 0.40 the population grew to 67,141 in 20 years. With 0.60 calf mortality the population declined to 8,631 following initial increases. At 0.50 calf mortality the population increased to 17,418. Thus increases of 25 percent and 20 percent in calf mortality resulted in decreases in the final population of 74 percent and 50 percent, respectively.

Calf mortalities of 0.40 and 0.60 are within the range of observed values for the Nelchina herd. The strong influence of variations in calf mortality values on rates of population increase (Appendix 3b) suggests the value of annual assessment of this parameter for inclusion in management considerations.

Runs numbered between 19 and 42, inclusive, apportioned proportional mortality to hunting and nonhunting causes with losses of adults to hunting occurring before losses to nonhunting causes. Losses to each of these two causes were assigned as either 0.050, 0.075, or 0.100. Total mortality for any run was the combination of the two rates assigned to that run. Total adult mortality then ranged between 0.0995 and 0.1900. Comparisons of runs with the same combination of mortality rates, but in reversed sequence (i.e. 0.05 followed by 0.10 and 0.10 followed by 0.05), were then a comparison of harvest yields only, as population size and rate of increase remained the same for each run.

Runs 22, 30, and 38 applied a 0.50 calf mortality rate and a 0.075 adult natural mortality rate while losses to hunting were 0.050, 0.075, and 0.100, respectively (Appendix 4[a and b]). The population in Run 38 showed little change through the run, increasing slowly at first and then leveling off and decreasing slightly in the last 4 years. The level of mortality on adults was equivalent to 0.1675. With reduced proportional hunting losses, Runs 30 and 22 showed progressively larger population increases. Of particular interest is the fact that over the 20-year period the total hunting yield was somewhat similar under the three regimes of hunting, approximately 19,000 to 23,000 (Appendix 4[a and b]). The rate of population increase of the population experiencing only 0.05 hunting mortality was such that by the end of the 20-year period the annual yield for this population surpassed those yields from populations with higher proportional kills. Under such a situation, the decision to implement a particular level of harvest would then depend on the ultimate population size desired. In comparing runs 22 and 38 in the perspective of long-term benefits to hunters, doubling the allowable harvest (on a proportional basis) only increased total yield by 19 percent, while it decreased the final population size by 59 percent. Of course one is not bound to a single level of utilization. The level of proportional take could be increased as the population grows. Restraints on allowable take would depend on management goals for population size.

Determination of natural mortality levels would bear on establishment of harvest levels. In the reduced Nelchina population, if natural mortality is 0.10 for adults, a harvest level of 0.10 as in Run 42 is clearly too great (Appendix 4b) and even a 0.075 harvest level does not allow for a substantial increase in the population. On the other hand, if natural mortality on adults is 0.075, a harvest level greater than 0.05 as in Run 22 would be desired if a population that may be in excess of the range carrying capacity is to be avoided.

The effect of varying calf mortality, while maintaining one set of adult mortality rates, was discussed with respect to runs 13, 14 and 15, and is similar in runs 28, 30 and 33 (Appendix 5[a and b]). In these runs, populations under the regimes of 0.40, 0.50 and 0.60 calf mortality and 0.075 adult mortality rates increased to 36,329, 19,407, and 9,641, respectively, with corresponding total yields of 32,643, 22,161 and 14,899. Again, relatively small changes in calf mortality rates produced relatively larger differences in end results over a 20-year period.

The final type of situation examined was that in which the number of adults killed by hunters was specified while natural mortality on adults was held to 0.05 and calf mortality was varied at 0.50, 0.40, 0.50 and 0.60 in runs 43, 44, 45, and 47, respectively. Results are presented in Appendix 6[a and b]. As indicated in Appendix 6b, the effect of the various calf mortality rates on rates of increase and final population size was very marked. Under the "code 2" schedule of density-independent mortality (Table 5) only the population with 0.50 calf mortality (run 45) responded in a manner that would be acceptable under current management goals. At 0.40 calf mortality the population reached the unmanageable size of 86,853, while at 0.60 calf mortality the run was terminated after 18 years due to extinction of an age class. When the kill schedule was changed to "code 1" (Run 43, Appendix 6[a and b]) with a 0.50 calf mortality level, the sustained rate of increase again exceeded that which would probably be desirable.

An additional variable not presented in the Tables or Appendices was that of harem size or the number of cows one bull is able to breed. A harem size of 4 was specified in some runs as an alternative to the harem size of 7 specified in most runs. No effects on population size or growth rate resulted in the use of a harem size of 4. The population specified under the initial sex and age distribution and operated upon by various reproductive and mortality parameters was not limited by the harem size specifications. As expected, the number of surplus males in the population was affected by harem size. The implications of harem size to management revolve around: 1) the manipulation of the population sex structure by means of selective hunting to optimize yields and reproduction, and 2) the assessment of unmanaged hunter selectivity on population dynamics and consequent allowable harvest levels.

