

# **WORMSPREAD: an individual-based model of invasive earthworm population dynamics. User Manual**

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## **Introduction**

This software is meant to simulate the spread of invasive earthworms over a specified geographic region. The software can be found [here](#).

## **Installation**

NetLogo (version 5.3.1 or later) is required to run this software. The latest version of NetLogo can be acquired [here](#). Once NetLogo is installed, the simulation program can be started.

Tip: We recommend looking at NetLogo's own [user manual](#) to get familiar with the general interface. Click on 'Interface Guide' on the left panel in the online manual. We will provide additional information about program specific controls later in this document.

## **Starting the Program**

Double-click the **"WORMSPREAD.nlogo"** file, present in the main **"WORMSPREAD"** folder, to start the program. This will start NetLogo. You will be greeted with the Interface tab.

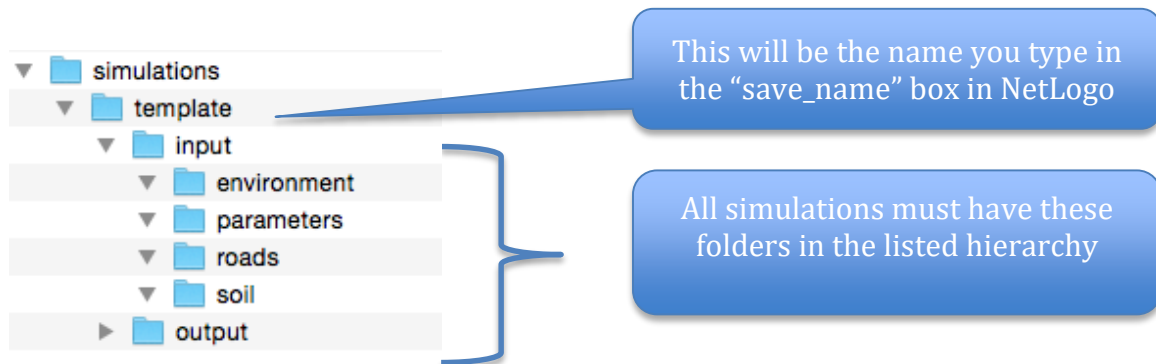
Alternatively, after starting NetLogo, go to **File > Open** in the menu bar and open the **"WORMSPREAD.nlogo"** file.

## Setting up Folders

The software requires a specific folder hierarchy in order to save or load data or import GIS. All simulations can be found inside the “simulations” folder. Each simulation directory will have a main folder, the name of which must be identical to the name the user chooses in the “save\_name” box in NetLogo. Sample simulation folders are provided with the program.

Note: We will be referring to this folder as *save\_name*, but you should replace this name with the folder name you have chosen for the simulation.

One of them is shown below:



Supplemental Fig. 1 template folder hierarchy

The sample simulation folders may be used for testing purposes and as templates for future simulations. To use the sample folders as templates for your own simulations, duplicate the template folder by right-clicking on the template folder and selecting “**Duplicate**”. Rename the top folder, “**template,**” with your desired simulation name. All the sub-folders of your simulation should have the same names as the sub-folders of the template (shown above). You will input data for your simulation into these folders, as described on the next page.

## Setting up Input Data

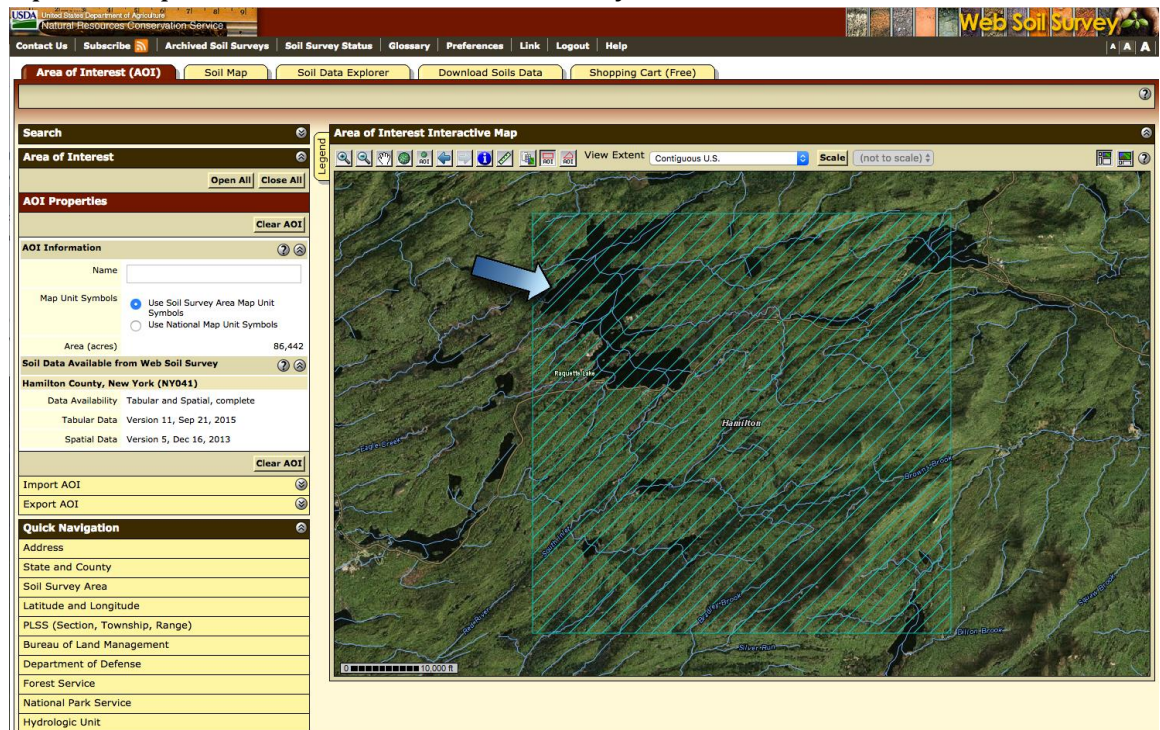
The following instructions will describe how to download the necessary data and store it properly so that the simulation can successfully access the data. Please read all directions before beginning to download GIS data.

