Design Document for Integrated Moose Habitat and Population Models

**ArborVitae Environmental Services Ltd,
M. Kuc, and KBM Forestry Consultants Inc.,**

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1.0 Introduction and Background

There are two broad means of influencing the state of wildlife populations – through manipulating habitat, and more directly through managing human activities which cause or prevent mortality (such as hunting and protection). Moose (Alces alces sp.) is a species of significant ecological and social importance in Canada's and Manitoba's boreal forests. Manipulation of moose habitat in the boreal forest comes mostly through the implementation of measures associated with forestry, and more direct population management comes primarily through the use and enforcement of hunting regulations.

The two broad means of influencing populations parallel the two general types of modeling tools which have been available to wildlife managers. Habitat models vary in detail and nature of output, ranging from those which track precise amounts of forage of different species and their use by moose (e.g. Roese et al. 1991) to spatial representations of various habitat attributes (e.g. Duinker et al. 1991). Habitat models with the broadest appeal are based on habitat suitability indices (HSIs). These types of models incorporate a range of habitat attributes and produce a value between 0 and 1.0, with 1.0 representing ideal habitat. HSI models which produce mapped output showing values on a raster-or polygon-basis are particularly useful. A robust HSI model has recently been developed for the area of the Manitoba Model Forest (KBM Forestry Consultants, 2006). This moose habitat model is designed to be part of the overall indicator modeling strategy in forest management planning on the Model Forest (see KBM Forestry Consultants (2006) for more detail and Section 3 of this report for an overview).

Population models vary from mechanistic process-oriented ones which track individuals (e.g. Moen 1998) though to broader ones which track populations based on demographic processes (e.g. Messier 1994). The simplest and most versatile models are based on life-table calculations (Caugley 1997). Life-tables facilitate the bookkeeping of such models by specifying age-and gender-specific rates of fecundity, survival, and mortality. A very robust and flexible life-table based model called RISKMAN has been developed and refined over a number of years by the Ontario Ministry of Natural Resources and the Department of Environment, Nunavut (Taylor et al. 2006).

In the general science of wildlife modeling, surprisingly little effort has been dedicated to developing models, or modeling systems, which combine the simulation of both habitat and population dynamics. Yet for management purposes, to look at one in the absence of the other can lead to incomplete perspectives of key aspects of population management. For many species, habitat can be present in quantities which are not limiting overall populations whereas for other species, manipulation of hunting and protection regulations is insufficient to facilitate reaching population targets, if habitat is a limiting factor.

1.1 Project Objectives and Overview

As noted above, for the region of the Manitoba Model Forest, a habitat supply model for moose has been developed. Although useful in itself, this model can also be one component of an overall system of examining the integrated effects of habitat and population management for moose. The broad intent of this effort is to link habitat and population models for moose so that integrated management options can be simulated and the effects examined.

In the initial vision of this project, a modeling system was to have been developed, however budget considerations have led to a scaling back of this objective. The intent of the present undertaking is to outline a vision for the integrated modeling system and identify the means through which the vision can be reached in this "design document".

The proposed product of the model integration is not a single piece of software operating both the habitat model and the linked population model. At present, we believe such a piece of software would not lend itself well to ongoing development of the integrated models or to continued development of the independent components (i.e. RISKMAN and the HSM). If the models were inextricably linked, a future version of RISKMAN would have to be emulated in the linked model (should the changes in the future version be desirable for the integrated model). Section 4 of this document describes the vision for the model integration in detail. For now, it is sufficient to note that the two main components will be linked by modules which translate the habitat model output into appropriate RISKMAN inputs

Another important challenge in integrating the models relates to their different spatial contexts. The HSM is a spatial model, RISKMAN is aspatial. We believe the most useful product will be one which has the capacity to produce population estimates on a spatial basis, similar to the manner in which the HSM works at present. Therefore, we have devised a means of linking the models so that the spatial features of the HSM will be emulated and population/density maps similar to those produced in the HSM will be the ultimate product of the integrated system. This is described in more detail in Section 4.2.1 of this report.

Another obvious challenge of linking the models is identifying the habitat variables (outputs from the HSM) which are best suited for translation to input into the population model. In Section 4.1 we present an approach for this translation. We are proposing that some of the food and cover indices produced by the HSM be translated via simple arithmetic means to inputs into the population model. However, we note that local expertise is needed into this component of the system. Manitoba users and experts should be involved in validating the approach and calibrating the relationships to be used. We envision that, in the next stage of this effort, a workshop, or some similar means of gathering local expertise and knowledge should be brought to bear on this aspect of system development.

2.0 Brief description of Moose Habitat Model

The moose spatial Habitat Supply Model (HSM) was developed to help assess forests in and around the Manitoba Model Forest for their potential to support moose. The basis for the model is the HSI developed for moose in this area (Palidwor et. al. 1995) and later adapted to the new forest inventory for the Duck and Porcupine Mountains (V. Crichton pers. comm.). The moose HSM is designed to be part of the overall indicator modeling strategy in forest management planning on the Model Forest (see Manitoba Model Forest Indicator Modeling Design Document Template - prepared by KBM Forestry Consultants: 23/03/2005).

The HSM is theoretical in nature as the relationships between habitat quality and environmental parameters have been assumed at the outset rather than derived from reverse fitting to actual field observations (Morrison *et. al.* 1998). Habitat models such as this should be considered a formalization of our knowledge about the system (Hall and Day 1977) or, more accurately, as a current working hypothesis of species-habitat relationships as opposed to a statement of definitive cause and effect (Van Horne and Wiens 1991, Morrison *et. al.* 1998).

For a complete description of the Moose Habitat Supply Model, please see KBM Forestry Consultants (2006).

2.1 Data requirements and structure of the Habitat Model

Figure 1 illustrates the overall work flow and processing components. The four main components are: forest data, moose habitat data model, habitat supply model, and analysis and interpretation.
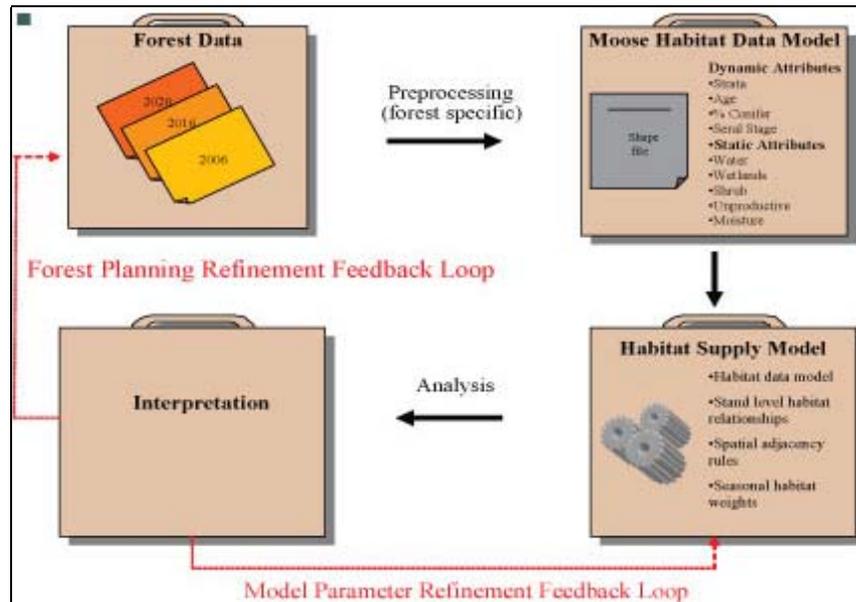
Figure 1. Information flow and process components of the Moose Habitat Model