CONCLUSIONS

Computerized population simulation can be an important adjunct to management and research of a big game population. The almost immediate quantification (approximation) of the long-term consequences of management alternatives can provide a useful guide to management decisions, particularly when multiple goals are considered simultaneously. Research needs are identified where knowledge for specifying input variables is incomplete. When used on a continuing basis, input of annual status evaluations and improved accuracy of specified parameters should yield more refined and therefore more valuable predictions.

The use of computerized population simulations should be tempered with an understanding of the limitations involved. The validity or applicability of output depends on how well the simulation represents the real life situation as well as on the accuracy of the input data. Simulation programs tend to oversimplify complex relationships and conclusions regarding the relative importance of various factors may be erroneous if the simulation fails to correspond to the causal relationships bearing on the population under study.

RECOMMENDATIONS

Computer simulations should be used as an aid in management in Alaskan big game populations under intensive use.

Further work needs to be done to establish:

1. The adequacy of existing computer programs.
2. The desirability of modifying existing programs or constructing models.
3. The feasibility of designing successful models via contractual arrangements with experienced people outside the Department.

ACKNOWLEDGEMENT

Appreciation and thanks are extended to Dr. F.C. Dean, Department of Wildlife Management, University of Alaska, for his help and time in explaining the mechanics of POPSID and the physical procedure of running a program from specification to output.

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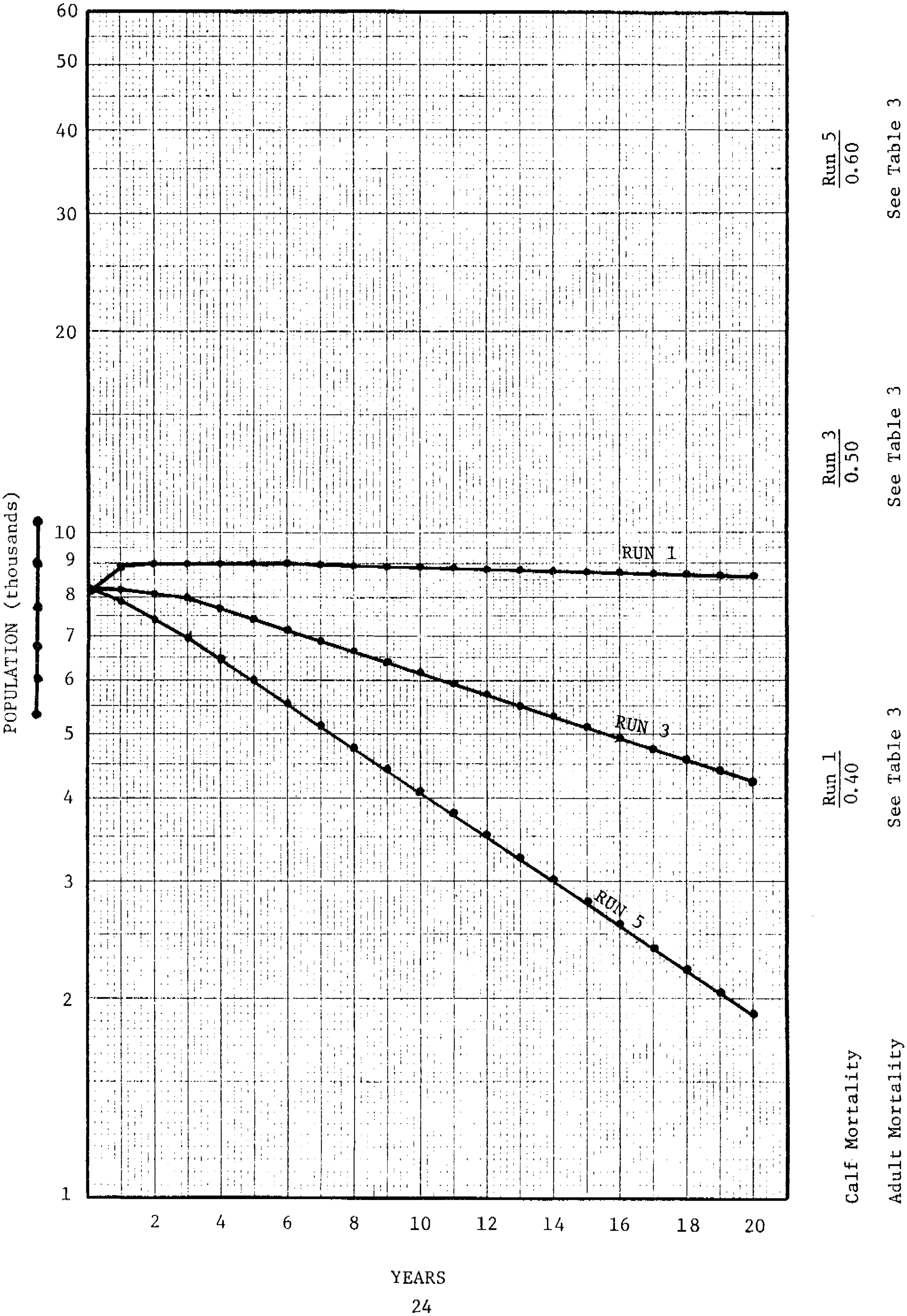
APPENDIX 1 a. POPSID Nelchina caribou cumulative population totals for runs 1, 3, 5.

