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A Risk-Based Method For Estimating The Carbon Sequestration Budget For a Mixed Hardwood Forest

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A RISK-BASED METHOD FOR ESTIMATING THE CARBON SEQUESTRATION BUDGET FOR A MIXED HARDWOOD FOREST

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ABSTRACT.

Carbon Dioxide (CO_2) levels in the atmosphere have risen from approximately 310 ppm in the 1950's to over 400 ppm as of 2015. This rise in CO_2 has likely resulted in the observed warming trend of the earth's atmosphere in the same time frame, causing significant concern in the scientific community. Several mitigation strategies have arisen to combat the upward trend of CO_2 emissions in recent decades, among them being carbon sequestration- the process of capturing CO_2 from the atmosphere and holding it for an extended period of time. This study used the U.S. Forest Service Tree Carbon Calculator (CTCC) to calculate the annual rate of CO_2 sequestration, the total mass of CO_2 stored, and the total above ground biomass of the SEFOR Land Holdings of the University of Arkansas. This unmanaged 243 hectare land area lies south of the University of Arkansas near the Ozark National Forest and consists mainly of hardwood tree species. The objectives of this exploration included gathering data on a representative sampling of the land holdings, characterizing the data into sub-groups, modeling sequestration rates using CTCC, and developing probability distributions of the sequestration and carbon storage potentials of the area. These results could then be used in land use valuation for the purposes of offsetting carbon emissions from a designated geography. This article details and develops a strategy for balancing the carbon budget of Northwest Arkansas. By using @Risk probability distribution software, it was determined that the SEFOR area sequesters, with 95% certainty, more than 10,087 metric tons of CO_2 per year. In 2013, the University of Arkansas produced approximately 145,000 metric tons of CO_2. Without forest management the SEFOR land holdings sequestered nearly 7% of the University's carbon emissions, with proper forest management and larger land area, this could be improved to offset the University's emissions. Proper forest management could have significant impacts on carbon offset in the future.

INTRODUCTION

According to the 2014 Intergovernmental Panel on Climate Change's (IPCC) Synthesis Report published in 2015, anthropogenic influences on our climate are clear, distinct, and unprecedented in their rate of change. The IPCC states that they are 95 percent certain that greenhouse gas emissions by humans are the cause of global warming. The IPCC found that it is extremely likely that humans have caused the approximately 0.6°C rise in average air temperatures since the 1950's, and that we have accelerated the rate of warming well beyond natural warming levels. The IPCC stated clearly that maintaining global temperature rise to less than 2°C is crucial to avoiding devastating climate and societal effects. Much of this warming can be attributed to increased levels of CO_2 in the atmosphere. Prior to the 1900's and for the at least 800,000 years before that, CO_2 levels rested at about 280 ppm (IPCC, 2015). In 2016, the world permanently crossed the 400 ppm threshold. These changes can and will have serious effects on societal growth and development, and finding ways to control the CO_2 concentration in the environment has become of primary concern for policy makers, industries, and municipalities. One of the Research Goals of the National Climate Assessment was to identify mitigation options that reduce the risk of longer-term climate change (NCA, 2016).

One of the proposed solutions to the rise in climate change is forest carbon sequestration. Trees take in CO_2 and release O_2 during the process of photosynthesis, transferring the carbon into biomass. Because of this, forests can store considerable amounts of carbon and serve as a sink for carbon emissions. Currently, U.S. Forests offset approximately 16% of U.S. emissions from burning fossil fuels. To enhance this value, the Climate Change Resource Center advises avoiding further deforestation, actively reforesting historically forested areas and post-fire regions, and promoting long-lived forest products (Ryan, Birdsey, & Hines, 2012). The question becomes, how do we take advantage of this process to maximize sequestration benefits for carbon budgets?

The process of forest carbon sequestration can be incorporated into a carbon budget for institutions. Carefully managed stands of trees can serve to sink institutional carbon emissions. By utilizing the natural sequestration that occurs in trees, institutions can offset some of their emissions, knowing that some of the CO_2 they produce is trapped within the woody biomass of the stand. For example, the University of Arkansas Climate Action Plan, published to detail the University's steps to achieve a more energy and resource efficient future, states that the University used approximately 145,000 metric tons of CO_2 equivalent in 2013 (University of Arkansas, 2014).

The goals of this study were to (1) develop a robust data collection and carbon modeling method for the SEFOR Land Holdings of the University of Arkansas and (2) apply the findings of the model to the carbon budget of the University of Arkansas, Arkansas and how proper forest management could aid Northwest Arkansas and other areas in reducing their carbon footprint.

METHODS

DATA COLLECTION

The area surveyed was the University of Arkansas' SEFOR land holdings. This area is northwest of the Ozark National Forest and consists mainly of hardwood tree species. The land holdings parcel data were acquired from the Center for Advanced Spatial Technologies (CAST) office of the University of Arkansas. ArcGIS software was used to create a 36" by 48" map of the parcel data with the latitude and longitude lines as X and Y axes of the region. The map covered the area from 35° 49' 35" to 35° 50' 42" N and 94° 17' 35" to 94° 16' 13" W. The imagery of the map was then used to divide the University owned parcels into 12 non-uniform sections. The sections were defined by natural changes across the landscape. Streams, grassy areas, and changes in canopy density (determined by darker colorations of aerial imagery) were used as section borders. After the sections were set, ArcGIS was used to approximate the acreage of each of the 12 sections. The map of the SEFOR area including the section delineations is given in figure 1. Based on information from the USDA on designing ecological sampling protocols, one transect was assigned per every 10 acres of section area (USDA, 2003). For each section, a coordinate system was created using the latitude and longitude increments that spanned the width and height of the section (Wilson, 2005), and then a compass direction was chosen at random. Each transect in that particular section followed the same compass direction to keep each transect parallel (USDA, 2003), but not every section's transects ran in the same compass direction. Transects were spaced out as evenly as possible. The random number generator function in Excel was used to select transect starting points. Any points that fell outside the boundary, would run outside the boundary towards the end of the transect length, or created transects that ran too close to one another, were discarded until each section had the correct number of transects (Wilson, 2005). For example, Section 2 was 33.7 hectares (83.3 acres) and 8 transects were assigned that ran to the southeast. In all, 60 transects were assigned across the 12 sections.

