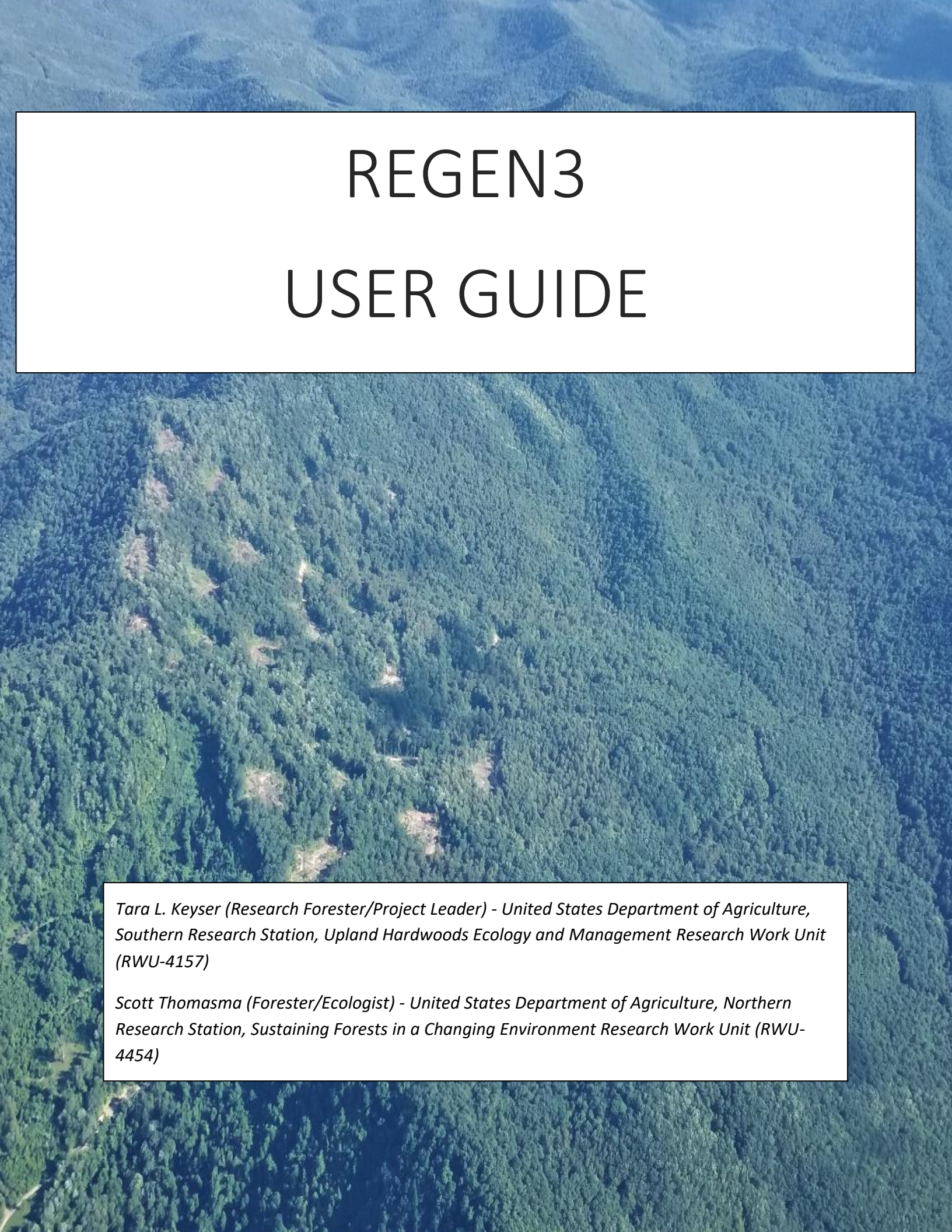
REGEN3

USER GUIDE



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INTRODUCTION TO REGEN3

Forest managers require the ability to predict the outcome of their management activities, among them, regeneration cuts designed to secure natural regeneration. Predicting these regeneration outcomes in forests that have many species that form a variety of associations across multiple environmental gradients is particularly challenging. Following a regeneration harvest, a new cohort is comprised of one or more of the following sources of regeneration: (1) new seedlings that become established during or soon after harvest; (2) advance reproduction, (i.e. seedlings and saplings that exist in mature stands at the time of harvest); (3) stump sprouts from harvested trees; and (4) root suckers (from those species capable of root suckering).

A model for forest regeneration –REGEN3 – was formulated to apply the concepts of Egler's (1954) initial floristics model and Nobel and Slatyer's (1976) vital attributes model to predict species composition following stand-replacing disturbance in upland hardwood forests in the southeastern United States (Boucugnani 2005). The overarching principle that guides REGEN predictions is that species composition of a new cohort following a regeneration harvest depends on two primary factors: (1) the sources of advance reproduction and stump or root sprouting potential that exist at the time of harvest; and (2) the potential for new seedlings and root suckers to establish soon after harvest. These two factors determine the pool of sources that become established in a short period of time after harvesting from which successful individuals will ultimately emerge over the longer term. Predictions are driven both by data and expert knowledge provided to the model. Data from a pre-harvest survey enumerate relevant regeneration sources to characterize the initial regeneration pool: (1) small (S), medium (M), and large (L) advance reproduction; (2) existing parent trees prone to produce stump sprouts (SP); and (3) existing parent trees prone to produce root suckers (RS). In addition, data on the presence of seed parent sources are provided to inform the model whether any new seedlings (SE) might become established immediately following regeneration disturbance. Simple probabilistic rules are applied for stump sprouts, root suckers, and seedlings when parents for these sources are noted in the pre-harvest survey, since the presence of a parent does not guarantee establishment in the regeneration pool.

Expert knowledge, apart from that encoded into the model structure itself, is provided in the form of **knowledgebases** (KB), which comprise lists of parameters that describe and quantify the relative likelihood of a particular regeneration source being successful (Table 1). Success is judged by the individual's presence in the regeneration pool/layer following a regeneration harvest or heavy thinning, and its ability to survive and grow at a rate sufficient to attain a dominant or co-dominant canopy

position at the time of canopy closure in the regenerating stand. Rankings of regeneration source success (Table 1) are deterministic in that, assuming resources are limited, any source having a higher rank (i.e., lower number) will outcompete any source with a lower rank (i.e., lower number) ranking. For example, in the rankings listed in Table 1, Yellow poplar stump sprouts (rank=1) will outcompete oak stump sprouts (rank=4). Parameters, including rankings of various species and regeneration sources, new seedling and root sucker establishment probabilities, and stump sprout probabilities vary across the Central Hardwood Region. As such, knoweldgebases are specific to certain geographic areas. Currently, there are knoweldgebases available for the southern and central Appalachians (northern Georgia, eastern Tennessee, western North Carolina, Virginia, and southern West Virginia) and the Cumberland Plateau and Mountains (Tennessee and Kentucky).

Knoweldgebases include parameters that define seedling and root sucker establishment probabilities as either constant values bounded on [0, 1], or by a logistic regression model in the case of stump sprouting, which is, for some species, a function of the parent tree stem diameter. In addition, the number of new seedlings and root suckers that become established in the regeneration pool, given their successful establishment, are specified by knowledge base parameters (on a per acre basis).

REGEN3 operates on a time step that simulates the interval following a treatment that reduces overall basal area below 50 ft^2/acre (e.g., regeneration cut, intense thinning) until the canopy closure – defined here as the stage in stand development where dominant and codominant crowns can first be readily distinguished in the canopy. In REGEN3, canopy closure is assumed to occur by 10 years post-treatment, recognizing that time to canopy closure is variable and dependent on site quality. An initial period of new seedling and/or root sucker establishment is implied in the overall time step, with establishment taking place in the span of time immediately following harvesting. Although not explicitly specified in the model, the establishment interval can be assumed to be a single growing season.

