WeedSearch

Weed Eradication Feasibility Analysis

Software Manual

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WeedSearch

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Background

This model combines population dynamics and search theory to calculate the probability that a weed invasion will be eradicated based on the amount of time invested in searching for it (search effort). The model is based on the paper of Cacho et al. (2006). The original paper was written based on a model programmed in the Matlab language. This version is programmed in Excel®.

This is work in progress. It is envisaged that the software will continue to evolve as it is tested by experts and feedback is received.

The original concept for this software was developed by Paul Pheloung (from the Australian Department of Agriculture Fisheries and Forestry) in connection with a project on the Galapagos Islands. The software evolved through the incorporation of search theory and matrix population models. The model is built around the concept of impedance factors (factors that impede eradication) explained by Panetta and Timmins (2004). Impedance factors fall into one of four categories:

- Logistic considerations
- Detectability
- Biological characteristics
- Management effectiveness

To this list we have added a set of economic factors based on the costs of search and control. The model is designed to be easy to use. It requires a small number of parameters. The values for some of these parameters may not be easy to find, but experienced weed managers may be able to come up with educated guesses and then undertake sensitivity analysis.

The structure of WeedSearch is presented in Figure 1. Essentially, WeedSearch has three components (or sub-models), illustrated by yellow boxes in Figure 1. These sub-models run in the background so the user does not need to be concerned about details. The inputs required are represented by blue ovals. Search parameters include the speed of search, the search effort (time per ha) and other factors explained later. Demographic parameters include germination, fecundity and juvenile survival etc. These parameters are entered by the user through a set of pages as explained in the following section. The control-feedback is shown as a dashed line to indicate that this is not an automatic feature of the model, but rather is a process that would be followed by a user who runs the model repeatedly to identify efficient control strategies.

The benefit side of eradicating the invasion (the oval on invasion costs shaded in gray) is a desirable feature of the model, but it is not included in the current version. There are obvious difficulties in valuing the environmental services affected by weeds and at this stage it remains a subjective aspect of the decision. A resource manager contemplating whether to attempt an eradication will look at the costs estimated by the model and assess (subjectively) whether these are likely to exceed the benefits. The manager may also look at the budget available and decide whether the eradication program is a realistic proposition.

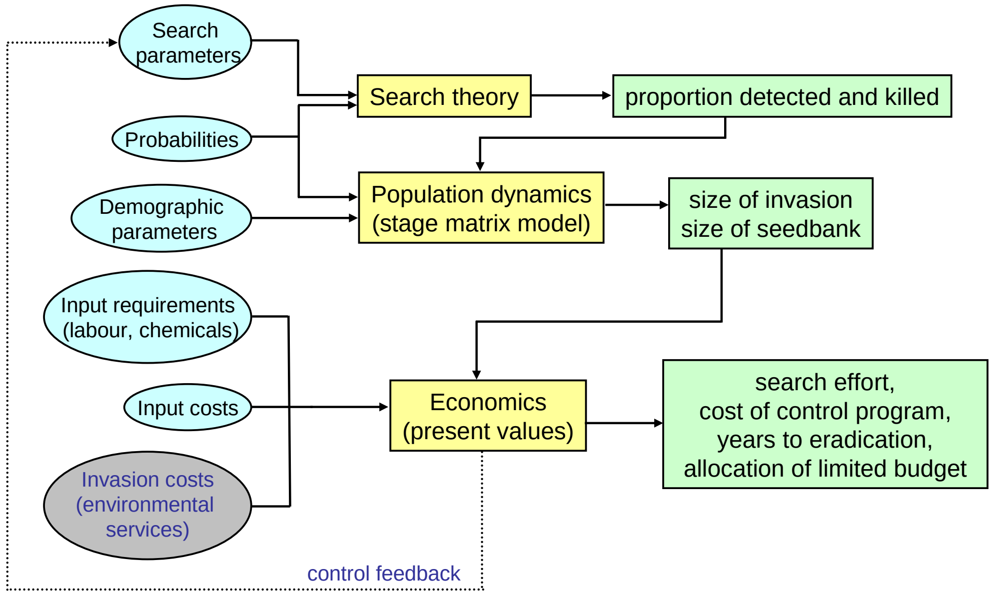


Figure 1. Structure of WeedSearch

Using the Model

The model requires Microsoft Excel to be installed on the computer. If Excel has high or medium security level enabled the model will not run. You must enable macros to use the model. From the Excel menu select Tools / Options, then select the Security tab and press the Macro Security button, then select the Low Security setting. You may need to exit Excel and restart it for these changes to take effect.

When the model is opened an information box will appear. Please read the disclaimer carefully and then click OK. The main screen of the model is shown in Figure 2.

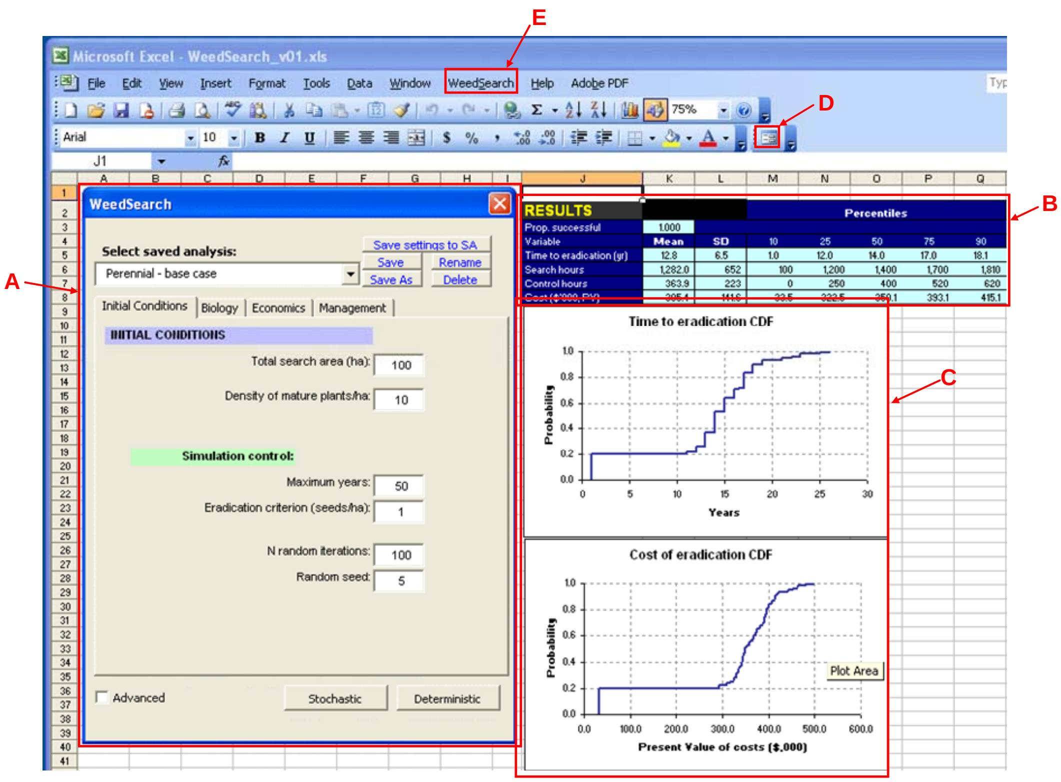


Figure 2. The main screen

(A) User Form. This is the main vehicle for interacting with the model. Here you will enter the parameter values that describe the weed, the environment, and the management strategy to be used.

