User guide:

Decision-support system linking caribou population dynamics and forest succession

Guy R. Larocque

Natural Resources Canada

Laurentian Forestry Centre

Introduction

This user guide contains instructions to execute the decision-support system for caribou. It comprises three main applications to link forest growth and succession, habitat quality and caribou population dynamics (Figure 1):

1- The forest succession (gap) model ZELIG-CFS;

2- Plugin developed in QGIS to compute habitat suitability indices within caribou ranges;

3- The population dynamics model CARIBOUMOD to simulate the development of caribou populations.

The ZELIG-CFS model is a mechanistic model that simulates the growth and succession of forest ecosystems. Further developments were made by including routines to simulate the effects of climate change. More information on its use, modifications and evaluation can be found in Larocque et al. (2011), Elzein et al. (2020), Larocque and Bell (2021) and Searle et al. (2021). Also, a specific user guide for ZELIG-CFS is available.

The application AMSIMOD (Application for the Management of SIMulation MODels) was developed to facilitate the execution of models (Larocque et al. 2015), including ZELIG-CFS and CARIBOUMOD. Simulation parameters are defined in project files. AMSIMOD projects are located within workspaces, along with input files and the executable (.exe) files of models. A workspace corresponds to a folder on a disk drive. The output files that are created when running a model are stored within result folders located in the same workspace that contains input files and executable versions of models. Result folders, which are created when a project is defined in AMSIMOD, are given the same name as the name of the project, but the extension "_results" is added. The user guide for AMSIMOD provides more detailed instructions about how to use the different functionalities to execute models, display results and run applications. For more information, consult the user guide AMSIMOD_User_Guide.pdf

The decision-support system uses digital maps to display forest polygons at the ecosystem level using eFRI (enhanced Forest Resources Inventory) data developed by the Ontario Ministry of Natural Resources and Forestry (see Ministry of Natural Resources, Ontario, 2009). Maps were prepared for use with QGIS (version 2.18), an open source geographic information system. Figure 2 shows an example of a digital map displaying eFRI data, along with an example of eFRI data used to generate input files for ZELIG-CFS. The digital maps opened in QGIS must include three types of files: (1) a .dbf (dBase database file) file that contains forest data, which consists of eFRI information for the present project, (2) a shape file (.shp) file that contains geometric data for the polygons and (3) a shape index format file (.shx) that is a positional index.

Two plugins were developed for use with QGIS: (1) Generate Ontario Tree List from eFRI to create input files for ZELIG-CFS using eFRI data and (2) HSM to compute habitat quality indices for caribou based on forest species and structure and presence of roads and mines in the area. This plugin is based on the approach developed by Leblond et al. (2014). Both plugins must be installed in the following folder: C:\Users\Username\.qgis2\python\ plugins. Replace ‘’Username” with the user account, such as mdeldago. For the present study, the boreal forest of northern Ontario where caribou herds are located were subdivided in ranges and sub-ranges (Appendix A). Datasets and models for forests, habitat quality indices (HSM) and caribou populations were created for each sub-range and caribou herd.

There are five steps in the application of the decision support system to link forest succession, habitat quality and caribou population dynamics. They are summarized in Table 1. Table 2 contains a list of applications that must be installed. Then, general instructions for using models and applications follow and additional detailed explanations are provided in Appendix B using data from a sub-range and caribou herd as an example.

Table 1: Sequence of applications for using the decision support system that link forest succession, habitat quality indices and caribou population dynamics.

Step #	Step	Models/Applications
1	Execution of ZELIG-CFS	Model: ZELIG_CFS_Model_v47_modified_eFRI.exe
2	Conversion of eFRI simulation results in .dbf format	Application: Convert_DBF_Form.exe
3	Computation of habitat suitability indices	Application: Plugin HSM in QGIS
4	Computation of the relative effect of disturbance on recruitment rate	Application: Compute_DisturbanceRecruitment.exe
5	Execution of the caribou population dynamics model	Model: CARIBOUMOD

Table 2: List of setup files to use for installing applications. The location where the applications are installed are indicated.

Setup file	Application	Location
AMSIMODsetup.exe	AMSIMOD	C drive
Zelig_Create_Input_Files_Setup.exe	Zelig_Create_Input_Files.exe	C drive
Zelig_Fertility_Factor_Setup.exe	Zelig_Fertility_Factor.exe	C drive
Create_Caribou_File_Setup.exe	Create_Caribou_File.exe	C drive
Compute_Disturbance_Recruitment_Setup.exe	Compute_Disturbance_Recruitment.exe	C drive
Convert_DBF_Form_Setup.exe	Convert_DBF_Form.exe	C drive
Zelig_CFS_Setup.exe	ZELIG_CFS_Model_v47_modified_eFRI.exe	Project workspace
CARIBOUMODSetup.exe	CARIBOUMOD.exe	Project workspace
QGIS-OSGeo4W-2.18.20-1-Setup-x86_64.exe	QGIS	C drive
QGIS Plugin	Generate Ontario Tree List from eFRI	User*
QGIS Plugin	HSM	User*

*Plugins must be installed in the following folder: C:\Users\Username\.qgis2\python\ plugins

Note: The setup files were defined to install shortcuts of the applications in the Start menu and on the desktop. In case that the shortcuts are not installed, it is possible to create the shortcuts in the folder for each application located in C:\Program Files (x86) and install them on the desktop or in the folder C:\ProgramData\Microsoft\Windows\Start Menu\Programs.

This Decision-support system for caribou presented in this user guide was developed for use in different ranges of northern Ontario listed in Appendix A. For each range, the applications presented in Table 1 must be used sequentially for each range. Detailed instructions follow and an example is presented using data for the range Brightsand_A.

Instructions:

As indicated in Table 1, there are different steps to follow for using the decision-support system. The following sections provide general information. Additional details and examples are provided in Appendix B.

1- Run the model ZELIG-CFS using AMSIMOD.

The execution of ZELIG-CFS requires specific input files to simulate the dynamics of forest ecosystems. Two methods can be used to create Input files. They both create input files with the appropriate format, ready to be used by ZELIG-CFS. The first method consists in using the application ZELIG_Create_Input_Files.exe, which was developed in Visual C++ (Figure 3). It contains a user-friendly graphic interface that facilitates information and data entry in edit fields. The labels associated with each edit field well explain the type of information or data to be entered. Detailed information are included in the user guide for ZELIG-CFS. The second method consists in using the plugin Generate Ontario Tree List from eFRI (Figure 4), which was developed for use with QGIS (version 2.18). This plugin works only for forest data contained in the eFRI dataset of Ontario and must be installed in the following folder: C:\Users\Username\.qgis2\python\plugins. Replace ‘’Username” with the username of the account, such as mdeldago. There are four tabs in this plugin. Use the first tab to enter information on eFRI source file, study area and output filename. This plugin generates climate data used by ZELIG-CFS. By selecting Default, routines included in BIOSIM (Régnière et al. 2017[1]) automatically computes monthly mean temperature and precipitation data for the area under investigation.

An input file may contain ecological information and tree data for many sample plots. For convenience, it is suggested to limit the size of input files to 20 MB, which may include as many as 2,000 sample for a plot area of 405 m^2. The plugin Generate Ontario Tree List from eFRI automatically limits the number of sample plots entered to avoid creating large input files. The second tab is used to identify the variables in an eFRI file associated with observation area, polygon type attribute, species composition, age, height, stocking and ecological type. The third tab is used to provide simulation parameters. The fourth tab is used to provide regeneration data for each species under study. Thus, if a particular species is not found in a specific forest ecosystem, the density and stocking data are equal to 0.