Sample data for the Raquette Lake region is provided with the package. If you would like to reuse some of the data from a simulation, you can copy and paste those folders into the new save folder, then repeat the download process for the new information.

### Soil

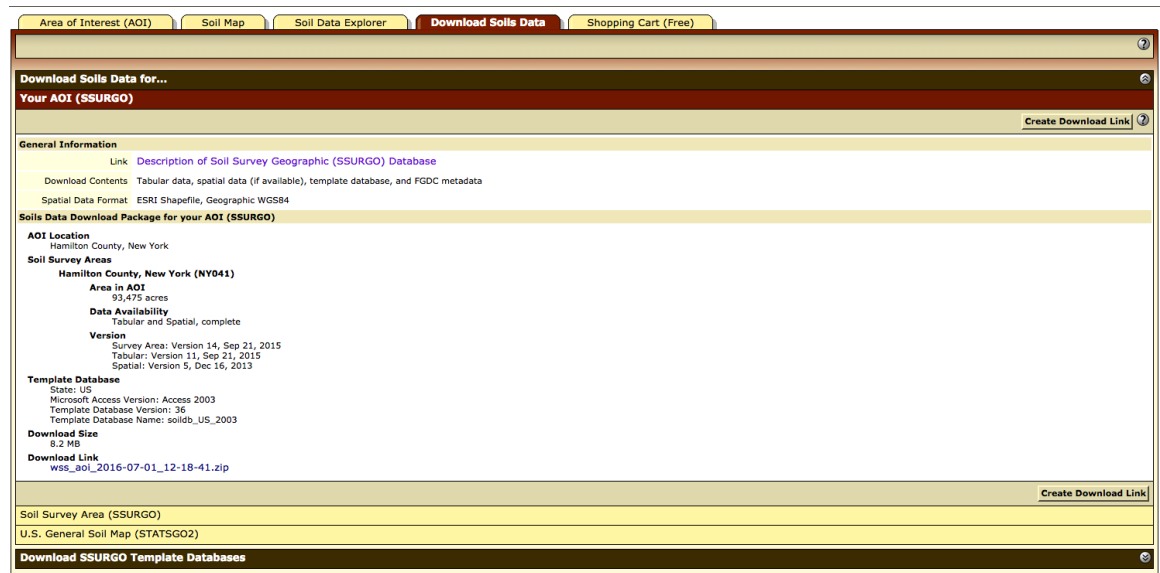
To download geo-referenced data about soil from the Web Soil Survey, you will first download the geo-referenced key values of your unique area of interest (AOI). Next, you will compile a key that associates the geo-referenced key with values of soil pH, soil depth and moisture. We recommend that you both download the data and compile your key in the same session.

1. Begin by opening the USDA Web Soil Survey (<http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>)
2. After zooming to the area you would like to study, select an Area of Interest with the AOI tool on the Interactive Map panel. The AOI should be roughly square-shaped. Note that the Web Soil Survey limits the size of AOIs.

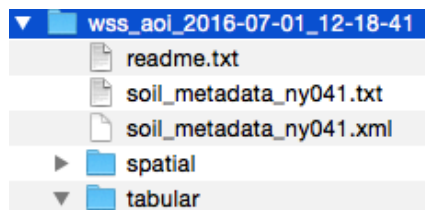


Supplemental Fig. 2 Shows what the Web Soil Survey interface should look like when you have selected an AOI

3. Once you have selected your AOI, go to the “Download Soils Data” tab and click “Create Download Link”. Once your download link has been created, download it by clicking the link.



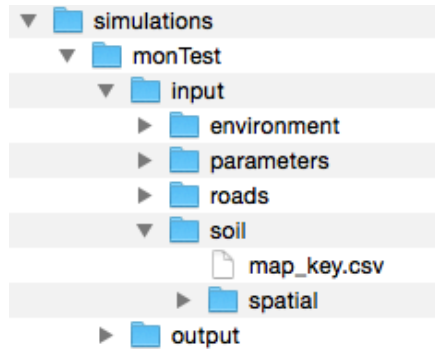
Supplemental Fig. 3 Shows what the interface will look like on the “Download Soils Data tab”



Supplemental Fig. 4 Shows the folder hierarchy of the folder containing the GIS data

The download link will create a zipped folder, which you can extract using the built-in program on your machine. (For more information on unzipping files and folders, please click [here](#).) Once the downloaded folder has been unzipped, open it and copy the “**spatial**” folder into the *WormSpread* simulation folder **simulations/save\_name/input/soil/**.

