WILDLIFE INFOMETRICS INC.

MODELING

Modeling the Population Dynamics of Northern Omineca Caribou

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MODELLING THE POULATION DYNAMICS OF NORTHERN OMINENCA CARIBOU

By

Vernon Remesz

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Abstract

This report details the step-by-step procedures used in an attempt to link a model of northern caribou population dynamics to computer-based geographic information. Parameters used in the population modeling process were generated from field data collected for the Northern Ominenca Caribou Project in MacKenzie, B.C. The Caribou Habitat And Assessment Supply Simulator (CHASE) provided spatial data describing the value of habitat across the landscape for a local herd of caribou known as the Wolverine herd. The linkage between the two data sets (i.e., habitat and population data) was modeled using RAMAS-GIS in order to assess it's cost-effectiveness at translating output of CHASE to a single indicator of spatially-explicit population health for the Wolverine herd.

Keywords
Caribou; Habitat; Model; Management ; Population

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1. INTRODUCTION

There are approximately 2300 mountain caribou, and 5170 northern caribou, that live in British Columbia (BC). The BC Conservation Data Center (CDC) systematically collects and disseminates information on the rare and endangered plants, animals and plant communities of BC. The CDC rates Northern Woodland Caribou (*Rangifer tarandus)* as a blue-listed species meaning the species is considered to be particularly sensitive or vulnerable to human activities or natural events. Figure 1 shows what a northern woodland caribou looks like.

Figure 1. Northern Woodland Caribou (*Rangifer tarandus)*

Habitat Supply Modeling (HSM) is a method used by resource managers to describe the long-term supply of habitat for wildlife. Habitat supply is the quantity of habitat present across a landscape. Habitat supply modeling is the representation, or projection of a descriptor of habitat supply. A habitat supply model takes input information about descriptors of the composition, structure, and arrangement of the abiotic and vegetative components of a particular land base (ie: habitat) and interprets these descriptors into an output that provides information about the value of the habitat for an organism (Stone, 2000).

The Chief forester of BC has requested information on non-timber resources such as wildlife quality and abundance, be available to him in a similar way as timber supply analysis is available. Other than the Ministry of Forest's timber supply modeling which can project future seral stage distribution at the Plan Area (i.e. Forest District) level, habitat supply modeling has not been an available tool, due to lack of resources and dedicated government agency personnel (Stone, 2000). There is currently a review and evaluation of current data models, techniques and tools for habitat supply modeling by the Ministry of Forests.

The Northern Ominenca Caribou Project (http://www.slocan.com/irm/projects/caribou/index.html) was initiated by Slocan Forest Products and Abitibi Consolidated to improve the understanding of the local ecological system involving caribou, moose, and wolves in the MacKenzie Timber Supply Area of British Columbia. The project utilizes the Caribou Habitat Assessment and Supply Estimator (CHASE), a strategic and operational planning framework for use in the management of caribou populations and their habitat in the Mackenzie TSA (McNay, 2002). CHASE links caribou and habitat information to forecast the distributions of caribou habitat and timber supply through time. However, CHASE does not forecast population predictions but represents a descriptor of habitat supply.

Spatially-explicit population models are an attempt to bridge population dynamics with the spatial configurations of habitats. RAMAS-GIS (Risk Analysis and Management Alternatives Software) is commercial software that allows this bridge. It has been used to provide the link between GIS data and an ecological model.

Figure 2 illustrates the modeling process used to construct a spatially explicit population model and the 2 types of data that are required by RAMAS-GIS.

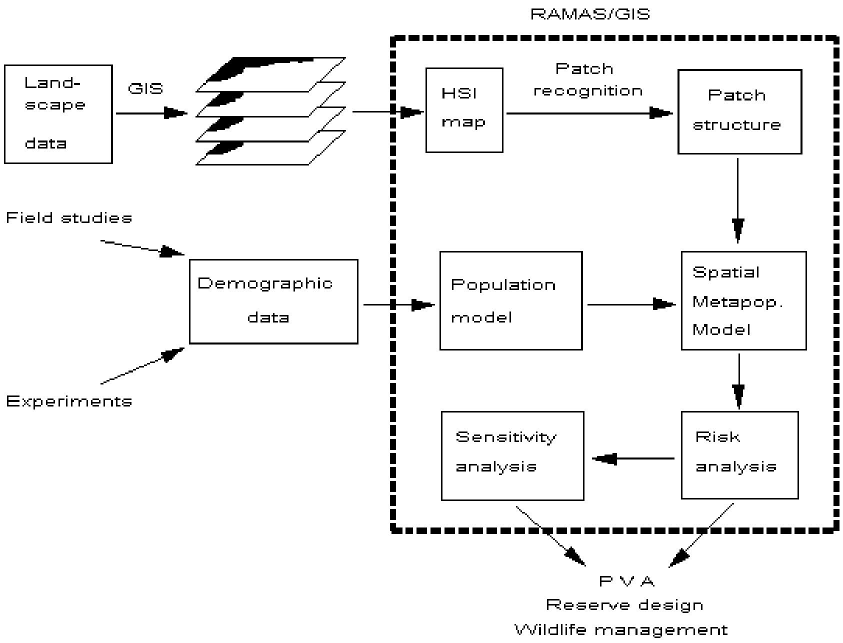


Figure 2. The modeling process using RAMAS-GIS.

2. OBJECTIVES

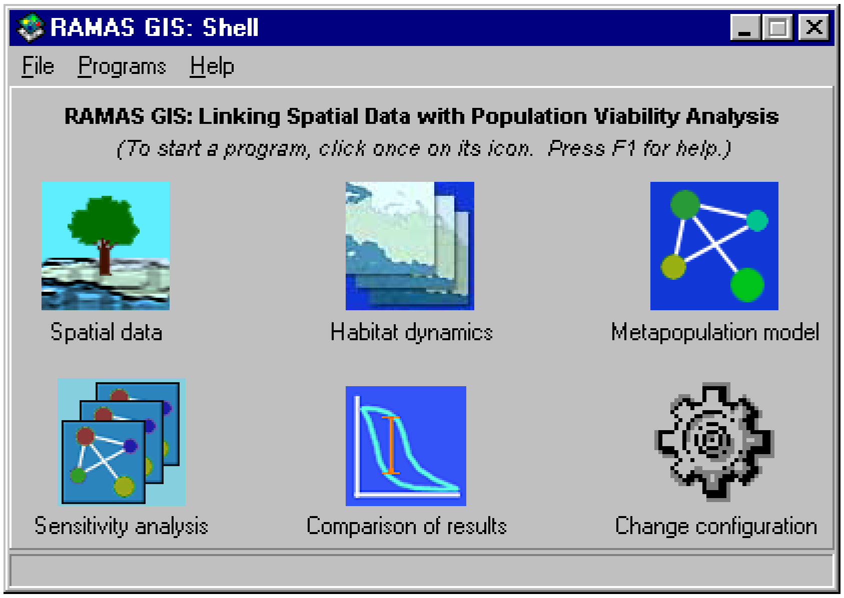
The objective of this project was to link spatially-explicit output of CHASE to a model of population dynamics using RAMAS-GIS. Demographic data for the Wolverine Caribou population was available from preliminary modeling based on survival and productivity of radio-collared caribou within the Wolverine herd (Appendix 1). The Wolverine population is located on the west side of the Williston Reservoir near Mackenzie BC (Appendix 2).