The main output produced by REGEN3 is a list of trees, by species, that survive and grow to attain dominant or co-dominant status at the time of canopy closure (assumed to be approximately 10 years post-harvest). Recent developments in REGEN3 now permit a data-driven estimate of stems/acre of each species in addition to a simple estimate of species composition. Estimates of density (stems/acre) are created using maximum crown competition factors (CCF) observed at the time of canopy closure (10 years) in upland hardwood/oak forests in the Central Hardwood Region (Krajicek et al. 1961). The Forest Vegetation Simulator (FVS) was used to forecast seedling/sapling size 10 years post-harvest of species in the eastern US (bareground simulations). Using FVS-predicted stem diameters, crown widths were predicted, and species-specific CCF values calculated. In REGEN3, CCF values of the regeneration sources are summed until the values detailed by Krajicek et al. (1961) at canopy closure (10 years post-harvest) are achieved.

Table 1. Knowledgebase showing expected post-harvest performance (i.e., rankings) for the various sources of regeneration typical of submesic upland forests located in the southern Blue Ridge Mountains Subsection (M221Dc) of the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow Province of the eastern US. SP=stump sprout; L=large advance reproduction: ≥4 ft in height but <1.5" diameter at breast height (dbh); M=medium advance reproduction: ≥2 ft and <4 ft in height; S=small advance reproduction: <2 ft in height; SE=new seedlings established after harvest.

Ranking	Species list
1	basswood(SP); black cherry(SP); black locust(SP); yellow poplar(SP)
2	cucumber-tree(SP); mountain magnolia(SP); red maple(SP); silverbell(SP); sugar maple(SP); sweet birch(SP); white ash(SP); black cherry(L); eastern white pine(L); sweet birch(L); yellow poplar(L)
3	basswood(L); black locust(L); black cherry(M); sweet birch(M); yellow poplar(M)
4	American beech(SP); black oak(SP); blackgum(SP); buckeye(SP); chestnut oak(SP); hickory(SP); mockernut hickory(SP); northern red oak(SP); pignut hickory(SP); scarlet oak(SP); serviceberry(SP); sourwood(SP); southern red oak(SP); black oak(L); chestnut oak(L); cucumber-tree(L); hemlock(L); mountain magnolia(L); northern red oak(L); red maple(L); scarlet oak(L); silverbell(L); southern red oak(L); sugar maple(L); white ash(L); black locust(M); eastern white pine(M); black cherry(S); sweet birch(S); yellow poplar(S)
5	flowering dogwood(SP); striped maple(SP); white oak(SP); American beech(L); blackgum(L); buckeye(L); flowering dogwood(L); hickory(L); mockernut hickory(L); pignut hickory(L); serviceberry(L); sourwood(L); white oak(L); basswood(M); black oak(M); chestnut oak(M); cucumber-tree(M); mountain magnolia(M); northern red oak(M); red maple(M); scarlet oak(M); silverbell(M); southern red oak(M); sugar maple(M); white ash(M); black locust(S); American beech(RS)
6	holly(SP); sassafras(SP); holly(L); American beech(M); blackgum(M); buckeye(M); hemlock(M); hickory(M); mockernut hickory(M); pignut hickory(M); sourwood(M); white oak(M); eastern white pine(S); white ash(S); black cherry(SE); sweet birch(SE)
7	American hornbeam(SP); hophornbeam(SP); flowering dogwood(M); holly(M); serviceberry(M); basswood(S); black oak(S); chestnut oak(S); cucumber-tree(S); mountain magnolia(S); northern red oak(S); red maple(S); scarlet oak(S); silverbell(S); southern red oak(S); sugar maple(S); sassafras(RS)
8	American hornbeam(L); hophornbeam(L); sassafras(L); striped maple(L); American beech(S); blackgum(S); buckeye(S); flowering dogwood(S); hemlock(S); hickory(S); holly(S); mockernut hickory(S); pignut hickory(S); serviceberry(S); sourwood(S); white oak(S)

THE REGEN3 MODEL

The installation package for REGEN may be downloaded using the following link: https://www.srs.fs.usda.gov/uplandhardwood/tools/regen3/

1. Once REGEN3 is downloaded, right click the .exe file and select **Run** or **Run Elevated**, depending on your administrative privileges**.**
2. Follow the steps in the installation package. Click **Finish** when done.
3. To start REGEN3, double-click the **REGEN3** icon on your desktop.

When using REGEN3, the **F1** key will produce detailed help pages.

PRE-HARVEST INVENTORY COMPATIBLE WITH REGEN3

The spatial scale for REGEN3 is defined by the plot size used to inventory the regeneration layer prior to any harvest. ***REGEN3 will accommodate plot sizes between 0.0033 acre (1/300th acre; 6.8 ft. radius) and 0.01 (1/100th acre, 11.8 ft. radius).*** In addition to the dependence of model logic being on small plot sizes, the effort needed to enumerate regeneration sources on sample plots is kept manageable by this feature. In most cases, where data from multiple plots are available, results generated at the plot-level are aggregated to provide stand-level predictions of regeneration outcomes.

An inventory of regeneration sources must be completed prior to conducting any harvest. The plot size used during the pre-harvest inventory is selected by the user. As always, sampling intensity should vary based on variability. However, given the inherent variability of regeneration potential in upland hardwood forests, a minimum of one plot per acre is recommended.

During the inventory, all regeneration sources are tallied by species into the following four size classes (see Table 2):

1. Small: stems <2 feet tall
2. Medium: stems ≥2 feet and <4 feet tall
3. Large: stems ≥4 feet tall and <1.5” dbh
4. Stump sprout: For all stems ≥1.5” dbh, measure and record dbh (these stems will be used in the model to predict stump sprouting of overstory trees following harvest)

Table 2. Example of the procedures used pre-harvest inventory of regeneration.

Stand: MixedOak1		Plot size: 1/300th acre (6.8 ft. radius)		Date: 8/26/2019
Plot: #1				Crew: TK/JA
Species	# seedlings <2 ft. tall	# seedlings ≥2 ft. and <4 ft. tall	# seedlings ≥4 ft. and <3.8" dbh	Diameter of stems ≥1.5" dbh (separate dbh values by commas)
ACRU				4.5, 6.6
QURU				12.6
QUAL				
LITU				14.2

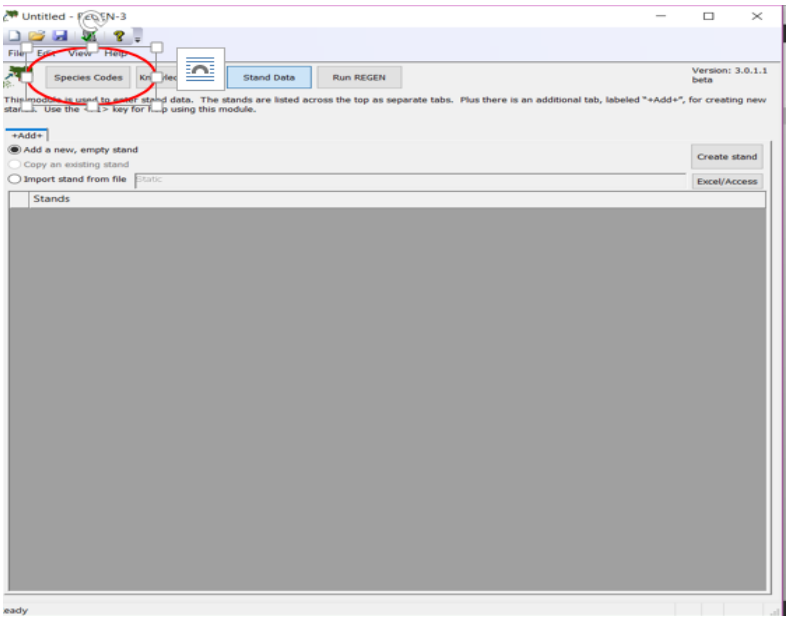
REGEN3 MODULES

There are four modules (tables) visible when REGEN is opened:

1. Species Codes
2. Knoweldgebases
3. Stand Data
4. Run REGEN

REGEN3 MODULE – SPECIES CODES

Navigate to the **Species Codes** tab. By default, a new REGEN3 file will contain REGEN3 mnemonic and numeric (FIA) codes. Users may also use the USDA Plants Database codes to enter species into REGEN3. Press F1 for a more detailed explanation of this module.