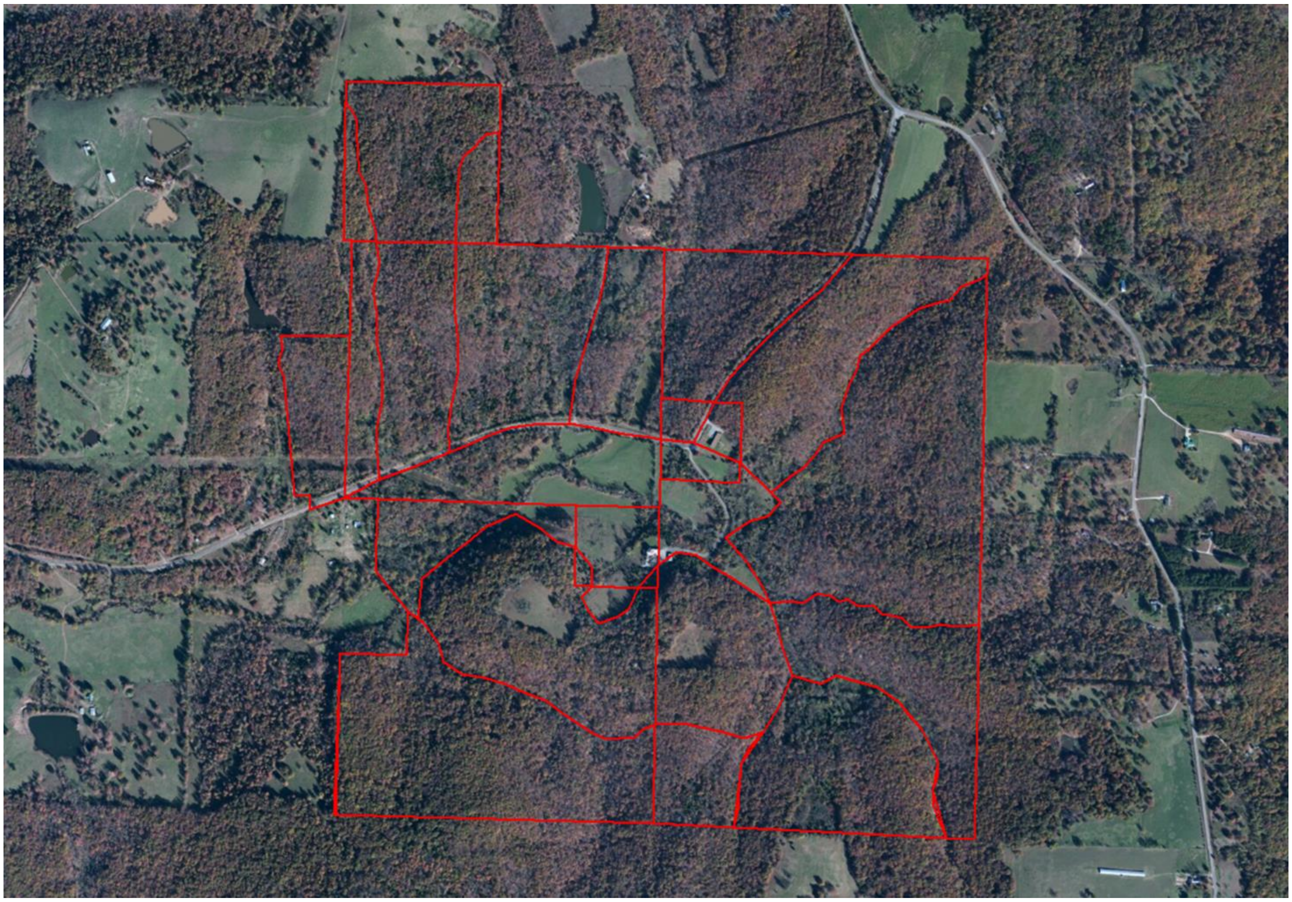


Figure 1. Arial imagery of the SEFOR Land Holdings, showing square parcels as well as division lines along which the sections were separated

Once all of the starting points were selected, hand-held GPS monitors were used to locate the coordinates in the field. Each transect was run 50 meters from the start in the pre-determined compass direction. At every even meter, the species, DBH (Diameter at Breast Height), and transect to tree distance were recorded on field data sheets for the closest tree to the left of the transect. The same was measured at each odd meter for the closest tree to the right of the transect. Pictures were taken and used to identify any unknown trees. This process was used for 56 transects spread between 11 of the sections. Four transects (all in Section 4) that had been predetermined were impassible due to heavy hanging thorn brambles and dense groundcover. This section of land area was excluded from the model, and not included as a sink of carbon in the area.

ANALYSIS

The flow diagram given in figure 2 illustrates the process of field data analysis that follows.