When running ZELIG-CFS, four output files are created that contain results at selected simulation years in the following order: basal area, stand density, eFRI values and individual tree dbh. However, when many sample plots are simulated, ZELIG-CFS can output results in several files to avoid the creation of very large files. When running ZELIG-CFS, end users may choose the filenames of the output files by entering them in an AMSIMOD project. However, for convenience, it is suggested to choose filenames that include descriptors associated with the type of output. For instance, files that contain results for basal area, stand density, eFRI values and individual tree dbh may include in their filenames descriptors such as …BasalArea…, …StDens…, …eFRI…, …DbhTrees…, respectively.

For more information on ZELIG-CFS and the procedure to create input files with Zelig_Create_Input_Files.exe, consult the document User_Guide_ZELIG-CFS.pdf.

2- Convert the eFRI simulation results in .dbf format

The files that contain eFRI results must be converted into a .dbf format, using the application ‘’Convert_DBF_Form.exe”, which was developed to make the conversion. The application

[1] Régnière, J.; Saint-Amant, R.; Béchard, A.; Moutaoufik, A. BioSIM 11 User`s manual. Natural Resources Canada, Can. For. Serv., 2017, Update of Inf. Rep.LAU-X-137.

can create a .dbf file from several eFRI files, which may found in a result folder of a project workspace. However, the .dbf file created must be located at the same level as the input files. Also, this type of file contains the extension ‘’_YEARS’’ to indicate that it contains eFRI results predicted by ZELIG-CFS at different simulation years. To be opened by QGIS, the new .dbf file must be opened along with a .shp file and a .shx file that must have the same name as the new .dbf file created. For instance, if the file ‘’Brightsand_A_RCP0_YEARS.dbf’’ is created, the files ‘’Brightsand_A_RCP0_YEARS.shp’’ and ‘’Brightsand_A_RCP0_YEARS.shx’’ must also be created. They can be created from the original .shp and .shx files used to open the original files of a QGIS project. The newly created .dbf file can be imported in QGIS from an original QGIS project by using the sub-menu ‘’Add vector layer’’ in the menu ‘’Layer’’.

3- Compute habitat suitability indices

Habitat suitability indices are computed using the plugin HSM in QGIS (Figure 5). It is based on the procedures and methods developed by Leblond et al. (2014). This plugin integrates the effects of habitat variables and the presence of human infrastructures to compute habitat suitability indices in 1-ha cells within a caribou range. Habitat variables are based on forest types and structure, such as presence of mature conifer forests, regenerating stands or sites recently harvested. Human infrastructures include the presence of roads or mines. Detailed information are provided in Leblond et al. (2014).

There are three types of input files: (1) an input file containing eFRI layer data, which consists of a .dbf file created by the application ‘’Convert_DBF_Form.exe’’; (2) a second input file that contains the layer of road network within a caribou range and (3) a third input file that contains the layer of mine locations within a caribou range. The computation of habitat suitability indices computed at different ages of the simulations can be saved in a file or can be visualized in the layers created by the plugin. The main results include partitions of the habitat suitability indices in the following intervals:

0.00 <= HSM < 0.50
0.50 <= HSM < 0.70
0.70 <= HSM < 0.80
0.80 <= HSM < 0.90
0.90 <= HSM < 1
HSM=1.

The number of HSM indices computed for each interval are provided, along with the proportions (%) in each interval. The output file created contains by default the extension ‘’_HSMmeans.csv’’.

4- Compute the relative effect of disturbance on recruitment

The application Compute_Disturbance_Recruitment.exe is then executed to relate HSM indices within a subrange to relative effect on recruitment rate. The file created in step 3 (which includes the keywords ''HSMmeans'') is used by the application and considers that the proportion of HSM indices lower than 0.50 is the level of disturbance that has a major effect on recruitment rate of caribou. The output file contains, for each simulated year included, the relative effect on recruitment rate, based on the model developped by Environment Canada (2008):

$$Y = 39.13 - 0.43 \times X$$

Where Y is the relative effect on recruitment rate of caribou (%) and X the percentage of range affected by anthropogenic disturbance. For instance, a typical file containing relative effect on recruitment rate is:

YEAR	Rel_Effect_Recruit
10	80
20	80
30	81
40	83
50	82

This information is then read by CARIBOUMOD to integrate the effect of habitat quality on recruitment.

5- Run CARIBOUMOD to simulate the population dynamics for a caribou herd

The model CARIBOUMOD was developed to be executed as an AMSIMOD project. An initialization file must be provided to run CARIBOUMOD. Figure 6 shows an example of an input file. The application Create_Caribou_file.exe is used to create input files (Figure 7). Information and data are entered in edit fields, which contain description about the types of information or data that must be provided, and the application outputs information and data in a format that can be read by CARIBOUMOD.

Basic information and data that must be provided in an input file include the following (Figures 6 & 7):

1- Name of a caribou region
2 Population density
3 Carrying capacity of a population
4 Recruitment rate
5 Mortality rate
6 Extraction rate (due mainly to hunting)
7 Proportion of females
8 Proportion of calf-adult female ratio
9 Population area

10 Number of simulation years.

End users may choose to perform uncertainty analysis by selecting ‘’yes” for random simulation. An algorithm based on Monte Carlo analysis was developed within CARBOUMOD. If random simulation is selected, the number of iterations must be indicated. Usually, a large number is entered, such as 10,000 iterations. When random simulation is selected, minimum and maximum values for female proportion, calf-Adult female ratio proportion, carrying capacity, recruitment rate and mortality rate must be entered. These minimum and maximum values are the boundaries that define the range of variation in the random selection process within which the Monte Carlo algorithm randomly selects values.

The application ‘’Create_Caribou_file.exe” allows user to modify the recruitment, mortality or extraction rates in the course of simulations. This can be very useful when it is desirable to simulate the outcomes of population dynamics when these rates are changed in the course of a simulation. For each change, three numbers must be provided:

1- The type of change: 1 for recruitment rate, 2 for mortality rate and 3 for extraction rate;
2- Simulation year for the change;
3- Percentage of change. (Positive value to simulate an increase and negative value to simulate a decrease).

There is no limit on the number of changes in these rates that can be provided.

It is also possible to indicate if a file to input disturbance data from HSM computations is provided by selecting the radio button ‘’Yes”. The type of file that contains disturbance values computed was discussed in (4).

Literature cited

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Ministry of Natural Resources, Ontario, 2009. Forest resources inventory technical specifications 2009. Forest information manual 2009.