	Run 1	Run 3	Run 5
Calf Mortality	0.40	0.50	0.60
Adult Mortality	See Table 3	See Table 3	See Table 3

Cycle	Run 1 Population	Run 3 Population	Run 5 Population
1	8901	8417	7933
2	9034	8248	7468
3	9063	8011	6991
4	9060	7748	6516
5	9046	7481	6062
6	9006	7199	5612
7	8960	6921	5187
8	8947	6675	4809
9	8947	6446	4464
10	8937	6221	4137
11	8911	5993	3828
12	8883	5769	3539
13	8860	5557	3276
14	8839	5353	3033
15	8812	5154	2803
16	8785	4961	2593
17	8759	4776	2396
18	8732	4601	2216
19	8706	4428	2051
20	8680	4264	1897

APPENDIX 1b. POPSID Nelchina caribou population trends for runs 1, 3, 5.

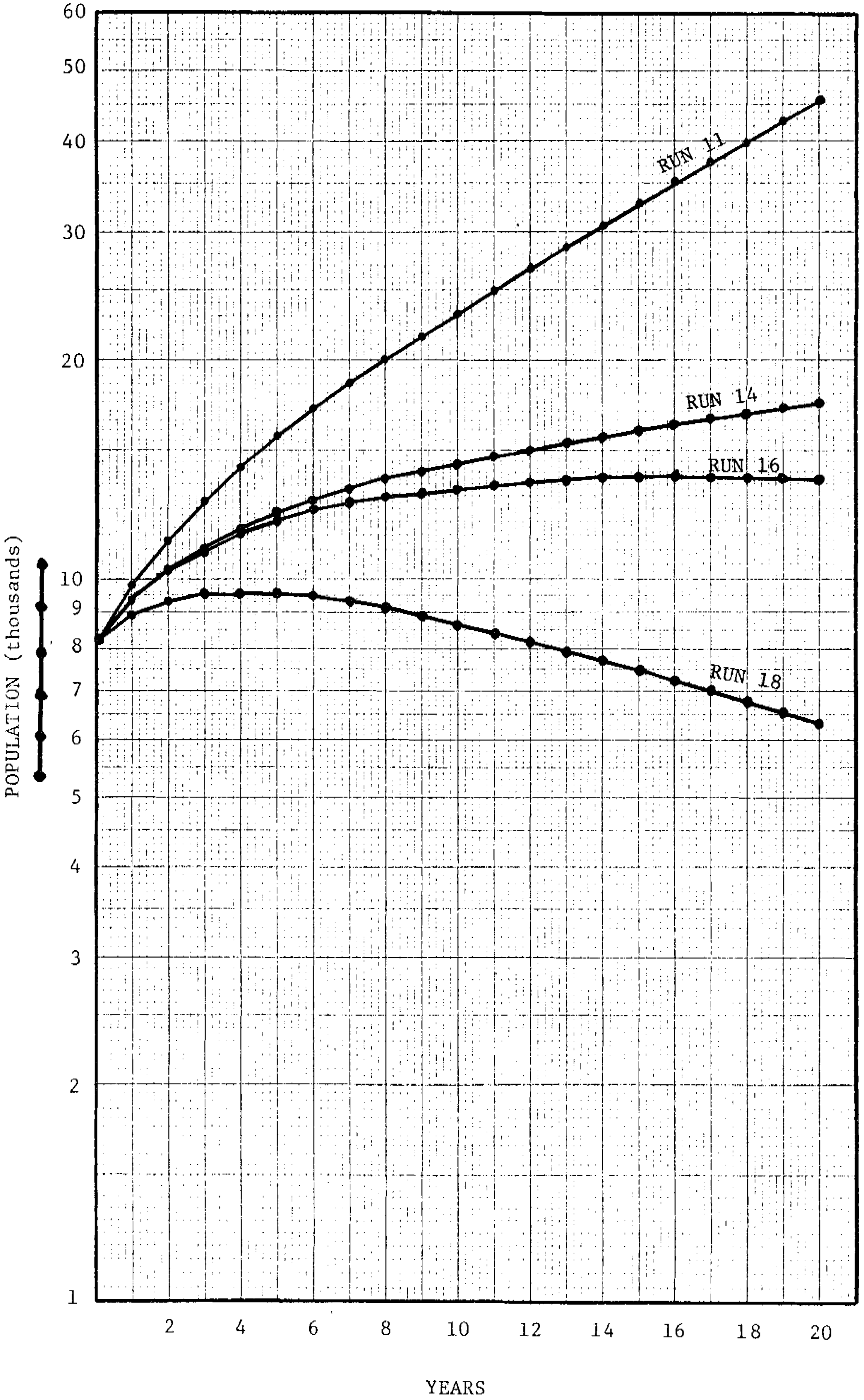


APPENDIX 2 a. POPSID Nelchina caribou cumulative population totals for runs 11, 14, 16, 18.