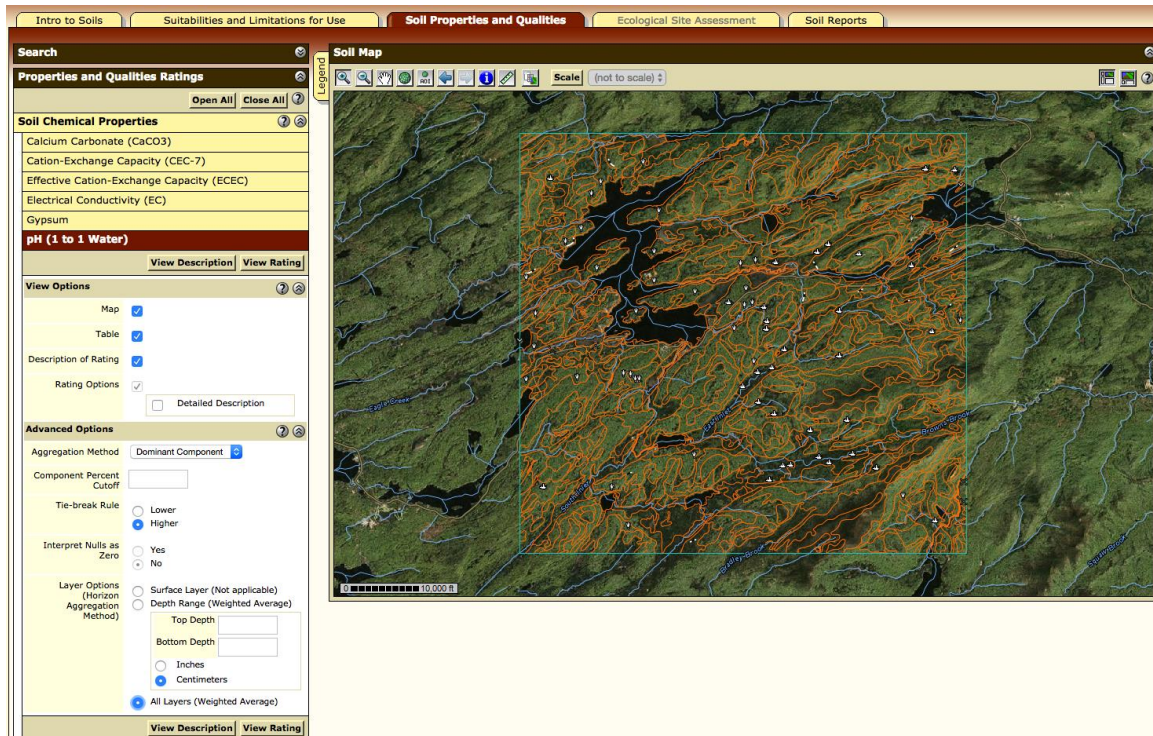
Note: When you are using a particular *save\_name* for the first time, you must create the folder with that name. If you have used a *save\_name* before, you should delete its contents before saving new data to it.



Supplemental Fig. 5 shows the folder hierarchy of the simulation with the GIS data properly added

4. Next, you must create the map key. Go to the “**Soil Properties and Qualities**” tab. When you select a trait and press “**View Rating**”, a table with the values of that trait will appear, as well as a key to the symbols on the map. In Microsoft Excel or another text editor, make a new file titled “**map\_key.csv**”. (Refer to Figures G and H for examples of the .csv and AOI interface.)
  - a. The first column of the .csv file should be the map unit symbol. It is important that this is typed just as it is in the table where it is given (the map unit symbols are case sensitive).
  - b. The second column should have the map unit name, e.g. Buckston-Wonsqueak complex.
  - c. The third, fourth, and fifth columns should contain the “Rating” for each the following traits, respectively:
    - i. Soil Chemical Properties -> pH
    - ii. Soil Qualities and Features -> Depth to Any Soil Restrictive Layer
    - iii. Soil Physical Properties -> Water Content, 15 bar
  - d. Save the .csv file in the folder **simulations/save\_name/input/soil**.





Supplemental Fig. 6 Shows what the interface looks like when a specific trait has been chosen (in this case, pH)

Tables — pH (1 to 1 Water) — Summary By Map Unit				
Summary by Map Unit — Hamilton County, New York (NY041)				
Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
24A	Bucksport-Wonsqueak complex	5.4	1,028.5	1.1%
25A	Wonsqueak-Colton-Rumney complex, 0 to 15 percent slopes	5.3	995.3	1.1%
26A	Wonsqueak-Rumney-Bucksport complex	5.3	4,100.1	4.4%
363A	Adams loamy sand, 0 to 3 percent slopes	5.3	39.7	0.0%
363B	Adams loamy sand, 3 to 15 percent slopes	5.3	227.1	0.2%
365A	Naumburg-Croghan complex	4.9	394.7	0.4%
367A	Searsport-Borosapristis-Naumburg complex	6.3	136.4	0.1%
375A	Colton-Adams complex, nearly level	5.5	1,348.8	1.4%
375C	Colton-Adams complex, rolling	5.5	283.8	0.3%
375D	Colton-Adams complex, hilly	5.5	265.4	0.3%
650C	Monadnock-Adams-Colton complex, rolling, bouldery	5.3	2,850.6	3.0%
651C	Monadnock-Tunbridge-Sabattis complex, rolling, very bouldery	5.3	511.4	0.5%
651D	Monadnock-Tunbridge complex, hilly, very bouldery	5.3	183.1	0.2%
653C	Monadnock fine sandy loam, 3 to 15 percent slopes, very bouldery	5.3	1,097.5	1.2%
653D	Monadnock fine sandy loam, 15 to 35 percent slopes, very bouldery	5.3	14.0	0.0%
654C	Monadnock-Sabattis complex, rolling, very bouldery	5.3	1,878.2	2.0%
707C	Adirondack-Becket-Hermon complex, rolling, very bouldery	5.2	590.0	0.6%
708B	Adirondack-Sabattis-Tughill complex, 0 to 8 percent slopes, very bouldery	5.2	1,764.0	1.9%
721C	Becket-Tunbridge-Skerry complex, 3 to 15 percent slopes, rocky, very bouldery	5.0	6,332.8	6.8%
721D	Becket-Tunbridge complex, 15 to 35 percent slopes, rocky, very bouldery	5.0	6,387.1	6.8%
721F	Becket-Tunbridge complex, 35 to 60 percent slopes, rocky, very bouldery	5.0	286.9	0.3%
723C	Becket fine sandy loam, 3 to 15 percent slopes, very bouldery	5.0	3,118.3	3.3%
723D	Becket fine sandy loam, 15 to 35 percent slopes, very bouldery	5.0	988.9	1.1%
725B	Skerry-Becket complex, 3 to 15 percent slopes, very bouldery	5.2	4,278.2	4.6%
727B	Skerry-Adirondack complex, 0 to 8 percent slopes, very bouldery	5.4	5,709.9	6.1%
831C	Tunbridge-Lyman complex, 3 to 15 percent slopes, very rocky	4.9	1,520.8	1.6%
831D	Tunbridge-Lyman complex, 15 to 35 percent slopes, very rocky	4.9	3,907.7	4.2%
831F	Tunbridge-Lyman complex, 35 to 60 percent slopes, very rocky	4.9	2,458.1	2.6%
833C	Tunbridge-Adirondack-Lyman complex, rolling, very bouldery	4.9	3,107.9	3.3%
835C	Tunbridge-Borosapristis-Ricker complex, rolling, very rocky	4.9	648.9	0.7%
861C	Lyman-Ricker complex, 3 to 15 percent slopes, very rocky	5.1	72.7	0.1%
861D	Lyman-Ricker complex, 15 to 35 percent slopes, very rocky	5.1	94.2	0.1%
861F	Lyman-Ricker complex, 35 to 60 percent slopes, very rocky	5.1	758.2	0.8%