Searle, E.B., F.W. Bell, G.R. Larocque, M. Fortin, J. Dacosta, R. Sousa-Silva, M. Mina and H.D. Deighton.2021. Simulating the effects of intensifying silviculture on desired species yields across a borad environmental gradient. *Forests* 12: https://www.mdpi.com/1999-4907/12/6/755

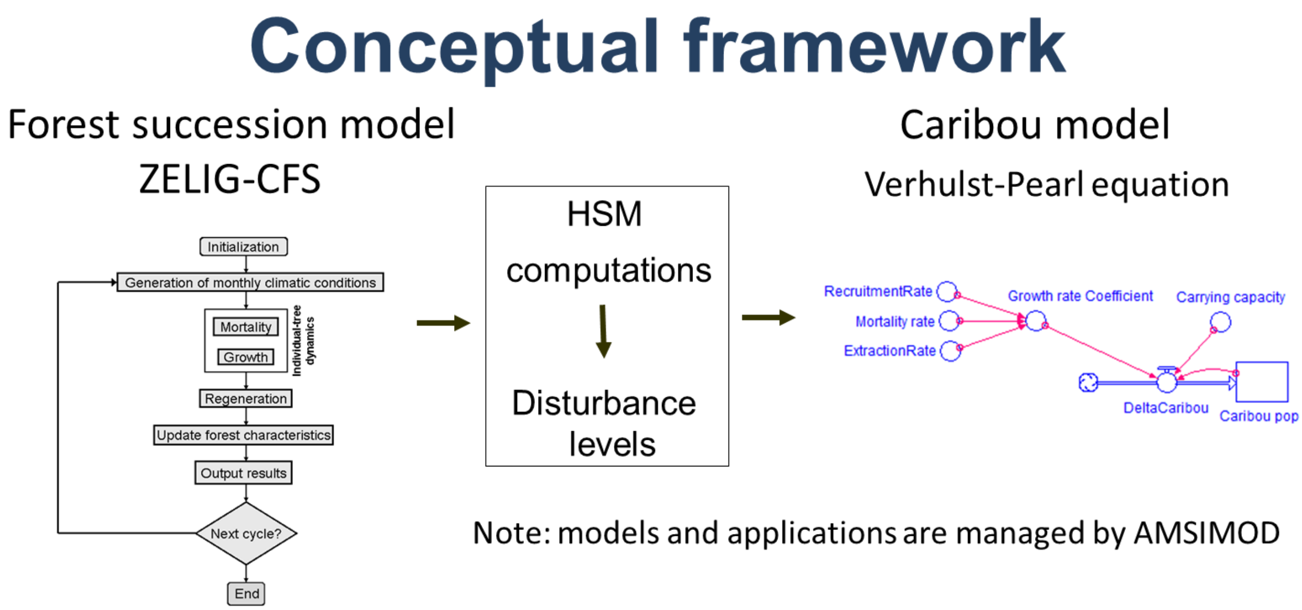
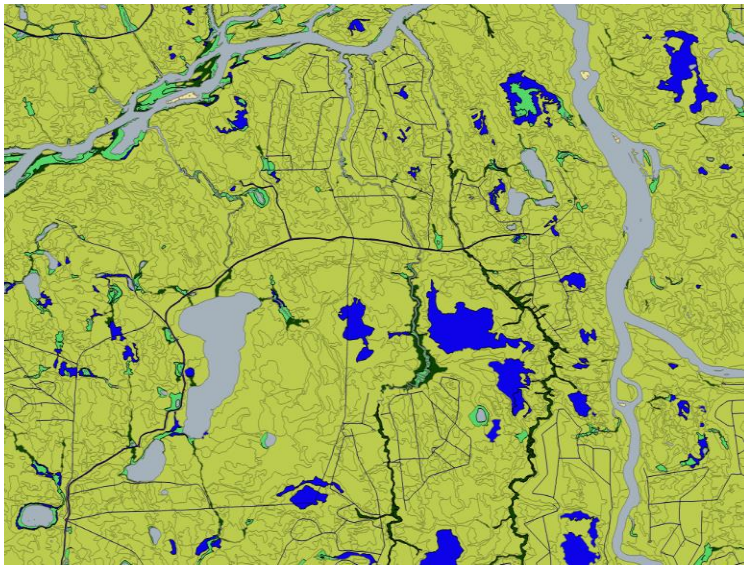


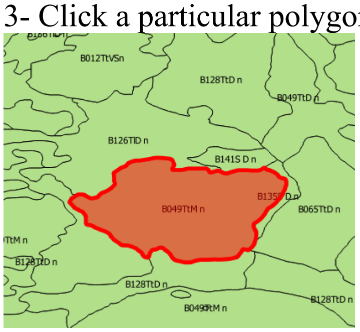
Figure 1: Conceptual framework of the decision support system for caribou. (HSM: Habitat Suitability Model).



OG_LAYER	POLYTYPE	SPCOMP	AGE	HEIGHT	STOCKING	ECOTYPE
CaribouForest	FOR	SB 70PO 20PJ 10	90	15.0	1.00	NW22D
CaribouForest	FOR	SB 60PO 40	90	14.0	1.00	NW21D
CaribouForest	FOR	SB 40PO 30BF 20BW 10	110	18.0	0.70	NW35
CaribouForest	FOR	SB 60PJ 20PO 20	100	17.0	1.00	NW36

Figure 2: Example of a map showing polygons within a forest area of the boreal region of northern Ontario. Each polygon is described using the tabular attribute descriptions of the enhanced Forest Resources Inventory of Ontario (see the Forest Information Manual 2009 of Ontario). The attributes listed above are used by the application Generate Ontario Tree List from eFRI to generate input files for ZELIG-CFS.

Procedure to visualize the details of a polygon:
1- Select the vegetation layer;
2- Click on ‘’Identify features’’ (),
3- Click a particular polygon, which will be highlighted like this:



4- the window ‘’Identify Results’’ will then appear.