	Run 11	Run 14	Run 16	Run 18
Calf Mortality	0.50	0.50	0.50	0.50
Adult Mortality	0.10	0.15	0.15	0.20
Yearling Sex Ratio	0.50 Males	0.50 Males	0.55 Males	0.50 Males

Cycle	Run 11 Population	Run 14 Population	Run 16 Population	Run 18 Population
1	9804	9394	9386	8980
2	11257	10287	10268	9359
3	12653	11021	10959	9523
4	14092	11692	11555	9596
5	15578	12308	12068	9595
6	17062	12839	12475	9510
7	18490	13250	12745	9324
8	19941	13614	12945	9101
9	21470	13961	13114	8874
10	23142	14333	13291	8657
11	24896	14695	13443	8431
12	26742	15039	13565	8200
13	28651	15360	13641	7961
14	30583	15632	13671	7705
15	32816	15989	13750	7488
16	35175	16339	13812	7274
17	37459	16593	13784	7022
18	39921	16866	13766	6785
19	42554	17140	13748	6557
20	45352	17418	13728	6335

APPENDIX 2 b. POPSID Nelchina caribou population trends for runs 11, 14, 16, 18.



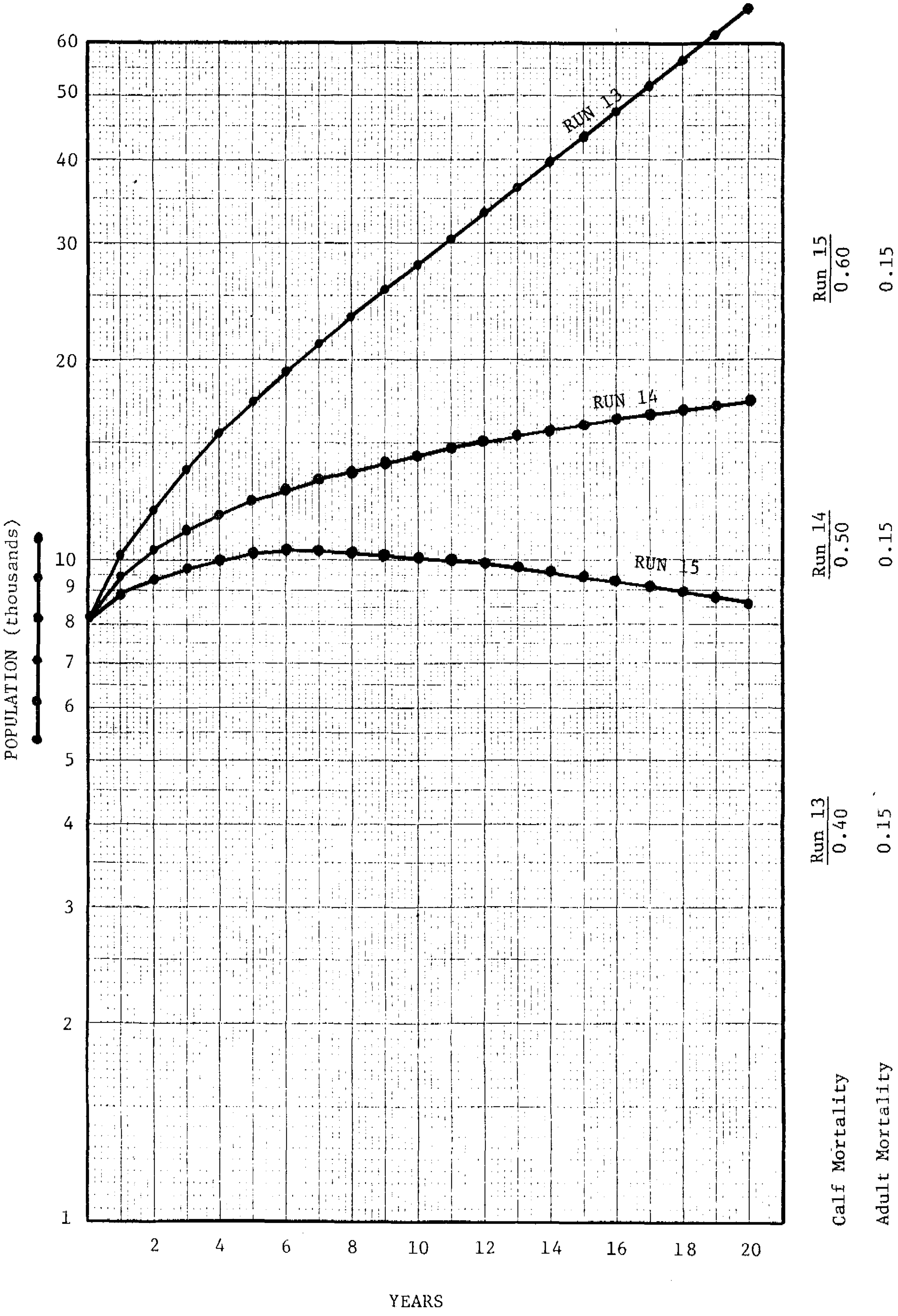
	Run 11	Run 14	Run 16	Run 18
Calf Mortality	0.50	0.50	0.50	0.50
Adult Mortality	0.10	0.15	0.15	0.20
Yearling Sex Ratio	0.50 Males	0.50 Males	0.55 Males	0.50 Males