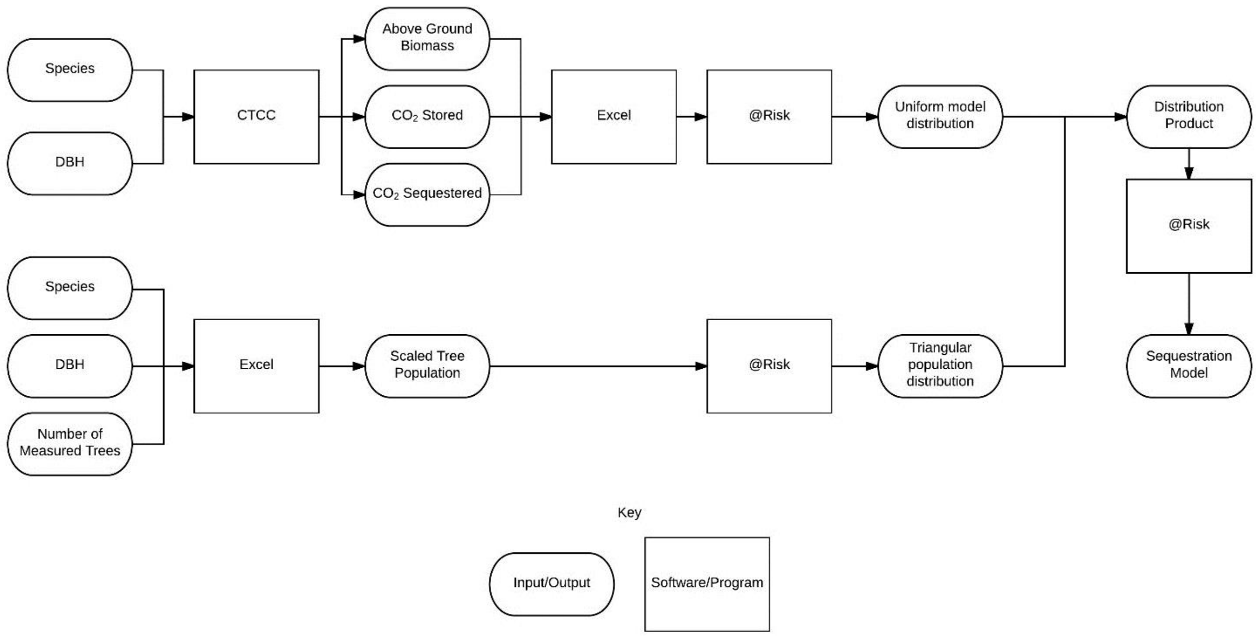


Figure 2. Species and DBH are entered into CTCC which returns model results to be recorded in Excel. @Risk is used to apply a uniform distribution to the CTCC model results. Species, DBH, and Number of Measured trees are recorded in Excel where the Number of Measured trees is scaled up to represent the entire tree population. @Risk is used to apply a triangular distribution to the scaled tree population. The product of the characteristic distributions is used to produce the final sequestration model.

The US Forest Service's CUFR Tree Carbon Calculator (CTCC) was used to transform the field data into sequestration predictions. CTCC can be downloaded from the US Forest Service's website (USFS, 2009). It has the capability of predicting heating and cooling energy effects on a building from individual nearby trees, but that functionality was not used for this research. The sequestration and related calculations that the calculator performs are based on the top 20-25 inventoried tree species from 16 reference cities. These cities are spread across the continental US and are used to divide the country into 16 climate zones. Northwest Arkansas falls on the edge of zones 13 and 14 (Lower Midwest and South, respectively). The calculator requires the user to choose a zone and tree species, and input tree sample DBH. The calculator then uses detailed, species- specific growth calculations to return three values: the CO_2 sequestered by that tree during its growth in the past year, the total CO_2 sequestered by a tree of that size and species in both above and below ground biomass, and the above ground biomass of the tree.

As stated before, there are 20-25 types of trees per climate zone in CTCC. CTCC does not contain an exhaustive tree library. As such, the field data had to be grouped into species classifications. For example, White Oak, Post Oak, and Bur Oak are all in the White Oak group of the Beech family (Sibley, 2009). CTCC does not have the capability of calculating Post Oak or Burr Oak sequestration. However, due to their species similarities, it was decided that all three of these could be run as “white oak”. Additionally, some trees present in the SEFOR land holdings did not have a family relationship with any of the trees in CTCC. Instead, they were assigned an equivalency. Equivalencies were established on a tree by tree basis, depending on average growth rate, lifespan, dry weight, and Phylogenic similarities to species in CTCC. In making these replacements it was most important to find a tree that had a similar wood density and growth rate due to the fact that those qualities have the largest impact on sequestration potential. The data recorded in the field were organized in Excel first by section, then species group/equivalency, then DBH range. Tree statistics are given in table 1.

Table 1. Tree Species present in SEFOR land holdings area, along with each species' CTCC model equivalency, frequency of occurrence, and DBH statistics for each species.

Species Grouping/Equivalency	Species Included	Incidence %	Max DBH	Mean DBH
Acer rubrum	*Acer rubrum*	3.6	22.6	5.8
	Acer saccharum	0.1	11.3	8.4
Betula nigra	*Betula lenta*	0.0		3.3
Catalpa speciosa	*Catalpa*	0.1	5.1	4.9
Celtis occidentalis	*Nyssa*	6.0	23.9	6.2
	Celtis	1.3	18.4	6.2
	Nyssa sylvatica	0.5	16.6	8
	Nyssa sylvatica	0.5	13.4	5.9
	Sassafras albidum	0.2	5.4	3.9
	Nyssa aquatica	0.0	10.1	10.1
	Nyssa biflora	0.0	3.5	3.5
Cercis canadensis	*Cercis*	0.0	3.8	3.8
Cornus florida	*Cornus florida*	6.6	12.4	3.4
	Diospyron virginiana	1.7	15.8	6.9
	Asimina triloba	0.1	7.6	3.9
Fraxinus americana	*Fraxinus americana*	4.5	21.2	5.8
	Fraxinus pennsylvanica	0.4	14.3	5.9
	Fraxinus	0.0	9.5	9.5
Gleditsia triacanthos	*Gleditsia aquatica*	0.0	14.2	14.2
Juglans nigra	*Carya texana*	3.3	21.3	7.6
	Carya tomentosa	2.8	20.4	9
Juglans nigra	*Carya cordiformis*	1.5	9.5	4.1
	Juglans nigra	0.5	20.4	12.7
	Carya aquatica	0.3	13.8	8.6
	Carya	0.1	11.8	10.8