(B) Results Table. Presents a summary of the results in terms of averages as well as percentiles. It also presents the probability that the invasion will be eradicated.

(C) Results Graphs. Present cumulative distribution functions (CDF) which show the probability that the weed will be eradicated in a given number of years and the possible cost of the eradication program.

(D) User-Form icon. The user form may be accidentally closed, or it may disappear when there is an unexpected error during execution of a model run. Clicking on this icon will bring the form back.

(E) Weed Search menu. This menu allows the user form to be restored and also presents an option to display the "About" box (the box displayed when the model is first opened).

Each of the components in Figure2 is explained in the sections below.

The User Form

This is where the model is controlled. The components of the User Form are presented in Figure 3.

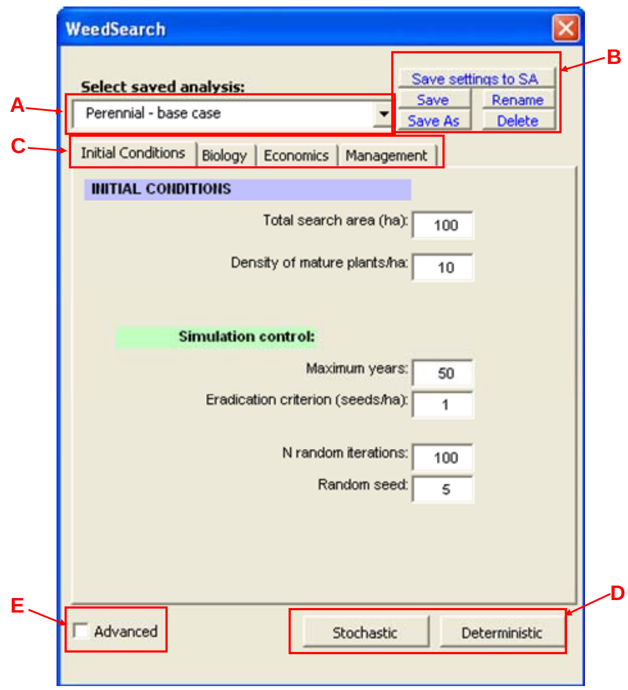


Figure 3. The User Form

(A) Species/Scenario box. This box allows the selection of weed species and scenarios that have been previously saved. A scenario refers to characteristics of the environment and the management strategy used. The combination of species and scenarios is refereed to as a 'case' for short. Whenever a case is selected from the pull-down box all the parameters associated with it will become active.

(B) Case-control buttons. These buttons allow the current case to be saved after it has been changed (Save button). The case may also be saved with a different name (Save As button), effectively creating a new case. The case can also be renamed (the old name will be lost) or deleted. There is also a button to save settings to the sensitivity analysis (SA) worksheet. This is an advanced feature that will be explained during the workshop.

(C) Tabs. There are four types of parameters that define a case; each has it own page accessible by clicking on the appropriate tab.

(D) Run buttons. Pressing these buttons will run the model. Using the Deterministic button will result in a single run of the model using the average parameter values. Using the Stochastic button will run the model many times using random numbers to simulate uncertainty in parameter value and variability in environmental conditions.

(E) Advanced tic box. This will cause additional features and worksheets to be displayed.

The current version contains several example cases (see Figure 4). These do not represent specific plant species but generic, hypothetical cases to help explain how the model works. As you select different cases you will notice changes in the parameters contained in the various pages. Once you enter your own cases, you may wish to name them with the species name followed by the location of the infestation.

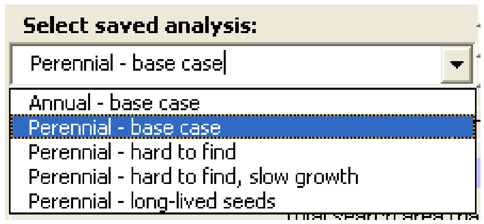


Figure 4. Species/Scenario pull-down box

The following sections explain how to setup and run a case

Initial Conditions

The first page on the User Form (Figure 5) contains parameters that control general features of the case to be simulated.

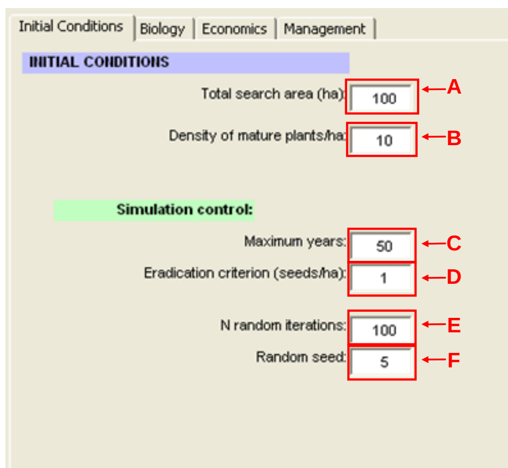


Figure 5. Initial Conditions page.

(A) Total search area. Enter the gross area infested (i.e. the area that will be searched rather than the area actually covered by weeds).

(B) Density of mature plants. Enter the estimated number of mature plants per hectare. This represents the average density of weeds in the search area.

(C) Maximum years. Indicate the maximum number of years the model will run. If the invasion is not eliminated within this number of years, the eradication attempt will be declared unsuccessful.

(D) Eradication criterion. Enter the density of seeds per hectare (in the seed bank) at which the invasion will be declared eradicated. The default is 1.0, meaning that when there is less then one seed per ha in the seed bank the invasion has been effectively eliminated (i.e. it is unlikely to recover unless new propagules are imported from outside the search area).

(D) Number of random iterations. When the model is run in stochastic (random) mode this entry will determine how many times the model will be run. The more iterations you run the more smooth your probability curves will become (up to a point because years to eradication are not a continuous variable, they are whole numbers).

(F) The random seed controls the sequence of random numbers that is used by the software. If you want to replicate a set of random results use the same random seed. You can enter any whole number in this box.

Once the initial conditions have been set proceed to the Biology page by clicking on the appropriate tab.

Biology

The Biology page is shown in Figure 6.

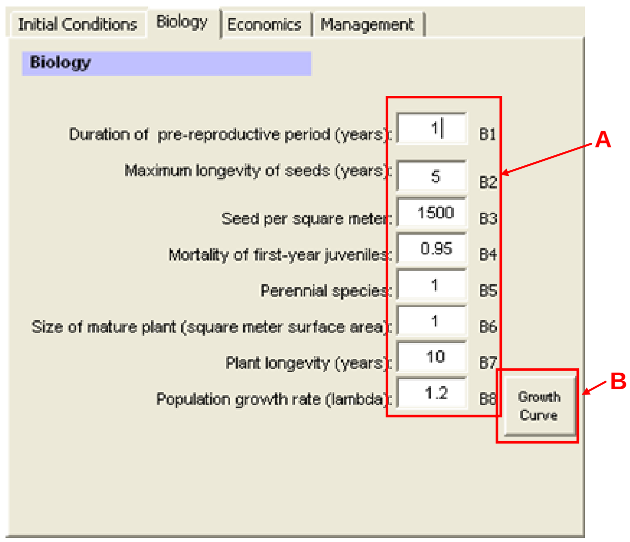


Figure 6. Biological parameters page.

(A) Biological Parameters. This box contains several parameters that are used by the model to create a population matrix. This forms the basis of population dynamics modeling (see Cacho et al., 2006 for details). The parameters are identified by the letter B followed by a number. Their roles are explained below.

B1. Pre-reproductive period. Indicates the number of years until a plant reaches maturity and starts producing seeds. This will determine the number of juvenile stages in the life cycle of the plant.