Forest Data
The forest data component provides the basic forest attributes for the HSM. A Forest Resource Inventory (FRI) GIS layer generally forms the base forest data layer. It should describe general forest conditions such as non-forested and forested areas along with species composition and stand age. The initial forest data may consist of a single time step (i.e., current forest land base) or a series of spatially explicit "snapshots" of future forest conditions. One method of generating future forest conditions is through the use of spatially explicit harvest scheduling and forest growth projection tools.

Moose Habitat Data Model
The moose habitat data model helps maintain a standard data structure. Utilizing a standard data model allows different forest data types with varying levels of detail to be used. The development of the moose data model is a required pre-processing step by the analyst.

The data model is a spatially explicit ESRI shape file containing two basic field attribute categories: static and dynamic. As the first category name suggests, static attributes are attributes that remain constant over time. They are considered stable because natural non-catastrophic changes that may occur are minimal over the short-term. Static attributes include water, wetlands, non-forested shrub sites, non-forested unproductive sites and a forested site's moisture regime.

Dynamic attributes refer to attributes that change over time due to forest succession, forest management activities, or natural disturbances (if modelled). Dynamic attributes only apply to forested stands. Attributes include stand strata, stand age, percentage of conifer species within the stand and its seral stage class.

Habitat Supply Model (HSM)
The HSM generates habitat suitability indices for each inventory period along with simple summary statistics and maps for various habitat quality indices and forest parameters. The model's graphical user interface (GUI) manages all model inputs within user defined scenario folders. All required parameters are entered or modified through the model's GUI.

The two main model components are: the moose data model (discussed in the previous section) and model input parameters. The moose data model describes the study area's current and future forest conditions. The data model is spatial, and this facility allows for an assessment of current and\or future potential moose habitat under various land use scenarios. The model parameters relate important forest attributes (e.g., seral stage) to moose habitat suitability, and define the spatial relationships between habitat and its proximity to specific land features (e.g., areas close to water) and home range size (e.g., 2,500 ha). The analyst can modify all model parameters to suit a specific region. The model's default parameter settings are regionally specific to the Mid Boreal Uplands Ecoregion in western Manitoba.

The HSM is raster based and generates suitability index and forest parameter output files formatted as ESRI grids.

Analysis and Interpretation
Most modeling exercises involve multiple simulation runs. Multiple runs result from the two feedback loops shown in Figure 1: model parameter refinement and forest planning

refinement. The model parameter refinement feedback loop occurs during the model validation and calibration stage. It generally involves adjusting specific model parameters (e.g., shifting a crown closure suitability index curve) and is usually linked to a sensitivity analysis. A sensitivity analysis is performed to determine which model parameters are the least sensitive to adjustment. The forest planning refinement loop is related to modifications of planned forest management activities. This may involve, for example, an adjustment to the harvest schedule to help maintain a specific level of potential moose habitat in a particular area. Any modification to the forest data model requires the analyst to rebuild the moose data model to rerun the HSM.

3.0 Overview and Parameter Requirements for RISKMAN

The RISKMAN model is described in somewhat more detail here than the Habitat Model was in Section 2.0 as Model Forest stakeholders are less familiar with RISKMAN than they are with the HSM.

RISKMAN is a decision support tool for RISK MANagement of harvested and/or unharvested animal populations. It estimates the response of the populations to a variety of demographic parameters. At the heart of RISKMAN is a simple life-table model (Cole 1954, Caughley 1997). The annual model built around the life-table matrix keeps track of births, aging and deaths of animals. As the animals age or change their encumbrance status (i.e. females with offspring), they change the membership to the appropriate cell in the life-table. For example, if a 5-year-old female has a male offspring, she is moved to a life-table cell representing females with one offspring (the offspring is also kept track of). If the following year her offspring subsequently dies or becomes independent she becomes a 6-year-old female without offspring (unencumbered). The user has a good deal of flexibility in setting parameters associated with the various events affecting animals' status.

RISKMAN also provides a capacity to simulate density dependence, where values of certain parameters may change depending on the number of other individuals present in the area being simulated. If needed, in the stochastic model RISKMAN can also estimate the degree of uncertainty in population levels using Monte Carlo analysis (see Taylor, Cluff 2002 for more details). In stochastic mode the model tracks fate of individual animals, while in deterministic mode the proportions of the population are allocated to the appropriate classes. Therefore, it is possible in the deterministic mode for a "part" of an individual to be allocated to a specific class, while in the stochastic mode only whole individuals are allocated.

The sections below outline the parts of the RISKMAN interface for specifying parameters most relevant to the current effort. Parameter values can be provided for individual age, sex and encumbrance cells or for a block of cells by defining the population strata. For example, we may define strata for adult males, adult unencumbered females and females with offspring to provide a single parameter values for the whole strata.

The parameters are saved in "project files" which specify the state of parameters for the full simulation. For complete description of RISKMAN structure and interface see the user manual (Taylor, et. al. 2006).

The main screen of RISKMAN graphically displays the results of the simulation run. It can display up to eight of the predefined output indices, each with potentially several sub-indices.