	Carya laciniosa	0.1	20.4	18.6
Juniperus virginiana	*Juniperus virginiana*	5.0	26	6.2
Liquidambar styraciflua	*Prunus serotina*	0.6	18.2	7.4
Morus	*Broussonetia papyrifera*	0.4	9.1	5.8
Prunus sp.	*Crataegus crus-galli*	0.1	3.3	3.25
Populus deltoides	*Populus heterophylla*	0.2	11.1	7.6
	Aesculus glabra	0.0	8	8
Quercus alba	*Quercus alba*	14.4	36	11.3
	Quercus stellata	12.4	26.7	8.8
	Quercus macrocarpa	6.0	31.5	10.7
	Quercus michauxii	0.3	15.8	9.4
	Quercus muehlenbergii	0.0	15.6	15.6
Quercus ilex	*Castanea pumila*	0.0	3	3
Quercus rubra	*Quercus velutina*	11.4	2.6	11.2
	Quercus rubra	3.0	26.7	11.2
	Quercus marilandica	1.0	16.9	6.9
Tilia Americana	*Tilia*	0.7	6.4	4
	Tilia Americana	0.0	2.1	2.1
Tilia cordata	*Platanus occidentalis*	0.0	26.2	26.2
Ulmus alata	*Ulmus alata*	7.9	15.3	4.7
	Ulmus pumila	1.0	16.1	4.9
	Ulmus americana	0.8	15.1	6.3
	Carpinus	0.1	6.7	5.9
	Ostrya virginiana	0.1	6	4.8

Trees measured in the field ranged in DBH from 2 inches to 32 inches. For the purposes of modeling, DBH measurements were divided up into six 5 inch increments from 2 to 32 inches. Size distributions are given in table 2.

Table 2. Size distribution probability of recorded trees in the SEFOR land holdings area.

Size Range	Incidence %
2-6.9	51.6
7-11.9	27.8
12-16.9	14.3
17-21.9	4.7
22-26.9	1.4
27-31.9	0.2

After the field data were organized into Excel, CTCC was used to predict the CO_2 sequestered in the past year, the total CO_2 sequestered, and the above ground biomass at the low end and high end of each DBH increment. This was done for each DBH range of each species grouping, for each section. Modeling the trees as groups based on size as opposed to modeling each individual tree introduces uncertainty into the model calculations. Using @Risk, a Palisade decision tools Excel add-in, a uniform (square) distribution was assigned for the CTCC model values, where the distribution represented an equal probability of selecting a particular size of tree within a specific size category. This created a linear distribution between the top and bottom of each size increment.

It should be noted that @Risk does not allow for equal uniform distributions when the trees are no longer growing and the CO_2 sequestration drops to zero. A varying triangular distribution was used for a large sycamore in section 12 and a large red maple in section 9. This distribution was used to show that the sequestration rate peaked, and then fell to zero due to there being no further growth past a certain size.

The scaled tree population was calculated by multiplying the number of trees per section, per species group, per DBH by the density of the section. The average density for each section was calculated using methods from *Ecological Methodology* (Krebs, 1989). The density of a population can be estimated using the equation $D=n/2La$ where n is the number of organisms per transect, L is the transect length, and a is the average distance from the transect to the individual. The resulting value, D, is the number of trees per area of transect. This was done for each transect, and the values of D were averaged per section. This average section D represents the density of the total transected area. The result of multiplying this value by the acreage of the section gives the section density. This was done for each of the sections. It was assumed that a statistical uncertainty of ±10% was introduced when the density of each section was used to scale up the field data. For the scaled tree population, it was assumed that the calculated population was the most likely value, and @Risk was used to create a triangular distribution function which used the calculated population as the tip of the triangle, with the probability falling off to 10% above and below the calculated population. A summary of the distribution inputs used in @Risk is given in table 3.

Table 3. Statistical distributions used in @Risk model with descriptions on why each distribution was chosen.

Input	Distribution	Description
Tree Quantity	Triangular	Used to propagate uncertainty for scaled tree population. Assumes scaled population is between 90% and 110% of the calculated value. Overall, gives a 20% distribution, decreasing left and right from the most probable value which forms the peak of the triangle.
CTCC	Uniform	Used to propagate uncertainty for CTCC model results. Assumes all inputs have an equal probability of falling anywhere within the distribution. Used for CTCC since it was assumed that a tree had an even probability of falling anywhere within any one size category, and thus an even probability of falling anywhere within the model results for that size range.
CTCC	Varying	Used to propagate uncertainty for CTCC model results once the tree was no longer growing. Similar to a triangular distribution, the calculated value forms the peak of the triangle, then instead of falling off evenly to the left and right, it falls off very drastically to the right, where the sequestration drops to zero on the high end of the size ranges.

MODELING

The number of scaled trees' triangular distributions and CTCC model's uniform distributions were used as @Risk inputs. The product of the triangular distribution of the scaled number of trees and the uniform distribution of the CTCC data represented the range of CO_2 sequestration, total CO_2 sequestered, and above ground biomass that a tree in that section, of that species, and of that size would hold. The sum of all of these values for a section was the range of CO_2 sequestration, total CO_2 sequestered, and above ground biomass that that section contained. The sum of those values from all sections represents the range of CO_2 sequestration, total CO_2 sequestered, and above ground biomass that the entire SEFOR land holdings area contains. Following the summation of the aforementioned parameters, @Risk was ran for 100,000 iterations for CO_2 sequestration, total CO_2 sequestered, and above ground biomass for each of the 11 sections with data as well as the area-wide totals. Only the @Risk results for the area-wide totals are included within this paper. A detailed flowchart of this modeling process is given in figure 3.