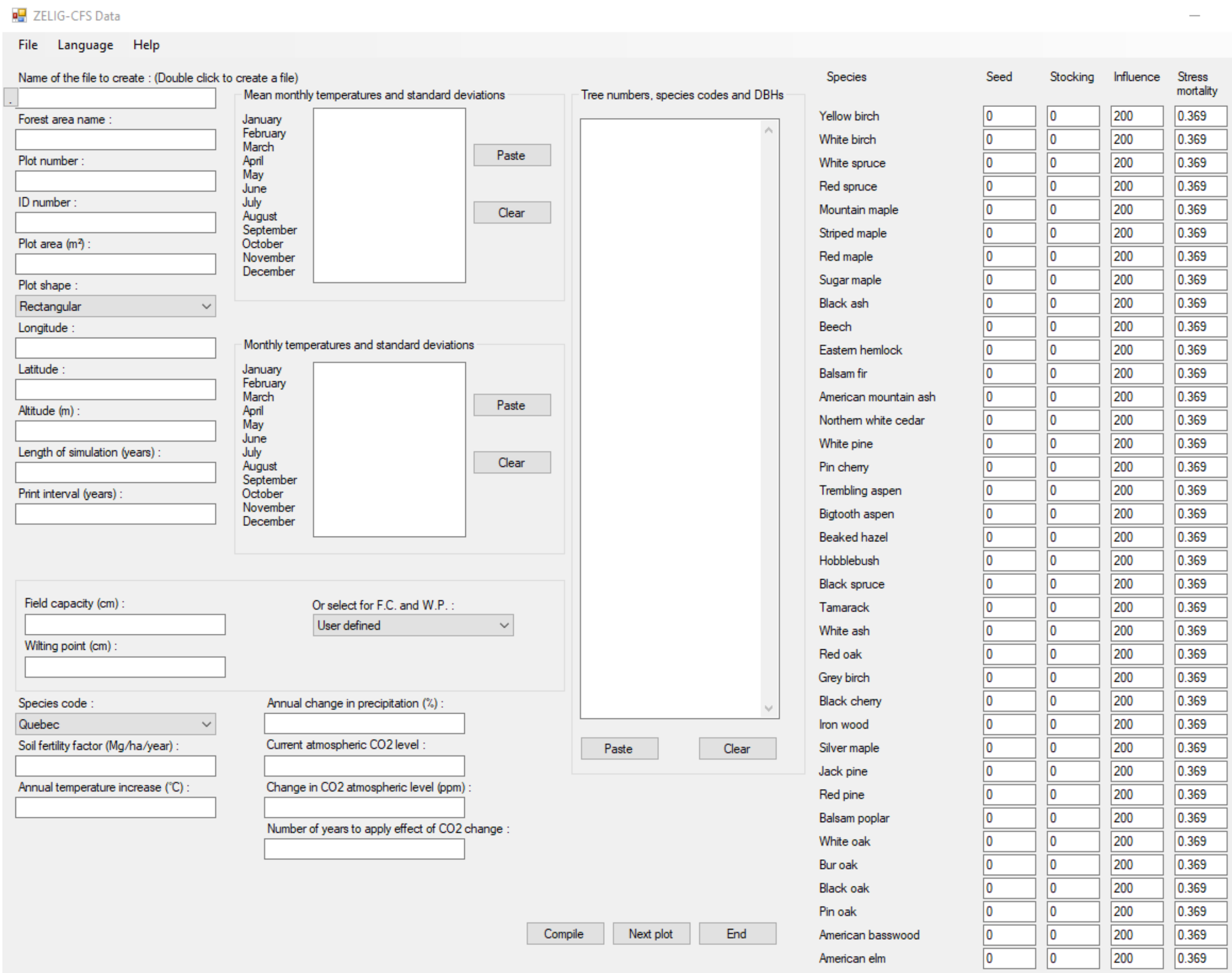


Figure 3: Main interface of the application ZELIG_Create_Input_Files.exe to create input files necessary to execute the model ZELIG-CFS.

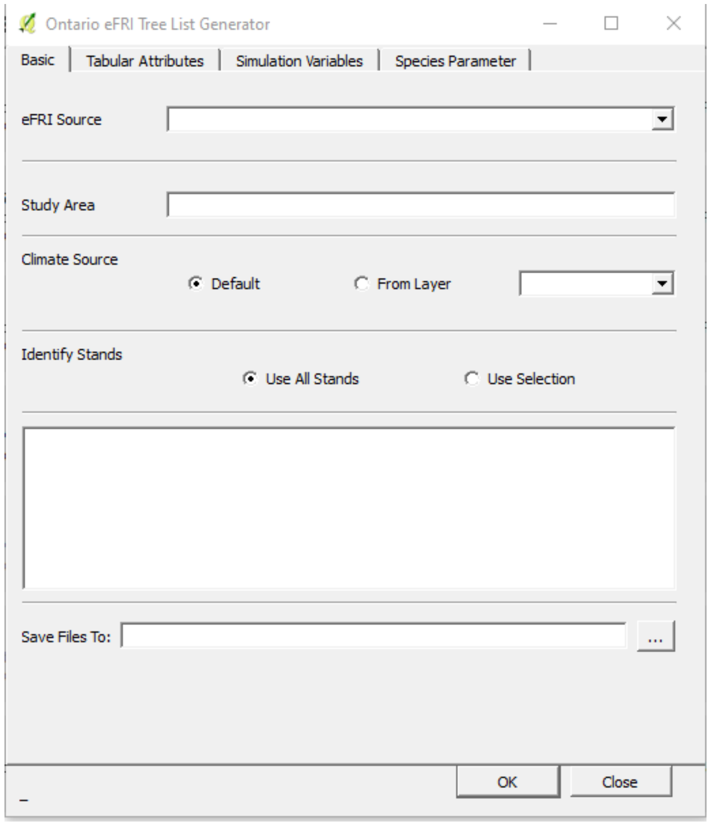


Figure 4: First tab of the graphic interface for the plugin Generate Ontario Tree List from eFRI.

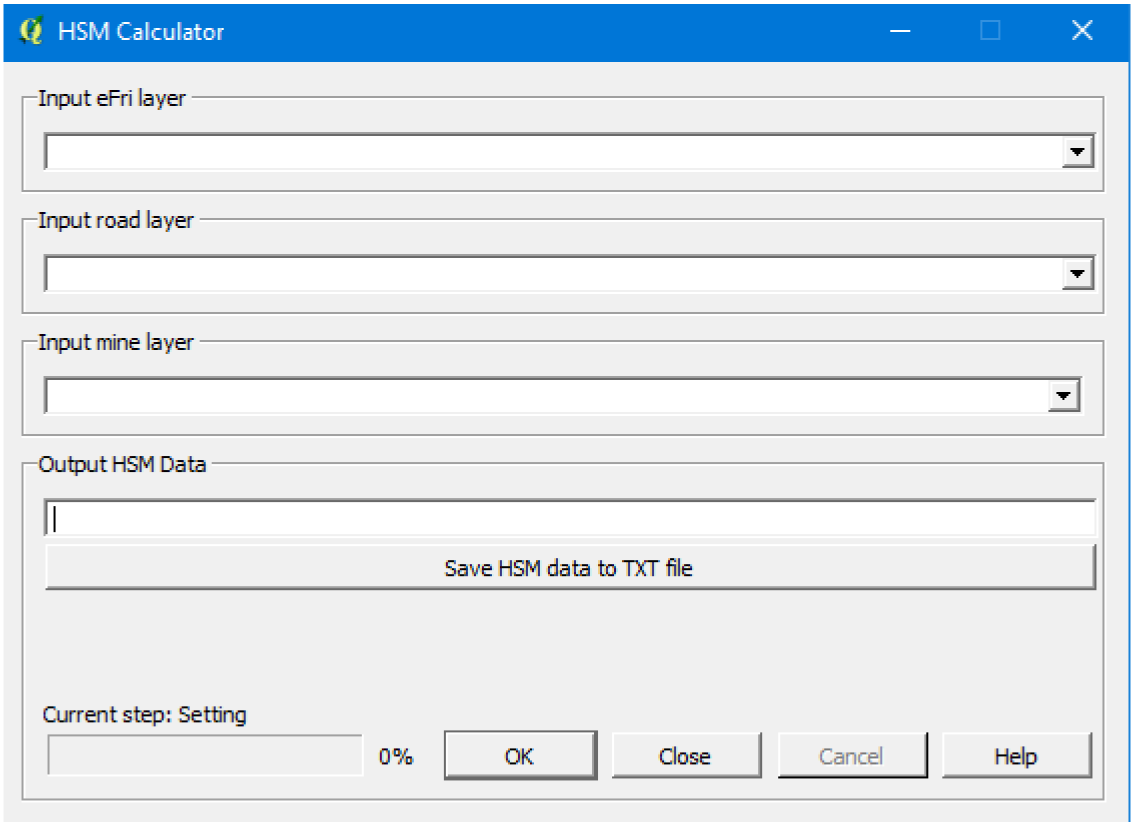


Figure 5: Graphic interface of the plugin HSM to compute habitat suitability indices for forest polygons located within a caribou range.

CaribouRegionID
Berens_A
PopDensity
0.0192
CarryingCap
0.0389
RecruitRate
0.0898
MortalRate
0.185
ExtractRate
0
FEM_Prop
0.6751
CAF_ratio
0.108
PopArea
1611
NumSimYears
100
Flag_RandSim,Number_IterRand
1 10000
DegVar_FEM_Prop_1,DegVar_FEM_Prop_2
0.6054 0.7449
DegVar_CAF_ratio_1,DegVar_CAF_ratio_2
0.048 0.239
DegVar_CarryingCap_1,DegVar_CarryingCap_2
0.0349 0.0430
DegVar_RecruitRate_1,DegVar_RecruitRate_2
0.0285 0.1512
DegVar_MortalRate_1,DegVar_MortalRate_2
0.03 0.315
Percent_changes_in_RecruitRate,_MortalRate,_ExtractRate_in_the_course_of_simulations
-99 -99 -99
Input_file_for_disturbance_0_if_no_input_file_1_for_input_file
0

Figure 6: Example of an input file for CARIBOUMOD. For each value necessary to perform a simulation, the underlined texts above provides information on the type of data.