Supplemental Fig. 7 Shows the table output by the Web Soil Survey. The entries in the “Rating” column contain the measurement of the trait that was selected in step 4c

	A	B	C	D	E
1	Map Unit Symbol	Map Unit Name	pH	Soil depth	Moisture, 15 bar
2	24A	Bucksport-Wonsqueak	5.3	200	30
3	25A	Wonsqueak-Colton-Rumney	4.6	200	21.4
4	26A	Wonsqueak-Rumney	4.6	200	21.4
5	363B	Adams loamy sand, 3	5	200	2.5
6	365A	Naumburg-Croghan co	4.7	200	3.5
7	367A	Searsport-Borosaprist	5.7	200	5
8	375A	Colton-Adams comple	5.2	200	1.5
9	375C	Colton-Adams comple	5.2	200	1.5
10	375D	Colton-Adams comple	5.2	200	1.5
11	650C	Monadnock-Adams-C	4.9	200	3.9
12	653C	Monadnock fine sand	4.9	200	3.9
13	654C	Monadnock-Sabattis c	4.9	200	3.9
14	707C	Adirondack-Becket-He	4.7	66	5.8
15	708B	Adirondack-Sabattis-T	4.7	66	5.8
16	721C	Becket-Tunbridge-Ske	4.5	84	4.3
17	721D	Becket-Tunbridge con	4.5	84	4.3
18	721F	Becket-Tunbridge con	4.5	84	4.3
19	723C	Becket fine sandy loam	4.5	84	4.3
20	723D	Becket fine sandy loam	4.5	84	4.3
21	725B	Skerry-Becket comple	4.7	86	4.7
22	727B	Skerry-Adirondack co	5	74	5.7
23	831C	Tunbridge-Lyman com	4.7	64	11.9

Supplemental Fig. 8 Example **map\_key.csv** file

## Temperature

The *WormSpread* simulations require mean daily temperature data. For our sample simulations, we obtained historical temperature data from the PRISM Climate Group for the past 30 years. If you would like to change the temperature on certain days for the simulations, please follow the following instructions:

1. Open the PRISM climate group's data explorer (<http://prism.nacse.org/explorer/>)
2. Find the area for which you want data, and click on a grid within the selected area.
3. Adjust the settings in the window to match the settings in Figure I within your chosen region. The start date should always be January 1, but the end date and the years chosen may vary, depending on the length of time you wish to simulate.
4. After you have chosen the correct settings, click **"Retrieve Time Series"**, followed by **"Download Time Series"**.
5. Save the data as **"temperaturelist.csv"** in the folder **simulations/save\_name/input/environment/**



Location

☒ State & County:
 New York
 Hamilton

☐ Coordinates:
 Latitude: 43.7902
 Longitude: -74.5917
 Elevation: 658m (2159ft)

Data Settings

☐ 30-year normals, 1981-2010  
(monthly and annual)
 Resolution:
 ☒ 4km
 ☐ 800m

☐ Annual values
 start: 2005
 end: 2014

☐ Single month values
 start: 2007
 end: 2016
 June

☐ Monthly values
 start: July
 end: June
 2007
 2016

☒ Daily values
 start: 1
 end: 4
 January
 July
 1986
 2016

Data Stability: **early (certain to change)**

Units:
 ☐ English
 ☒ SI (metric)

☐ Interpolate grid cell values (see text)

Climate Variable

☐ Precipitation
 ☐ Mean dewpoint temp

☐ Minimum temp
 ☐ Minimum VPD

☒ Mean temp
 ☐ Maximum VPD

☐ Maximum temp
 ☐ Maximum VPD

Controls

Retrieve Time Series

Download Time Series

Restore Previous Settings

Once settings are complete, retrieve the results

Click to select. Click & drag to pan. Use mouse wheel to zoom.

Supplemental Fig. 9 The PRISM data explorer user interface

## Highways

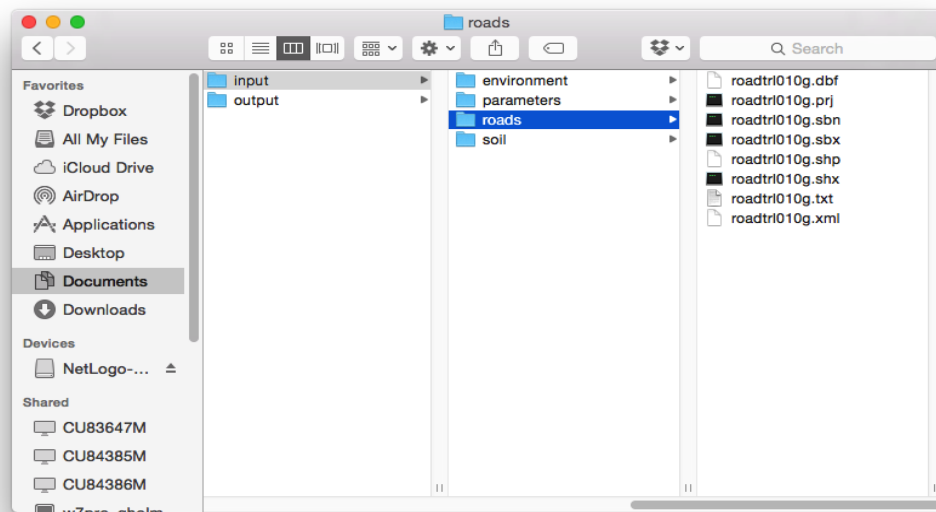
*WormSpread* is capable of incorporating major US roads using GIS data. If you would like to model an area extending outside of the United States, you will need to find another dataset, but the compatibility of non-U.S. datasets with our program is not guaranteed.