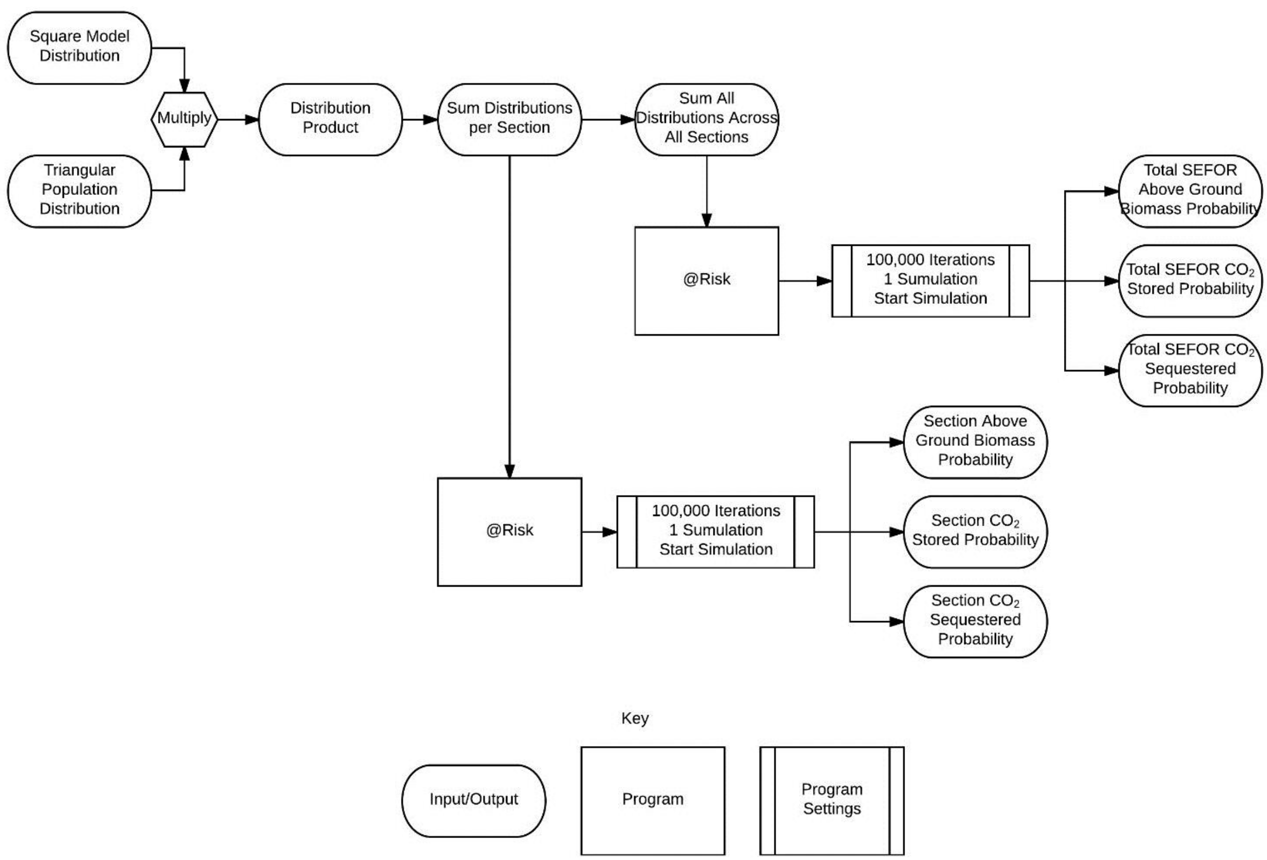


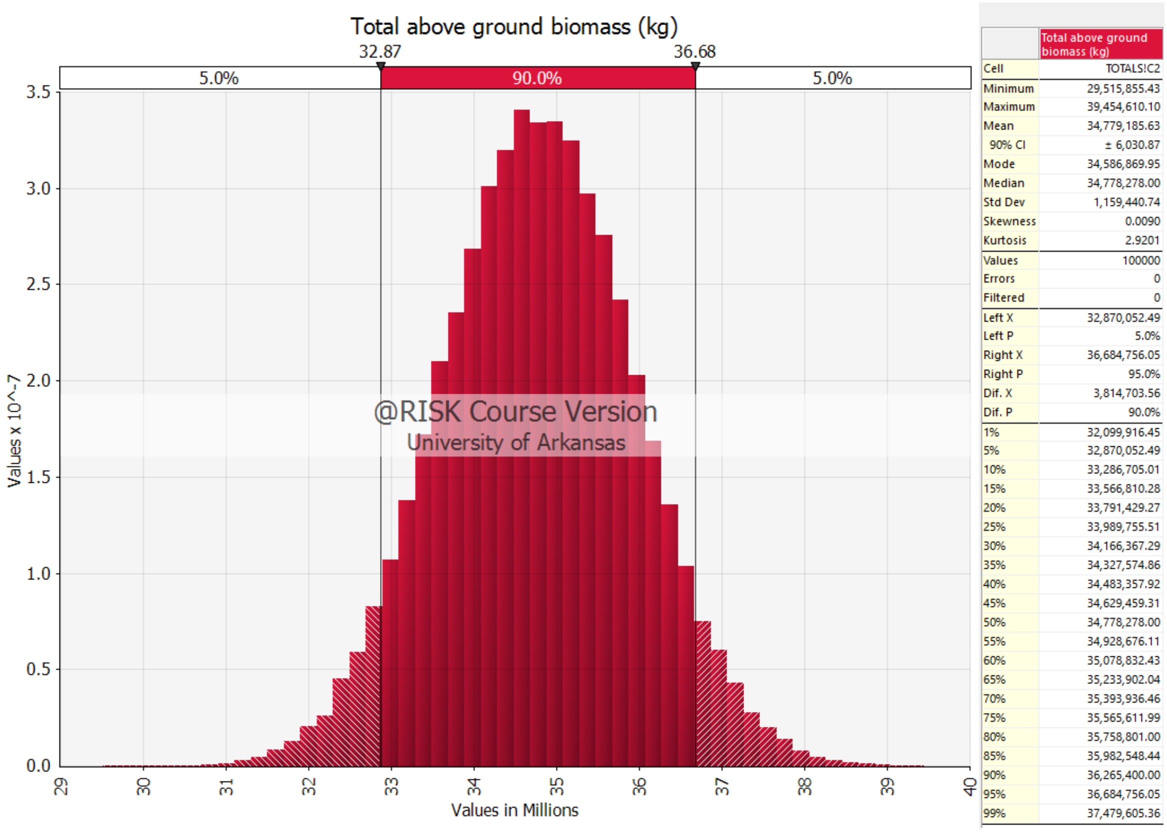
Figure 3. Probability Calculation Flow Diagram. After @Risk distributions were assigned as inputs, the product of the distributions was taken for each species/size combination in each section. Each section had a column for CO_2 sequestration distribution, total CO_2 stored distribution, and above ground biomass distribution for each tree/species combination. To calculate section (and subsequently SEFOR area) CO_2 sequestration probability, total CO_2 stored probability, and above ground biomass probability, the sum of these results was calculated for each category in each section, and then used to calculate the sum of the three categories across the total area. @Risk used these section and total values to run probability analysis using 100,000 iterations to return the parabolic probability results given below.