B2. Maximum longevity of seeds. Seed longevity accounts for the fact that seeds which do not germinate in the year after they are produced may survive for a number of years as part of the seed bank.

B3. Seeds per square meter. This represents the plant fecundity measured as seeds per m^2. As an example, if the average plant size is 0.5 m^2 and each plant produces 400 seeds you should enter 800 here.

B4. Mortality of first-year juveniles. This represents the proportion of juveniles that die in their first year of life under average conditions. This may be difficult to estimate, but you may be able to come up with an educated guess, which could later be subjected to sensitivity analysis.

B5. Perennial species. Enter a 1 for a perennial plant and a 0 for an annual plant. If an annual plant (0) is indicated here the parameters B1, B4 and B7 are ignored by the model when creating the population matrix. For a biannual plant enter 1 in the perennial box and 2 years in the plant longevity box (B7 below).

B6. Size of mature plant. This is the average size of mature plants (in m^2 per plant). For long-lived plants that can reach large sizes enter the best estimate of the average size during their mature life (not the size of the largest plants).

B7. Plant longevity. Enter the number of years an 'average' plant will live. This number must be greater than the duration of the pre-reproductive period (B1).

B8. Growth rate (λ). This is a measure of average population growth and its calculation is explained in Cacho et al. (2006). Growth rate is expressed as the size of the population next year relative to the current year. For example, 1.2 means that next year the population will be 20% larger than in the current year. A value of 1.0 means that there is no population growth (the population size will remain constant). A number less than 1.0 means the population will eventually disappear even in the absence of control.

(B) Growth Curve button. This button will generate a growth curve for the parameters that have been entered. This allows the user to set the growth rate through trial and error, by looking at how many years it would take for the area at risk to be completely invaded in the absence of control. Whenever you use the Growth Curve button come back to the main form by clicking on the **Return button** (see Figure 7).

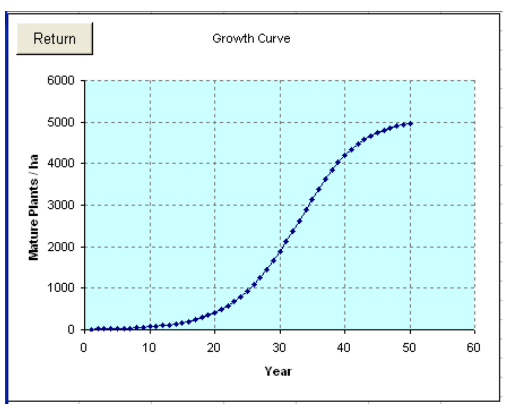


Figure 7. Growth curve for lambda=1.2.

Figure 8 illustrates the growth curves generated for two different growth rates (lambdas) in the absence of control. Assuming that we start with 10 mature plants per hectare, a growth rate of 1.2 will result in a population density of 5,000 plants/ha after 50 years (Figure 7a). In contrast, when the growth rate is 1.05 the population density will only be about 120 plants/ha after 50 years (Figure 7b).

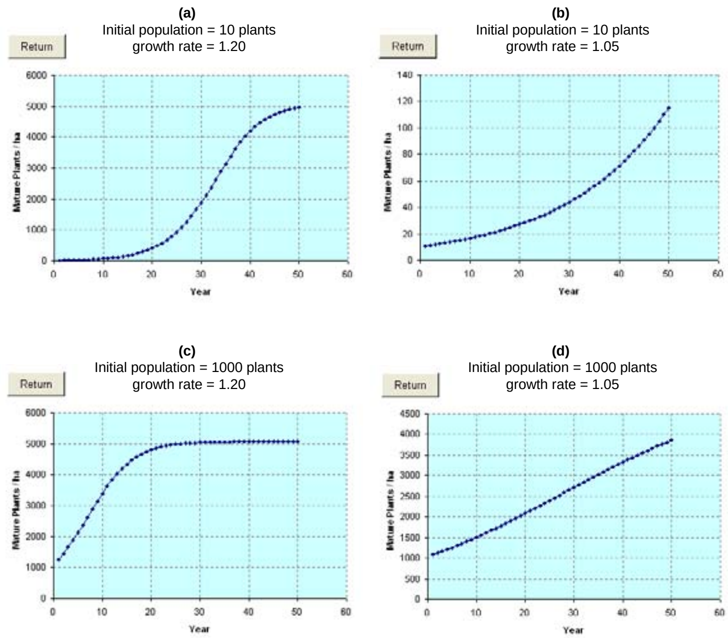


Figure 8. Growth curves generated for two different growth rates and two initial population sizes.

The model is designed to ensure that the population matrix derived from the biological parameters is internally consistent. The seed bank and number of juveniles are automatically calculated based on the number of mature plants. This ensures that the population structure of the invasion is consistent with the population matrix implied by the biological parameters. Note that a larger initial number of mature plants (entered in box C in the Initial Conditions page) would appear to produce a 'faster' growth curve (compare Figure 7a against 7c and 7b against 7d), but this is not the case. Essentially, in the latter case the invasion is older when discovered (with 1000 plants/ha) than in the former case (with 10 plants/ha), so the same growth curve starts from a different base.

In the model, density dependence is introduced based on the area occupied by weeds, and this determines the maximum number of mature plants (the asymptote) in Figure 8.

Economics

The economics page contains information on the inputs required to control weeds and the costs of these inputs (Figure 9).

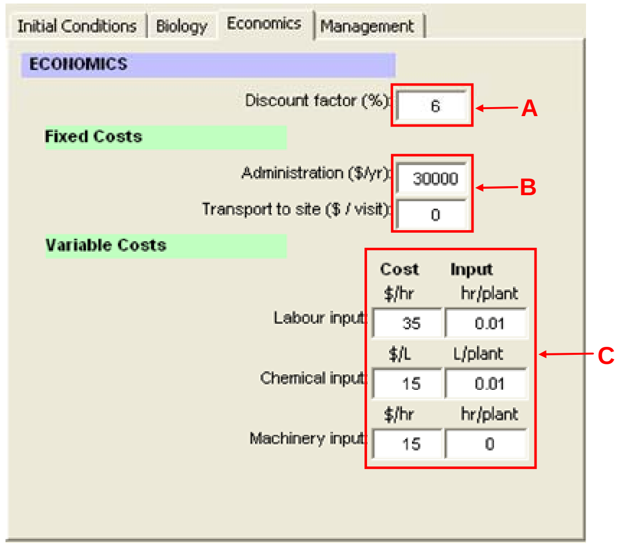


Figure 9. Economic parameters.

(A) Discount Factor. This is the discount rate used to calculate the present value of a long-term stream of expenditures. In general rates ranging between 3% and 7% are used for public expenditures.

(B) Fixed Costs. These are costs that are independent of the density of the invasion, but which occur every year (administration) or every time the invasion is visited (transportation costs).

(C) Variable Costs. These costs depend on the density of the invasion. They are expressed in terms of two variables: cost per unit of input ($ per hour or per liter) and input required per plant.

This section of the model may require some future refinement because the amounts of inputs required may depend on the age and/or size of plants that are killed. For example, a small seedling may take just a second to be pulled out, whereas large woody plants may take more than a minute to be cut and painted with herbicide. Similarly, if the plants are being chipped to prevent re-sprouting, a large tree will take more machinery time than a small plant.

Management

The management page contains information on the search and control strategy (Figure 10).