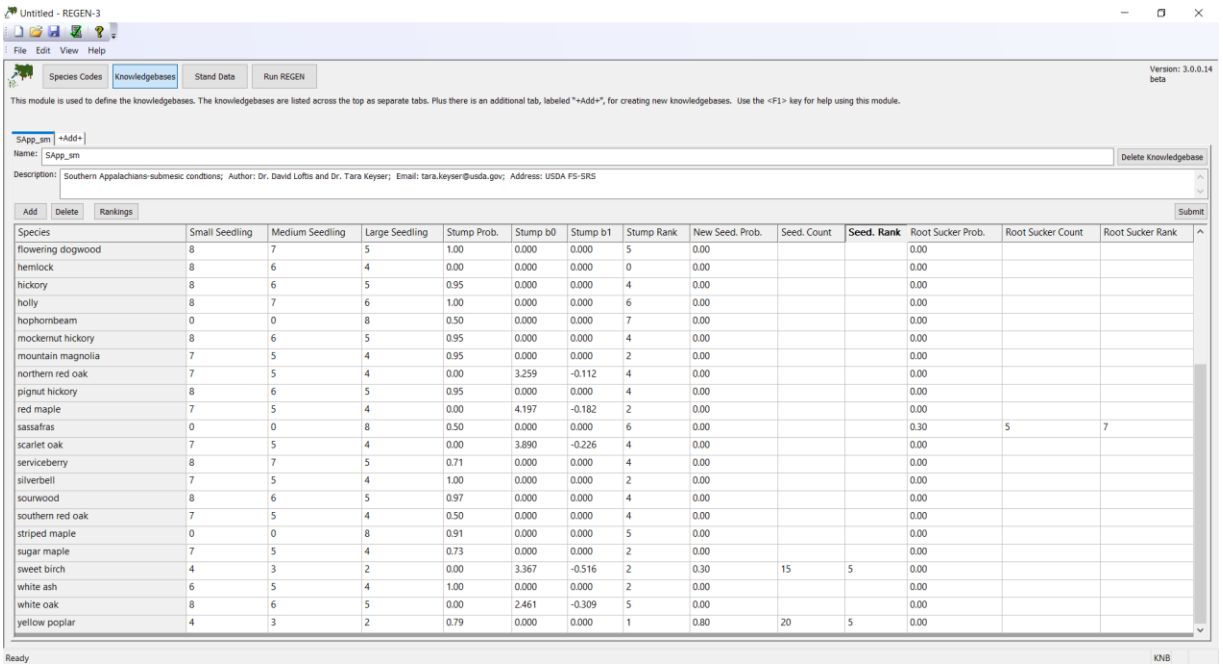


REGEN3 MODULE – KNOWELDGEBASES

There are nine, pre-loaded expert knoweldgebases (KBs) available for use in REGEN3. Knoweldgebases contain the parameters used to forecast species composition and are specific to the geographic area and site quality (xeric, subxeric, submesic, mesic) of the stand being modeled. Expert KBs are available for stands of various site qualities in the southern and central Appalachians and the southern and northern Cumberland Plateau. Although the definitions of xeric subxeric, submesic, and mesic vary across geographic areas, general guidelines are as follows:

1. Xeric = stands where site index for oak (SI_{oak}) (base-age 50) is less than 60 ft.
2. Subxeric = stands where (SI_{oak}) is between 60 and 75 ft.
3. Submesic = stands where (SI_{oak}) is between 75 and 85 ft.
4. Mesic = stands where (SI_{oak}) is greater than 85 ft.

The parameters included in a KB include rankings that describe the competitiveness of various regeneration sources, probability of stump sprouting, root suckering, and new seedling establishment, and the number of new seedlings and root suckers to add to the regeneration layer. For example, **figure 1** contains parameters specific to the SApp_sm KB. In this particular KB, the rank of small, medium, and large yellow-poplar advance reproduction is 4, 3, and 2, respectively. The probability of stump sprouting for yellow-poplar is 79% (0.79), and the rank of yellow-poplar stump sprouts is 1. Yellow-poplar is able to regenerate via new seedling establishment, with new seedling establishment on a given plot occurring at a probability of 80% (0.80). A total of 20 new yellow-poplar seedlings will be added to the plot, with a rank of 5. Parameters in the knowledgebase can be modified if expert opinion justifies changing a parameter. Changing a value of any parameter (by changing the value in a given cell) in the knowledgebase does not alter the original knowledgebase.



Species	Small Seedling	Medium Seedling	Large Seedling	Stump Prob.	Stump b0	Stump b1	Stump Rank	New Seed. Prob.	Seed. Count	Seed. Rank	Root Sucker Prob.	Root Sucker Count	Root Sucker Rank
flowering dogwood	8	7	5	1.00	0.000	0.000	5	0.00			0.00		
hemlock	8	6	4	0.00	0.000	0.000	0	0.00			0.00		
hickory	8	6	5	0.95	0.000	0.000	4	0.00			0.00		
holly	8	7	6	1.00	0.000	0.000	6	0.00			0.00		
hophornbeam	0	0	8	0.50	0.000	0.000	7	0.00			0.00		
mockernut hickory	8	6	5	0.95	0.000	0.000	4	0.00			0.00		
mountain magnolia	7	5	4	0.95	0.000	0.000	2	0.00			0.00		
northern red oak	7	5	4	0.00	3.259	-0.112	4	0.00			0.00		
pignut hickory	8	6	5	0.95	0.000	0.000	4	0.00			0.00		
red maple	7	5	4	0.00	4.197	-0.182	2	0.00			0.00		
sassafras	0	0	8	0.50	0.000	0.000	6	0.00			0.30	5	7
scarlet oak	7	5	4	0.00	3.890	-0.226	4	0.00			0.00		
serviceberry	8	7	5	0.71	0.000	0.000	4	0.00			0.00		
silverbell	7	5	4	1.00	0.000	0.000	2	0.00			0.00		
sourwood	8	6	5	0.97	0.000	0.000	4	0.00			0.00		
southern red oak	7	5	4	0.50	0.000	0.000	4	0.00			0.00		
striped maple	0	0	8	0.91	0.000	0.000	5	0.00			0.00		
sugar maple	7	5	4	0.73	0.000	0.000	2	0.00			0.00		
sweet birch	4	3	2	0.00	3.367	-0.516	2	0.30	15	5	0.00		
white ash	6	5	4	1.00	0.000	0.000	2	0.00			0.00		
white oak	8	6	5	0.00	2.461	-0.309	5	0.00			0.00		
yellow poplar	4	3	2	0.79	0.000	0.000	1	0.80	20	5	0.00		

Fig. 1. Knowledgebase parameters associated with the SApp_sm knowledgebase.