1. Click [here](#) to access national map data.
2. Download the shapefile for the “Roads, One-Million Scale” data (roadtrl010g.shp.tar.gz).

Roads, One Million-Scale	April 2014	March 2014	Shapefile : roadtrl010g.shp.tar.gz	35.8 / 114.2
			Geodatabase : roadtrl010g.gdb.tar.gz	27.7 / 47.4

3. After downloading, extract the contents of the file and copy them to **simulations/save\_name/input/roads/** as shown below. (For more information on extracting the contents of files and folders, please click [here](#).)

4. If you have copies of the files already saved for other simulations, they can be copy and pasted into the proper file path of a new *save\_name*



Supplemental Fig. 10 Sample **roads** folder

## Setting up a Simulation

Once all the files are in the correct folders, you can start a simulation from NetLogo. The following steps will guide you through running a simulation. We will use "testSim" as the name for our example simulation, but you may choose a different name for your simulation.

1. Click "Initialize".
2. Click "Load GIS".

Note: This may take a few minutes, depending on your machine.

3. Enter the command *initialize\_monitors* into the Command Center at the bottom of the screen.

Note: This step will add preset monitors to the simulation. You may choose to skip this step and add your own monitors and save their names. For more information, look at the **Monitors** section of the environment controls.

4. Click "Save Environment". This will save the environment for faster loading in the future.
5. Under *Species Control*, click on the *species\_number* drop-down menu and select "1".
6. Slide the *worm\_population* slider to 25
7. *ph\_tolerance*, *temperature\_tolerance*, *species\_genetic\_diversity*, and *insertion\_frequency* should all be set to 0.
8. Set *speed* to 0.5.

Note: Ideally, this speed should be calculated according to the dimensions of the region you are simulating.

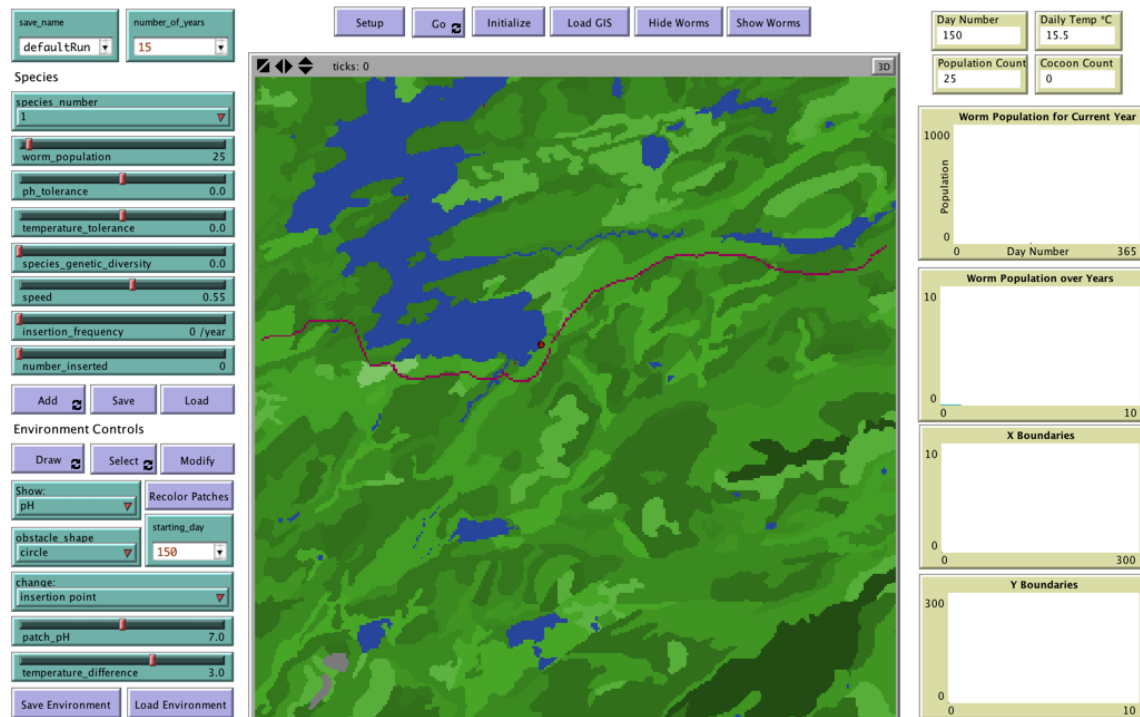
9. Click "Add".
10. Click on any point on the map.

Note: This will add the worms onto a single point on the map. Alternatively, you could select a region and add them randomly. For more information, see the **Environmental** section.

11. Click *Save* under *Species Control*.

12. Enter “10” into *number\_of\_years* text box.

13. Click “Go”.



Supplemental Fig. 11 The interface will look like this when a simulation has been set up correctly

You should see the simulation start and run for 10 years. Once it finishes, it will store all the data collected into the “output” folder in your simulation directory.

Tip: In the future, if you want to load the same simulation environment and agents, you only need to click “Setup Simulation”.