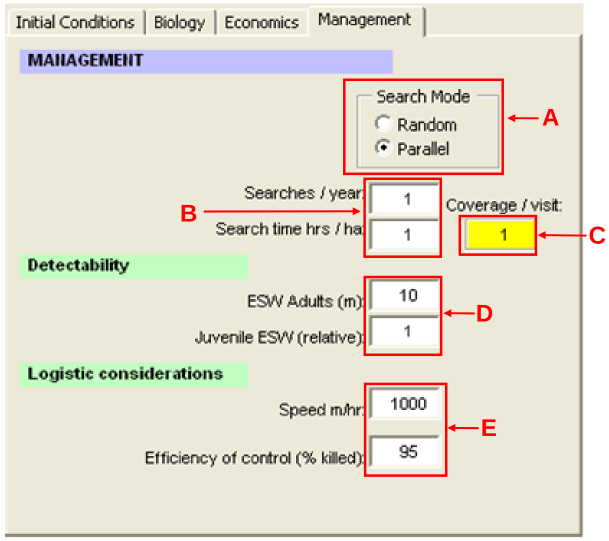


Figure 10. Management parameters.

(A) Search mode. Indicate whether the search will follow a random pattern within the search area or whether the area will be searched following a series of equally-spaced parallel sweeps.

(B) Searches per year and **search time** represent the control effort. Search time (hr/ha) is the main decision variable. It will determine the number of years required for eradication and the associated costs.

(C) Coverage per visit. This variable represents the intensity of search relative to the area invaded and it is used to estimate the probability of detection (see Figure 1 in Cacho et al. 2006 for details). The box is yellow to indicate that this number is not to be changed by the user. It is calculated based on search time, search speed and ESW. It is presented for convenience, so the user can determine the amount of search effort required to achieve a given level of coverage.

(D) Detectability parameters. The effective sweep width (ESW) is a key concept in search theory. It measures the distance at which the weed can be detected from the search path (in meters). The relative juvenile ESW indicates the detectability of first-year juveniles relative to adults, for example if ESW adults=10 m, a value of juvenile ESW (relative)=0.5 indicates that the ESW of juveniles is 5 m.

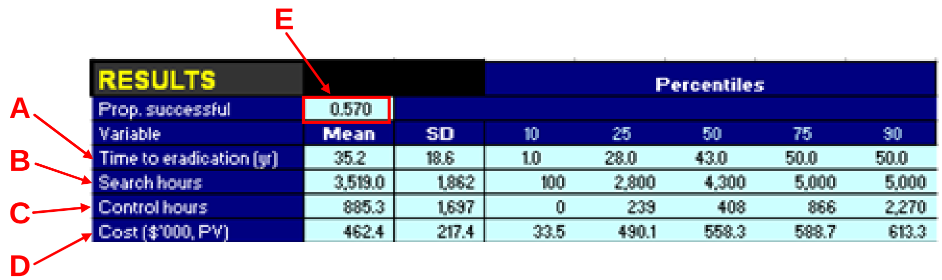
(E) Logistic parameters consist of two variables: speed in terms of m/hr, which depends on the nature of the environment and the search strategy (i.e. how difficult it is to traverse and how fast the searcher must move to achieve the assumed ESW). Effectiveness of control indicates the percentage of weeds that are killed when treatment is applied. The maximum possible value is 100.

Results

Once all the parameters values have been set the model is run by clicking on either the Deterministic or the Stochastic button.

Results Table

The results are saved in the background and a summary is presented in the Results Table (Figure 11).



RESULTS			Percentiles				
Prop. successful	0.570						
Variable	Mean	SD	10	25	50	75	90
Time to eradication (yr)	35.2	18.6	1.0	28.0	43.0	50.0	50.0
Search hours	3,519.0	1,862	100	2,800	4,300	5,000	5,000
Control hours	885.3	1,697	0	239	408	866	2,270
Cost ($'000, PV)	462.4	217.4	33.5	490.1	558.3	588.7	613.3

Figure 11. Results Table.

The results depend on whether the model was run in deterministic or stochastic mode. The standard deviation and percentiles do not apply in deterministic mode.

(A) Time to eradication. Presents the average (Mean) number of years required to eradicate the invasion based on the parameters used and the search effort applied. If the model was run in stochastic mode this row also includes the standard deviation (SD) and percentiles. In Figure 11 the 25th percentile, for example, indicates that there is a 25% probability that eradication will be achieved in 28 years or less.

(B) Search hours. This is the total number of hours spent searching for weeds in the simulated control program. In this example an average of 3,519 hours would be used over 35.2 years, so the average labour used would be about 100 hours per year.

(C) Control hours. The number of hours spent killing weeds once they have been found. This is the total over the duration of the program. In this example 885 hours over 35 years means that an average of about 25 hours per year will be used. However this may change considerably over time, because more weeds will be killed in the early years, whereas in later years only new seedlings may have to be controlled. To see the distribution of control labour through time consult the Results worksheet (see the Advanced section later in this manual).

(D) Cost. This is the present value of the total cost of control for the duration of the eradication program. In this example a cost of $462,000 over 35 years indicates an average annual cost of about $13,000 (in present-value terms). This run assumes a search area of 100 ha, therefore the cost would be about $130 per ha per year.

(E) Proportion successful. This is an estimate of the probability that eradication will be successful (the proportion of simulations in which eradication was achieved). This interpretation only applies for stochastic simulations; in deterministic simulations this variable can only have a value of 0 (failure) or 1 (success). The relationship between search effort and probability of success is explained later.

Probability Graphs

The cumulative distribution functions (CDFs) show the cumulative probability of an event occurring. The model produces two CDFs (Figure 12) one for years to eradication and one for costs. These graphs present more detailed information than the percentiles in the Results Table. For example, here we can see the probability that the invasion will be eradicated in 15 years or less is about 60% (0.6 indicated by the red line in Figure 12.)

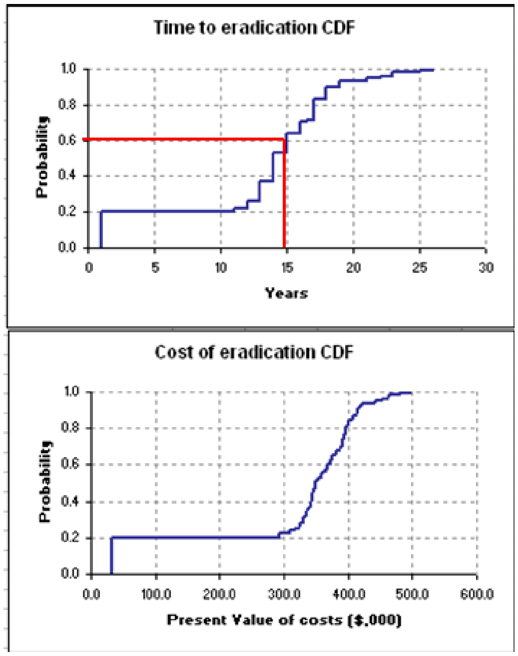


Figure 12. Cumulative Distribution Functions

Advanced Features

Clicking on the Advanced box at the bottom of the user form causes a new page to appear (Figure 13).