REGEN3 MODULE – STAND DATA

In the Stand Data module, users enter pre-harvest regeneration data in one of two ways: (1) directly into REGEN3 or (2) import the pre-harvest regeneration inventory data into REGEN3 from an Excel or Access file. Details related to the pre-harvest inventory are also pecified in the stand module, including regeneration plot size (default is 0.0100 acres) and site index (oak, base-age 50). Site index in the Stand Data module of regen REGEN is classified as low (<60 ft), medium (60-80 ft), and high (>80 ft), and is used to calculate density (stems/acre) statistics during the REGEN3 simulation. Specifically, REGEN3 selects 'winners' (stems that are dominant/co-dominant at crown closure (10 years) until a specific crown competition factor (CCF), based on site index, is achieved (Table 3; Krajicek et al. 1961). In general, the site index value used to calculate CCF cut-offs at canopy closure will be linked to the KB selected. For example, if a submesic or mesic KB is selected, the site index cut-off selected in the Stand Data module used to calculate the CCF cut-off will be high; subxeric KB will be medium; and a xeric KB will be low.

Also specified in the Stand Data module are whether or not potential regeneration from new seedling establishment should be included in the REGEN3 simulations. The Stand Data module is also where treatments that would alter the species composition and size distribution of the pre-harvest regeneration pool (e.g., site-preparation) are designed and specified.

Table 3. Crown competition factor (CCF) after a regeneration harvest in upland mixed-oak stands in the Central Hardwood Region. CCF values are 10-years post-harvest and represent the approximate time of canopy closure (Krajicek et al. 1961).

	SI_{oak}=60	SI_{oak}=70	SI_{oak}=80
CCF	219	190	166

REGEN3 MODULE – RUN REGEN

The Run REGEN3 module is the part of the model where the simulation is conducted. This module is where the user is able to specify the Forest Vegetation Simulator (FVS) variant that may be used to forecast stand development beyond canopy closure in FVS via the creation of an FVS keyword file. This module is where the main output produced by REGEN3 is displayed. The main output is a list of trees, by species, that survive and grow to attain dominant or co-dominant status at the time of canopy closure (assumed to be approximately 10 years post-harvest).

REGEN EXERCISE #1 – REGENERATING AN UNDISTURBED, UPLAND MIXED-HARDWOOD STAND WITHOUT SITE-PREPARATION TREATMENTS

In Exercise #1, we forecast species composition after a regeneration harvest in a mature (95 yr), previously undisturbed upland hardwood forest in western North Carolina. The stand is on a highly productive site, where site index for oak (base-age 50) is approximately 88 ft. The stand is typical of an undisturbed upland hardwood stand: basal area of all stems ≥1" dbh is 149 ft^2/acre, with 115 ft^2/acre of basal area in the overstory/sawtimber size class (stems ≥11" dbh) and 34 ft^2/acre of basal area in the midstory size class (stems ≥1.5" and <11" dbh).

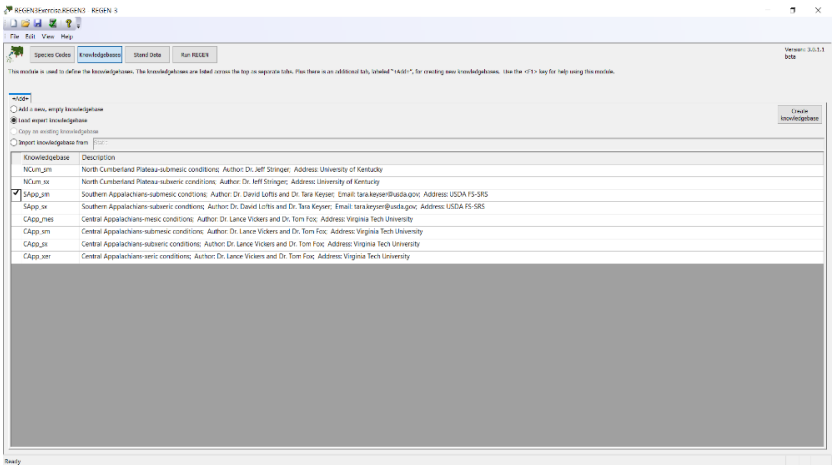
Prior to the planned two-aged regeneration harvest (where the harvest will leave 30 ft^2/acre of residual basal area), an inventory of the overstory, midstory, and regeneration layers was conducted. Sampling points were systematically located across the 10 acre stand at an intensity of one plot per acre (10 plots total). At each sampling point, stems ≥5" dbh were inventoried (species and dbh recorded) using a 20-factor prism. The regeneration potential of the stand was assessed using a 0.01 acre (11.8 ft. radius) plot at each sampling point. On each 0.01 acre plot, species were inventoried using the protocol outlined in the "Pre-harvest inventory compatible with REGEN3" section (page 4). No site-preparation activities are planned for this stand prior to, or following the regeneration harvest. The goal is to regenerate a mixed-hardwood stand that contains a substantial oak component.

EXERCISE #1: CREATE A PROJECT FILE

1. Open REGEN3 by double-clicking the **REGEN3** icon on your desktop.
2. Save the REGEN3 project as **REGEN3Exercise.REGEN3** (File > Save As > XXXXXX > REGEN3Exercise.REGEN3).
3. ***Remember to save the project file periodically throughout each exercise.***

EXERCISE #1: SELECT A KNOWLEDGEBASE

1. Navigate to the **Knoweldgebases** module.
2. Click **Load expert knowledgebase**.
3. For all three exercises, we will use the KB specific to upland hardwood forests in the southern Appalachians on submesic sites (SApp_sm).
4. Select the SApp_sm KB by double-clicking the blank column to the left of the SApp_sm KB.
5. Click **Create knowledgebase**. The parameters associated with the SApp_sm KB will be displayed.



EXERCISE #1: ENTER PRE-HARVEST INVENTORY DATA INTO REGEN3

1. In this exercise, the pre-harvest regeneration inventory data will be directly entered into REGEN3.
2. Navigate to the Stand Data module
3. Ensure the radio button for "Add a new, empty stand" is selected. And click **Create stand**.
4. Type **Undisturbed mixed hardwood – no site prep** in the Name: column
5. Make sure the plot size is set to 0.0100 ($1/100^{th}$ acre regeneration subplot).
6. Using the site index dropdown menu, select **high.** This will force the model to select individual stems until a CCF of 160 (Table 3) is achieved during the model run.
7. In the Description section, type: **Species composition following a regeneration harvest (2-aged with 30 ft^2/acre of residual basal area) without any site-preparation treatments prior to, or following the harvest. This 10 acre stand contains 10, 0.01 acre regeneration plots.**
8. To enter the pre-harvest inventory of plot #1, click **Add** under the **Plot Data** tab. Enter the following pre-harvest regeneration data into REGEN3 (don't forget to save periodically through data entry process to ensure information is not lost). When entering DBH values into the Stump Sprout DBH list, separate multiple values by a comma. Order in which DBH values are entered do not matter.
9. To add additional lines to a given plot, ensure that plot is listed and click **Add.**
10. To add new plots (there are 10 plots to enter for this stand), use the **Plot:** dropdown menu and select **Add plot** and then click **Add.**

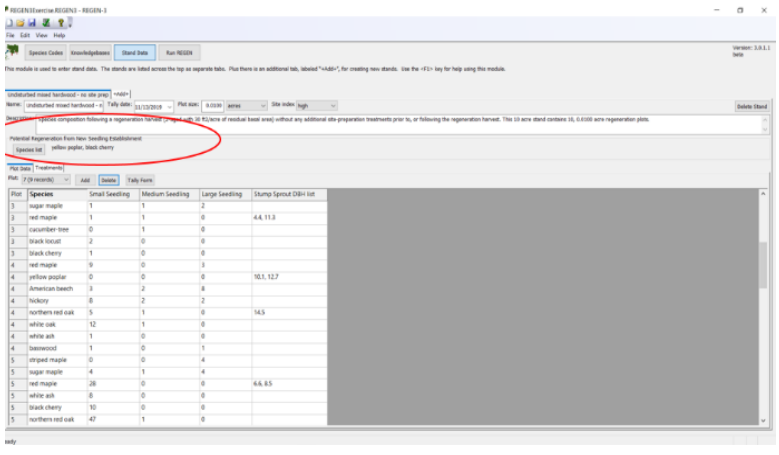
Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
1	HALES	1		17	3.3
1	ACRU	4			5.5, 4.6
1	CARYA	6			
1	PRSE2	4			
1	QURU	3			
1	FRAM2	2			
1	ACPE	5		1	
1	QUAL	3			
2	ACSA3				9.8
2	ACPE			1	
2	FRAM2			4	
2	QURU	12	1		
2	ACRU	5	1	5	
2	CARYA	10		2	14.4
3	FRAM2	3	5	4	

Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
3	HALES				6.6, 7.3, 2.5
3	QURU	19			
3	CARYA	4	4	3	
3	ACSA3	1	1	2	
3	ACRU	1	1		4.4, 11.3
3	MAAC		1		
3	ROPS	2			
3	PRSE2	1			
4	ACRU	9		3	
4	FAGR	3	2	8	
4	CARYA	8	2	2	
4	QURU	5	1		14.5
4	QUAL	12	1		
4	FRAM2	1			
4	TILIA	1		1	
4	LITU				10.1, 12.7
5	ACPE			4	
5	ACSA3	4	1	4	
5	ACRU	28		3	6.6, 8.5
5	FRAM2	8			
5	PRSE2	10			
5	QURU	47	1		
5	OSVI	1			
5	QUVE	3			
5	CARYA	3			
6	QUPR2	32	1		
6	ACRU	1		3	9.7, 10.5
6	SAAL5	6	1	1	
6	CARYA	2			
6	LITU	3			17.4
6	QURU	11			

Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
6	QUVE	1			14.9
6	PRSE2	2	2		
7	ACSA3	1	2	1	5.5
7	FRAM2	5			
7	ACRU	15		5	
7	CARYA	1	1		10.1
7	QUPR2	25	1		15.4
7	SAAL5	1		1	
7	AMELA	3	2		
7	QUAL	9	1		16.6
7	LITU	1			14.2, 11.9
8	SAAL5	23		1	
8	QURU	24			
8	ACSA3			1	
8	QUPR2	12			14.5
8	QUVE	4			
8	CARYA	3			
8	ACRU	18		4	8.7, 6.9, 7.4
8	MAAC	2			
8	PRSE2	1			
9	LITU	2			16.5
9	FRAM2	11	4	7	
9	ACRU	23		6	9.8,4.4
9	CARYA	4			
9	PRSE2	2			
9	NYSY			1	8.7
9	TILIA		1		
9	COFL2	2			4.5, 5.7
9	ACPE	2	1	3	3.3
9	QUVE	14			12.6
9	QUAL	9	1		

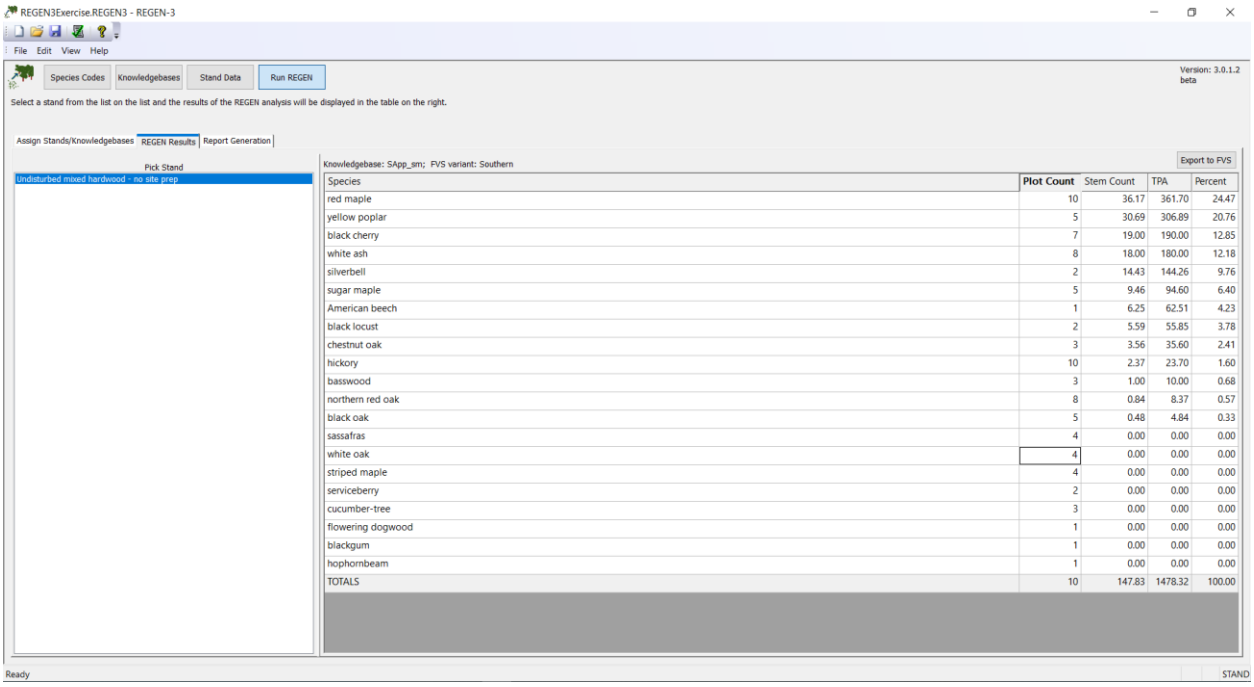
Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
10	ACRU	8	4	3	6.3
10	CARYA	4		1	
10	QUVE	4			
10	SAAL5	4	1	1	
10	LITU	3	1		12.5
10	FRAM2	3	2	3	
10	ROPS		3		
10	PRSE2		3	1	
10	AMELA		1		
10	QURU	18			13.3
10	TILIA		1		
10	MAAC	2			

11. The next step in the process is to select whether or not new seedling establishment (for those species capable of regenerating from newly established seedlings soon after disturbance) will be included in the model simulation. In upland hardwood forests on high-quality stands (e.g., submesic), such as this stand, there are three species that are capable of regenerating successfully (i.e., being in the dominant/co-dominant canopy positions at the time of crown closure) after a stand-replacing disturbance. These include:
    a. Yellow-poplar (*Liriodendron tulipifera*)
    b. Sweet birch (*Betula lenta*)
    c. Black cherry (*Prunus serotina*)
12. In this stand, seed sources for two species are present within the stand as per the inventory: black cherry and yellow-poplar. Consequently, the model simulation will include new seedling establishment from these two species. To include these two species in the simulation, click **Species list** located under the **Potential Regeneration from New Seedling Establishment** header. Check **black cherry and yellow poplar**. Click **Ok**. Under the **Potential Regeneration from New Seedling Establishment** header, yellow poplar and black cherry should now be listed.