The output can also be exported to files for further analysis as tab delimited or comma delimited files or viewed on the screen in notepad or a spreadsheet application such as Microsoft Excel®.
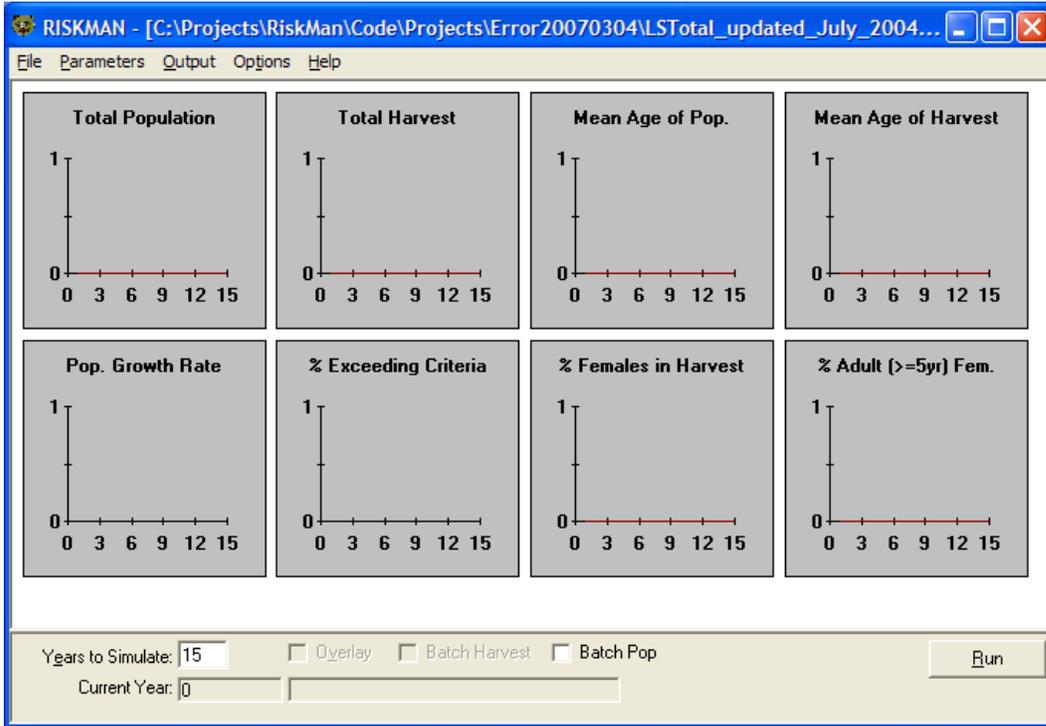

Figure 2. RISKMAN graph output screen

3.1 Species Definition

RISKMAN is capable of simulating animals with 1-, 2-, or 3-year reproductive cycle. This and other general population parameters are set on the Species Definition screen.

The most relevant parameters for the current effort are the:

Species section, where the user can specify the reproductive length cycle (*Annual Model* for the Moose).

Hunting Seasons section allows selection of how often the harvest of the animals (if any) will be applied. The setting of *None* assumes that there is no mortality due to harvest. The *Annual* harvest applies the harvest once. The *Spring and Fall*
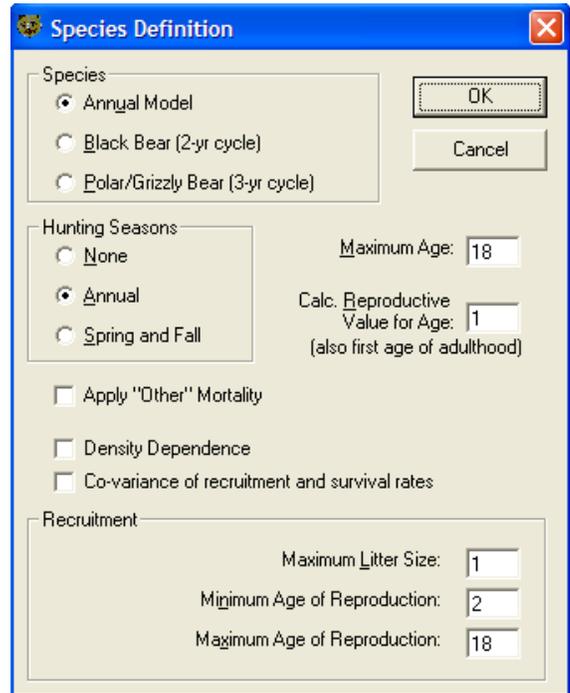

Figure 3. Species definition screen

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setting allows for two independently specified sources of harvest (e.g. licensed kill and native harvest).

The **Apply "Other" Mortality** allows yet another independently specified source of mortality (e.g. illegal hunting).

The **Maximum Age** value specifies how many age classes the model keeps track of. The setting of 18 tells the model to keep track of 18 age classes. Animals older than the Maximum Age are assumed to die of natural causes. This mortality is not included as part of another source of mortality (e.g. survival rate mentioned later).

The **Recruitment** section sets the bounds for the size of the recruitment matrix. The example above says that there will be at most one offspring (*Maximum Litter Size*) and that the adults have offspring between ages of two and eighteen (*Minimum* and the *Maximum Age of Reproduction*).

3.2 Recruitment

The Recruitment screen provides age specific rates of reproduction and the sex ratio of offspring. The dimensions of the matrix are defined on the Species Definition screen.
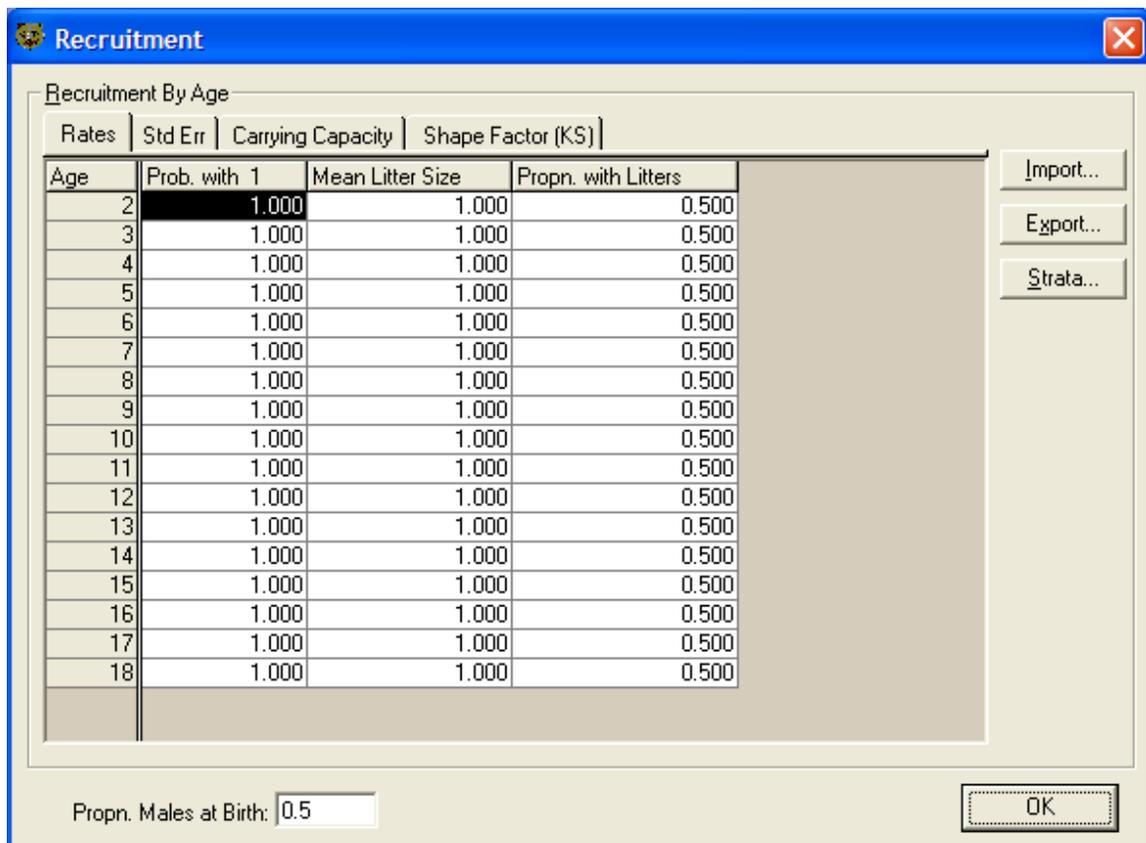