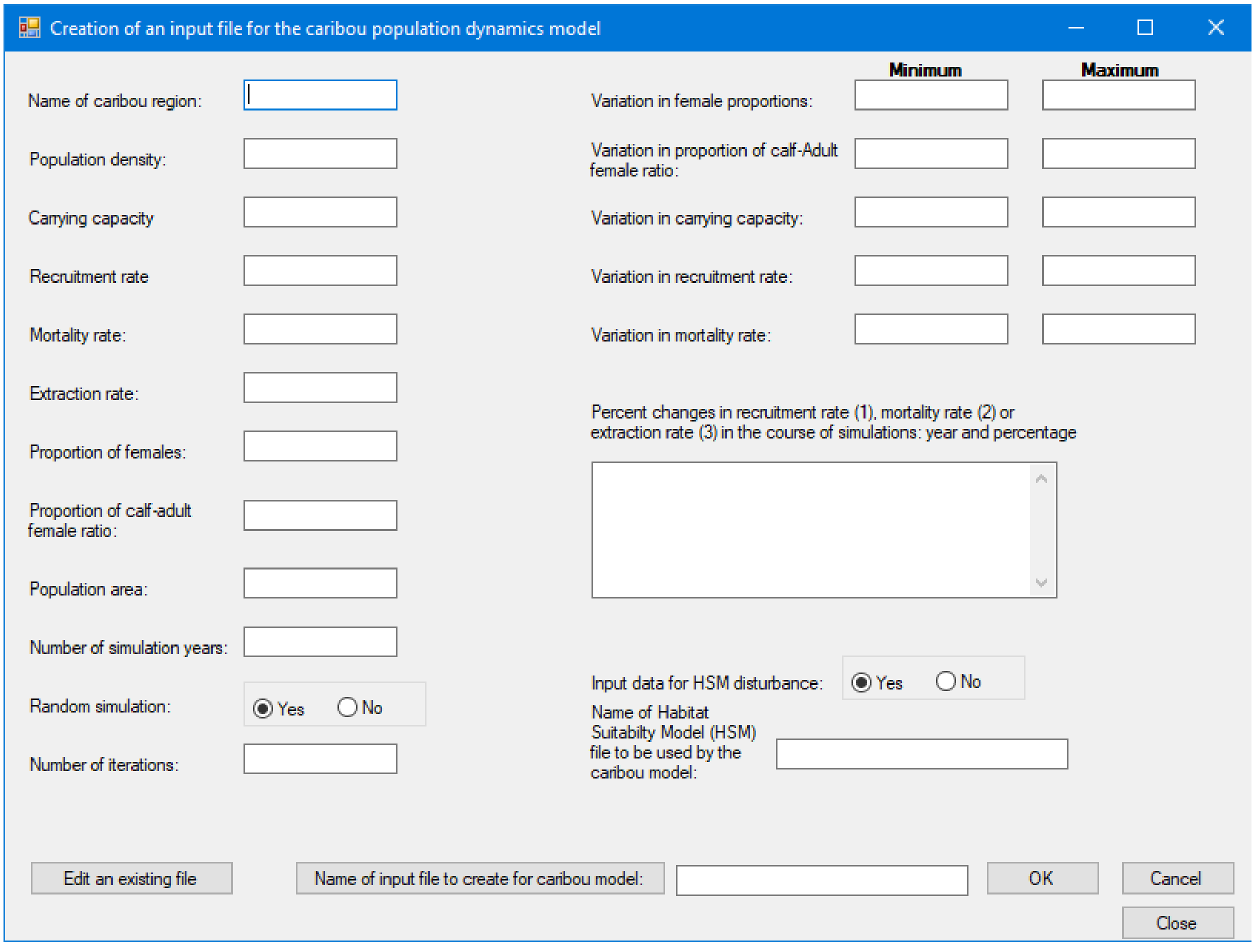


Figure 7: Main window of the application ‘’Create_Caribou_file.exe’’ that is used to create input files for the model CARIBOUMOD.

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Appendix A: Basic characteristics of caribou subranges in the boreal forest of northern Ontario that were used to link forest succession, habitat suitability indices and caribou population dynamics.

Subrange	Area (km^2)	Population size	Number of polygons
Brightsand_A	4,350	140	39,222
Brightsand_B	1,843	42	13,523
Churchill_A	2,841	60	29,111
Churchill_B	1,502	60	14,878
Churchill_C	1,763	72	14,653
Kesagami_A	2,782	22	3,713
Kesagami_B	2,452	22	14,881
Kesagami_C	10,725	110	45,172
Nipigon_A	3,374	52	23,314
Nipigon_B	2008	9	5,697
Nipigon_C	2,784	48	17,125
Nipigon_D	2,009	32	18,801
Pagwachuan_A	2,250	26	14,392
Pagwachuan_C	1,635	7	13,843

Appendix B: Detailed explanations and examples on the use of the decision-support system for caribou.

Data, applications and models in the range Brightsand are used as an example in this Appendix to provide detailed information on the use of the decision-support system to manage and simulate forest succession, changes in habitat quality and caribou population dynamics. The same sequence of applications is used for each range listed in Appendix A. Data, input files and applications for the ranges listed in Appendix A are contained in the workspaces Brightsand, Churchill, Kesagami, Nipigon and Pagwachan. When these workspaces are installed, the folder Ontario Roads and Mines must be at the same level to compute the effects of roads and mines on habitat quality.

The decision-support system uses utilities and plugins adapted for the Geographic Information system QGIS (V 2.18). Basic eFRI forest data, along with road and mine location data, are stored in files with the extensions .dbf, prj, .qlr, .qpj, .shp and .shx. For each range, they are grouped in a QGIS project file (ending with extension .qgis). For the Brightsand_A caribou subrange, the QGIS files include Brightsand_A.dbf, Brightsand_A.prj, Brightsand_A.qlr, Brightsand_A.qpj, Brightsand_A.shp and Brightsand_A.shx. All these files are grouped in the QGIS project file Brightsand_A.qgs and are located in the workspace (folder) Brightsand. As this QGIS project includes road and mine locations, the QGIS files located in the folder Ontario Roads and mines must be located at the same level as the Brightsand folder. Also, the Brightsand folder contains all the forest and caribou data, models and applications and AMSIMOD project files.

1- Creation of input files for ZELIG-CFS from eFRI data

For all the caribou ranges, including Brightsand, Churchill, Kesagami, Nipigon and Pagwachuan, basic forest data were obtained from eFRI files maintained by the Ontario Ministry of Natural Resources and Forestry (Table B1). Definitions of the terms used can be found in Ministry of Natural Resources, Ontario (2009)[2].

Table B1: Example of file containing eFRI data

OG_LAYER	POLYTYPE	SPCOMP	DISTURBANC	DISTURBA_1	AGE	HEIGHT	STOCKING	ECOTYPE
CaribouForest	TMS			0	0	0.0	0.00	
CaribouForest	BSH			0	0	0.0	0.00	
CaribouForest	TMS			0	0	0.0	0.00	
CaribouForest	OTH			0	0	0.0	0.00	
CaribouForest	FOR	SB 70PJ 30	FTGNAT	0	115	15.0	1.70	NW12
CaribouForest	FOR	SB 100	FTGNAT	0	140	7.0	0.30	NW35

[2]Ministry of Natural Resources, Ontario, 2009. Forest resources inventory technical specifications 2009. Forest information manual 2009.