EXERCISE #1: RUN REGEN3

1. Click the **Run Regen** module.
2. There are three tabs: Assign Stands/Knowledbases; REGEN Results, and Report Generation.
3. Navigate to the **Assign Stands/Knowledbases** tab.
4. Right-click on the empty cell next to the Undisturbed mixed hardwood-no site prep stand. Three FVS variant choices will be listed: Southern, Northeastern, and Lake States. The stand used in this exercise is in western North Carolina; an area within the footprint of the Southern variant of FVS. Therefore, after right-clicking the empty cell, select **Southern**.
5. To view the results of the simulation, click the **REGEN Results** tab under the Run REGEN module.
6. The table displayed represented the forecasted number of stems per acre in the dominant/co-dominant canopy positions after the simulated two-aged regeneration harvest at the time of canopy closure, which in REGEN3 is 10 years.
7. For the Undisturbed mixed hardwood-no site prep stand, the regenerated stand (10 years post-harvest) is estimated to be 24.5% red maple, 20.8% yellow-poplar, 12.9% black cherry, 12.2% white ash, 9.8% silverbell, and 6.4% sugar maple.
8. If the regeneration results produced by exercise #1 are needed to model stand dynamics beyond 10 years post-harvest, click **Export to FVS**. This will produce a keyword file that contains the regeneration results (species and stems/acre) that can be copied and pasted into FVS.
9. Was the goal to regenerate an upland hardwood stand that contained a substantial oak/hickory achieved? NO!! The most abundant oak was chestnut oak, which comprised only 2.4% of the dominant/co-dominant stems 10 years post-harvest.
10. What additional steps could be taken to increase the abundance of oak and hickory and/or modify the species composition in the regenerated stand? – **Proceed to exercise #2 to find out!**



REGEN EXERCISE #2 – REGENERATING AN UNDISTURBED, UPLAND MIXED-HARDWOOD STAND WITH SITE-PREPARATION TREATMENTS

The same stand data used in Exercise #1 will be used in Exercise #2. The goal is to regenerate a mixed-hardwood stand that contains a substantial oak component. Because the regeneration harvest without any additional site-preparation activities did little to promote oak after the regeneration harvest, this exercise will forecast species composition under the same regeneration harvest (two-aged with 30 ft^2/acre of residual basal area) with additional site-preparation activities.

Site-preparation activities are treatments that manipulate a site in efforts to enhance the success of regeneration prior to or immediately after a harvest. Treatments can include bedding (pines), burning, chemical spraying, chopping, disking, drainage, raking, and scarifying and are designed to modify the soil, litter, or vegetation in such a manner that is more conducive to the regeneration of desired species. REGEN3 is limited in the site-preparation treatments it can model. In this exercise, we will conduct a targeted herbicide treatment (basal spray and hack and squirt) of some of the undesirable species and regeneration sources in an effort to increase the success of oak and hickory species.

EXERCISE #2: ENTER PRE-HARVEST INVENTORY DATA

1. Because we are using the exact same stand data as used in exercise #1, a copy of the existing stand data (Undisturbed mixed hardwood – no site prep) will be used. Similarly, the same KB used in exercise #1, will be used in exercise #2, so no change in the knowledgebase module is necessary.
2. Navigate to the **Stand Data** module.
3. Click the **+Add+** tab next to the stand name.
4. Select **Copy and existing stand**.
5. Ensure the Undisturbed mixed hardwood – no site prep stand is checked.
6. Click **Create stand**. This should create a duplicate stand.
7. We need to change the name of the duplicate stand. To do so, change the Name: **Undisturbed mixed hardwood – with site prep**.
8. Change the Description: **Species composition following a regeneration harvest (2-aged with 30 ft2/acre of residual basal area) with site-preparation treatments. This 10 acre stand contains 10, 0.01 acre regeneration plots.**

EXERCISE #2: IMPLEMENT THE SITE-PREPARATION TREATMENTS

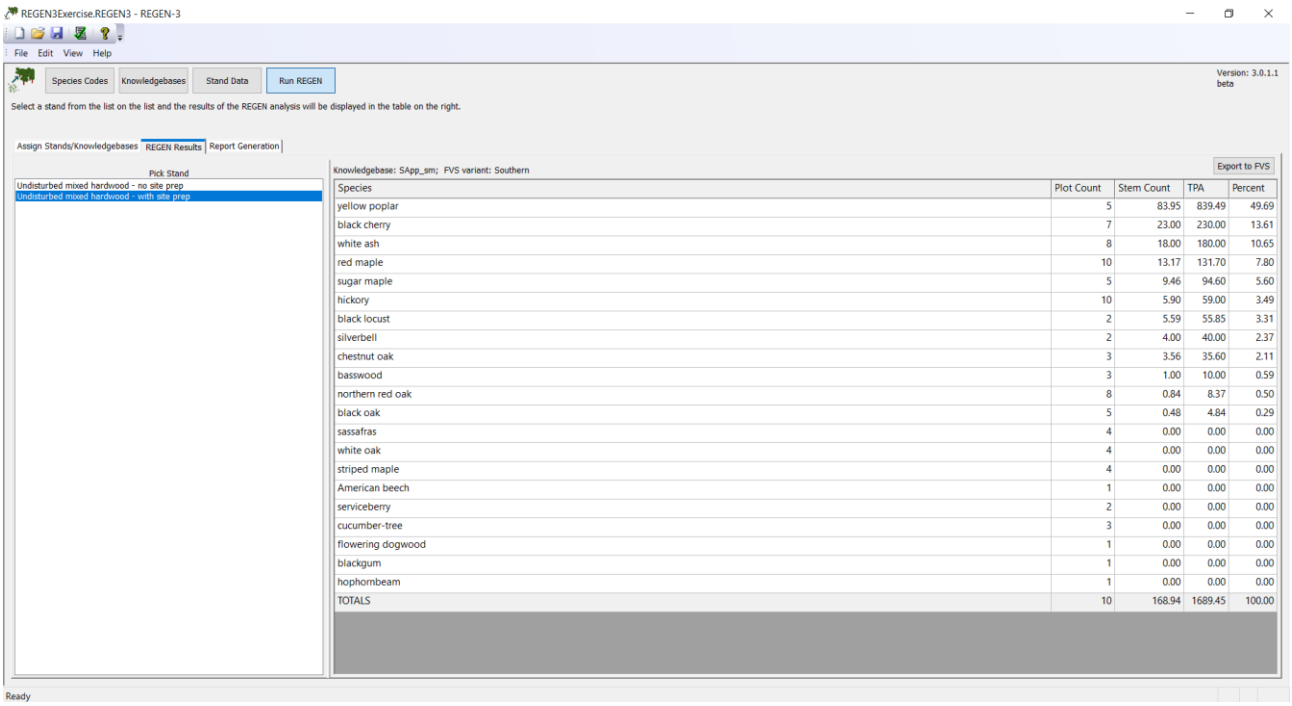
1. Navigate to the **Stand Data** module. Click the **Treatments** tab. This screen allows users to remove regeneration sources by mimicking a hack and squirt herbicide application (stems with a DBH value) and basal herbicide application to individual seedlings.
2. Based on the species composition following harvest in exercise #1, the herbicide treatments will focus on removing the regeneration potential from undesirable species in the large seedling and stump sprout potential size classes. Undesirable species will be: American beech, red maple, silverbell, yellow-poplar, striped maple, blackgum, and sassafras.

3. In the treatments tab, navigate to the silverbell. Here, type **1.00 in the Lg. Seed.** column and **1.00 in the Stump spr.** column. N*ote: a 100% probability of removal can be entered as 100 or 1.00; similarly a 75% probability of removal can be entered as 75 or 0.75*. These numbers tell REGEN3 to remove 100% of the large silverbell seedlings (basal herbicide application) and 100% of all potential stump sprouting trees (hack and squirt herbicide application). Alter the regeneration pool of the following species and regeneration sources by entering the removal percentages specified in the table below:

Species	Sm. Seed.	Med. Seed.	Lg. Seed.	Stump spr.
American beech			1.00	0.75
blackgum			1.00	0.50
red maple			1.00	0.75
sassafras			1.00	
silverbell			1.00	1.00
striped maple			1.00	0.75
yellow poplar				0.50

EXERCISE #2: RUN REGEN

1. Click the **Run Regen** module.
2. There are three tabs: Assign Stands/Knowledbases; REGEN Results, and Report Generation.
3. Navigate to the **Assign Stands/Knowledbases** tab.
4. Right-click on the empty cell next to the Undisturbed mixed hardwood-no site prep stand. Three FVS variant choices will be listed: Southern, Northeastern, and Lake States. The stand used in this exercise is in western North Carolina; an area within the footprint of the Southern variant of FVS. Therefore, after right-clicking the empty cell, select **Southern**.
5. Navigate to the **REGEN Results** table.
11. In the **Pick Stand** section, select the stand used in exercise #2: **Undisturbed mixed hardwood – with site prep**.
12. The table displayed represented the forecasted number of stems per acre in the dominant/co-dominant canopy positions after the simulated two-aged regeneration harvest with site-preparation treatments at the time of canopy closure, which in REGEN is 10 years.
13. For the Undisturbed mixed hardwood-with site prep stand, the regenerated stand (10 years post-harvest) is estimated to be 49.7% yellow-poplar, 13.6% black cherry, 10.7% white ash, 7.8% red maple, 5.6% sugar maple, and 3.5% hickory.