APPENDIX 3 a. POPSID Nelchina caribou cumulative population totals for runs 13, 14, 15.

	Run 13	Run 14	Run 15
Calf Mortality	0.40	0.50	0.60
Adult Mortality	0.15	0.15	0.15

Cycle	Run 13 Population	Run 14 Population	Run 15 Population
1	10139	9394	8910
2	11928	10287	9400
3	13696	11021	9739
4	15509	11692	10000
5	17382	12308	10199
6	19276	12839	10307
7	21189	13250	10301
8	23213	13614	10243
9	25414	13961	10161
10	27848	14333	10100
11	30482	14695	10017
12	33331	15039	9915
13	36411	15360	9782
14	39752	15632	9595
15	43511	15989	9481
16	47591	16339	9351
17	51856	16593	9164
18	56520	16866	8984
19	61602	17140	8805
20	67141	17418	8631

APPENDIX 3 b. POPSID Nelchina caribou population trends for runs 13, 14, 15.

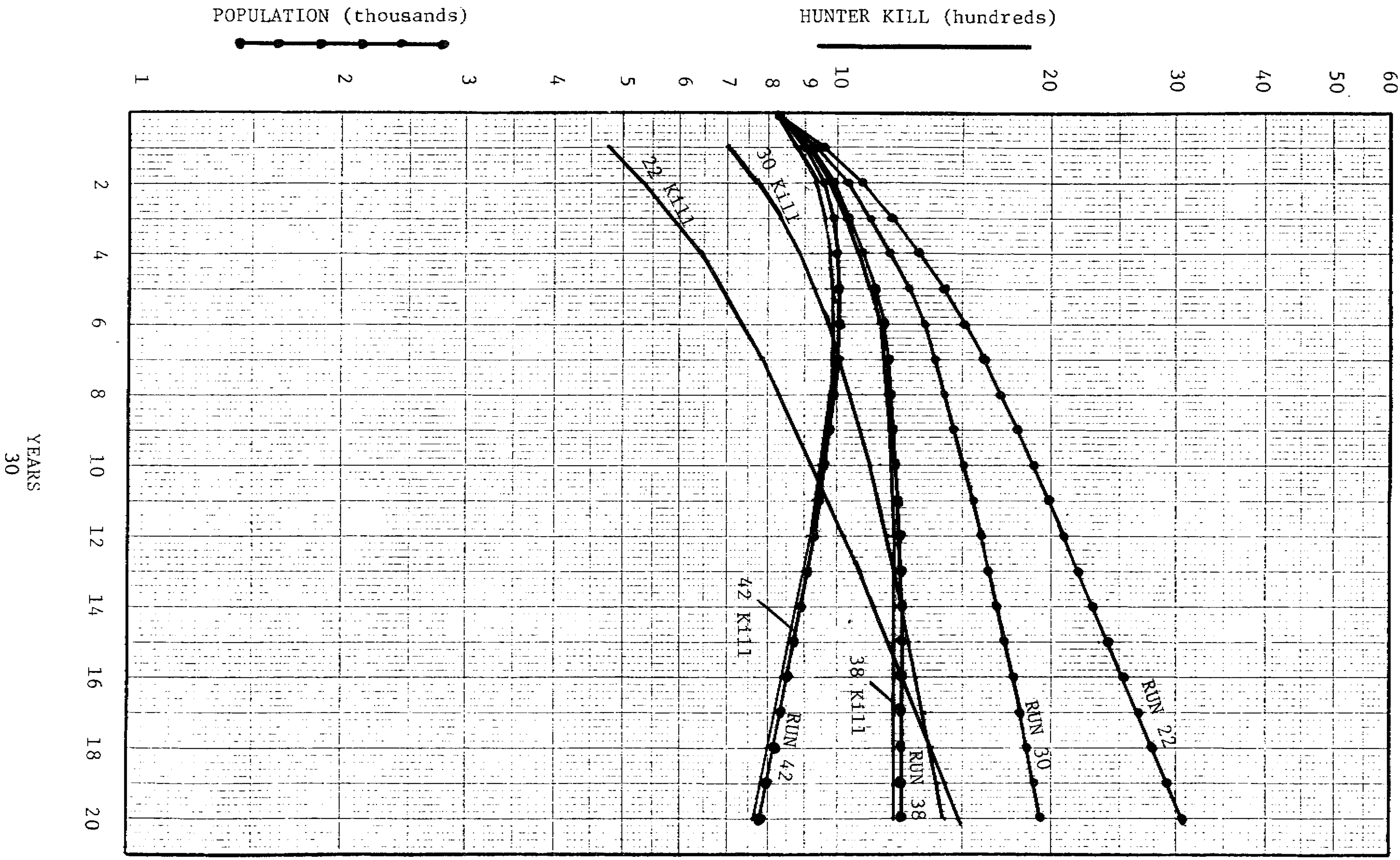


APPENDIX 4 a. POPSID Nelchina caribou cumulative population and annual hunter kill totals for runs 22, 30, 38, 42.

	Run 22	Run 30	Run 38	Run 42
Calf Mortality	0.50	0.50	0.50	0.50
Adult Natural Mortality	0.075	0.075	0.075	0.100
Adult Hunter Kill	0.050	0.075	0.100	0.100
Total Adult Mortality	0.121	0.144	0.168	0.190

	Run 22		Run 30		Run 38		Run 42	
Cycle	Population	Harvest	Population	Harvest	Population	Harvest	Population	Harvest