Each line corresponds to forest data and properties within a polygon. As the forest area for a caribou sub-range can be very large, there may be many polygons. For instance, eFRI data for the sub-range Brightsand_A includes 39,222 polygons within 4,350 km^2 (Appendix A). However, not every polygon consists of a forest area. In the example of Table B1, there are four polygon types, but only the polygon type “FOR” corresponds to a forest ecosystem. The polytypes TMS, BSH and OTH correspond to treed wetland, brush and alder and others, respectively.

Input files for ZELIG-CFS are created using the plugin Ontario eFRI Tree List Generator () in QGIS. When the QGIS project Brightsand_A is opened, three layers are displayed: (1) Brightsand Brightsand_A, (2) Ontario Roads and Mines… and (3) Mines 900A_68th_Producing Mines. In the main tab, the eFRI source, the name of the study area and output file created for ZELIG-CFS are provided. Climate data can be provided either from a “climate layer” or by a default source, which will generate automatically monthly mean temperature and precipitation. In the tab Tabular attributes, variables in the eFRI file associated with Observation area, Polygon Type Attribute, Species Composition, Age, Height, Stocking and Ecological Type are provided. For each attribute, the corresponding variables are OG_LAYER, POLYTYPE, SPCOMP, AGE, HEIGHT, STOCKING and ECOTYPE in the Brightsand Brightsand_A layer. In the simulation tab, parameters for the simulation are provided. In particular, it is possible to provide information on annual changes in climatic conditions. In the “Species Parameter” tab, data on regeneration are provided. For seed, species-specific potential number of seedlings per square meter that may germinate and stocking are entered. It is possible to enter regeneration data for 37 species. However, only the species that can be found in the area being modelled must be provided.

For Brightsand_A, the names of the input files for ZELIG-CFS that were created all contained “Brightsand_A_OutputZelig…”. The names that were chosen ensure that they would be differentiated from Brigthsand_B and the inclusion of “OutputZelig” indicates that the files contained initialization data for ZELIG-CFS. There were 20 input files that were created for Brightsand_A. The reason for creating many files is to ensure that the sizes of input and output files would be manageable. Also, three groups of input files were created to simulate scenarios of climate change: _RCP0, RCP4_5 and RCP8_5. These correspond to three scenarios of climate change: Control (RCP0), annual increase in temperature, precipitation and atmospheric CO_2 under scenarios of RCPs 4.5 and 8.5, respectively, according predicted changes for northern Ontario (https://climateatlas.ca).

As mentioned before, the execution of ZELIG-CFS is managed by AMSIMOD, which requires the definition of projects. AMSIMOD project files have the extension “.pro” and include the name of the model (ZELIG_CFS_Model_v47_modified_eFRI.exe), an input file, such as Brightsand_A_OutputZelig_RCP0.csv and output files, such as Treedbh_Output_1, Basal_Area_Output_1, Density_Output_1, eFRI_Results_1. The project file “Brightsand_A_Zelig_RCP0.pro” is a good example that contains a list of simulations to be performed using several input files for ZELIG-CFS. The names of these output files were chosen to be associated with the types of output. For the examples provided above, the names of the files are associated with tree dbh, basal area, stand density and eFRI results, respectively. These output files are created within a separate folder that is created when a project is defined. This separate folder has the same name as the project name followed by the extension "_results".

2- Conversion of eFRI results into a .dbf file

The next step consists in creating a .dbf file that can be opened by QGIS from the files that contain eFRI results. For Brightsand_A, these files are named "…eFRI_Results_*.txt, * varying from 1 to 20, in the folder Brightsand_A_RCP0_results (simulation results for the RCP0 scenario). This conversion is made using the program "Convert_DBF_Form.exe". All the eFRI result files must be added in the application (Figure B1). The .dbf file "Brightsand_A_RCP0 _YEARS.dbf" created contains the eFRI data computed at different simulated years by ZELIG-CFS. This file can be opened in QGIS only if it is associated with corresponding .shp and .shx files. These can be obtained by making copies of Brightsand_A.shp and Brightsand_B.shx to Brightsand_A_RCP0_YEARS.shp and Brightsand_A_RCP0_YEARS.shx. The newly created .dbf file Brightsand_A_RCP0_YEARS. dbf can be imported in QGIS from the original project Brightsand_A.qgs by using the sub-menu "Add vector layer" in the menu "Layer". The file Brightsand_A_RCP0_YEARS.dbf becomes visible in the Layers panel of QGIS (Figure B2).

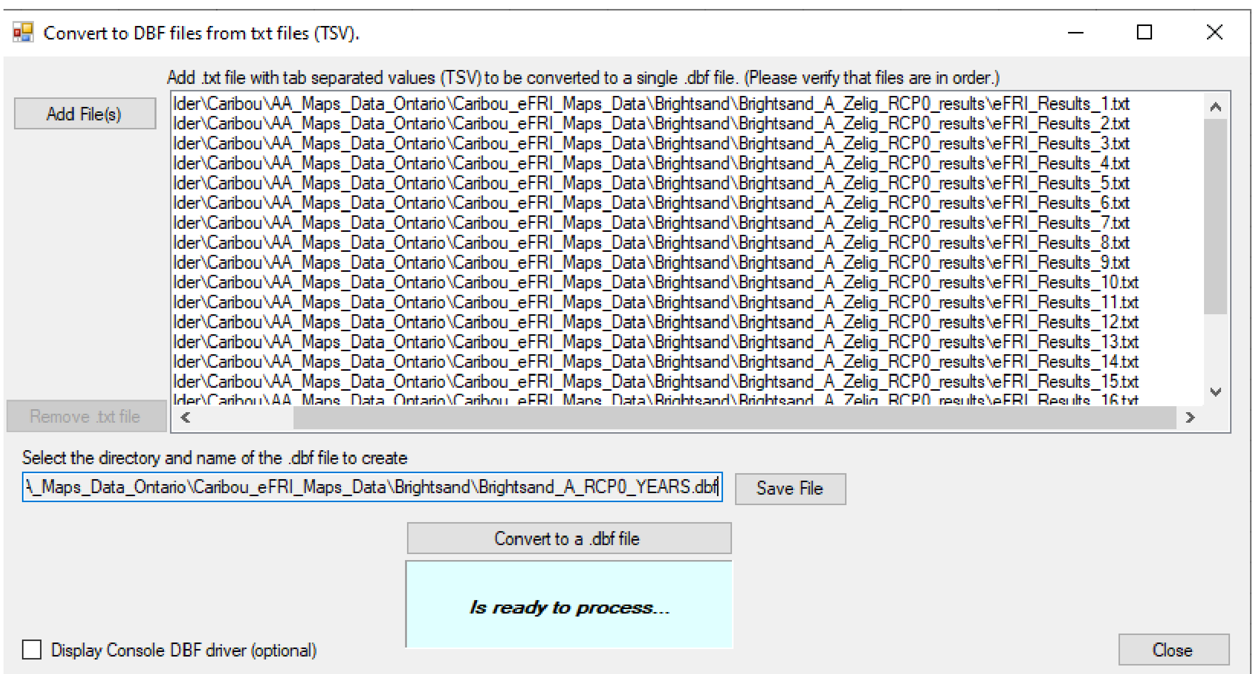

Figure B1: Example illustrating the use of the program "Convert_DBF_Form.exe" to convert the eFRI results simulated by ZELIG-CFS into a .dbf file that can be opened by QGIS.