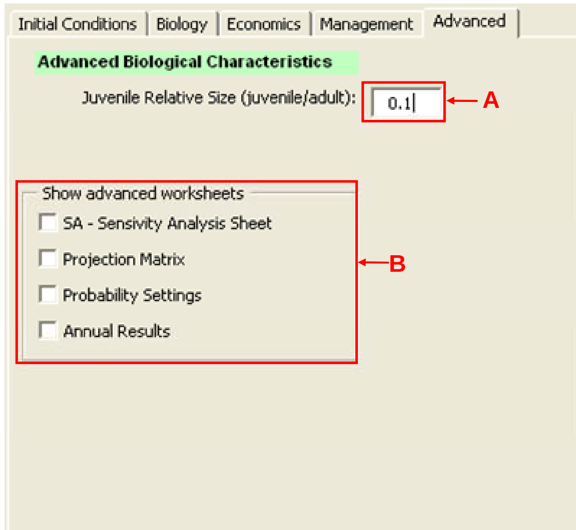


Figure 13. The Advanced page

(A) Juvenile relative size. This is the size of first-year juveniles relative to adults (0.1 means that a juvenile is 10% of the size of an adult). This variable is potentially important because the carrying capacity of the environment is calculated based on the area occupied per plant. When the population model is created, the size of older juvenile stages before the plant reaches maturity is calculated by interpolating between the size of first-year juveniles and the size of mature plants (entered as parameter B6 in the Biology page).

(B) Advanced worksheets. Clicking on these boxes will cause additional worksheets to be displayed. These worksheets are hidden from the average user to avoid confusion and clutter. But they can be useful in more advanced work. Advanced worksheets are explained in the following sections.

Sensitivity Analysis

Many of the parameters associated with a case (the species/location combination) are uncertain. Therefore it is important to perform sensitivity analysis by changing these values and evaluating their effects on results. Sensitivity analysis can also be used to explore the effect of search effort, speed of search and other assumptions on the probability of success and the potential cost of the eradication program. At this stage the sensitivity analysis worksheet does not include economic variables. This will be available in future versions.

Sensitivity analysis could be performed by (1) changing values in the user form, (2) running the model and (3) copying results from the Results table to a different worksheet. By repeating steps 1 to 3 for as many parameter values as desired allows you to create a dataset of results that can be analysed later. Effectively this process is equivalent to running experiments; except these experiments take place on the computer rather than on the field. The Sensitivity Analysis worksheet (Figure 14) allows you to avoid this repetitive process by providing a way of setting up and running an experiment as a batch of model runs.

	A	B	C	D	E	F	G	H	I	J
1	**SENSITIVITY ANALYSIS**				Run SA	A				
2	Stochastic?	1	B							
3	N Treatments:	8								
4	INPUTS		1	2	3	4	5	6	7	8
5	Search Decisions	(hr/ha)	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
6		Visits/yr	1	1	1	1	1	1	1	1
7	Search Type	(P or R)	P	P	P	P	P	P	P	P
8	Initial mature plants/ha		10	10	10	10	10	10	10	10
9	Speed	L1	1000	1000	1000	1000	1000	1000	1000	1000
10	ESW	D1	20	20	20	20	20	20	20	20
11	Juvenile Rel ESW	D2	1	1	1	1	1	1	1	1
12	Kill rate	M1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
13	Time to maturity	B1	1	1	1	1	1	1	1	1
14	Seed longevity	B2	5	5	5	5	5	5	5	5
15	Seed per sq m	B3	1500	1500	1500	1500	1500	1500	1500	1500
16	Juvenile mortality	B4	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
17	Perennial	B5	0	0	0	0	0	0	0	0
18	Size of mature plant	B6	1	1	1	1	1	1	1	1
19	Plant longevity	B7	1	1	1	1	1	1	1	1
20	Growth Rate (r)	B8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
21	Juvenile size (relative)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
22										
23	OUTPUTS									
24	Success	prop.	0.09	0.26	0.63	0.83	0.94	1	1	1
25	Time (years)	Mean	48.28	44.16	35.48	28.97	21.94	17.67	15	13.21
26		SD	7.433	12.788	14.249	13.083	10.512	7.694	6.524	6.046
27		Median	50	50	36	25.5	18	16	14	12
28		90 pctl	50	50	50	50	39	28	22.1	20
29	Search Labour (hr)	Mean	1448.4	1766.4	1774	1738.2	1535.8	1413.6	1350	1321
30		SD	222.999	511.515	712.425	784.970	735.838	615.496	587.181	604.578
31		Median	1500	2000	1800	1530	1260	1280	1260	1200
32		90 pctl	1500	2000	2500	3000	2730	2240	1989	2000
33	Control Labour (hr)	Mean	151485.14	15989.65	401.57	68.32	43.52	38.50	36.99	34.36
34		SD	274176.59	47027.59	2446.17	146.74	22.60	17.93	17.12	16.17
35		Median	14078.12	183.16	46.79	42.29	36.08	35.35	34.42	31.27
36		90 pctl	509438.76	39523.45	251.71	99.94	77.22	61.85	58.49	54.33
37	Cost ($'000 present value)	Mean	1291.51	570.94	461.57	433.56	389.86	354.88	327.18	304.11
38		SD	1456.12	286.09	115.85	99.56	93.17	94.70	89.05	91.01
39		Median	597.66	529.08	494.37	440.82	374.40	353.12	327.96	299.28
40		90 pctl	3092.34	717.63	536.42	539.34	516.51	468.13	426.20	408.56

Figure 14. Sensitivity Analysis worksheet

The top table on the worksheet (shaded green) contains the data inputs. These are the parameters to be tested. Each column represents a different experimental treatment. In this example (Figure 14) we have 8 treatments. The variable being tested is the search effort in hours per ha (note that all other values are the same across columns in the Inputs table). So the purpose of this experiment was to test the effect of search effort. The results of this experiment are discussed later.

You can add as many columns as you want, up to 256, which is number of columns available in an Excel worksheet. This should allow you to create detailed experimental designs (including full factorials on combinations of parameters). You can fill up the input columns manually, or you can change parameter values in the User Form and click on the “Save settings to SA” button. Each time you click this button a new column will be added to the SA worksheet.

After filling up the Inputs table (number your columns sequentially as shown above) click on the “Run SA” button (box A in Figure 14). The model will run and place results in the Outputs table (shaded in pink). The cell labeled “Stochastic?” (box B in Figure 14) indicates whether you want to run your experiments in stochastic mode (1) or deterministic mode (0). Deterministic experiments are run on the average values of parameters; there is only one run per treatment, so results are obtained relatively quickly. Stochastic experiments are run for the number of iterations given in the user form (the default is 100), so it may take a while to complete the experiment. Since the process is automated, however, you can click on RunSA, go home for the night and come back the next morning to find your results.

A selection of results from the Sensitivity Analysis worksheet from Figure 14 is plotted in Figure 15. These plots were produced by copying the outputs from the SA Worksheet into a new worksheet and producing X-Y scatter plots with Excel.

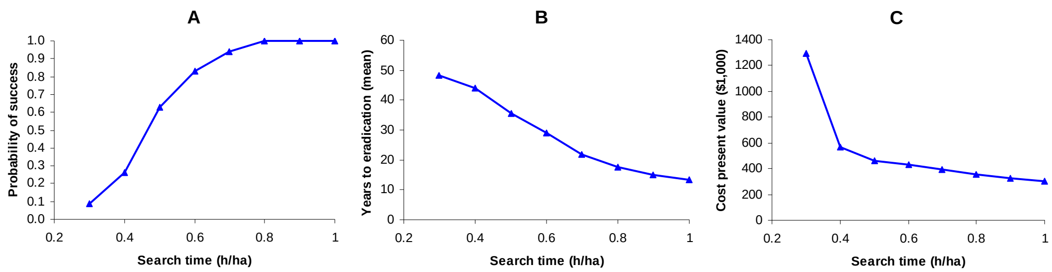


Figure 15. Sensitivity Analysis results

Figure 15 presents plots of three important outputs against search effort. As the search effort increases the probability of successful eradication increases (Figure 15A), the years to eradication decrease (Figure 15B) and, interestingly, the total cost of the eradication effort decreases (Figure 15C). This last result indicates that reducing search effort in order to save money may be more expensive in the long run.