Figure 4. RISKMAN recruitment screen

The main feature of this screen is the **Recruitment By Age** matrix. Within the matrix the user can specify the probability of different number of offspring. The total of these probabilities must sum to 1. The individual probabilities determine the *Mean Litter Size*. The *Propn with Litters* specifies the probability of having offspring at the given age. Once an animal is determined to have offspring it is allocated to the appropriate encumbrance class. The settings show in Figure 4 above indicate that half of the females in each age class have a litter, and that the mean litter size is 1. (The maximum litter size is set in the Species Definition Screen, shown in Figure 3, as 1)

The *Propn Males at Birth* specifies the probability of an offspring that are born male.

3.3 Individual Survival

The Individual Survival screen specifies the age and encumbrance specific (for females) survival rates.
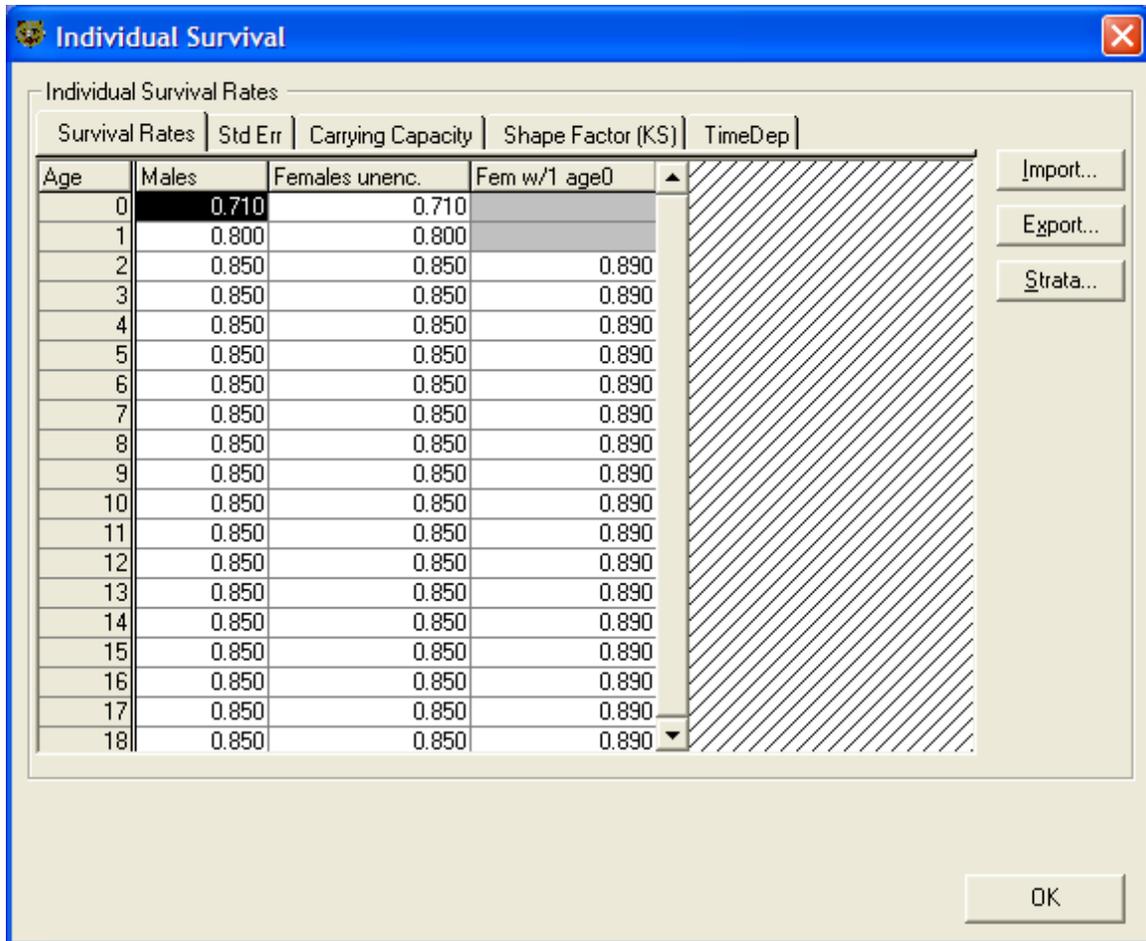
Figure 5. RISKMAN individual survival screen

The values specified here determine what proportion of the population is removed for each sex and encumbrance class.

As mentioned earlier, all individuals older than the maximum age defined within the model (18 in the above example) are also removed from the population. This source of mortality is not included here. If it is necessary to do so one could add one more age class and set the survival for that class to 0.

A block of cells in the display above is grayed out. That means that animals described by the cells are not possible. In the example above it is not possible to have 0- or 1-year old females with offspring since we have specified that the minimum age of reproduction is two.