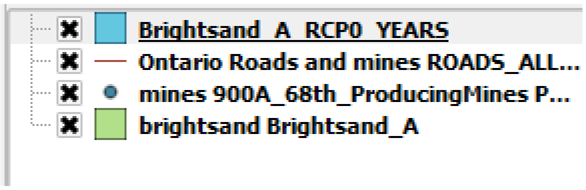

Figure B2: The .dbf file Brightsand_A_RCP0_YEARS.dbf was imported in QGIS.

3- Computation of habitat suitability indices

Habitat suitability indices for Brigthsand_A were computed using the HSM plugin in QGIS (See "HSM" button on QGIS and Figure B3). When the HSM plugin is called, the eFRI, road and mines layers must be entered in the edit fields Input eFri Layer, Input road Layer and Input mine layer, respectively, along with the name of the output file. For Brightsand_A, the output file is "Brightsand_A_RCP0_HSMmeans.csv" and contains for each simulated year the numbers and percentages of cells with HSM values in the intervals mentioned in section 3 above. It is also possible to create a file containing the HSM values for each cell by selecting the option "Output HSM Data for each cell?".

The computation of HSM indices creates new layers that allow the visualization of HSM indices within the sub-range (Figure B4). Each new layer contains HSM values computed for each simulated year. When a layer is selected, it is possible to visualize on the map the HSM values computed for the selected simulated year (Figure B5). For Brightsand_A, five layers were created for the simulated years 10, 20, 30, 40 and 50. The new maps can't be saved completely in a QGIS project, but can be exported as images.

4- Computation of the relative effect of disturbance on recruitment

As mentioned above, the file *Brightsand_A_RCP0_HSMmeans.csv* contains the percentages of cells in different HSM intervals. These results are used to compute the relative effect of disturbance on recruitment by using the program "Compute_Disturbance_Recruitment.exe" (Figure B6). For Brightsand_A, the output file is "Brightsand_A_RCP0_HSM_Recruit.txt", which will be used to take into account the relative effect of disturbance on caribou population dynamics.

5- Execution of CARIBOUMOD

Running CARIBOUMOD requires an AMSIMOD project file and an initialisation file. For Brightsand_A, the project file, "Brightsand_A_Caribou.pro", contains the initialization file "Brightsand_A_RCP_Input_Caribou.txt" and the file "Brightsand_A_RCP0_HSM_Recruit.txt", which contains the relative effects of disturbance on recruitment rate at different simulated years (Figure B7). The output file, "Brightsand_A_MonteCarlo_RCP0.txt", is created within the folder "Brightsand_A_Caribou_Results". This result file contains predicted variables for selected simulated years and can be opened using Excel. The results can also be visualized using graphic utilities in AMSIMOD (see AMSIMOD user guide).

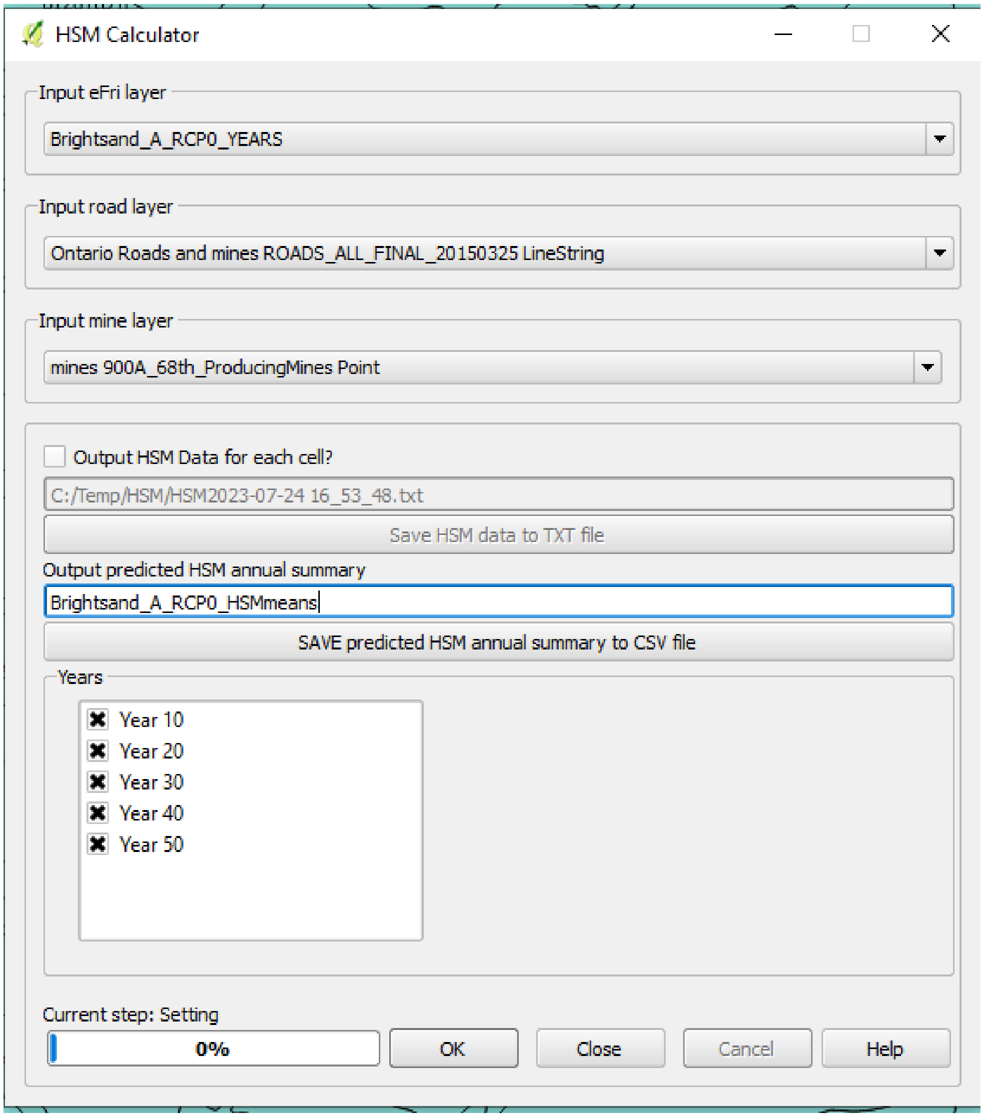

Figure B3: Main window of the plugin HSM to compute HSM indices for a specific caribou sub-range.

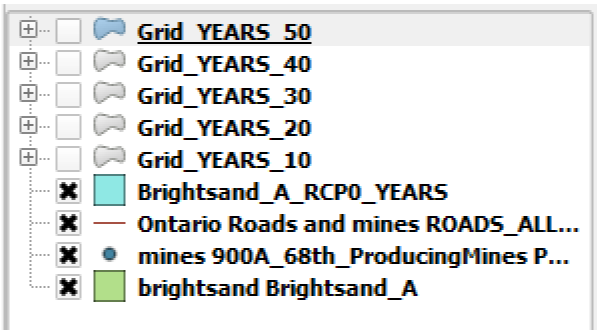

Figure B4: New layers created in the QGIS project Brightsand_A.qgis following the computation of HSM indices.

