Modeling the Water Budget and Annual Carbon Balance for Martha's Vineyard

Jen Peters[1]

Advisor: Chris Neill[2]

December 2005

1Bard College, Annandale-on-Hudson, NY, 12504
2The Ecosystem Center, Marine Biological Laboratory, Woods Hole, MA 02543

Abstract: Carbon and Water models can be used to assess productivity and health of an ecosystem. Land use changes affect the carbon and water budgets. Martha's Vineyard has experienced drastic vegetation changes over the past century. In this study calculated the carbon and water budgets for Martha's Vineyard using canopy height, leaf area, soil texture, soil carbon, tree density and tree diameter at breast height (DBH) measurements for the five dominant forest types on Martha's Vineyard. I model an island wide ground water recharge, evapotranspiration, carbon flux, soil and tree carbon stocks. I then addressed management questions using the model values and modified vegetation cover areas. I found that later successional species, including non-native species, store more carbon and are able to sequester more carbon form the atmosphere then others. Larger stature forests are more likely to become water stressed. Restoration of early successional species reduces carbon stocks, but dose not affect ground water recharge. Ground water recharge is a major ecosystem serves but should not drive restoration decisions because changes among current and target vegetation types are small

Key words: Martha's Vineyard, Water budget, Carbon balance, Forest management.

Introduction:

Carbon and Water models can be used to assess productivity and health of an ecosystem. A carbon budget quantifies how much new growth an ecosystem is generating. A water balance illustrates the water exports of a system. With it we can evaluate how much water is entering the ground water and how much ground water recharge is necessary to maintain the level of ground water. The structure of vegetation and soil controls ecosystem water and carbon balance. Canopy structure, such as leaf area and canopy height, controls water loss and carbon gains. A forest's leaf area controls how much photosynthesis an ecosystem can perform. That level of photosynthesis in turn requires a certain amount of atmospheric carbon and a certain amount of water to transport nutrients throughout the tree. A higher canopy height is able to support more leaf area, more production and therefore is able to use more atmospheric carbon. The timing of the canopy structure is also very important. Phenology, the seasonal timing of biological activities, controls the time over which carbon and water exchanges can take place. For example the length of time during the year a tree has leaves is the only time that tree can photosynthesize. Soil structure contributes to the control of an ecosystem's carbon and water balance. Soils have different water holding capacities based on the soil texture or grain size of the soil. The soil water holding capacity controls when and how much water is available to plants. These three controls, canopy structure, phenology and soil water retention, can change among different vegetation and soil types.

Soil and vegetation structure are influenced by geology and climate. In the New England region, glacial activity has created till soils and outwash soils. Till soils are a mix of soils with varying textures formed by the carving out of soil by a glacier and piling different soils on top of each other. Outwash soils, which have a coarse sand texture, were formed when the glacier began to melt and water carried the sand down off the moraine to form an outwash plain. Soil texture controls water holding capacity and could influence vegetation structure. Oak, beech, maple, birch, white pine and hemlock forests prefer moister till soils. Oaks and pitch pine are often found on outwash soils. Elevation and latitude create climate and temperature gradients that influence phenology. On a local scale even topographical differences can influence leaf emergence (Fisher 2005).

Since the time of European settlement, humans have been changing the vegetation structure in the northeastern United States. Historically, forests have been cleared for agricultural land and development, crop trees have been grown in place of native forests, and forests have been reintroduced through the subsequent restoration of old farmland. Man's control over the lands fire regime has also directed forest development. By removing fire as a natural process, forest succession has progressed to a more mature forest then was originally present and species diversity has been compromised. Recently, in the northeast, there is emphasis on restoring a more natural forest species composition in remaining forested areas. All of these changes have had an important influence on the water balance and carbon exchange of the region.

Martha's Vineyard has experienced all of these land use changes. Now it is a mosaic of forest stands of different dominant tree species, some native and some not. Even over the last century, vegetation on the island has changed dramatically. Forest fires used to periodically burn sections of forest, resetting succession. Now Fires are extinguished and later succesional species have taken over in much of the island. In the early 1900's, hundreds of acres of non-native pine species were planted completely changing the vegetational structure in the area.