14. If the regeneration results produced by exercise #2 are needed to model stand dynamics beyond 10 years post-harvest, click **Export to FVS**. This will produce a keyword file that contains the regeneration results (species and stems/acre) that can be copied and pasted into FVS.
15. Was the goal to regenerate an upland hardwood stand that contained a substantial oak/hickory achieved?
    a. NO! Even with the additional site-preparation treatments, the most abundant oak was chestnut oak, which comprised only 2.1% of the dominant/co-dominant stems 10 years post-harvest. Although the site-preparation treatments eliminated much of the competitive red maple that dominated the stand without site-preparation activities (exercise #1), oak was still not successful. Instead, yellow-poplar dominates the stand. This is due to (1) the removal of much of the large seedling and stump sprout origin red maple which facilitated the recruitment of seed-origin yellow-poplar (i.e., large seedling and stump sprout origin red maple are more competitive than seed-origin yellow-poplar (*examine the KB and rankings*); and (2) the stand lacked large oak seedlings in the stand prior to the harvest.
    b. Take home: To be competitive following a regeneration harvest, oak seedlings must not only be present in a stand prior to harvest, but they must be sufficiently large (i.e., in the large seedling category) to compete with the numerous other regeneration sources typical of upland hardwood forests in the South.

REGEN EXERCISE #3 – REGENERATING AN UPLAND MIXED-HARDWOOD STAND THAT HAD PREVIOUSLY RECEIVED A MIDSTORY REMOVAL PRIOR TO HARVEST WITH SITE-PREPARATION TREATMENTS

In exercise #3, we forecast species composition after a regeneration harvest in a mature (95 yr) upland hardwood forest in western North Carolina. Unlike the stand used in exercises #1 and #2, this stand had received a midstory removal treatment 10 years prior to the planned regeneration harvest (*note REGEN3 was not used to implement this midstory removal treatment, rather REGEN3 is being used to examine the regeneration outcomes that may result from this type of treatment prior to the regeneration harvest*).

The stand is on a highly productive site, where site index for oak (base-age 50) is approximately 90 ft. The stand is atypical of an upland hardwood stand in the region. Basal area of all stems ≥1" dbh is 102 ft^2/acre, with almost all basal area (95 ft^2/acre) in the overstory/sawtimber size class (stems ≥11" dbh). Due to the removal (via hack and squirt herbicide application) of all stems between 1 and 10" dbh 10 years ago, the midstory size class (stems ≥1.5" and <11" dbh) contains only 7 ft^2/acre of basal area. The result of this midstory removal 10 years ago was an increase in light in the understory, which facilitated the development of large oak and hickory seedlings in the regeneration layer. Unfortunately, the increased light also facilitated the development of large seedlings of undesirable species, too. Consequently, site-preparation treatments will be implemented in an effort to control competition between these undesirable species and desirable oak and hickory species.

Prior to the planned two-aged regeneration harvest (where the harvest will leave 30 ft^2/acre of residual basal area), an inventory of the overstory, midstory, and regeneration layers was conducted. This inventory was conducted 10 years after the midstory removal treatment occurred. Sampling points were systematically located across the 30 acre stand at an intensity of one plot per acre (30 plots total). At each sampling point, stems ≥5" dbh were inventoried (species and dbh recorded) using a 20-factor prism. The regeneration potential of the stand was assessed using a 0.01 acre (11.8 ft. radius) plot at each sampling point. On each 0.01 acre plot, species were inventoried using the protocol outlined in the "Pre-harvest inventory compatible with REGEN" section (page 4). The goal is to regenerate a mixed-hardwood stand that contains a substantial oak component. To expedite data entry for this exercise, data from only 7 of the 30 plots will be used.

EXERCISE #3: ENTER PRE-HARVEST INVENTORY DATA

1. Exercise #3 will use the same SApp_sm KB used in exercises #1 and #2. Therefore, no further action related to the **Knowledgebase module** is required.
2. In Exercise #3, the pre-harvest regeneration inventory data will be directly entered into REGEN3
3. Ensure the radio button for "Add a new, empty stand" is selected. And click **Create stand**.
4. Type **Midstory removal mixed hardwood – with site prep** in the Name: column
5. Make sure the plot size is set to 0.0100 (1/100th acre regeneration subplot).
4. Using the site index dropdown menu, select **high.** This will force the model to select individual stems until a CCF of 160 (Table 3) is achieved during the model run.
5. Type in the Description: **Species composition following a regeneration harvest (2-aged with 30 ft2/acre of residual basal area) with site-preparation treatments. The regeneration harvest is**

being conducted 10 years after a midstory removal treatment implemented via hack and squirt herbicide application.

6. To enter the pre-harvest inventory of plot #1, click **Add** under the **Plot Data** tab. Enter the following pre-harvest regeneration data into REGEN3. To add additional lines to a given plot, ensure that plot is listed and click **Add.**
7. To add new plots (there are 7 plots to enter for this stand), use the **Plot:** dropdown menu and select **Add plot** and click **Add.**

Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
1	HALES	2		5	2.1, 2.2
1	ACRU	9	4	2	1.9
1	QURU	5	3	4	13.3, 1.6
1	QUAL	2	2	3	
1	LITU	3			15.8
1	PRSE2	2			
1	FRAM2	3	3	2	1.6, 1.8
1	CARYA	2	1	1	
1	ACPE		3	5	
2	ACPE	3	4	2	1.6, 1.7
2	QURU	4	2	3	1.8
2	LITU	4	1		12.4
2	ACRU	3	1	3	1.8, 1.9
2	QUVE	1	1		
2	AMELA	3	1		
2	MAFR			1	
3	ACSA3	3	1	1	1.6, 1.6, 1.7
3	HALES		1	3	
3	TILIA			1	
3	ACPE			3	1.5
3	QURU	2	2	4	1.5, 16.3
3	LITU	4	1	1	
3	AMELA	3	2		
3	OSVI	1	1		
3	COFL2			1	

Plot	Species	Small seedling	Medium seedling	Large seedling	Stump Sprout DBH list
4	QUAL	17	1	2	15.5, 13.2
4	QUPR2	8	2	4	14.4
4	NYSY	3		1	
4	SAAL5		3	4	
4	FRAM2	4	2	2	1.5, 1.5
4	CARYA		2	3	1.5
5	LITU	2	2	1	1.6, 12.1
5	PRSE2	1	1	1	
5	ACRU	18	1	3	1.5, 1.8, 2.1, 11.1
5	ACSA3		2	2	2.1, 10.2
5	ACPE	1	4	4	
5	QURU	4	3	4	1.5, 13.2, 1.8
5	OSVI	1	1		
5	CARYA	2	1	2	1.8
6	NYSY			3	
6	QUVE	2	2	3	1.5, 1.6, 12.4
6	QUAL		1	1	14.3
6	ACRU			9	2.2, 10.3, 2.4, 1.5
6	ACPE				1.9
6	PRSE2	3	1		
7	QUVE		4	1	
7	LITU	6	1	2	15.1
7	PRSE2	3			14.1
7	HALES		3	3	1.6, 1.7, 2.1
7	ACPE			1	
7	ACSA3	7	2	1	1.8, 10.4
7	QURU	25	1		1.5
7	QUAL		3		
7	OSVI			3	

13. In this stand, seed sources for two species are present within the stand as per the inventory: black cherry and yellow-poplar. Consequently, the model simulation will include new seedling establishment from these two species. To include these two species in the simulation, click **Species list** located under the **Potential Regeneration from New Seedling Establishment** header. Check **black cherry and yellow poplar**. Click **Ok**. Under the **Potential Regeneration from New Seedling Establishment** header, yellow poplar and black cherry should now be listed.