## Running Multiple Simulations

*BehaviorSpace* is a tool for running multiple automatic simulations.

1. Delete everything from the output folder in your simulation directory.
2. Click “Tools” in the **Menu** bar.
3. Select “BehaviorSpace”.
4. Click “New”.
5. Type in “test” as the experiment name.
6. Delete everything in the text box holding all the variables.

7. Type the bracketed text instead (do not copy/paste): [`"ph_tolerance" 0 0.1`]

Note: This will run two simulations, one with *ph\_tolerance* set to 0 and the other with *ph\_tolerance* set to 0.1.

8. Set *Repetitions* to "3".
9. Delete all commands in *Setup Commands*, and instead type `"setup_bs"`.
10. Click "OK".
11. Select *test* from the *BehaviorSpace* menu and click "Run".
12. Make sure *Spreadsheet output* and *Table output* values are unchecked.
13. Click "OK"

Note: Any value not changed in *BehaviorSpace* will be used from the program's Interface screen.

The simulations will begin to run. You can increase the slider from *normal speed* to the right to make the simulations run faster. After the simulations are done, the results can be plotted following the instructions on the next page.

## Plotting Results

You will first need to open the folder where the *WormSpread* program is saved.

1. Open **simParams.txt**.
2. Delete all text.
3. Enter a line with the following format:

`<save_name> <repetitions> <BehaviorSpace argument>`

Ex: `testSim 3 ["ph_tolerance" 0 0.1]`

Note: This line can be copied from the "Vary variables" argument in *BehaviorSpace*. The format for plotting parameters will always be the same.

4. Save the file and exit.
5. Double click *plot.command* in the main folder.

The command will plot a bar chart showing earthworm densities across five regions for the two different pH tolerance levels

Tip: You can use the directions above to plot images for temperature tolerance, genetic diversity and number of random insertions.

## Comparing Simulations

If you would like to compare the results of simulations in different environments (including obstacles such as roads), you will need to run at least two different simulations. This will require a different format for *BehaviorSpace* arguments. The steps below outline a simulation testing the impact of future road construction on the spread of worms over a region.

1. Create a simulation directory named “defaultRun” and fill it with the GIS data and parameter tables required for a normal simulation

Tip: It is recommended to keep a ‘default’ directory at all times for control purposes and as a backup folder.

2. Create a copy of the default simulation directory and name the new one “roadTest” (we will edit this to create a map with more roads)
3. Start the program and type “roadTest” in the *save\_name* box
4. Click “Initialize”, “Load GIS”, and then “Save Environment”.
5. On the top (next to the speed slider) change updates from *on ticks* to *continuous*.
6. Click on the *change* dropdown menu and select *highway*.
7. Under *Environmental Controls* click “Draw” to begin drawing.
8. Using your mouse, draw roads on the map.

Note: Draw slowly; otherwise, you will see gaps in the road.

Tip: If at any point you need to reset the map, click on “Load Environment”.

9. Click “Draw” again to stop drawing.
10. Click “Save Environment”.
11. From *Species Controls*, add earthworms and click “Save”.
12. Type in “defaultRun” in the *save\_name* box.
13. Click “Initialize”, “Load GIS”, and then “Save Environment”.
14. Add earthworms and click “Save”.



Tip: Adding earthworms in the same place as in roadTest will allow for a better comparison (you can assure that earthworms are being placed in the correct spot by using the “insert\_earthworms” function).

15. Open *BehaviorSpace*.
16. Create a new experiment.
17. In the “Vary variables...” text box, enter the bracketed text: [“save\_name”  
“roadTest” “defaultRun”]

Note: The format is [“save\_name” <first sim> <second sim> ... ]

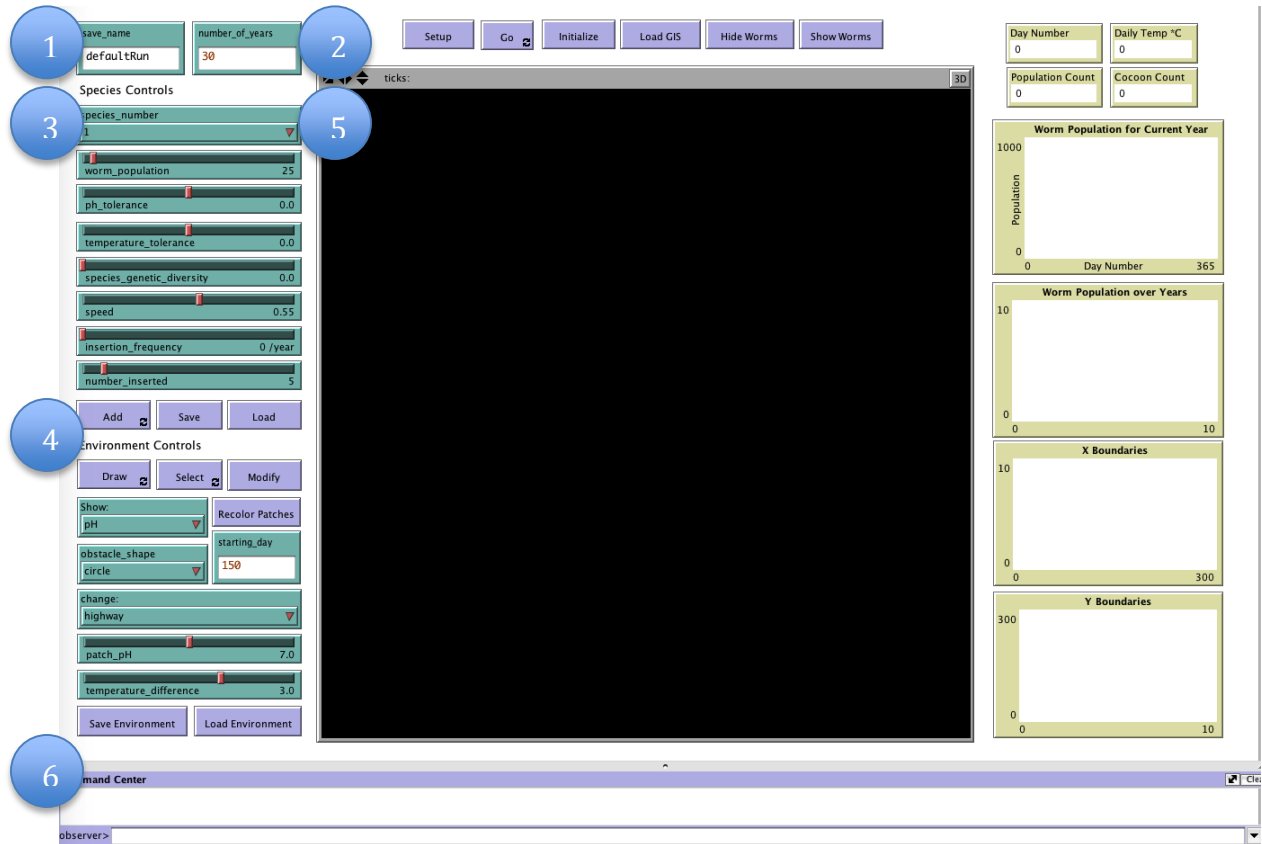
Setting “save\_name” as the first argument allows the user to run different simulations from their respective directories. This experiment will run roadTest first and then defaultRun using the values saved for these simulations.