A second objective of the project was to evaluate the cost-effectiveness of RAMAS-GIS software in providing a link between habitat and population modeling. In general, the project serves as a preliminary attempt to moving field data collected from the Northern Ominenca Caribou Project to a spatially-explicit model of population dynamics.

3. METHODS

3.1 Sequence of Modeling Events.

Modeling population dynamics using RAMAS-GIS occurs in a set fashion. The software provides 6 different modules that accomplish different tasks. Figure 3 shows the interface to RAMAS-GIS and the 6 modules.



RAMAS GIS: Linking Spatial Data with Population Viability Analysis

(To start a program, click once on its icon. Press F1 for help.)

Figure 3. RAMAS-GIS Shell.

Typically population dynamics are modeled using the Metapopulation model (also known as RAMAS Metapop). Population parameters such as initial abundances, age class structure, fecundities, and survival rates are input here. Modeling population dynamics occurs as the first step. These population parameters are then used by the spatial component of RAMAS-GIS in the second step of the modeling process.

The second step uses the Spatial data module (see Figure 3). This program locates geographic patches by identifying areas of high suitability where a population might survive (Akcakaya, 2002). It uses habitat data as input to create a spatially-explicit population model that is then used in combination with the Metapopulation model to simulate the caribou's population growth.

The Methods section of this report is laid out in the order that modeling events took place in RAMAS-GIS and consists of:

- 3.1 Sequence of Modeling Events
- 3.2 CHASE inputs GRIDS (the input data)
- 3.3 Population Modeling with Metapopulation model.
    - 3.3.1 Specify the Age Structure of the Caribou Population
    - 3.3.2 Development of The Leslie Matrix
    - 3.3.3 Density Dependence
    - 3.3.4 Environmental Stochasticity
- 3.4 Defining the Spatial structure of the habitat with Spatial data.
    - 3.4.1 Calculate a Habitat Suitability Function
    - 3.4.2 Specify the Input Data
    - 3.4.3 Link the Spatial Data to the Metapopulation Model
- 3.5 Spatial population modeling back in the Metapopulation model.

3.2 CHASE Input GRIDs

CHASE data was provided in Arc/Info GRID ASCII format. Andrea Doucette of Wildlife Infometrics supplied four files. The filenames were corr2000.asc, csr2000.asc, hewr2000.asc, and plwr2000.asc. CHASE provides habitat supply modeling for four habitat types. The four models are based on habitat range types considered most likely to be either limiting or important to caribou populations (McNay, 2002). The file corr2000.asc represented caribou movement corridors, csr2000.asc represents caribou calving and summer range, hewr.0asc representing high-elevation winter range, and plwr2000.asc representing pine-lichen winter range. Figure 4 shows the time period during the year that the caribou inhabit each range type.

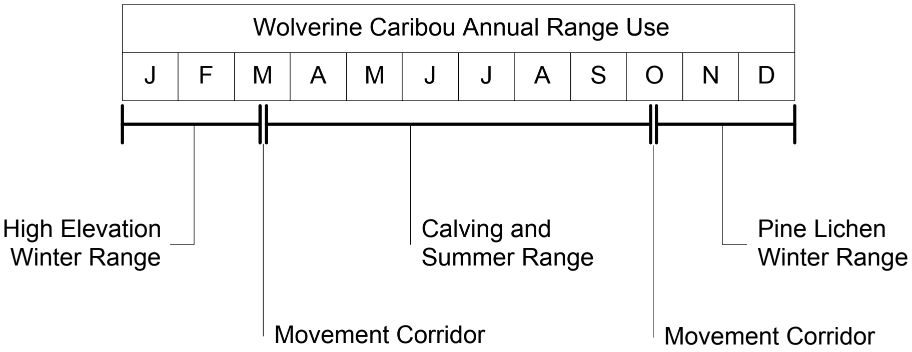


Figure 4. Wolverine caribou annual range use.

Each range type was imported and viewed in ArcView using the Spatial Analyst. Figure 5 shows Pine Lichen Winter Range (plwr2000.asc) is viewed ArcView. In discussions with Scott McNay it was decided to use plwr as the caribou habitat to be used in modeling.