1	9624	476	9439	700	9251	915	9063	897
2	10834	534	10395	768	9959	981	9545	941
3	11934	588	11196	828	10481	1034	9817	968
4	13021	640	11942	881	10923	1075	10000	984
5	14100	688	12640	926	11296	1104	10106	988
6	15132	735	13259	967	11580	1127	10122	986
7	16061	782	13762	1006	11744	1146	10025	979
8	16970	831	14217	1045	11854	1163	9889	971
9	17903	879	14662	1081	11946	1175	9739	959
10	18909	928	15137	1116	12048	1185	9601	945
11	19932	977	15603	1149	12135	1193	9452	930
12	20979	1025	16054	1178	12210	1196	9288	911
13	22029	1080	16482	1214	12256	1205	9111	897
14	23050	1134	16866	1246	12263	1209	8911	880
15	24241	1183	17344	1271	12327	1206	8754	857
16	25471	1237	17821	1299	12377	1205	8592	837
17	26591	1292	18197	1328	12351	1203	8385	818
18	27780	1350	18588	1356	12336	1202	8183	799
19	29025	1410	18991	1386	12319	1200	7991	780
20	30322	1473	19407	1416	12305	1199	7807	762
TOTAL HARVEST		19242		22161		22923		18089

APPENDIX 4 b. POPSID Nelchina caribou population and hunter kill trends for runs 22, 30, 38, 42.



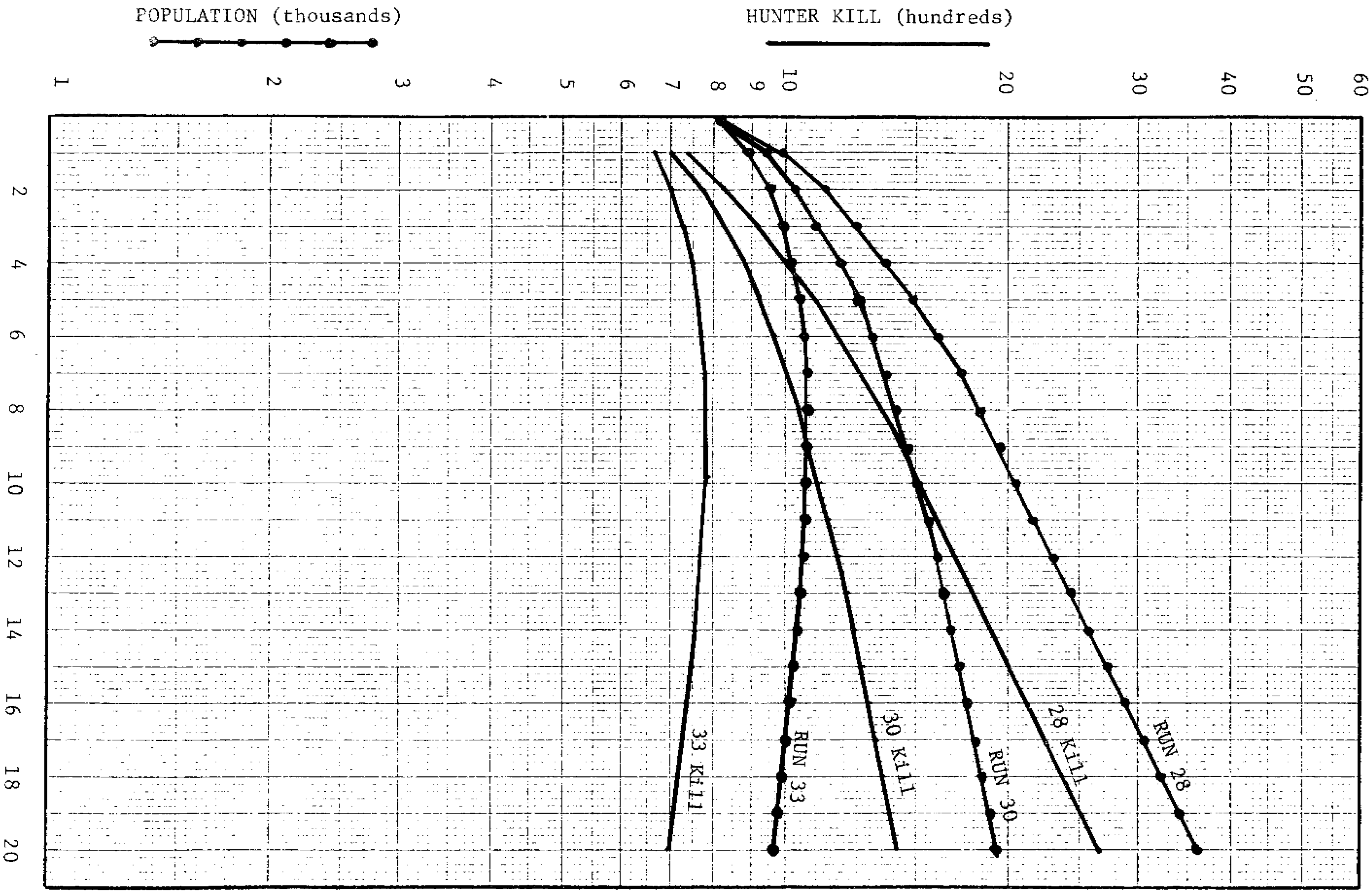
	Run 22	Run 30	Run 38	Run 42
Calf Mortality	0.50	0.50	0.50	0.50
Adult Natural Mortality	0.075	0.075	0.075	0.100
Adult Hunter Kill	0.050	0.075	0.100	0.100