EXERCISE #3: IMPLEMENT THE SITE-PREPARATION TREATMENTS

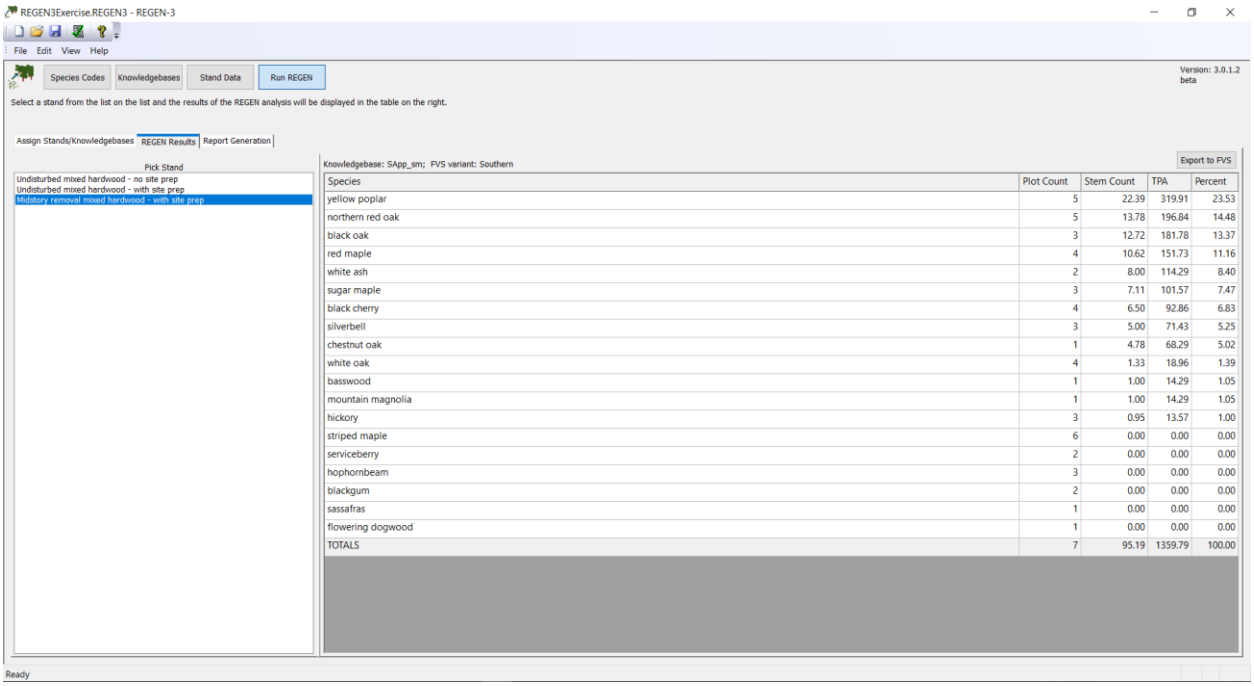
1. In the **Stand Data** module, click the **Treatments** tab. This screen allows users to remove regeneration sources by mimicking a hack and squirt herbicide application (stems with a DBH value) and basal herbicide application to individual seedlings.
2. Based on the number of stems of undesirable species in the large seedling and stump sprout potential size classes in response to the previous midstory removal treatment, the herbicide treatments will focus on removing the regeneration potential from undesirable species in the large seedling and stump sprout potential size classes. Undesirable species will be: American beech, red maple, silverbell, yellow-poplar, striped maple, blackgum, and sassafras.
8. In the treatments tab, alter the regeneration pool of the following species and regeneration sources by entering the removal percentages specified in the table below:

Species	Sm. Seed.	Med. Seed.	Lg. Seed.	Stump spr.
blackgum			1.00	0.50
red maple			1.00	0.75
sassafras			1.00	
silverbell			1.00	1.00
striped maple			1.00	0.75
yellow poplar			1.00	0.50

EXERCISE #3: RUN REGEN3

1. Click the **Run Regen** module.
2. There are three tabs: Assign Stands/Knowledbases; REGEN Results, and Report Generation.
3. Navigate to the **Assign Stands/Knowledbases** tab.
4. Right-click on the empty cell next to the Undisturbed mixed hardwood-no site prep stand. Three FVS variant choices are listed: Southern, Northeastern, and Lake States. The stand used in this exercise is in western North Carolina; an area within the footprint of the Southern variant of FVS. Therefore, after right-clicking the empty cell, select **Southern**.
5. Navigate to the **REGEN Results** table.
6. In the **Pick Stand** section, select the stand used in exercise #3: **Midstory removal mixed hardwood – with site prep**.

7. The table displayed represented the forecasted number of stems per acre in the dominant/co-dominant canopy positions after the simulated two-aged regeneration harvest with site-preparation treatments at the time of canopy closure, which in REGEN3 is 10 years.
8. For the Midstory removal mixed hardwood – with site prep stand, the regenerated stand (10 years post-harvest) is estimated to be 23.5% yellow-poplar, 14.5% northern red oak, 13.4% black oak, 11.2% red maple, 8.4% white ash, and 7.5% sugar maple.



9. Was the goal to regenerate an upland hardwood stand that contained a substantial oak/hickory achieved?
    a. YES! Oak comprised a substantial component of this stand. This is due to the presence of large seedlings present in the stand at the time of harvest. These large oak seedlings developed in response to the midstory removal treatment conducted 10 years prior to the regeneration harvest. The abundance of oak after the regeneration harvest is also due to the site-preparation treatments that removed undesirable competing competition (e.g., red maple and striped maple) that also developed in response to the midstory removal treatment.
10. If the regeneration results produced by exercise #3 are needed to model stand dynamics beyond 10 years post-harvest, click **Export to FVS**. This will produce a keyword file that contains the regeneration results (species and stems/acre) that can be copied and pasted into FVS.

EXPORTING REGEN3 SIMULATION DOCUMENTATION

1. Detailed reports that document the specifics of each model simulation can be generated and saved.
2. To generate a detailed report, navigate to the **Run REGEN** module.
3. Click the **Report Generation** tab.
4. A list of reports available is displayed. By default, available reports are selected. To unselect a specific report, click the checked-column next to the unnecessary report. For this exercise, keep all default checked reports.
5. Under the **Report Generation** tab, click **Folder** and navigate to the folder where reports will be saved.
6. Click **Select Folder**.
7. Click **Generate Reports**. Navigate to the user-specified folder and verify the reports are present.

LITERATURE CITED

Boucugnani, D.A. 2005. REGEN AGENT: A modular and generalized forest regeneration agent (Unpublished master's thesis). University of Georgia, Athens, GA.

Egler, F.E. 1954. Vegetation science concepts I. Initial floristic composition: A factor in old-field vegetation management. Vegetatio 4: 412-417.

Krajicek, J.E., Brinkman, K.A., Gingrich, S.F. 1961. Crown competition – a measure of density. Forest Science 7: 35-42.

Noble, I.R., Slatyer, R.O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43: 5-21.

Vickers, L.A., Fox, T.H., Loftis, D.L., Boucugnani, D.A. 2011. Predicting forest regeneration in the central Appalachians using the REGEN expert system. Journal of Sustainable Forestry 30: 790-822.

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