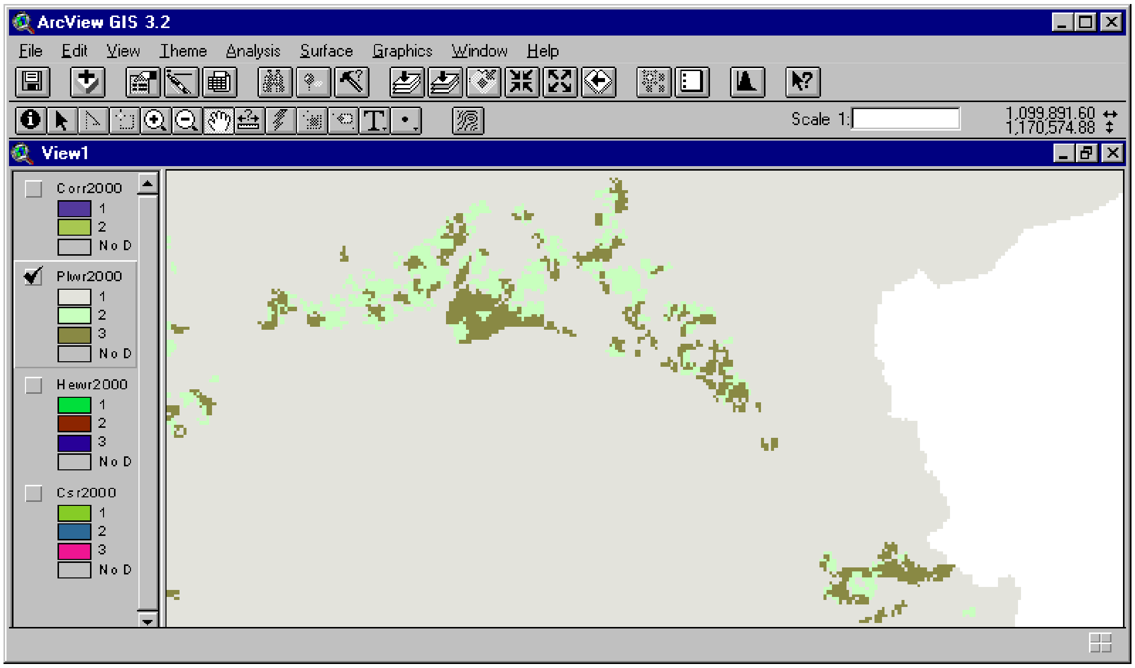


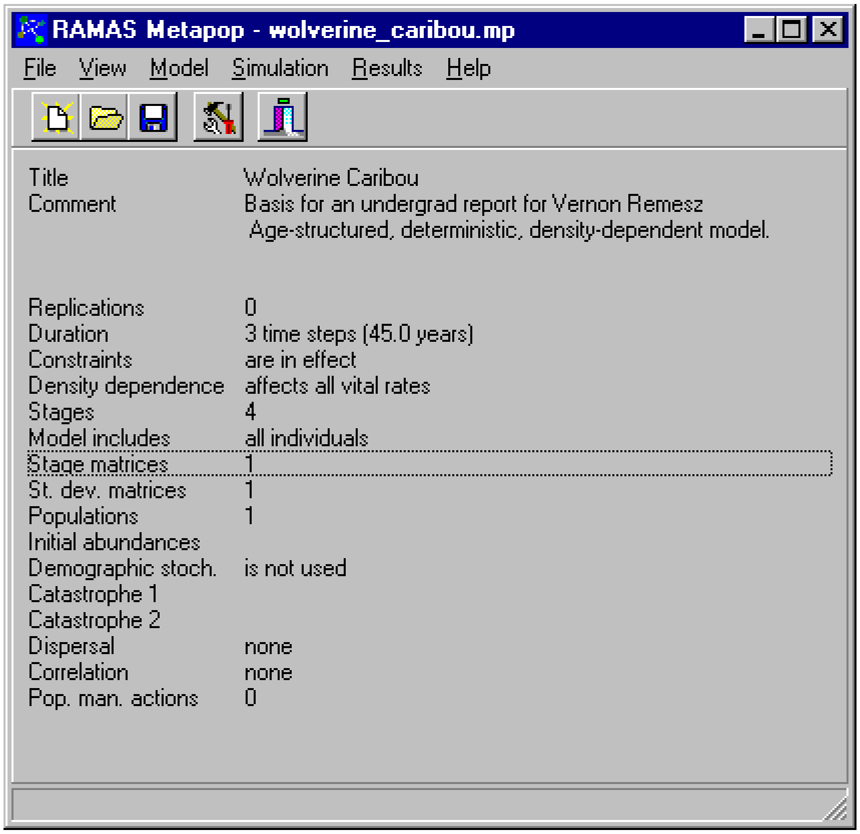
Figure 5. ArcView program interface showing habitat suitability values.

Original data was replaced by a more recent dataset for Pine Lichen Winter Range (plwr_cap.asc). It consisted of habitat suitability values generated by CHASE in October of 2002. This dataset was provided in Arc GRID format and was exported to ASCII format using Spatial Analyst for use with RAMAS-GIS. RAMAS-GIS uses Arc data in ASCII format.

3.3 Population Modeling with RAMAS Metapop.

The Metapopulation model (RAMAS Metapop) was used to model the population dynamics of the Wolverine Caribou population. An age structured, deterministic, non-density dependent, non-stochastic model was constructed as a result of consultations with Scott McNay. This section outlines the parameters entered to model the population dynamics of the Wolverine caribou. Figure 6 shows the

Windows interface to RAMAS Metapop and shows the general information for the model.



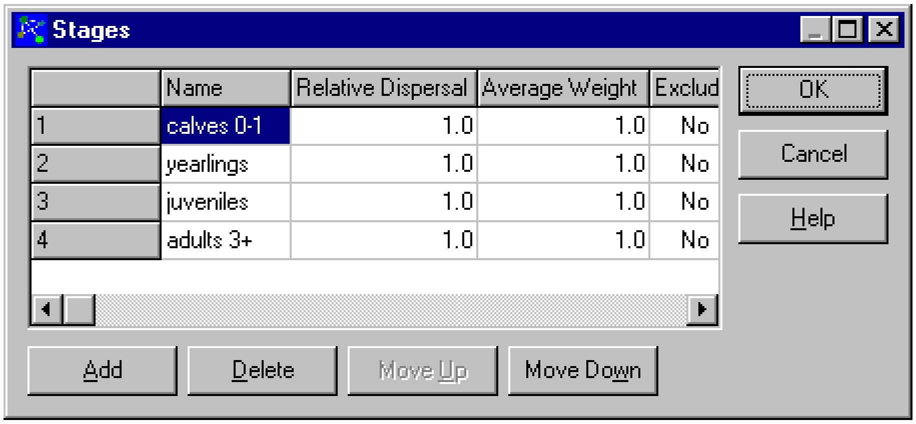
Title	Wolverine Caribou
Comment	Basis for an undergrad report for Vernon Remesz Age-structured, deterministic, density-dependent model.
Replications	0
Duration	3 time steps (45.0 years)
Constraints	are in effect
Density dependence	affects all vital rates
Stages	4
Model includes	all individuals
Stage matrices	1
St. dev. matrices	1
Populations	1
Initial abundances	
Demographic stoch.	is not used
Catastrophe 1	
Catastrophe 2	
Dispersal	none
Correlation	none
Pop. man. actions	0

Figure 6. Interface to RAMAS Metapoop.

Scott McNay provided population parameters to be used in RAMAS in the form of a MS Excel spreadsheet. This worksheet is found in Appendix 1. Survival rates and maternity rates were information obtained from the worksheet in order to construct a metapopulation model from field data collection produced by the Northern Ominenca Caribou Project. The data was produced by analysis from CHASE.

3.3.1 Specify the Age Structure of the Caribou Population

The physical structure of the population has to be specified in a dialog box called Stages. The parameters provided on the worksheet indicated the caribou have 4 age classes and live for 15 years. Calves live from year 0 to 1, yearlings from year 1 to 2, juveniles from year 2 to 3 and adults from 3 to 15 years old. This age structured model is illustrated in Figure 7 via the Stages Dialog box in RAMAS and Figure 8.



	Name	Relative Dispersal	Average Weight	Exclud
1	calves 0-1	1.0	1.0	No
2	yearlings	1.0	1.0	No
3	juveniles	1.0	1.0	No
4	adults 3+	1.0	1.0	No

Figure 7. Stages Dialog box show population age structure.

Duration of the model was set to 15 years with one time step equaling 1 year so the adult age class contained 12 time steps (12 years) to form a composite age class as shown in Figure 8.

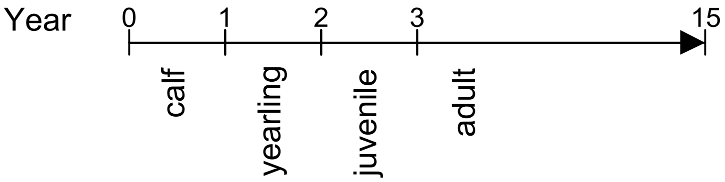


Figure 8. Caribou age structure.