Error

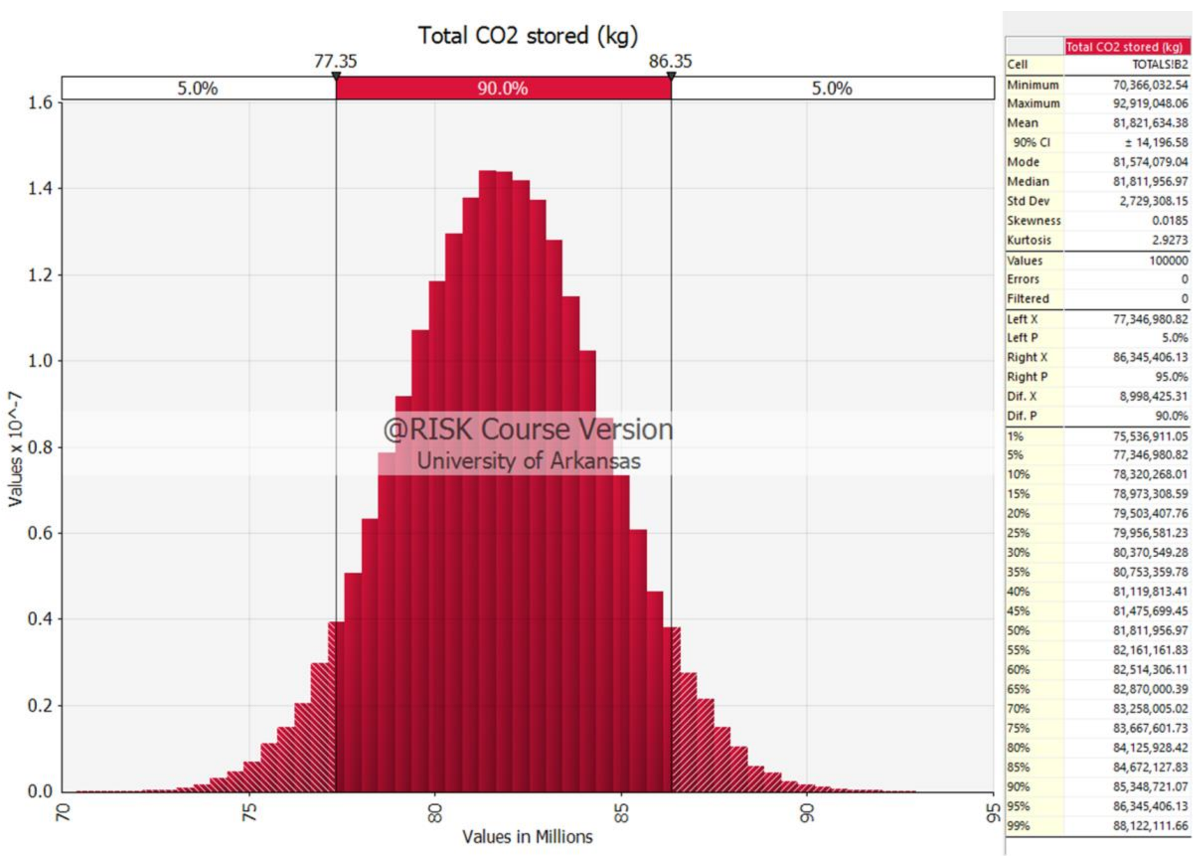
There were four main sources of error in this research. The first came from identifying tree species in the field, as the field researchers were not dendrologists. To reduce this error, field guides were used to identify each tree as it was encountered. Much of this error was reduced when the trees were placed into species groups, care was taken to ensure each tree was placed into the correct genus at the very least. The second source of error was from assigning the trees into species groups and equivalencies. Sibley's (2009) guide was used as accurately as possible to assign species groupings by growth rate, density, C: N ratio, and lifespan. The final two sources of error were scaling the raw tree data to represent the population, and modeling species in size groupings as opposed to individual trees. The error associated with these was accounted for in the @Risk input distributions. Any errors associated with the CTCC model are outside the scope of this research and are not accounted for.