Projection Matrix

The Projection Matrix worksheet (Figure 16) is likely to be used only by truly advanced users or for troubleshooting when a given set of biological parameters is unable to produce the desired value of Lambda. You may need to close the user form or move it out of the way to view this section of the worksheet. As explained earlier, the projection matrix is generated based on the parameters entered in the Biology page.

	A	B	C	D	E	F	G
1	Lambda	1.2	D2:G5	New Seeds	Seedbank	Juv-Adult	
2	r_calc	0.182322		0	0	0	1500
3	Sum:	0.262359	Create Matrix	0.251189	0.251189	0	0
4				0.011171	0.011171	0	0
5				0	0	0.05	0.464159
6			Find Germ.				
7							
8							
9							

Figure 16. The Projection Matrix worksheet

The matrix illustrated in figure 16 represents a perennial plant which reaches maturity in its second year of life (the pre-reproductive period, parameter B1, is 1 year) and has a growth rate (lambda) of 1.2. The matrix occupies the range D2 to G5. The rows and columns of the matrix represent four different life stages: new seeds, seed bank, juveniles and adults. The remaining cells in the worksheet contain calculations that are used by the model to create the matrix and check that it is internally consistent.

The entries in the matrix (range D2:G5) represent the proportion of plants surviving from one life stage to another. For example, the entry in cell D4 is the germination rate (the proportion of new seeds transitioning to juveniles). The entry in cell G2 does not represent a proportion, but the number of viable seeds produced by an adult plant.

The two buttons in this worksheet are there to help you check the matrix without having to run the whole model. Clicking on “Create Matrix” determines the number of life stages, based on the duration of the pre-reproductive period, calculates the matrix entries based on the biological parameters and estimates the germination rate that will result in the desired growth rate (lambda). Clicking on “Find Germ.” estimates the germination rate only (once the matrix has been created). The germination rate is estimated by an algorithm that calculates the dominant eigenvalue of the matrix (See Cacho et al., 2006 for details).

To see how the Matrix worksheet may help you calibrate a model take the perennial-base case plant and change the duration of pre-reproductive period (parameter B1 in the Biology page) to 4 years. You will receive the message shown in Figure 17.

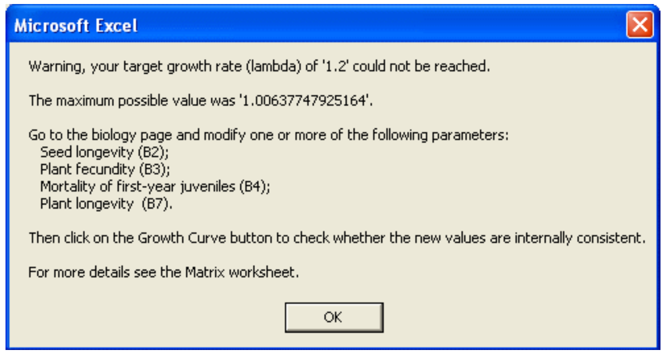


Figure 17. Error message when the target growth rate cannot be reached

In this case you could increase plant longevity to 30 years, click OK, then click the Growth Curve button as instructed in the warning box (Figure 17) and see that your parameters are now internally consistent (i.e. there is no error message and the target growth rate of 1.2 was achieved). To get a better understanding of what is happening you may prefer to go to the Matrix worksheet.

Figure 18 helps illustrate how the Matrix worksheet can be used for troubleshooting and model calibration. Here we have a perennial plant which reaches maturity in its fifth year (this is the plant that cause the error message explained above). The matrix has 7 columns and 7 rows, representing new seeds, the seed bank, 4 juvenile stages and one adult stage.

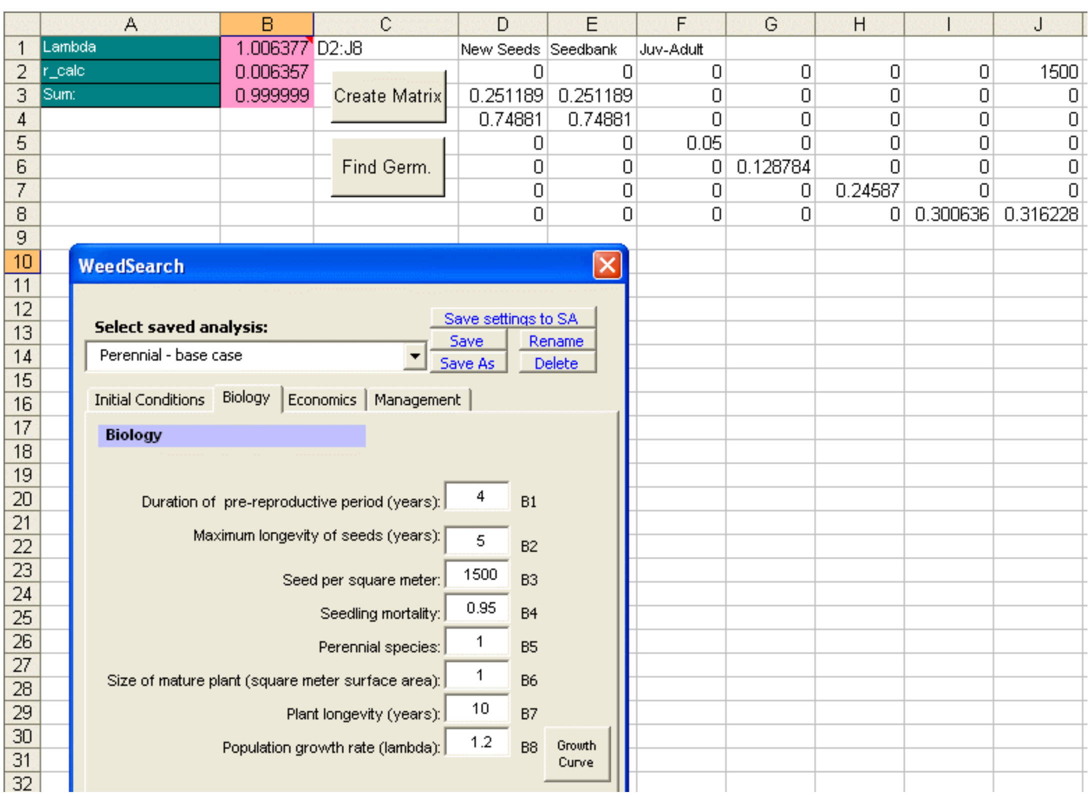
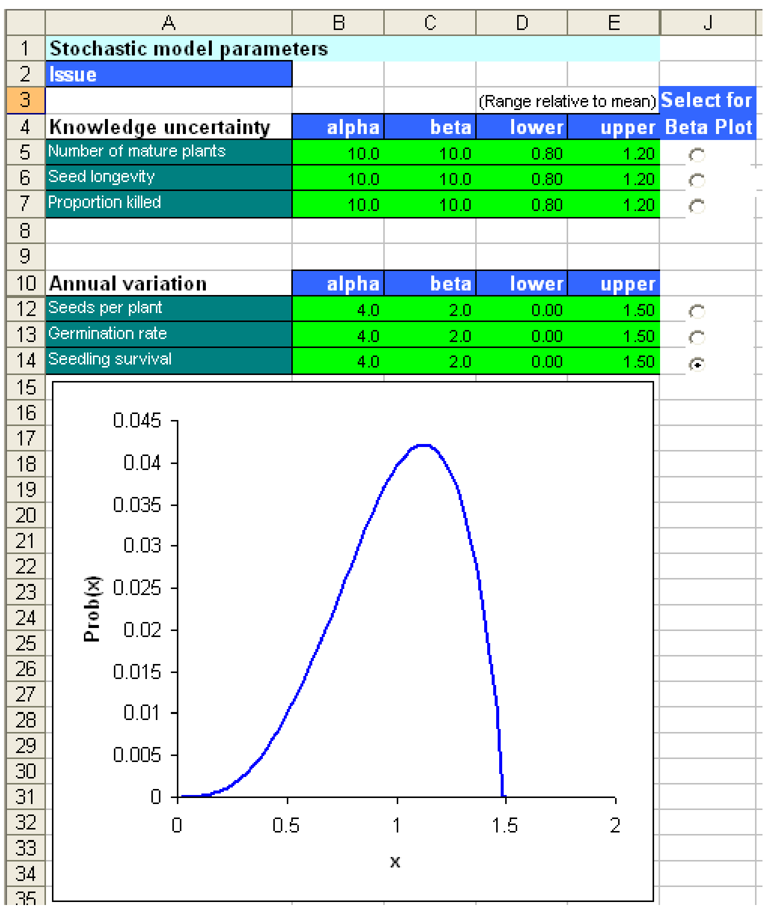