Initial abundances were given verbally from Scott McNay based on his estimates and the age classes were divided into 30 calves, 20 yearlings, 20 juveniles and 280 adults for a total of 350 animals in the Wolverine population.

3.3.2 Development of The Leslie Matrix

In RAMAS Metapop parameters such as survival and maternity rates are combined to model population dynamics in the form of a Leslie Matrix. The Leslie Matrix is used to determine the growth of the population, as well as the age distribution within the population over time. This type of model is formulated using matrix algebra. The model of Leslie is one of the most heavily used models in population ecology. This model is mostly used to answer the following two questions (Sharov, 1996):

1. What is the rate of exponential growth (intrinsic rate of increase)?
2. What is the proportion of each age class in the stable age distribution?

A Leslie Matrix representing four age classes has the form as show in Figure 9.

$$L = \begin{Bmatrix} F_1 & F_2 & F_3 & F_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{Bmatrix}$$

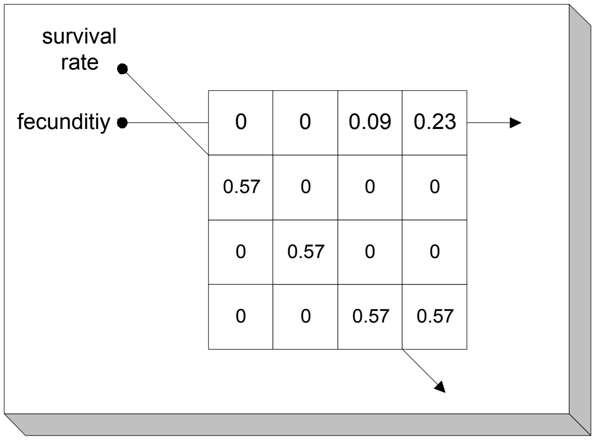
Figure 9. General form of the Leslie Matrix given four age classes.

F_1, F_2, F_3 and F_4 represent the fecundities of each of the age classes. S_1, S_2, and S_3 represent survival rates of each age class. Fecundity is defined by the American

Heritage Dictionary (2000) as "**fe·cun·di·ty** the quality or power of producing abundantly; fruitfulness or fertility". With RAMAS fecundity is calculated as the birth rate multiplied by the survival rate for a post-breeding census. In this model the final age class has no survival rate indicating the end of the organisms life cycle (Figure 9) at that age class.

The Excel worksheet (Appendix 1) provided population parameters in the form of birth rates and survival rates for 15 age classes. The model constructed for RAMAS grouped some of this data (birth and survival rates) into the adult age class. Birth rate maintained its value throughout the animals' adult lifespan but survival rates ranged from 0.57 to 0.54 over the life cycle. These numbers were averaged to form a composite survival rate for use in the initial Leslie Matrix to model the caribou population.

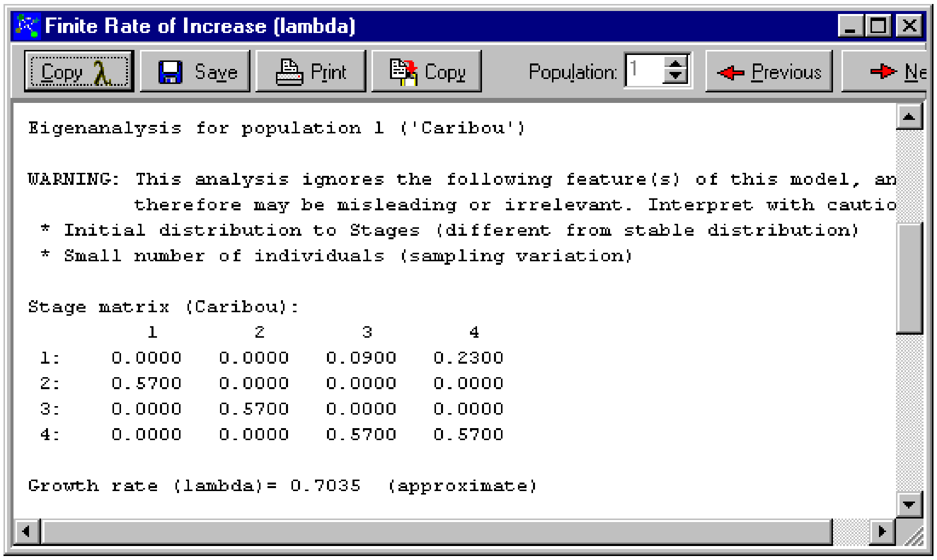
The Leslie Matrix required that fecundities be calculated for each age class. Fecundities calculated for each age class are listed in row one of Table 1 (page 13) and survival rates are listed in the sub-diagonal of the matrix. This is the format specified by the general format of the Leslie Matrix. The presence of a survival rate in the diagonal (lower-right corner element of the matrix) indicates that there can be individuals older than 3 and that abundances are pooled in the last age class. The values used for the initial matrix were computed from the field data contained in the Excel worksheet.



0	0	0.09	0.23
0.57	0	0	0
0	0.57	0	0
0	0	0.57	0.57

Table 1. Leslie Matrix derived from caribou field data.

The function of the Leslie Matrix computes a rate of increase (growth rate) for the population. This value is represented in mathematical terms by lambda (l). A l value below 1 such as 0.92 means that the population would decrease 8% per time step. A value over 1 such as 1.2 would mean that the population would grow by 20 percent per time step. The value calculated by RAMAS from the parameters given in the Excel worksheet for l was approximately 0.7035 and is shown if Figure 10.

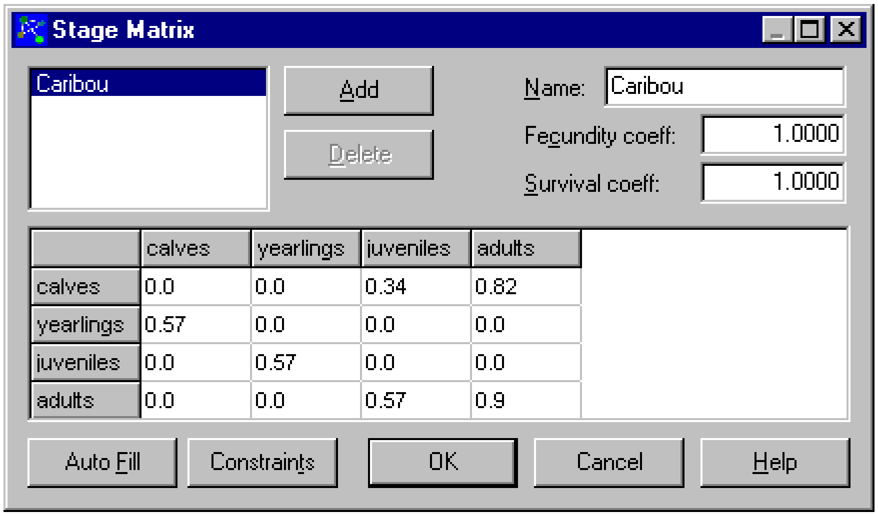


```
Eigenanalysis for population 1 ('Caribou')

WARNING: This analysis ignores the following feature(s) of this model, an
         therefore may be misleading or irrelevant. Interpret with cautio
 * Initial distribution to Stages (different from stable distribution)
 * Small number of individuals (sampling variation)

Stage matrix (Caribou):
          1         2         3         4
 1:     0.0000    0.0000    0.0900    0.2300
 2:     0.5700    0.0000    0.0000    0.0000
 3:     0.0000    0.5700    0.0000    0.0000
 4:     0.0000    0.0000    0.5700    0.5700

Growth rate (lambda)= 0.7035  (approximate)
```