3.4 Hunting and "Other" Mortality

The Hunting Mortality and the Other Mortality screens together allow specification of up to three sources of mortality in addition to the mortality due to natural causes (Individual Survival).
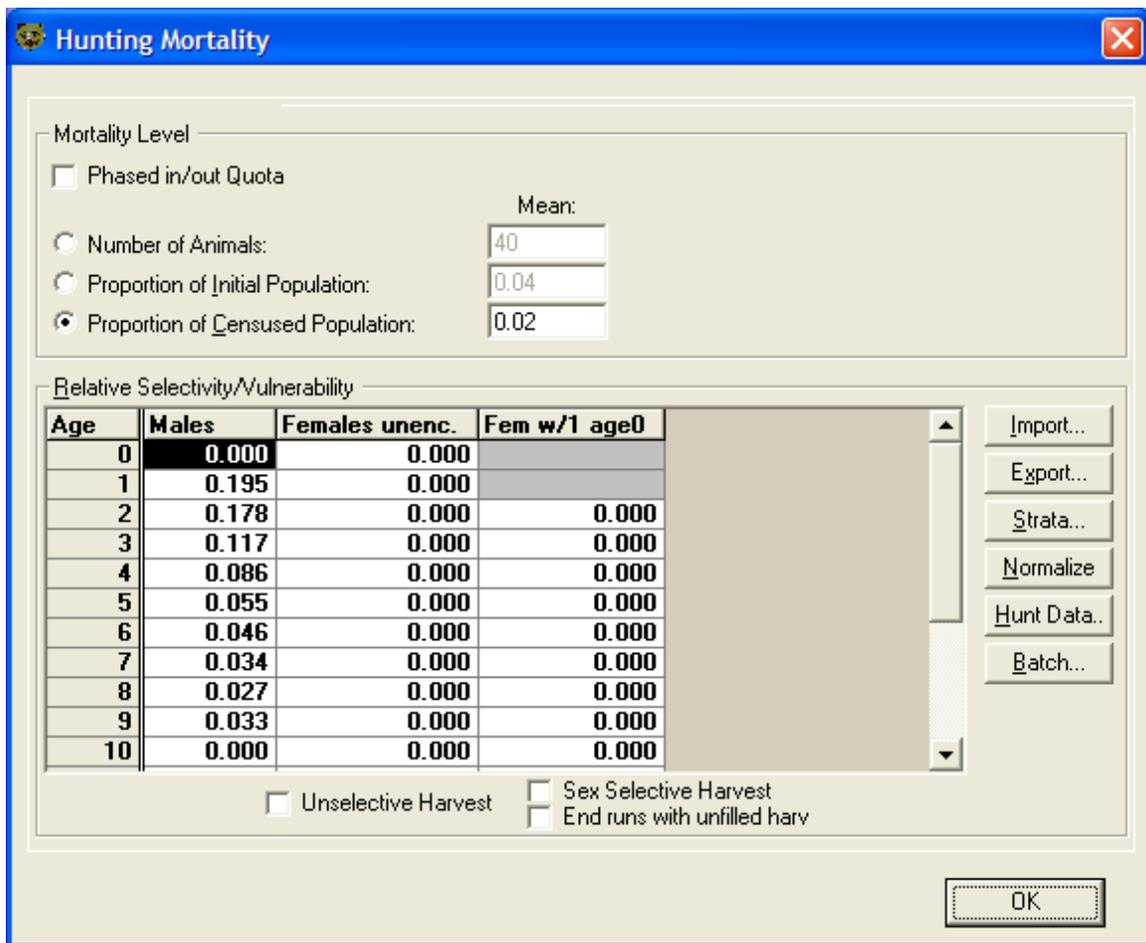

Figure 6. RISKMAN hunting mortality screen.

The level of the hunting mortality can be defined in one of three ways as a specific number (e.g. 40 animals), as a proportion of initial population (which keeps the harvest

constant through the simulation) or as the proportion of the population at the beginning of each simulation year (census).

The matrix of values specifies the relative selectivity/vulnerability of animals to hunting. The absolute magnitude of the values is not as important as their relative magnitude. In the example above 1-year-old males are almost six times as likely to be successfully hunted as the 9-year-old males. The value of zero (0) means that the animals falling into this class are not susceptible to hunting (e.g. hunting for those animals is not allowed).

3.5 Initial Population

The Initial Population screen specifies the state of the population at the beginning of the simulation.
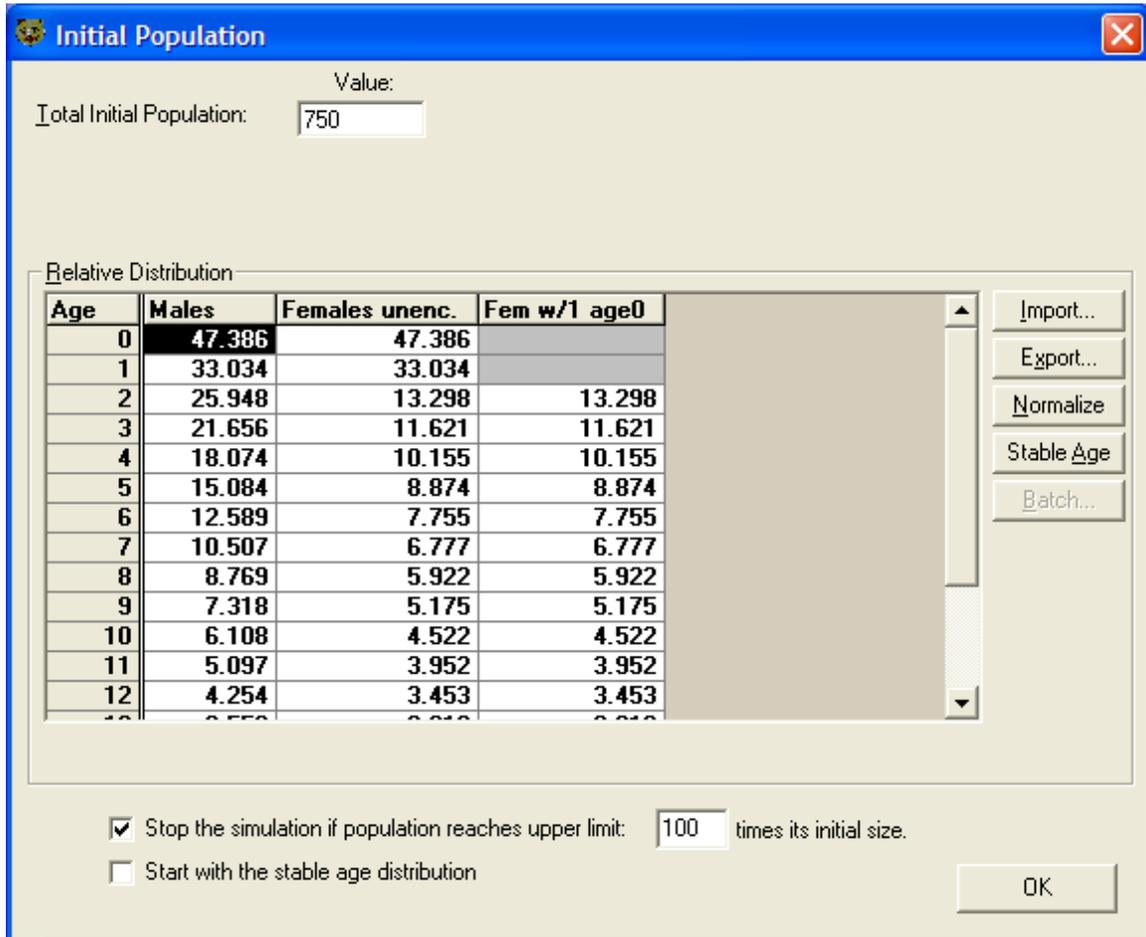
Figure 7 RISKMAN initial population screen.

The initial number of animals is specified in the *Total Initial Population* field. The relative distribution of those individuals is specified in the *Relative Distribution* matrix, shown above in Figure 7. The system allocates the proportion of the initial population based on the relative distribution specified.

The distribution may not be known to the degree of detail required by the model; therefore, the system can estimate the "stable age" distribution. The stable age

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distribution is estimated by running the deterministic model for 100 years without the hunting mortality. If the population does not collapse completely within that time period the relative distribution of individuals can be used for simulation. There are two methods for calculating the stable age distribution: one is by pressing the *Stable Age* button which enters the values into the Initial Population screen. The other is by checking off the *Start with the stable age distribution* box, which tells the system to perform the calculations as the first step in the simulation. The process for both is the same. The latter way allows preservation of the user provided matrix to, for example, compare the results of the simulation with a user specified initial population distribution and the stable age distribution.