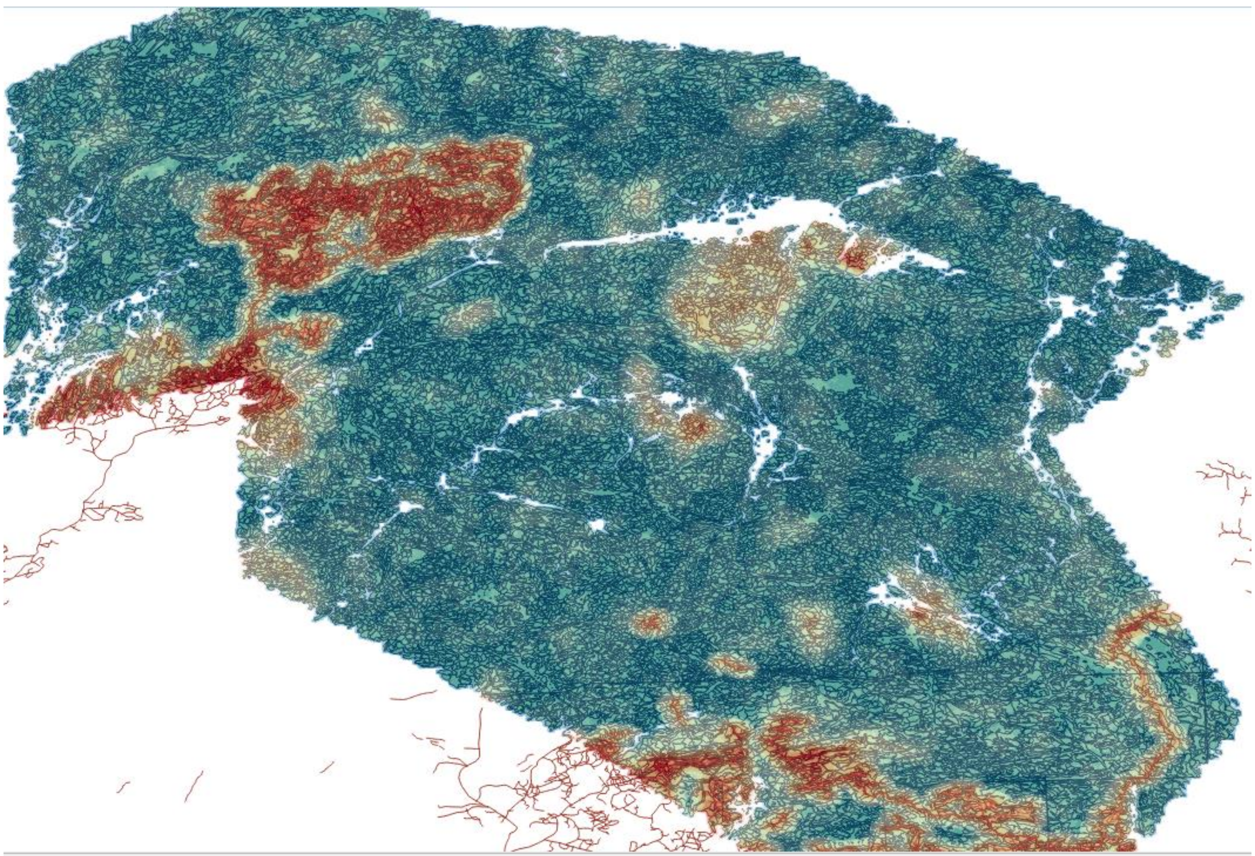

Figure B5: Map showing the HSM indices for Brightsand_A computed for simulated year 30.

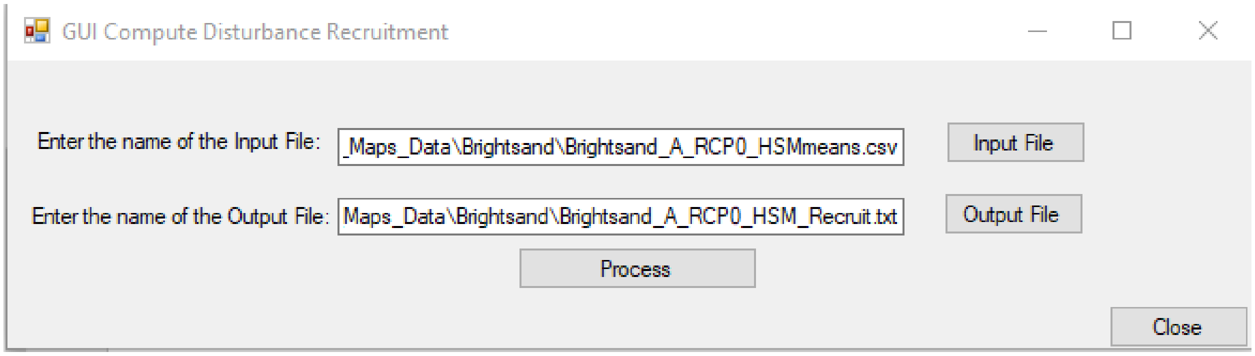

Figure B6: Main window of the application "Compute_Disturbance_Recruitment.exe" to compute the relative effect of computed HSM indices on recruitment rate.

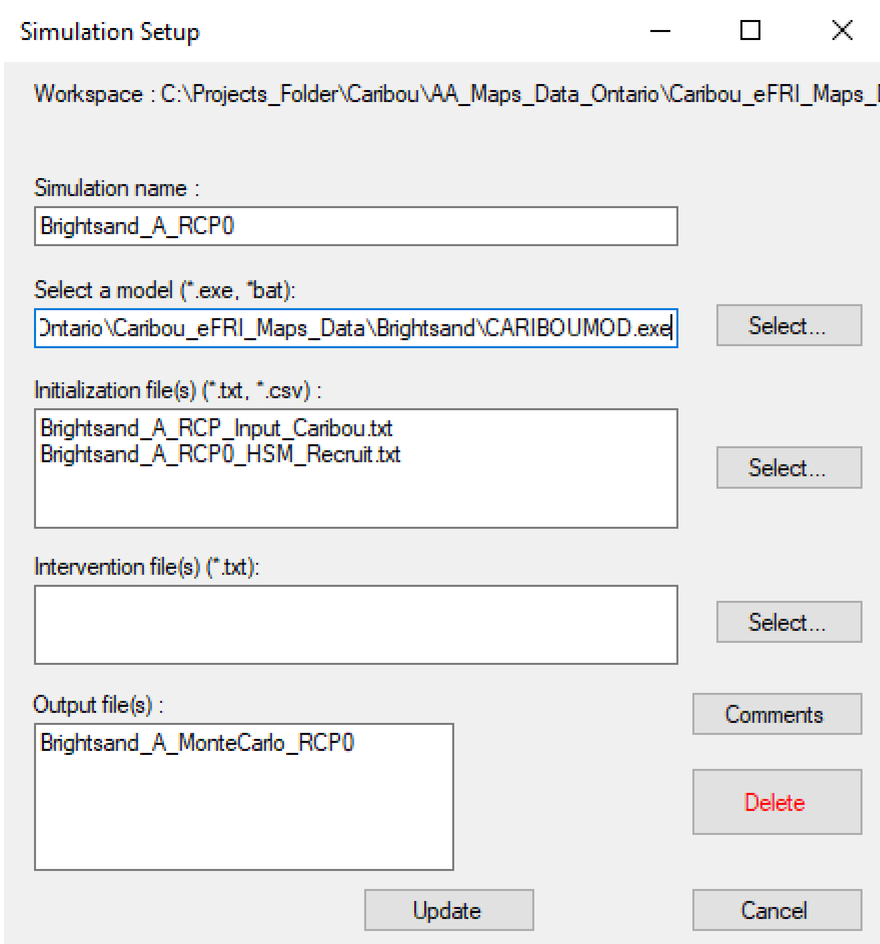

Figure B7: Simulation setup for simulating caribou population dynamics in Brightsand_A under scenario RCP0.