Figure 10. Results of Eigenanalysis using RAMAS Metapop.

This result differed from the Lambda value for the caribou population indicated on the worksheet. Lambda on the worksheet can be found in cell B20 (Appendix 1). The rate of increase can be found calculated as 1.116. This rate of increase represents the growth rate of 11.6% per time step of one year. RAMAS Metapop has no way of entering in an already calculated l, as this is only one of the functions of the equation (Leslie Matrix) as it is used in RAMAS-GIS.

After consultation with Scott McNay and reviewing the data on the worksheet new values for the Leslie Matrix were entered into the metapopulation model. The original matrix produced a population growth rate of minus 29% when in actual fact the population is growing by 11.6%. Figure 11 shows the new parameters used by the project. The matrix computed a growth rate (lambda) of 1.0466 (growing by 4.6%)



Name: Caribou
Fecundity coeff: 1.0000
Survival coeff: 1.0000

	calves	yearlings	juveniles	adults
calves	0.0	0.0	0.34	0.82
yearlings	0.57	0.0	0.0	0.0
juveniles	0.0	0.57	0.0	0.0
adults	0.0	0.0	0.57	0.9

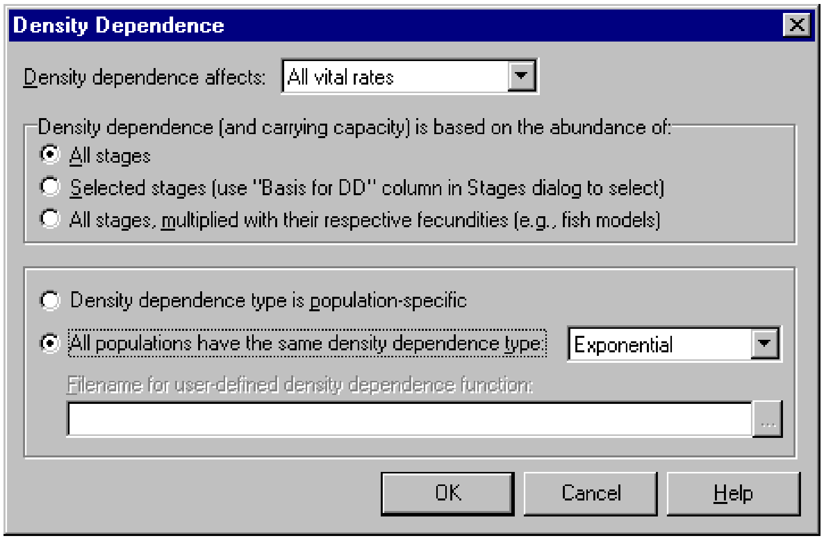
Figure 11. Revised Leslie Matrix

3.3.3 Density Dependence

Modeling density dependence in RAMAS Metapop was quite straightforward. In order to properly enter the values required by RAMAS three questions needed to be answered relating to density dependence.

1. What type of density dependence function to use? This function must be compatible and available within RAMAS Metapop.
2. What vital rates do the density dependence function effect? The function can only affect fecundity, survival or both of these.
3. Does the density dependence function affect all age classes?

After consultation with Scott McNay it was decided to model density dependence using exponential density dependence. Exponential is defined in RAMAS Metapop as "No density dependence. All parameters related to density dependence are ignored, only the stage matrix is used in calculations" (Akcakaya, 2002). A screenshot of the parameters as entered in the Density dependance dialog box in RAMAS Metapop is shown in Figure 12.



Density Dependence

Density dependence affects: All vital rates

Density dependence (and carrying capacity) is based on the abundance of:

● All stages
○ Selected stages (use "Basis for DD" column in Stages dialog to select)
○ All stages, multiplied with their respective fecundities (e.g., fish models)

○ Density dependence type is population-specific
● All populations have the same density dependence type: Exponential

Filename for user-defined density dependence function:

Figure 12. Density dependence parameters entered in RAMAS Metapop.

3.3.4 Environmental Stochasticity

Environmental stochasticity was no modeled for the caribou in this project. This was done in order to keep the process of modeling the population at a more conceptual level.

3.4 Defining the Spatial Structure of the habitat.

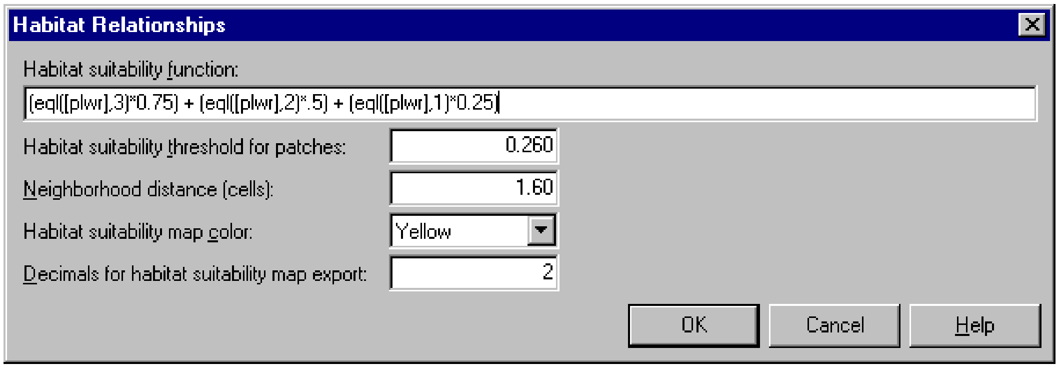
Modelling the spatial structure of habitat is accomplished using the module called Spatial Data. This is the spatial component of RAMAS-GIS. It allows the import of one or more data layers in order to analyze habitat data to create a habitat suitability map. The habitat suitability map is then used to locate patches that indicate the spatial structure of the population.