18. Make sure the Setup Command is *setup\_bs* and click “OK”.
19. Run the simulation and plot the results as previously described.

# Interface Guide

## Program Controls

This section of the guide will look at controls specific to the program



Supplemental Fig. 12 Graphic user interface of WormSpread

### 1. Simulation Parameters:

- save\_name*: The name of the simulation. This will tell WormSpread which files to use when saving/loading agents and the environment.
- number\_of\_years*: The number of years that the simulation will run.

### 2. Simulation Controls:

- Setup Simulation*: Initializes global parameters and loads all data from files associated with *save\_name*.

- b. *Go*: Runs the simulation. If the button is black, the simulation is running. Pressing the button a second time will stop the simulation.
- c. *Initialize*: Initializes default parameters and loads weather data and mortality functions. Use this button when initially setting up a simulation from GIS data. In order for this function to work properly, the “**parameters**” folder must include **pH-table.csv**, **temp-table.csv**, and **temperaturelist.csv** in the proper format and location (see \_\_\_\_\_ for correct locations).
- d. *Load GIS*: Users can call “Load GIS” after using “Initialize”. As long as GIS data has been set up properly, this button will create a geographically accurate representation of your region in NetLogo.
- e. *Hide Worms*: Makes the earthworms in the simulation invisible to the user. The earthworms will still continue their processes in the background, and the results of the simulation will be unchanged. This feature may be useful if the user wants to see the underlying traits of overpopulated regions in a simulation.
- f. *Show Worms*: Makes earthworms that are hidden visible again.

### 3. Species Controls:

- a. *species\_number*: Refers to which set of traits earthworms added with the “Add” button will have. If the trait sliders are not the same when a second set of earthworms with the same species number are added, they will take the set of traits given to the original earthworms with that species number.
- b. *worm\_population*: The number of earthworms that will be added when a user clicks the “Add” button.
- c. *ph\_tolerance*: Adjusts the earthworms’ mortality due to pH. Increasing this value decreases earthworm mortality due to pH, while decreasing this value increases pH-related mortality. For instance, an earthworm with a pH tolerance of 0.1 will have the same mortality at a pH of 6.6 that a normal earthworm does at 6.7, increasing likelihood

of survival. This feature only applies to the earthworms of the species number being added.

- d. *temperature\_tolerance*: Adjusts the earthworms' mortality due to temperature. Increasing this value decreases earthworm mortality due to temperature, while decreasing this value increases temperature-related mortality. For instance, an earthworm with a temperature tolerance of -1 will have the same mortality at 20°C that a normal earthworm has at 19°C, decreasing the chance of survival. This feature only applies to the earthworms of the species number being added.
- e. *species\_genetic\_diversity*: A measure of parameter randomness within a species. If *species\_genetic\_diversity* is 0, then the traits of a single species are homogeneous. If *species\_genetic\_diversity* is greater than 0, then the parameters of initial earthworms of the species are randomly distributed, with the mean equivalent to the values of the parameters on the sliders, and the standard deviation proportional to the genetic diversity of the species. Subsequent generations of earthworms will inherit the traits of their parents.
- f. *speed*: A measure of how quickly earthworms move in meters per day.
- g. *insertion\_frequency*: Determines the number of times that earthworms are inserted at a random location during the insertion period.
- h. *number\_inserted*: Determines the number of earthworms inserted each time that earthworms are added at a random location during the insertion period.
- i. Add: Adds *worm\_population* number of earthworms at any point in the environment that the user clicks on. The added worms will have the traits of the user-selected species number. If a region has been selected with the region selection tool and then "Add" is clicked, the earthworms will be randomly distributed within this region.
- j. Save: Will save the location and characteristics of all currently living earthworms and cocoons to a file in the *save\_name* folder.

- k. Load: Loads the agents last saved with the current *save\_name*.

#### 4. Environment Controls:

- a. Draw: If “Draw” is selected and “change” is set to “water” or “highway”, then the user can drag their mouse around the NetLogo world to draw either of these features. Tips: Make sure the “view updates” chooser on the top bar of the Interface panel is set to “continuous”. In addition, drawing slowly will improve accuracy.

Note: Make sure to not have “Draw” selected at the same time as “Add” or “Select.”