Figure 18. A tricky Projection matrix

After the matrix is created, the model attempts to find the germination rate (cells D4 and E4 in Figure 18) that will make lambda (worksheet cell B1) equal to 1.2 (the growth rate specified in the UserForm). But this proves to be impossible. The highest growth rate achievable for the given demographic parameters is 1.006. The reason for this limit is that the sum of the entries in a column cannot exceed 1.0 (except in the case of adults that produce seeds), as this would imply that more individuals move into other life stages than were initially available at the life stage represented by the column. In this example (Figure 18) the seed bank survival plus germination rate already add up to 1.0 (or 0.99999 as shown in worksheet cell B3, labeled “Sum:”); therefore germination rate (and lambda) cannot be increased any further. This indicates that you need to revise your demographic parameters in the User Form. You can increase fecundity, reduce juvenile mortality, increase the plant longevity, or use any combination of these changes as explained earlier.

Probability Settings

The model accounts for two types of stochastic variables: knowledge uncertainty and annual variation. Both types of variables are represented by Beta probability distributions. Three variables are subject to knowledge uncertainty: the initial number of mature plants, seed longevity and the proportion of plants treated that are killed. Three variables are subject to annual variation: Seeds produced per plant, germination rate and juvenile survival (Figure 19).



	A	B	C	D	E	J
1	Stochastic model parameters					
2	Issue					
3				(Range relative to mean)		Select for
4	Knowledge uncertainty	alpha	beta	lower	upper	Beta Plot
5	Number of mature plants	10.0	10.0	0.80	1.20	
6	Seed longevity	10.0	10.0	0.80	1.20	
7	Proportion killed	10.0	10.0	0.80	1.20	
8						
9						
10	Annual variation	alpha	beta	lower	upper	
12	Seeds per plant	4.0	2.0	0.00	1.50	
13	Germination rate	4.0	2.0	0.00	1.50	
14	Seedling survival	4.0	2.0	0.00	1.50	

Figure 19. Probability parameters

Knowledge uncertainty is simulated by drawing a random number from the corresponding Beta distribution at the beginning of each stochastic iteration (i.e. each time a new 50-year simulation is started). Annual variation is represented by drawing a random number from the corresponding Beta distribution every year of every stochastic simulation.

Beta distributions are used because of their flexibility. They can assume different shapes and have clear bounds (as opposed to the normal distribution which ranges from $-\infty$ to ∞). The Beta distribution is defined by four parameters: alpha, beta, lower bound and upper bound (Figure 19). The bounds are defined relative to the mean; an upper value of 1.5 means that the variable could be as high as 1.5 times the average value for that variable. For example, if the juvenile survival is 0.5 and the upper value is 1.5, the actual juvenile survival in a given (randomly selected) year could be as high as 0.75.

The alpha and beta parameters determine the shape of the Beta function. Both parameters must be greater than zero. If alpha = beta, the distribution is symmetric around the mean (the left tail is a mirror image of the right tail). If alpha > beta the function is slanted toward the right (as in figure 19). If alpha < beta the distribution is slanted towards the left. Smaller values of alpha and beta result in “fatter” functions. You can explore the shapes of the assumed function by clicking on the radio button next to each row of parameters (see Figure 19).

Annual Results

The Annual Results worksheet (Figure 20) presents the average results for each year. Note that the number of seeds, juveniles and adults are presented as number of organisms per hectare; whereas labour inputs and costs are presented for the total search area.

	A	B	C	D	E	F	G
1	Year	Seeds (per ha)	Juveniles (per ha)	Adults (per ha)	Search labour	Control Labour	Annual Cost ($1000)
2	0	17886.61	166.4988	11.32338	100	133.4401	40,172
3	1	8732.165	199.7389	3.389587	100	152.4303	41,122
4	2	3462.416	97.51786	2.885288	100	75.34383	37,267
5	3	1949.915	38.67202	1.551214	100	30.18404	35,009
6	4	1070.541	21.78066	0.662307	100	16.84149	34,342
7	5	516.8623	11.95838	0.348535	100	9.235267	33,962
8	6	260.3147	5.773653	0.18961	100	4.47491	33,724
9	7	136.3743	2.907895	0.094017	100	2.252674	33,613
10	8	69.45394	1.523402	0.04718	100	1.178586	33,559
11	9	35.10944	0.775854	0.024477	100	0.600578	33,530
12	10	17.98273	0.3922	0.012518	100	0.303705	33,515
13	11	9.203454	0.200881	0.006345	100	0.155505	33,508
14	12	4.687079	0.10281	0.003242	100	0.079583	33,504
15	13	2.391034	0.052358	0.001659	100	0.040535	33,502
16	14	1.221534	0.02671	0.000846	100	0.020678	33,501
17	15	0	0	0	0	0	0

Figure 20. Annual deterministic results

The output in Figure 20 is for a deterministic run, so there is only one set of results that also represents the average. In this case we can see that 100 hours of search labour are used each year for 14 years, when the invasion is eradicated (there are zero seeds and plants from year 15 onwards). Note that search labour is constant, but control labour is high initially and drops to virtually nothing the last few years, when only a few seedlings need to be killed.

The annual results output is different when the model is run in stochastic mode (Figure 21), because the average results are calculated from a number of model runs (100 iterations in the default case). In this example search labour decreases through time because in some of the model simulations the plants were eliminated early. The 96 hours of labour from years 1 to 9 indicate that, in 4 simulations (out of 100), the invasion didn't survive beyond the first year. This would happen if there were an alignment of negative conditions for the plant (in terms germination rates, juvenile survival and plant fecundity), which did not allow the invasion to recover after the first treatment. If this is not a realistic possibility for the plant of interest, then you should consider modifying the parameters of the Beta distribution as explained in the previous section.