APPENDIX 5 a. POPSID Nelchina caribou cumulative population and annual hunter kill totals for runs 28, 30, 33.

	Run 28	Run 30	Run 33
Calf Mortality	0.40	0.50	0.60
Adult Natural Mortality	0.075	0.075	0.075
Adult Hunter Kill	0.075	0.075	0.075
Total Adult Mortality	0.144	0.144	0.144

	Run 28		Run 30		Run 33	
Cycle	Population	Harvest	Population	Harvest	Population	Harvest
1	9923	737	9439	700	8955	664
2	11295	836	10395	768	9501	701
3	12530	928	11196	828	9893	730
4	13761	1017	11942	881	10215	751
5	14984	1101	12640	926	10478	763
6	16173	1186	13259	967	10652	771
7	17283	1270	13762	1006	10703	777
8	18392	1358	14217	1045	10701	781
9	19537	1447	14662	1081	10678	782
10	20768	1538	15137	1116	10675	781
11	22049	1632	15603	1149	10652	778
12	23379	1727	16054	1178	10601	769
13	24753	1834	16482	1214	10516	766
14	26154	1943	16866	1246	10375	759
15	27726	2046	17344	1271	10307	747
16	29382	2159	17821	1299	10221	737
17	30962	2277	18197	1328	10069	726
18	32654	2402	18588	1356	9927	716
19	34444	2533	18991	1386	9781	705
20	36329	2672	19407	1416	9641	695
TOTAL HARVEST		32643		22161		14899

APPENDIX 5 b. POPSID Nelchina caribou population and hunter kill trends for runs 28, 30, 33.