Results

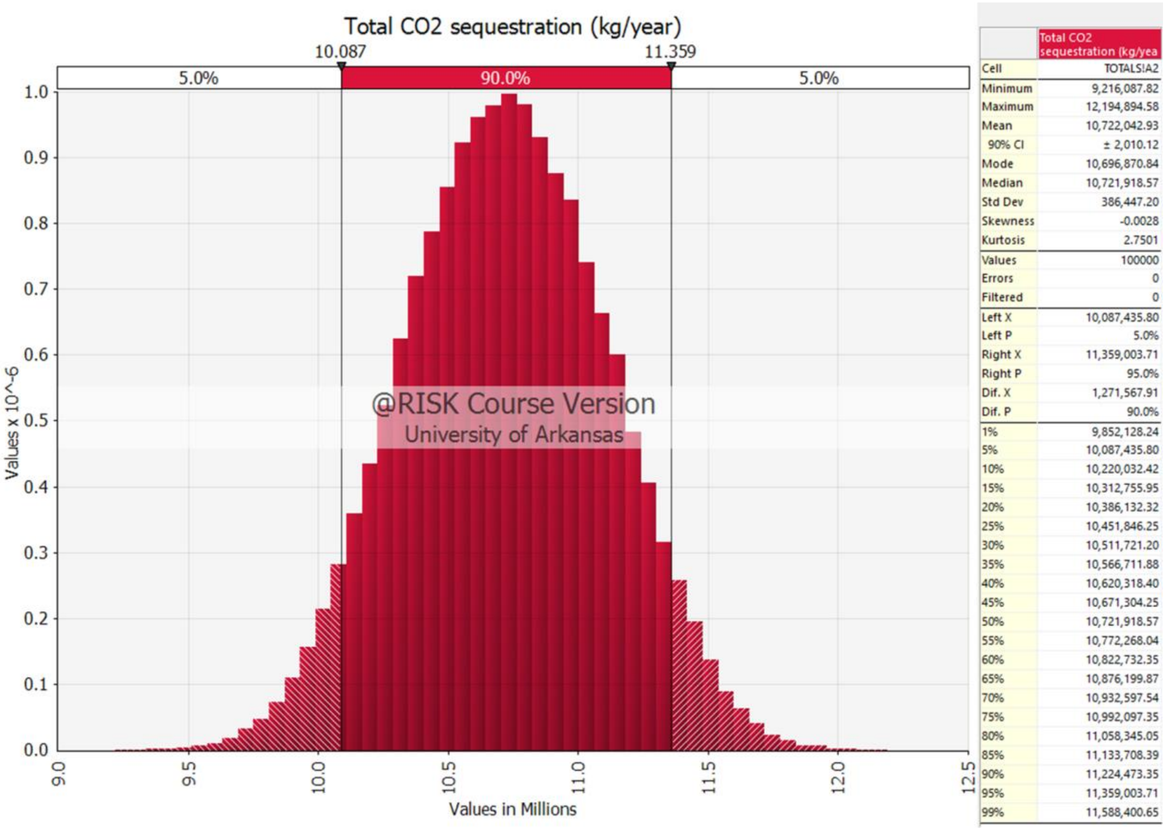
The initial survey collected data from 11 sections, 56 transects, and 2,686 trees, spread over 243 hectares. These data were used to propagate uncertainty distributions of aboveground biomass, CO_2 storage, and CO_2 sequestration rates in the SEFOR Land holdings to 90% certainty. The SEFOR land holdings (excluding Section 4) had a total population of, with 90 % certainty, between 105,818 and 121,351 trees, with a most likely population of 113,585 trees. With a 90% confidence interval, it was calculated that the estimated population had an aboveground biomass between 32,870 and 36,685 metric tons (figure 4a), stored between 77,347 and 86,345 metric tons of CO_2 (figure 4b), and would sequester between 10,087 and 11,359 metric tons of CO_2 annually (figure 4c).


Total above ground biomass (kg)
32.87
36.68
5.0%
90.0%
5.0%
Values x 10^-7
Values in Millions
@RISK Course Version
University of Arkansas
Total above ground biomass (kg)
Cell TOTALS!C2
Minimum 29,515,855.43
Maximum 39,454,610.10
Mean 34,779,185.63
90% CI ± 6,030.87
Mode 34,586,869.95
Median 34,778,278.00
Std Dev 1,159,440.74
Skewness 0.0090
Kurtosis 2.9201
Values 100000
Errors 0
Filtered 0
Left X 32,870,052.49
Left P 5.0%
Right X 36,684,756.05
Right P 95.0%
Dif. X 3,814,703.56
Dif. P 90.0%
1% 32,099,916.45
5% 32,870,052.49
10% 33,286,705.01
15% 33,566,810.28
20% 33,791,429.27
25% 33,989,755.51
30% 34,166,367.29
35% 34,327,574.86
40% 34,483,357.92
45% 34,629,459.31
50% 34,778,278.00
55% 34,928,676.11
60% 35,078,832.43
65% 35,233,902.04
70% 35,393,936.46
75% 35,565,611.99
80% 35,758,801.00
85% 35,982,548.44
90% 36,265,400.00
95% 36,684,756.05
99% 37,479,605.36

(a)


Total CO2 stored (kg)
77.35
86.35
5.0%
90.0%
5.0%
Values x 10^-7
Values in Millions
@RISK Course Version
University of Arkansas
Total CO2 stored (kg)
Cell TOTALS!B2
Minimum 70,366,032.54
Maximum 92,919,048.06
Mean 81,821,634.38
90% CI ± 14,196.58
Mode 81,574,079.04
Median 81,811,956.97
Std Dev 2,729,308.15
Skewness 0.0185
Kurtosis 2.9273
Values 100000
Errors 0
Filtered 0
Left X 77,346,980.82
Left P 5.0%
Right X 86,345,406.13
Right P 95.0%
Dif. X 8,998,425.31
Dif. P 90.0%
1% 75,536,911.05
5% 77,346,980.82
10% 78,320,268.01
15% 78,973,308.59
20% 79,503,407.76
25% 79,956,581.23
30% 80,370,549.28
35% 80,753,359.78
40% 81,119,813.41
45% 81,475,699.45
50% 81,811,956.97
55% 82,161,161.83
60% 82,514,306.11
65% 82,870,000.39
70% 83,258,005.02
75% 83,667,601.73
80% 84,125,928.42
85% 84,672,127.83
90% 85,348,721.07
95% 86,345,406.13
99% 88,122,111.66

(b)



(c)

Figure 4. Probability distribution for (a) total above ground biomass (b) total stored carbon and (c) the total annual amount of sequestration for SEFOR. With 90% confidence, (a) total above ground biomass is between 32,870.05 and 36,684.75 tons (b) total stored carbon is between 77,346.98 and 86,345.41 tons of CO_2 and (c) the annual sequestration is between 10,087.44 and 11,359.00 tons of CO_2

CONCLUSION

In this study the carbon sequestration potential was calculated for a forested area in Northwest Arkansas surrounding the SEFOR Nuclear Reactor. This was done by conducting a thorough field survey using USDA ecological sampling protocols, using The US Forest Service's CUFR Tree Carbon Calculator (CTCC) to model sequestration rates for specific species and sizes, and finally by using @Risk software to develop population-wide carbon sequestration distribution potentials of the annual sequestration rate , the overall population sequestration, and the aboveground biomass.