	A	B	C	D	E	F	G
1	Year	Seeds (per ha)	Juveniles (per ha)	Adults (per ha)	Search labour	Control Labour	Annual Cost ($1000)
2	0	15951.19	153.9827	10.42429	100	123	39,659
3	1	8085.676	196.3442	3.287538	96	150	39,636
4	2	3337.447	100.5755	3.055781	96	77	36,032
5	3	2080.592	41.88966	1.743934	96	33	33,786
6	4	1241.287	26.51761	0.789832	96	20	33,175
7	5	641.5906	15.98269	0.468918	96	12	32,770
8	6	360.2978	8.317728	0.28475	96	6	32,478
9	7	213.1675	4.711602	0.154399	96	4	32,340
10	8	120.9012	2.810077	0.087459	96	2	32,267
11	9	69.02984	1.603232	0.052063	96	1	32,221
12	10	40.63663	0.920352	0.030178	95	1	31,860
13	11	23.86022	0.54461	0.017473	93	0	31,176
14	12	13.97048	0.320953	0.010347	89	0	29,827
15	13	8.235432	0.187666	0.006102	78	0	26,137
16	14	4.827235	0.109642	0.003545	62	0	20,774
17	15	2.822443	0.064081	0.002071	50	0	16,752
18	16	1.644186	0.037168	0.001209	40	0	13,401
19	17	0.938628	0.021005	0.000685	31	0	10,386
20	18	0.499805	0.011207	0.000358	20	0	6,700
21	19	0.237199	0.005307	0.000162	10	0	3,350
22	20	0.110363	0.002428	7.52E-05	5	0	1,675
23	21	0.056595	0.001268	3.75E-05	3	0	1,005
24	22	0.02871	0.000648	1.83E-05	2	0	670
25	23	0.011476	0.000274	7.49E-06	1	0	335
26	24	0	0	0	0	0	0

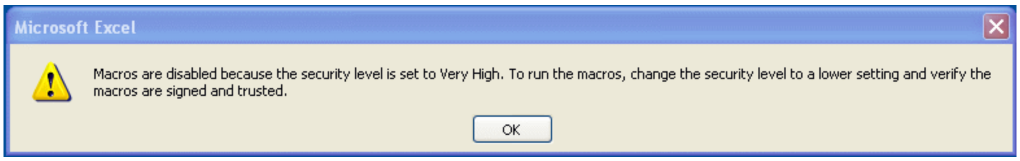
Figure 21. Annual stochastic results

In the stochastic case (Figure 21) the output contains positive entries for 23 years, instead of 14 years in the deterministic case (in Figure 20), because in some stochastic runs it takes longer than average to eliminate the plants. The annual results worksheet shows that it is important to continue visiting the invasion site for a few years even if there are virtually no new adults spotted for a few years (note that 0.01 plants per ha is equivalent to 1 plant in 100 ha), because there may be viable seeds left in the seed bank.

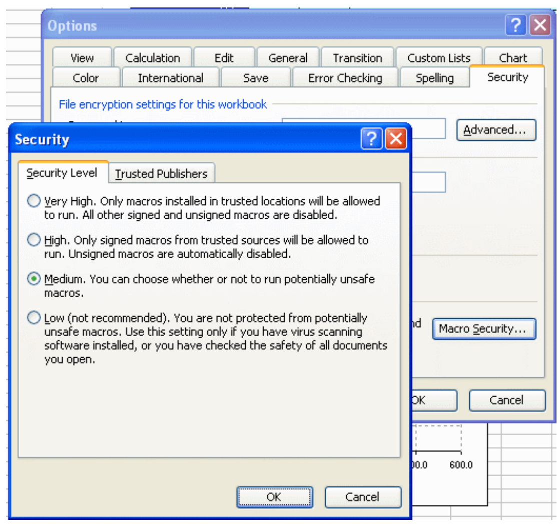
Troubleshooting

Before using the model for the first time

If you have security set at high or very high in Excel, WeedSearch will not run. You will get an error message such as this:



Click OK; then select the Tools / Options menu, click on the Security tab; then click on the Macro Security button. A Security window will appear, click on the Medium or Low radio button:



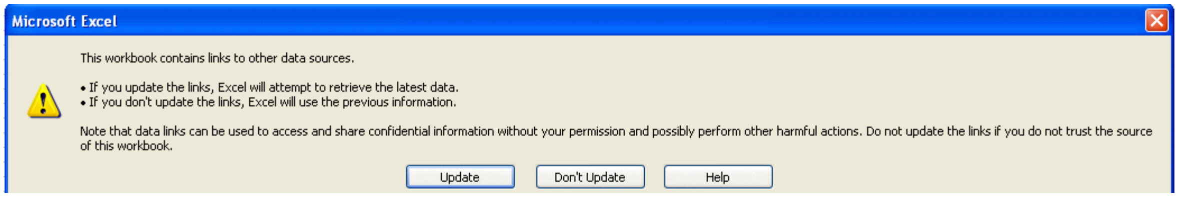
Then click OK, and OK again. Exit Excel. Open Excel again. Now you should be able to run WeedSearch.

If you set security to Medium, each time you open WeedSearch Excel will ask whether you want to enable macros. Click on the Enable Macros button and the UserForm will appear. If you set your security to Low, you will not be asked this question, but be aware that your computer may be at risk if you happen to pickup an Excel file that contains malicious macros.

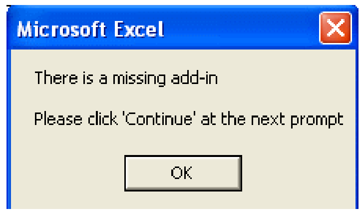
Opening the model for the first time

WeedSearch uses an add-in that is included in standard versions of Excel, but this add-in may not be loaded automatically when you open Excel. If this is the case, WeedSearch will attempt to load the add-in for you. This process will produce a series of messages that may be confusing.

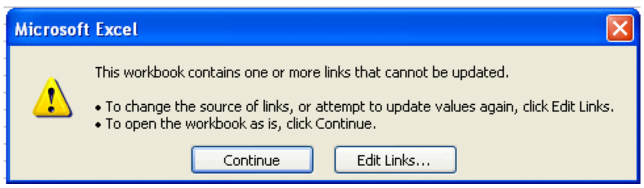
The first message tells you there is a missing link:



Click on Update, the next message appears:



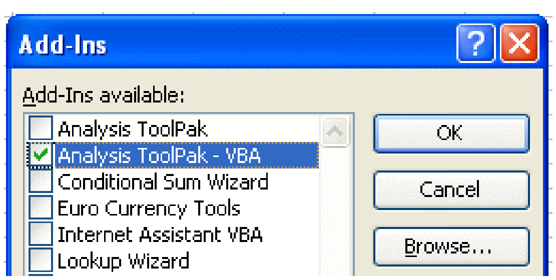
Click OK, the next message is:



Click on Continue, the final message appears:

Now exit Excel. Next time you click on the WeedSearch icon Excel should open and the model should run. This set of questions will not reappear unless you change computers or manually unload the required add-in.

If this process did not work and you continue to receive a message telling you there is a missing add-in, you may need to load it manually. Select the Tools / Add-ins menu and click the checkbox for "Analysis ToolPak - VBA" (see below). Click OK. Now you are ready to run WeedSearch.



If the "Analysis ToolPak – VBA" does not appear on your list of add-ins, it is possible that you have an incomplete install of Excel. You will need to re-install the Excel software on your computer and ask for a full install.

References

Cacho, O.J., Spring, D., Pheloung, P. and Hester, S., 2006. Evaluating the feasibility of eradicating an invasion. *Biological Invasions,* 8:903-917.

Panetta, F.D., and Timmins, S., 2004. Evaluating the feasibility of eradication for terrestrial weed incursions. *Plant Protection Quarterly,* 10:5-11.