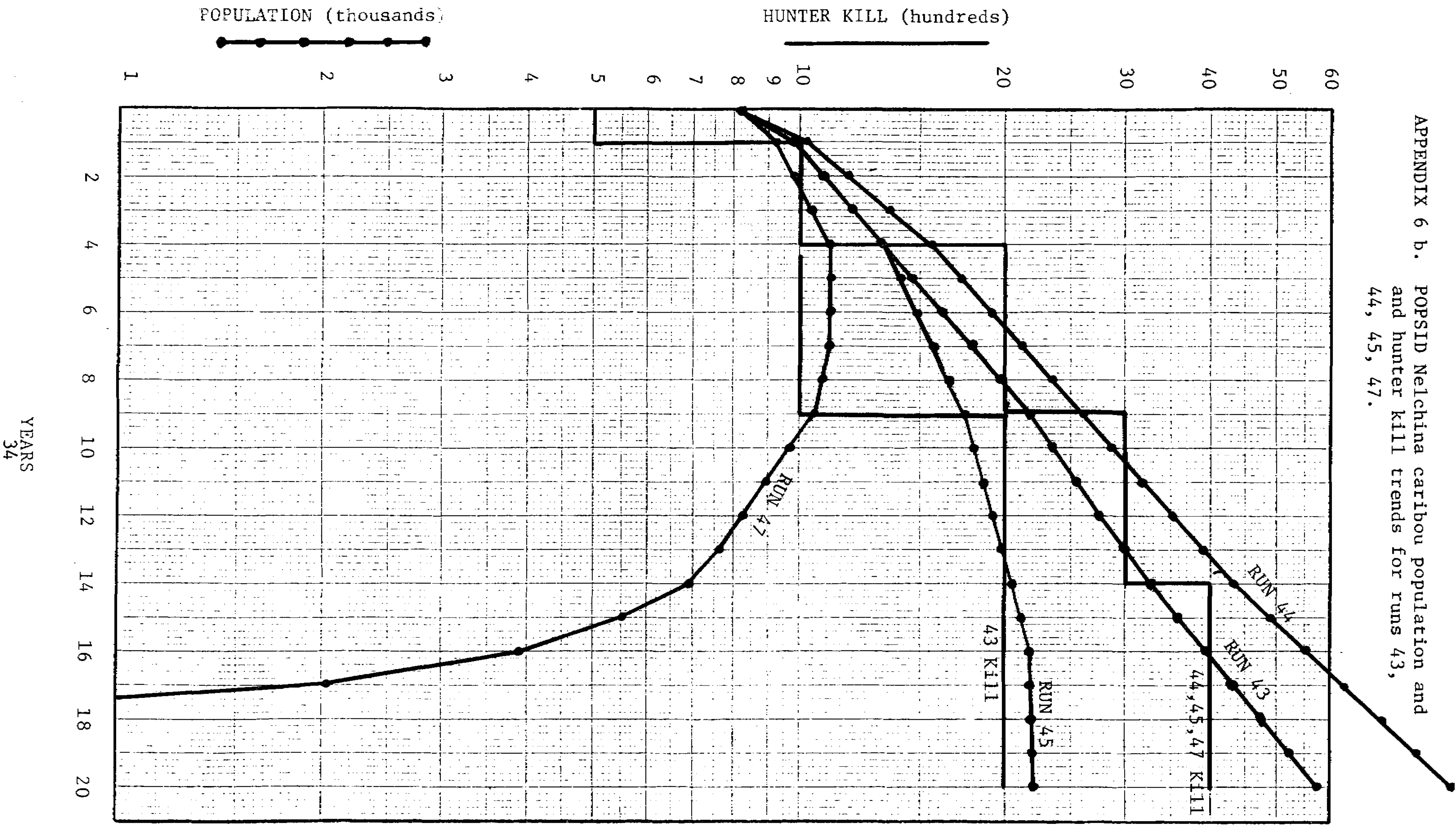
	Run 28	Run 30	Run 33
Calf Mortality	0.40	0.50	0.60
Adult Natural Mortality	0.075	0.075	0.075
Adult Hunter Kill	0.075	0.075	0.075

APPENDIX 6 a. POPSID Nelchina caribou cumulative population and annual hunter kill totals for runs 43, 44, 45, 47.

	Run 43	Run 44	Run 45	Run 47
Calf Mortality	0.50	0.40	0.50	0.60
Adult Natural Mortality	0.05	0.05	0.05	0.05
Specified Hunter Kill	Schedule 1	Schedule 2	Schedule 2	Schedule 2

	Run 43		Run 44		Run 45		Run 47	
Cycle	Population	Harvest	Population	Harvest	Population	Harvest	Population	Harvest
1	9796	500	10276	500	9796	500	9316	500
2	10883	1000	11854	1000	10883	1000	9916	1000
3	12016	1000	13571	1000	12016	1000	10498	1000
4	13311	1000	15594	1000	13311	1000	11141	1000
5	14796	1000	17254	2000	14093	2000	11168	2000
6	16423	1000	19180	2000	14976	2000	11199	2000
7	18073	1000	21216	2000	15779	2000	11047	2000
8	19869	1000	23512	2000	16617	2000	10810	2000
9	21910	1000	26213	2000	17592	2000	10570	2000
10	23547	2000	28664	3000	18005	3000	9713	3000
11	25503	2000	31578	3000	18526	3000	8950	3000
12	27661	2000	35043	3000	19180	3000	8371	3000
13	30035	2000	39059	3000	19899	3000	7764	3000
14	32538	2000	43650	3000	20633	3000	6960	3000
15	35824	2000	49494	4000	21105	4000	5542	4000
16	39585	2000	55577	4000	21589	4000	3897	4000
17	43337	2000	61850	4000	21700	4000	2015	4000
18	47593	2000	69037	4000	21796	4000	480	4000
19	52389	2000	77345	4000	21920	4000	---	---
20	57750	2000	86853	4000	22014	4000	---	---
TOTAL HARVEST		30500		52500		52500		52500

APPENDIX 6 b. POPSID Nelchina caribou population and hunter kill trends for runs 43, 44, 45, 47.



	Run 43	Run 44	Run 45	Run 47
Calf Mortality	0.50	0.40	0.50	0.60
Adult Natural Mortality	0.05	0.05	0.05	0.05
Specified Hunter Kill (See Table 5)	Schedule 1	Schedule 2	Schedule 2	Schedule 2