3.4.1 Calculate the Habitat Suitability Function.

The Spatial Data module calculates a habitat suitability function specified by the user in order to create a map (grid) of habitat suitability, but the CHASE model already accomplished this task. The CHASE model supplied a grid data set that indicated habitat suitability with a numerical rating system representing habitat preference classes of 1, 2, or 3. A value of 1 is habitat that is avoided, 2 are equivocal, and 3 are preferred habitat. This value system output from CHASE represents an indicator of habitat suitability.

In the Spatial Data subprogram the habitat suitability function was used to convert the CHASE index to a more traditional suitability index system with values between

0 and 1 as seen in Figure 13. The habitat suitability threshold was set at 0.26 in order to eliminate cells designated by CHASE as ‘avoided’ being included into a population patch. A neighborhood distance of 1.6 cells was used to group like valued cells into similar patches.



Habitat suitability function:
(eql([plwr],3)*0.75) + (eql([plwr],2)*.5) + (eql([plwr],1)*0.25)

Habitat suitability threshold for patches: 0.260

Neighborhood distance (cells): 1.60

Habitat suitability map color: Yellow

Decimals for habitat suitability map export: 2

Figure 13. Habitat Relationships dialog box in RAMAS Spatial Data.

3.4.2 Specify the Input Data

The map grid used for input in population modeling was plwr_cap.asc as noted in section 3.2. Specifying an input grid for use in RAMAS is done in the Input Maps dialog box. Plwr_cap.asc was derived from the Pine Lichen Winter Range model of CHASE. It had a resolution of 1237 rows and 1513 columns. Each cell had a resolution of 1 hectare or 0.1 km^2. This resolution of grid was too fine for the spatial calculations to be performed by the Spatial Data subprogram (particularly neighborhood distance). The cell resolution of this grid was changed to km^2 and thus contained 124 rows and 151 columns.

3.4.3 Linking the Spatial Data to the Metapoulation Model.

The link between the spatial data and the population model is specified in the Link to Metapopulation model dialog box. In this dialog box, you can enter functions that specify how the habitat suitability values (or HS values) are to be used to calculate the parameters of the metapopulation model (Akçakaya, 2002). It is in this box that carrying capacity of caribou per cell value are entered. From discussions with Scott McNay three different carrying capacities were specified in number of caribou per cell for each habitat value derived in CHASE. If the patch had and average habitat suitability of 0.75 then that patch had a carrying capacity of 4 caribou per cell. I the patch had an average habitat suitability of 0.5 (equivocal) then that patch had a carrying capacity of 2.75 caribou per cell. If the patch had an average habitat suitability of 0.25 (avoided) then it had a carrying capacity of 0.075 caribou per cell. The carrying capacity function to the following form:

eql(ahs,.75)*4 + eql(ahs,.5)*2.75 + eql(ahs,.25)*0.075

The actual link to the metapopulation model was made in Other data from entry box. This is used to specify a default metapopulation model (a file with extension .MP) for parameters not calculated by the Spatial Data subprogram (Akçakaya, 2002). Once the default population model is constructed and the spatial parameters have been entered analysis is ready to begin.

4. RESULTS

After entering parameters in both the Metapopulation module and the Spatial Data module the modeling process can occur. Results obtained from the Find Patches menu of the Spatial Data module are illustrated in the Habitat Suitability Map shown in Figure 14. 56 patches were found that were suitable for caribou.

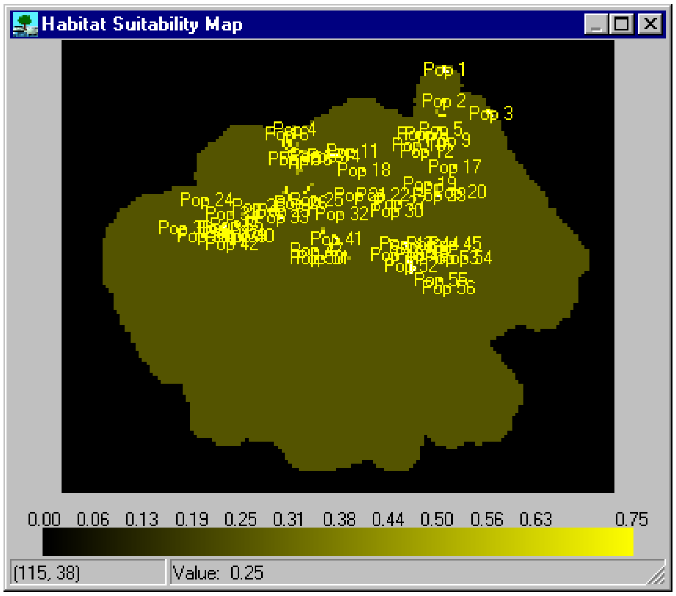


Figure 14. Habitat Suitability map show locations of 56 patches.

Carrying capacities for each patch were calculated as shown in Figure 15.

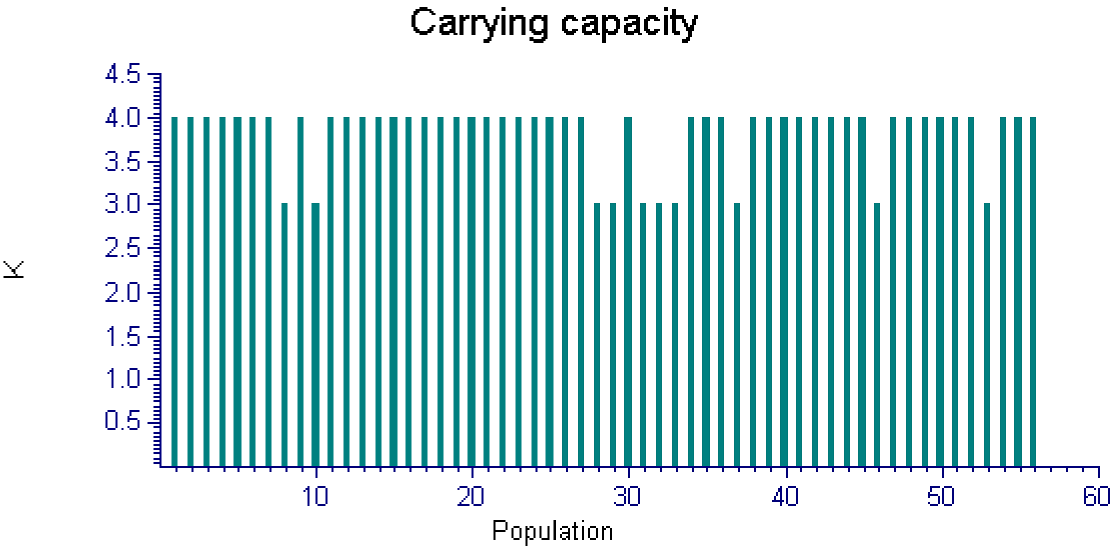


Figure 15. Carrying Capacity of each patch.