- b. Recolor Patches: Will change the color of patches in the environment to reflect the attribute chosen in the “Show” box.
- c. Select: When “Select” is on, clicking and dragging on the NetLogo world will create a box around a selected region. Once drawn, users can modify the parameters of this box in a variety of ways.

**pH and/or Temperature:** If the user wants to change the pH and/or temperature within the box, they should adjust the *patch\_ph* and *temperature\_difference* sliders to the desired parameters. Then, select the desired shape from the “obstacle\_shape” box. Choosing “rectangle” will fill the entire selected box with the chosen parameters. “Circle” will fill in a circle with diameter of the shorter side of the box and a center at the center of the box with the parameters in the box. “Mountain” will draw a circle, but instead of uniform parameters, it will create a gradient from the current parameters, on the edges, to parameters on the sliders, in the center.

**Monitors:** Choosing “Monitor” in the “obstacle\_shape” box will draw a new monitor in the selected box; it will not modify any of the other parameters in the box. After choosing the desired settings, press “Modify” to implement them. Once your monitor has been added, you must name it by typing “name\_monitor ”

followed by the monitor name into the observer line of the command center.

Note: After use, deselect the area by clicking on any point in the NetLogo world.

**Insertion Regions:** If “change” is set to “insertion\_points”, the patches contained by the obstacle will be encoded as locations where earthworms can spawn when *insertion\_frequency* is greater than 0. When a random insertion occurs, every individual patch will have an equal chance of having earthworms spawn. For example, a big square will have higher chance of having earthworms spawn at random insertion intervals than a smaller square.

- d. *Show*: Allows the user to decide which attribute to show in the NetLogo world. After changing *Show*, the user will have to press “Recolor Patches” to see the selected attribute.
- e. *starting\_day*: Allows the user to decide what day of the first year to start the simulation on.
- f. *Save Environment*: Saves the characteristics of all patches to a file in the *save\_name* folder.
- g. *Load Environment*: Loads the characteristics of all patches from the most recent save in the *save\_name* folder.

## 5. Visualization

- 6. *Additional Useful Functions*: Using the following commands in the observer line of the command center will enable the user to have more precise control over the environment they are manipulating. To use one of these functions, first type the one-word command in the observer line, followed by the desired parameters, substituted for the words in italics.

- a. *initialize\_monitors*

This command automatically generates population density monitors in the four corners and center of the NetLogo world.

- b. *draw\_monitor x\_low x\_high y\_low y\_high*



Draws a rectangular population density monitor with corners at  $(x\_low, y\_low)$   $(x\_low, y\_high)$   $(x\_high, y\_low)$  and  $(x\_high, y\_high)$ . All coordinates need to be integers because they refer to patch coordinates.

c. `insertion_region  $x\_low$   $x\_high$   $y\_low$   $y\_high$`

Draws a rectangular insertion region with corners at  $(x\_low, y\_low)$ ,  $(x\_low, y\_high)$ ,  $(x\_high, y\_low)$ , and  $(x\_high, y\_high)$ . All coordinates must be integers.

d. `insert_worms  $x$   $y$   $number$   $species\_number$`

Inserts *number* earthworms at location  $(x, y)$  with the attributes of the species with *species\_number*.

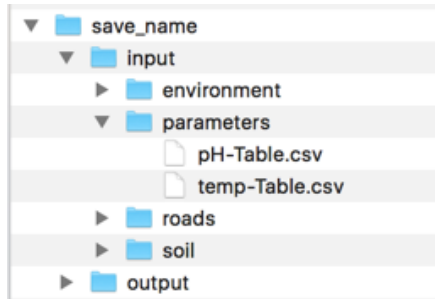
e. `name_monitor  $monitor\_name$`

Names monitors, one at a time with the name *monitor\_name*, in the order that they were placed. The user can place multiple monitors before naming them, but all monitors that have been placed must be named before running a simulation.

## Updating pH- and temperature-dependent functions

In order to update functions based on pH and temperature, users of WORMSPREAD will have to change the values of the functions in excel files.

1. Find the pH- and temperature-dependent functions, located in the “input -> parameters” folders within each simulation. The files are called “pH-Table.csv” and “temp-Table.csv” respectively.



Supplemental Fig. 13 file-path to the .csv's containing pH- and temperature-dependent functions

2. Open the appropriate file for the function you wish to change.
3. Then, in the row with the attribute (e.g. Survival Probability) you are trying to change, edit the value for the attribute in the same row as the pH/temperature value for which you would like to change it.
4. If you have an explicit function for any of the traits, you can use the formula builder in excel to implement the function in the proper rows.

1	Temperature C	Survival Probability	Cocoon Hatching Probability
496	19.5	1	0.9951
497	19.6	1	0.99508
498	19.7	1	0.99506
499	19.8	1	0.99504
500	19.9	1	0.99502
501	20	1	0.995
502	20.1	0.983	0.99488
503	20.2	0.966	0.99476
504	20.3	0.949	0.99464
505	20.4	0.932	0.99452
506	20.5	0.915	0.9944
507	20.6	0.898	0.99428
508	20.7	0.881	0.99416
509	20.8	0.864	0.99404
510	20.9	0.847	0.99392
511	21	0.83	0.9938
512	21.1	0.813	0.99368
513	21.2	0.796	0.99356
514	21.3	0.779	0.99344
515	21.4	0.762	0.99332
516	21.5	0.745	0.9932
517	21.6	0.728	0.99308
518	21.7	0.711	0.99296
519	21.8	0.694	0.99284
520	21.9	0.677	0.99272
521	22	0.66	0.9926
522	22.1	0.643	0.99248
523	22.2	0.626	0.99236
524	22.3	0.609	0.99224
525	22.4	0.592	0.99212

Supplemental Fig. 14 This is what the temp-Table.csv file looks like. Cells in the “Survival Probability” and “Cocoon Hatching Probability” columns can be edited to affect those values for the corresponding temperature in the WORMSPREAD simulation