In summary, the SEFOR land holdings sequester, with 95% confidence, more than 10,087 metric tons of CO2 each year. Additionally, SEFOR land holdings currently store with 95% confidence, more than 77,347 metric tons of CO_2. The estimated population has an aboveground biomass of more than 32,870 metric tons.

The annual sequestration rate is nearly 7% of the University of Arkansas carbon emissions of 145,000 metric tons of carbon. With proper management, i.e., removing older trees whose sequestration rates have slowed and storing the biomass in long-term projects, planting tree species with naturally high sequestration potentials, and maintaining the area as a continuous new- growth site, could improve the carbon off-set potential for the University. Northwest Arkansas is a highly forested area. Implementing these methods across the region could provide a significant carbon sink for the region. Using these methods in other forested areas across the country could have similar impacts. This could be one of many methods used to tackle increasing carbon emissions with urgency. Using forest management as a method of carbon budgeting could be a significant way for institutions to offset the carbon emissions from their enterprise. By claiming a section of forested area, and managing it properly, the area could be used to offset measured emissions.

In a study done by Sandefur, Matlock, and Johnson (2014) that used the 2004 North Little Rock Street Tree Inventory, aerial imagery, and CTCC, it was predicted that the urban forest of approximately 1,113,000 trees in North Little Rock, Arkansas sequestered 76,000 metric tons of CO_2 per year. The survey size of this paper was approximately 10.2% of the North Little Rock survey and sequestered approximately 13.3% of the amount that the urban forest of North Little Rock did. The discrepancies in sequestration can be attributed to differences in tree species and age of stand growth. This shows CTCC to be internally consistent.

Nowak and Crane (2002) calculated the carbon sequestration of urban trees in the USA. Their sample used similar field methods to those outlined in this research and individual species equations to calculate sequestration estimates. Nowak and Crane estimated that the approximately 29,234,000 trees across 10 cities in the US can be used to extrapolate sequestration of 22,845,000 metric tons of carbon per year. This survey used 0.01% of the tree population that Nowak and Crane used to extrapolate data and sequestered 0.04% as much carbon.

In a study by Schmind and others (Schmind, Grimmond, Cropley, Offerle, & Su, 2000), it was determined that a mixed hardwood forested area in Indiana sequestered 2.4 ± 10% tons of carbon per hectare per year. The SEFOR area sequestered with 95% certainty, more than 41 metric tons per hectare per year, which is a significantly higher value, and could indicate overestimation. It must be noted, however, that the calculation methods used by Schmind are significantly different from those in this study. The research conducted by Schmind used air monitoring of carbon flux in the atmosphere above the forested area. Barford and others found similar average sequestration values when using this method, at 2.0 ± 0.4 metric tons per hectare per year. (Barford, et al., 2001). While carbon emissions from detritus could account for some of the discrepancies between these methods, much of the discrepancy is unaccounted for.

While there may be discrepancies in carbon sequestration potentials between using air carbon flux calculation methods and land survey calculation methods, the rate that carbon emissions are increasing demand immediate remediation actions, on a broad scale. In both sequestration calculation methods, forested areas served as a sink of CO_2 emissions, and even the slightest offset could produce positive societal effects.

ACKNOWLEDGEMENTS

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REFERENCES

Barford, C. C., Wofsy, S. C., Goulden, M. L., Munger, J., Pyle, E. H., Urbanski, S. P., . . . Moore, K. (2001). Factors Controlling Lond- and Short- Term Sequestration of Atmospheric CO2 in a Mid- Lattitude Forest. *Science*, 1688-1691.

Core Writing Team, Pachauri, R., & Meyer, L. (2014). *Climate Change 2014 Synthesis Report.* Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Krebs, C. J. (1989). Estimating Abundance: Quadrant Counts and Line Transects. In C. J. Krebs, *Ecological Methodology.* New York: HarperCollin

Melillo, J. M., Richmond, T., & Yohe, G. (2014). *Climate Change Impacts in the United States: The Third National Climate Assesment.* Washington, DC: U.S. Global Change Research Program.

Microsoft. (2010). Excel. Ver. 14. Redmond, Wash.: Microsoft Corp.

Nowak, D. J., & Crane, D. E. (2002). Carbon Storage and Sequestration by Urban Trees in the USA. *Environmenal Pollution*, 381-389.

Palisade. (2011). @Risk. Ver. 5.7. Ithaca, N.Y.: Palisade Corp

Ryan, M., Birdsey, R., & Hines, S. (2012, October). *Forests and Carbon Storage.* Retrieved from U.S. Department of Agriculture, Forest Service, Climate Change Resource Center.

Sandefur, H. N., Matlock, M. D., & Johnston, R. Z. (2017). Comparison of Methods for Quantifying Carbon Sequestration in the Urban Forest of North Little Rock, Arkansas. *Biological Engineering Transactions*, 221-231.

Schmind, H. P., Grimmond, C. B., Cropley, F., Offerle, B., & Su, H.-B. (2000). Measurements of CO2 and Energy FLuxes Over a Mixed Hardwood Forest in the Mid-Western United States. *Agricultural and Forest Meterology*, 357-374.

Sibley, D. (2009). *The Sibley Guide to Trees.* New York: Knopf.

USDA. (2003). *Multiparty Monitoring and Assessment Guidelines for Community Based Forest Restoration in Southwestern Ponderosa Pine Forests.* Albuquerque, N.M: U.S. Dept. of Agriculture, Forest Service, Southwestern Region.

USDA. (2012). *Tree carbon calculator (CTCC)*. USDA Forest Service, Climate Change Resource Center. Retrieved from www.fs.fed.us/ccrc/tools/ctcc.shtml

Wilson, M. V. (2005). 6. Simple Randon Sampling in the Field. In M. V. Wilson, *Field Methods in Vegetation Science.* Oregon State University.