The area of each patch is shown in Figure 16.

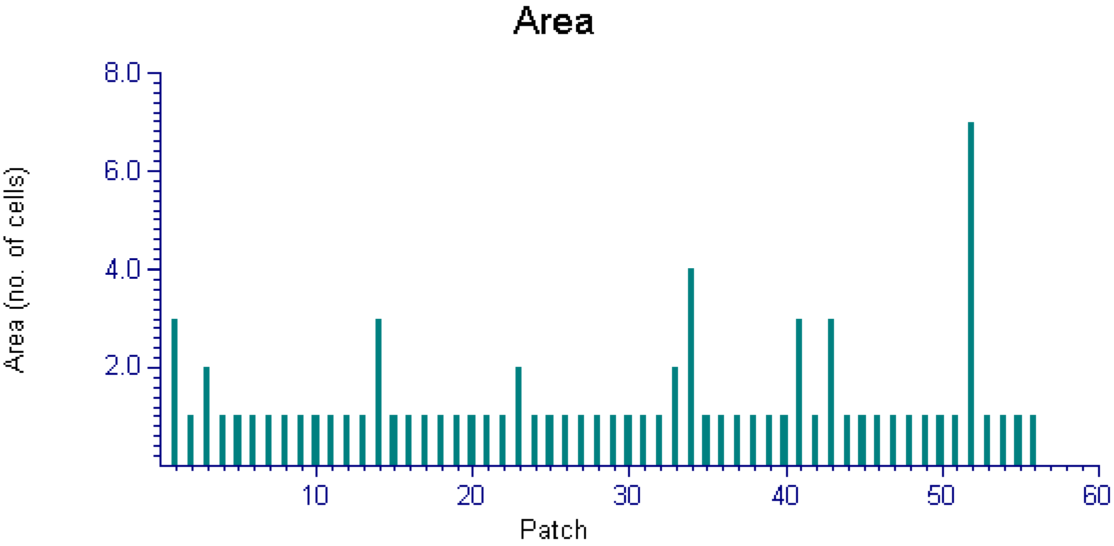


Figure 16. Area (no. of cells) per patch.

The initial abundance of each patch is shown in Figure 17.

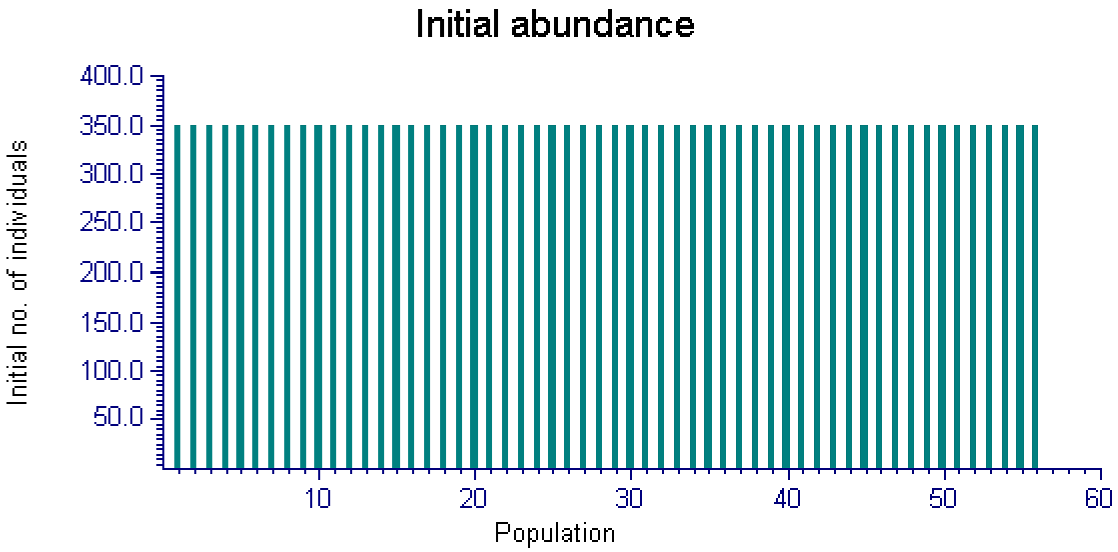


Figure 17. Initial abundances of each patch.

After locating the patches using the Spatial Data subprogram the menu File -> Save RAMAS Metapop file… was used to export a .mp file for use within RAMAS Metapop. This file would contain a metapopulation model constructed from the information entered in our original metapopulation model as well as information about the spatial location of each population patch.

A simulation was run modeling the caribou in 56 spatially located patches. Results in the form of trajectory summaries for each patch as well as a composite trajectory summary for all the patches were produced. These summaries illustrate projected population growth. Figure 18 shows the composite trajectory summary for all patches. Figure 19 show the trajectory summary for a typical patch (patch #1).

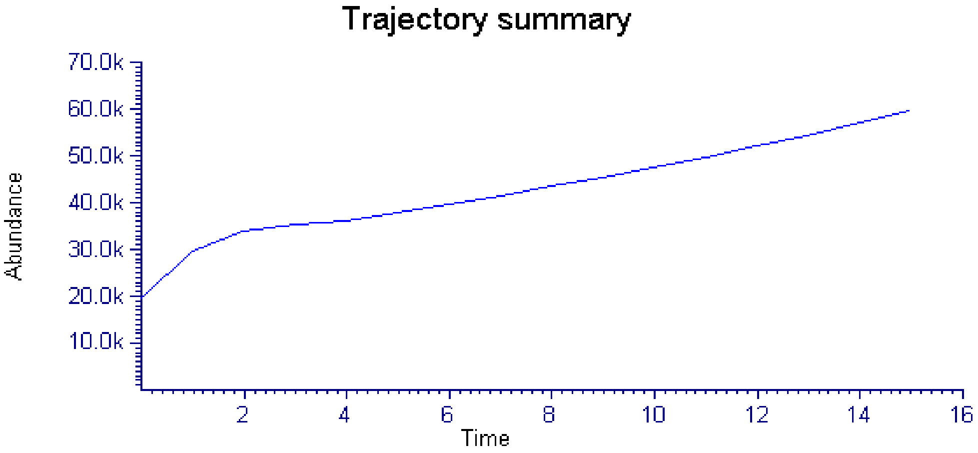


Figure 18. Composite trajectory summary

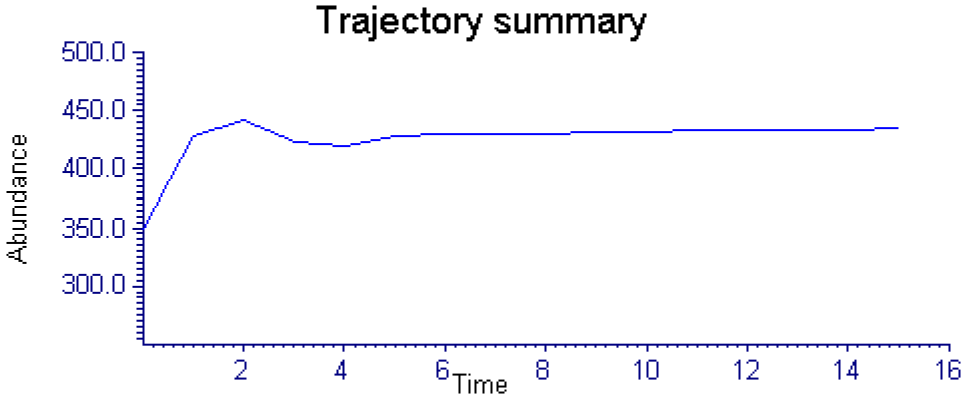


Figure 19. Trajectory summery for patch #1.