3.6 Output Options

The RISKMAN system can display the results on graphs at the end of the simulation run or export the results to an external file for processing and analysis elsewhere.

The following are indicators currently available in RISKMAN:

Total Population – shows the total population as well as population split by sex for each year of the simulation.
Total Harvest – tracks the harvest by sex.
Mean Age of the Population – indicates the mean age by sex; this may be important to track if the population structure changes (e.g. due to changing vulnerability of different age classes).
Mean Age of Harvest – tracks the sex specific age of animals being harvested; the value may change if there is intensive harvest of certain age classes.
Population Growth Rate – indicates the rate at which the population is growing or shrinking.
Reproductive Value – tracks the reproductive viability of the population.
% Exceeding Criteria – is used primarily in stochastic simulation and can be used to track the proportion of runs in which the population has gone extinct.
% Female in Harvest – tracks the composition of harvest.
% Adult Female in Harvest – displays the proportion of the harvest composed of adult (and reproducing) females.
Adult Male/Female – tracks the sex composition of the population.

These outputs may suffice for indicators for the integrated models. The possibility of additional indicators may be explored during the integration of the two models.

3.7 Model Availability

The RISKMAN system along with the user documentation is available for download free of charge at:

http://www.nrdpfc.ca/RISKMAN/

The site is maintained by the Ontario Ministry of Natural Resources (custodians of the model). Registration is required mostly to advise users of new system updates available for download.

4.0 Proposed Integration Approach

4.1 Algorithms affecting life history parameters

As described in Section 2 of this report and in KBM Forestry Consultants (2006), the Moose HSM integrates spatial forest information (primarily on cover type, successional stage, crown closure, and moisture regime) to produce a number of intermediate variables and indicators of moose habitat quality. Of the challenges to system development described in Section 1.1, the most fundamental is to identify which habitat variables are best suited for translation into inputs into the population model.

The HSM document (KBM Forestry Consultants 2006) describes the input variables used in the model, they include:

- Summer and winter forage by % conifer
- Summer and winter forage by seral stage
- Summer and winter forage by crown closure
- Summer cover by percent conifer
- Summer and winter cover by seral stage

- Summer cover by percent conifer
- Summer and winter forage by moisture class
- Summer cover by moisture class
- Winter cover by moisture class

These and other variables are combined using mathematical formulae to produce integrative indices which vary from 0 to 1.0, with 1.0 being ideal values. The indices include:

- Summer food
- Summer cover
- Early winter food
- Early winter cover
- Late winter cover

- Summer habitat
- Early winter habitat
- Late Winter habitat
- Overall habitat

Section 3.0 has identified that key input variables in the population model include recruitment by age, and survival and hunting vulnerability by age and sex. (RISKMAN provides the ability to identify cohorts as whatever classes of age and sex groups the user feels is appropriate.)

We envision a system, whereby RISKMAN is initially parametarized with "ideal" values for the population input variables. The "ideal" values are those which represent the maximum possible in the area being simulated. Relevant suitability indices which affect the population model input variables are then identified and weighted in such a manner so that their combined sums can be used to modify the baseline values.

For example, say that the annual survival rate for adult males is 0.85 (meaning that under ideal conditions, 85% of bulls survive). Also, say that the habitat variables (calculated as indices by the HSM) which affect bull survival rate are summer food, summer cover, early winter food, and late winter cover.

We propose that one means of combining the effects of these independent (habitat) variables on the dependent (population model input) variables would be to use an approach similar to that used to developing the HSI models. For example each of the

independent variables is assigned a weighting (e.g. summer food value weighting of 0.5, summer cover value weighting of 0.1, etc.) so that the sum of the weights is 1.0. These values could then be multiplied by the calculated values for their related indices and the four products (in this example there are four products – one for each of summer food, summer cover, early winter food, and late winter cover) are then summed to produce a value which is used to modify the baseline rate (here it is 85% bull survival). Although hard to explain, the following tables provide an example of this computational method.

Table 1. Example 1 of proposed computational method – calculation of bull survival rate

Independent Variable	HSI (a)	Importance Weight (b)	Product (a X b)	
Summer Food	1.0	0.5	0.5	Therefore the adult bull survival rate is 0.85 (1.0 * 0.85)
Summer Cover	1.0	0.1	0.1	
Early Winter Food	1.0	0.1	0.1	
Late Winter Cover	1.0	0.3	0.3	
Total	N/a	1.0	1.0	

Table 2. Example 2 of proposed computational method – calculation of bull survival rate

Independent Variable	HSI (a)	Importance Weight (b)	Product (a X b)	
Summer Food	0.8	0.5	0.4	Therefore the adult bull survival rate is 0.56 (.67* 0.85)
Summer Cover	0.6	0.1	0.06	
Early Winter Food	0.9	0.1	0.09	
Late Winter Cover	0.4	0.3	0.12	
Total	N/a	1.0	0.67	

Both Table 1 and Table 2 are based on example calculations of adult bull survival rate. Example 1 represents an ideal habitat in which the HSI values for each of the four independent variables are each set at 1.0. Note that the sum of the importance weights (which portray the relative importance of each of the independent variables) is 1.0. Note also that the sum of the products of the importance weights X their related independent variables is 1.0. This is because the HSIs are all 1.0. In this example, when the baseline bull survival rate (0.85) is multiplied by the summed product (1.0), the calculated survival rate is also 0.85 (again, because this example represents ideal habitat).

Example 2 (Table 2) represents a different habitat scenario. Here the HSIs of the independent variables are all less than 1.0, varying from 0.4 to 0.9. When the products of the importance weights and HSI's are summed, a value of 0.67 is obtained. In this example, the calculated bull survival rate is 0.56 (0.67 X the ideal value of 0.85).

We suggest that this approach could be used to calculate the input parameters used by RISKMAN and described to some extent in Section 3. This approach would require several steps including:
- Identification of appropriate cohorts;
- Identification of baseline values for all input variables;
- Identification of independent (habitat) variables to be used in calculating each of the input values;
- Identification of importance weights for each relationship; and
- Review and validation of the relationships

We identify this means of calculating inputs as a possible approach. We remain open to other possibilities should they arise during subsequent stages of system development. However, we believe that this approach has several advantages:

- It is tractable – not overly complex;
- It provides a basis for input from local experts; and
- It is malleable – key values can be changed easily providing a basis for gaming and validation.

4.2 Systems Integration

Key aspects of the system integration relate to its spatial aspects, and the design and management of component files.

Currently there are two independent software systems. The HSM system analyzes habitat data and produces a variety of moose suitability indices for a given area. The RISKMAN system simulates moose (or other species) population's response to the demographic parameters affecting that population. There is a gap between the two systems which needs to be bridged in order for the two to work together: the habitat suitability measures need to be incorporated into the demographic factors so that the population is responsive to habitat conditions.

4.2.1 Spatial Aspects of Integration

Population Zones

The linkage between the HSM and RISKMAN will be based on spatially and temporally linked population zones, approximately 2,500 ha in size. A population zone approximates the home range for moose within the western part of Manitoba but can be adjusted to suit other regions if required.

The population zones are defined by a square grid layer from which average habitat suitability indices will be calculated for each time period. Figure 8 illustrates a proposed population zone layer for Louisiana Pacific's Duck Mountain Forest Management Unit (FMU). (Figure 8 illustrates the zones as non-overlapping, however based on further consideration, a decision will be made as to whether the zones should be overlapping, or non-overlapping. Non-overlapping zones would result in a simpler integration, however overlapping zones may depict a more realistic situation.)
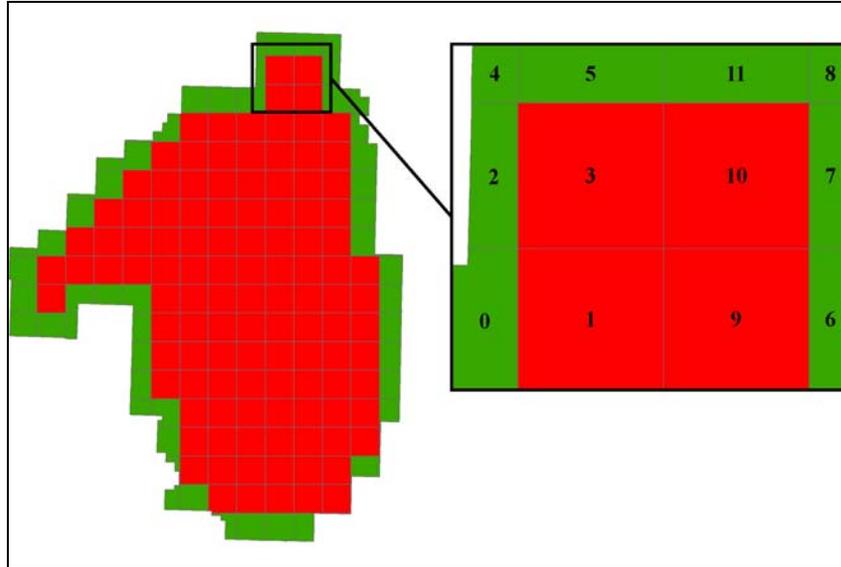
Figure 8. Proposed population zones for Louisiana Pacific's Duck Mountain FMU. (Red zones indicate zones equal to 2,500 ha. Population zones along the FMA boundary are shown in green and are less than 2,500 ha in size.)

Population Zone Statistics

For each population zone, the key habitat variables needed for the algorithms to be used in calculating inputs into the population model will be produced.

Table 3 summarizes, as an example, the mean summer forage variable by population zone and simulation period. Similar output tables would be produced for each habitat variable which will be translated into recruitment and survival parameters suitable for the RISKMAN model. Population zone numbers listed in Table 3 correspond to zone labels shown in Figure 8.

Table 3. Sample summary output for summer forage showing population zone averages for each 10 year simulation period.

Popn. Zone	Area (ha)	0	10	20	30	40	50	60	70	80	90	100
						Period (yrs)						
0	2319	0.57	0.60	0.60	0.58	0.56	0.55	0.54	0.56	0.56	0.55	0.54
1	2500	0.57	0.59	0.61	0.61	0.59	0.57	0.56	0.56	0.57	0.58	0.56
2	825	0.51	0.56	0.55	0.52	0.50	0.48	0.48	0.48	0.47	0.47	0.47
3	2500	0.50	0.53	0.54	0.51	0.49	0.47	0.45	0.46	0.47	0.49	0.48
4	640	0.54	0.54	0.51	0.48	0.45	0.40	0.44	0.44	0.43	0.41	0.40
5	2021	0.55	0.59	0.57	0.54	0.53	0.50	0.49	0.50	0.51	0.47	0.47
6	2350	0.63	0.66	0.65	0.63	0.62	0.57	0.58	0.58	0.56	0.54	0.54
7	1547	0.59	0.60	0.57	0.57	0.55	0.52	0.54	0.51	0.48	0.47	0.46
8	1225	0.58	0.59	0.57	0.54	0.52	0.49	0.49	0.51	0.49	0.45	0.45
9	2500	0.60	0.63	0.65	0.62	0.59	0.57	0.55	0.57	0.58	0.56	0.54
10	2500	0.59	0.62	0.61	0.61	0.57	0.56	0.55	0.54	0.55	0.56	0.54

One feature of population modeling in which interest has been expressed is recognizing increased susceptibility to hunting based on proximity to, or density of roads in the local area. Using the population zone approach, and assuming roads information (via road layers in the GIS data) are available, variations in susceptibility based on road density or presence/absence of roads in a zone, can be built into the integrated model. This can be done using the "other mortality" feature of RISKMAN (see Section 3.4.) or by varying susceptibility using an approach similar to that described in Section 4.1 for calculating algorithms affecting life-history parameters.

As described in Section 4.2.2, the spatial end-product of the system will be a series of population estimate maps.