Final stage abundances were calculated for each patch and are shown in Figure 20.

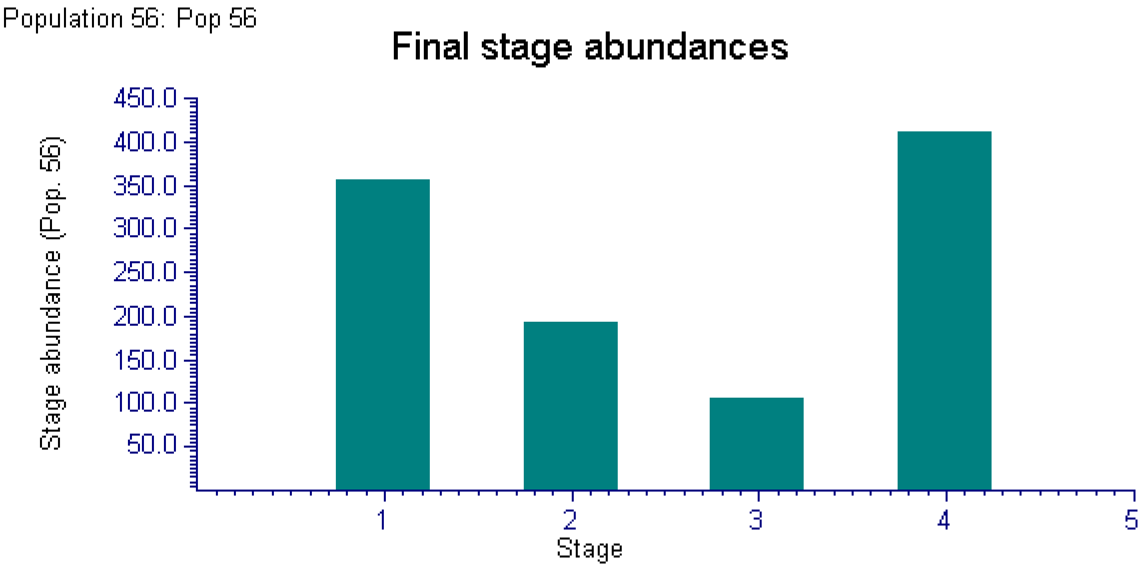


Figure 20. Final stage abundances for patch #56.

5. CONCLUSION

The objectives of the project were to link the spatially explicit output derived from CHASE and link it’s habitat supply data to a model of population dynamics. The project achieved this by producing a spatially explicit metapopulation model file (.mp) and examining population growth rates and stage abundances after a simulation in RAMAS Metapop.

A number of technical problems have been identified using the software. One of the technical problems consisted of incorrect initial abundances. As can be seen from Figure 17 (Initial Abundances), each population patch was assigned an initial abundance of 350 animals. 350 animals are estimated to live in the entire study area not in each patch. This is reflected in Figure 18 (Composite Trajectory summary) with an initial abundance of 19,600 animals. 350 initial animals multiplied by the 56 patches designated by the Spatial data module. If the values for the original habitat suitability grid are compared to the derived patches the locations derived make sense.

Neighborhood distance is a parameter that groups like calls together to form patches. Figure 16 shows the area of each patch. The typical patch was 1 km^2 . A value for neighborhood distance is needed that would more accurately model the caribou at a 1 ha grid resolution. This would allow the use of the original 1ha resolution data.

Parameters entered to model carrying capacities need refinement. A carrying capacity does not have to be calculated for CHASE designated avoided areas as they are excluded from our habitat suitability grid output by the Spatial module. As can be seen from Figure 15 (Carrying Capacity) most patches had a carrying capacity of 4 but some had a carrying capacity of 3. This value could not be obtained given our Carrying Capacity function (see section 3.4.3).

The objective of the report was also to evaluate the software and serve as a first attempt to model the population dynamics of the Northern Ominenca Caribou. The modeling process in RAMAS-GIS is very flexible. While a spatially explicit population model has been achieved in this modeling attempt some of the results obtained indicate that more work needs to be done to obtain a more accurate and realistic model.

6. RECOMMENDATION

I would recommend further work into modeling the population dynamics of the Northern Ominenca Caribou with RAMAS-GIS. RAMAS-GIS is very flexible and with more work may be serve as a cost effective means to monitor and evaluate CHASE results. What should be remembered is that this project was a first attempt and can serve as direction to another Undergraduate project or personal work.

Development of the Leslie Matrix from field data for the caribou would be a major task of any further work and could even form the basis for separate project. The initial population parameters also need work to build a more realistic model. Technical problems illustrated in the conclusion could be further tested.

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Appendices

Appendix 1 – MS Excell Spreadsheet showing Caribou vital statistics.

Parameters	Initialization Values	Age															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
		C	Y	J	A												
Number cows			0	0	22												
Apparent no calf			0	0	4				22.0%	calves as % of population (assuming 1:1 sex ratio for non-calves)							
Tagged by age		18							56.3%	calves per 100 adult females							
Dead by age		9	0	0	6												
Mortality		0.500	0.000	0.000	0.273												
Total Death	0.00	0.50	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Birth	0.00	0.00	0.00	0.00	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	
Survive	1.00	0.50	0.50	0.50	0.48	0.45	0.43	0.41	0.39	0.36	0.34	0.32	0.30	0.27	0.25	0.23	
sb	0.00	0.00	0.00	0.00	0.20	0.38	0.56	0.73	0.88	1.03	1.17	1.30	1.42	1.53	1.64	1.73	
isb	0.00	0.00	0.00	0.00	0.78	1.71	2.77	3.94	5.21	6.55	7.94	9.37	10.82	12.27	13.70	15.10	
Ro=sb	1.73		Calf Mortality		0.50												
Gt=isb/Ro	8.73		Juv Mortality		0.00												
r=log(Ro)/Gt	0.06		Adult Mortality		0.02												
k	400.00																
Lambda	1.065																

Appendix 2. Map showing location of Wolverine Caribou population.