4.2.2 System Components

The approach presented here for integrating modeling components suggests creating a stand-alone system which analyzes the suitability indices and produces the demographic parameters necessary to run RISKMAN. Following the simulation run the new system will analyze the simulation results and produce integrated output and overall summaries. Therefore, the integrated system will consist of three basic components: 1) The moose HSM and its associated files; 2) RISKMAN and its associated files; and 3) new components which translate HSM outputs into RISKMAN inputs, and which translate RISKMAN results into spatial output. (Figure 9)
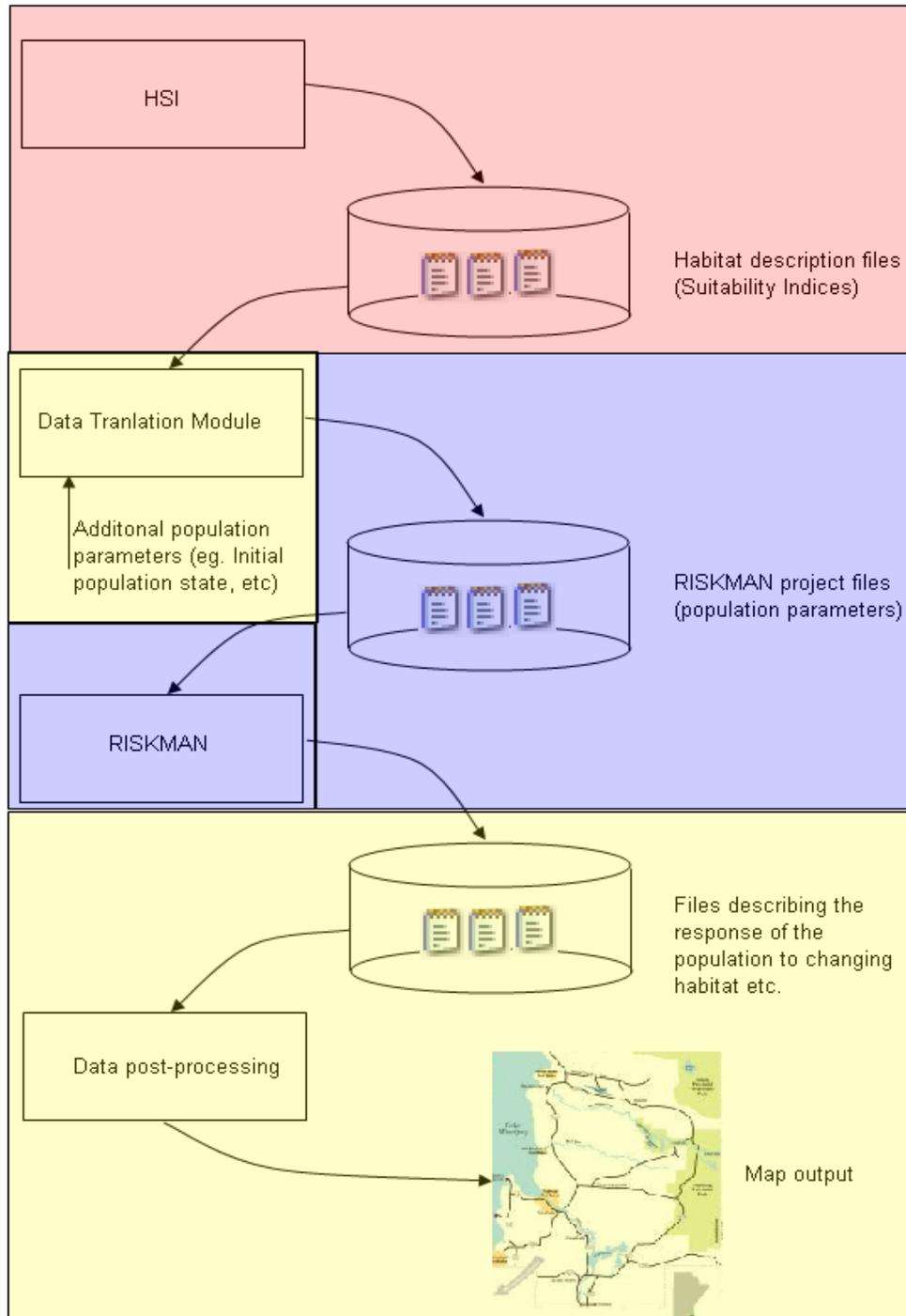
Figure 9. Components of the integrated modeling system. Components shaded red are those associated with the moose HSM; those shaded blue are associated with RISKMAN, and those shaded yellow are new components developed to facilitate the integration of the models.

Data Translation Module

A new stand-alone module will analyze HSM output for each of the areas and produce "project files" required by RISKMAN containing sets of recruitment, survival and other demographic parameters. These will be based on the algorithms affecting life history parameters described in Section 4.1.1. If required the parameters will be interpolated between the decadal values by providing the slope of the change for the next 10 year period.

Additional parameter values will be required such as the initial population level, parameters related to hunting, etc. Some of these will only be applicable to the first project file in the series (e.g. initial population levels). Others will provide base values to be modified depending on the HSI system output.

RISKMAN Simulation

At present we envision that the RISKMAN system will run for 10 years based on each of the project files. Some of the parameters, such as the current population level, will be carried forward between the successive project files. There is no feedback intended between the neighboring areas.

The name of the next project file can be saved as part of the current project file or a sequence of project files can be specified for the batch run. The implementation will depend on what is easier and more appropriate for the situation.

The RISKMAN system will produce output annually, by the decade, and/or final value for the simulation. The output parameters may include any of the built-in indices described in Section 3.6. The results of the run can be viewed graphically on the built-in graphs and/or redirected to a file for analysis elsewhere.

Re-integration of the Results

Since the total area of the Manitoba Model Forest will be divided into a series of population zones (as described in Section 4.2.1), the data will have to be re-integrated to produce overall statistics. The integration will be more complex if the population zones are overlapping than if they are non-overlapping. Most of these output value will be re-integrated by averaging (weighted by the population level) over the applicable areas.

The re-integration will be carried out outside of the RISKMAN system.

Population Estimate Maps

The integrated model will produce output values by population zone in tabular form. Since the output values are spatially linked to the population zones (through the population zone labels), output value maps can be generated for the display and further spatial analysis of output values performed if required.

Implementation

As described in Figure 9, the following are major modules for which development and/or modification will be required:

- The HSM system will require adaptation to produce data for the population zones.
- A new module for translating the suitability indices into demographic parameters will at least initially be separate from the RISKMAN. This system will pre-process the HSI data. The output from the module will be the decadal project files for each part of the area of interest.
- RISKMAN will have to be modified to run a "batch" of project files carrying some parameters (e.g. the population matrix) between the successive project file runs.
- Interpolation of values within the simulation for each of the decadal project files is currently not implemented, although discussions related to implementation of this facility are currently underway as part of another RISKMAN related effort.
- RISKMAN will require a modification to allow annual and/or decadal automatic saving of output parameters.
- The blending/reintegration module will need to be developed. It will combine the output from the RISKMAN system and translates it into a format usable by other applications.

Advantages of this approach

The main advantage of this approach is the fairly easy integration with the existing RISKMAN and the HSM systems. Few modifications will be required to either system which will minimize the impact on other parts of the two systems thus decreasing the overall effort required.

The bulk of the effort will be in generating the decadal project files based on the HSM output, and processing the RISKMAN output.

Limitations of this approach

Since the individual areas are run independently the feedback (e.g. migration of individuals) between the areas will not be possible to simulate. This will be alleviated, to a degree, by the overlap of areas of interest.

Building of a model with migration would require a lot more effort. The system would also have to be stochastic since movement of individuals cannot be predicted.

5.0 Next Steps

In continuing with the approach of provincial participation, which was very important in the development of the HSM, we believe the next step in the development of the integrated model should facilitate involvement of provincial experts. While this could take several forms – e-mail surveys, telephone interviews, etc., we believe the best format would be a facilitated meeting or workshop. The workshop should be attended by Model Forest personnel, provincial biologists, and the project proponents.

Prior to the workshop, the project team would contact the participants and distribute background material. Ideally participants would be familiar with the HSM and have had an opportunity to experiment with RISKMAN.

Following the workshop, a modified design template could be produced (if necessary) and development of the integrated models could commence. At some point during the development of the model, interim versions could be distributed for comment. At a point when the model is reasonably well developed, another workshop/meeting could be held to solicit input, and from there, final development of the products could proceed.

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