Martha's Vineyard was formed by glaciers. The island has two moraines, one on the northwest side and one on the northeast. These were probably formed by two lobes of the Wisconsin ice sheet that receded 25,000years ago. the two moraines are different in composition. The northwest moraine is a thrusted moraine, where costal sediments were thrust to the surface. This area consists of well drained sandy and loamy soils (Fletcher and Roffinoli 1986, 145). The northeast coast of Martha's Vineyard is a terminal moraine. This moraine is comprised primarily of sand and gravel (Fletcher and Roffinoli 1986, 3). Between these two moraines a level outwash plain was formed from sand and gravel carried by melting ice. The soil is distinctive in these three sections of the island and a difference in vegetation is notable. There are five dominant forest types on Martha's Vineyard: scrub oak and stunted tree oak predominate on the outwash plain; the northwest moraine is covered by a mixed deciduous forest comprised of sassafras, beech, maple and oak; the northeast moraine predominantly supports pitch pines and oak trees; plantations of white, red and scotch pine were planted within the state forest on the outwash plain and northeast moraine. These differences in soil may dictate what spices are able to thrive in which areas.

Scrub oaks used to be the dominate species on the outwash plain. Scrub oaks are some of the first species to recolonized after fire; because fires have not been allowed to burn, the scrub oaks have been out competed in many areas by tree oaks and pitch pines. This transition to larger trees may have caused a greater sequestration of carbon. Similarly, the non-native pine trees planted in the state forest are very large and can store more carbon then bushy scrub oaks or tree oaks.

In addition, a recent study has shown that in particular areas of Martha's Vineyard, spring leaf out occurs much later then most of the vegetation on the island (Fisher J). These areas with delayed phenology have been mapped as scrub oak dominated areas. This means scrub oaks have a narrow window of time to photosynthesize each year, about two and a half months. This limits their ability to sequester carbon.

A large portion of the island is state forest or conservation land. In these areas, the definition of conservation is being debated. To managing such areas it has been proposed that land should be returned to what it use to be through controlled burning and replanting areas now dominated by non-native species with native ones. Others just want to protect the forest from human development. Many invasive species and later successional species are thought to be more productive then native species and primary successional species. From what we know about scrub oak's late phenology, its restoration could decrease the carbon flux from the atmosphere to biota and change the water budget on the island. Cutting plantations to restore native vegetation and allowing periodic fires to favor scrub oaks may reduce carbon stocks. Conversely native species might be better suited to deal with water shortages or severe coastal conditions such as high winds, storms and salt spray. Conservationists that are interested in restoring land to its native state could be compromising the productivity of this forest. By understanding how the ecosystem has changed over the last century and making predictions as to the impact any proposed changes could have, we can better address conservation.

In this study, my objective was to construct a water and carbon budget for Martha's Vineyard as a whole region. I first examined the importance of different controls, such as soil and vegetation structure and phenology, on the water budget and carbon balance. Then applied the models, using vegetation maps, to the island. Finally, I manipulated the model to address management questions, such as: how has the structure of the major vegetation communities on MV changed during the past century? How have these changes altered the annual water and carbon exchange on an island wide scale? And what would be the effect of regional water and carbon exchanges associated with managemental burning or land clearing? Based on current conditions, I can simulate what effect vegitational changes could have on the carbon and water cycling of the island.

Methods:

I compared canopy height, leaf area, soil texture, soil carbon, tree density and tree diameter at breast height (DBH) measurements for the five dominant forest types on Martha's Vineyard. These measurements were used to model ground water recharge, evapotranspiration, carbon flux, soil and tree carbon stocks for each forest type. These values were applied to the areas occupied by a specific forest type to calculate a water budget and carbon balance for Martha's Vineyard. I then addressed management questions using the model values and modified vegetation cover areas.

Study site:

I surveyed and collected samples from fifteen sites on Martha's Vineyard. The sites were chosen based on dominant vegetation of the island. I used three sites from each of five vegetation types, scrub oak, tree oak, mixed deciduous trees, pitch pine and evergreen plantations. These sites also span the three different soil types on the island. All the mixed deciduous sites are on moraine soil. Two pine plantation sites, two pitch pine sites and two tree oak sites are situated on moraine soil covered by outwash plain. The other six sites sit within the central outwash plain (Table 1).

Field sampling:

At each of my 15 sites, I surveyed the tree species and DBH of each tree in a 20 meter diameter area. I measured canopy height using a telescoping meter pole and leaf area using a Li-COR LAI 20000, which was programmed to average nine readings as I walked a transect across the site. I collected soil density samples with a soil corer at 0-10cm, 10-20cm and 20-30cm depths from one soil pit per site. Soil samples for carbon and texture analysis were taken at 0-10cm, 10-20cm and 20-30cm depths from three random locations within each site using a soil auger. I combined the three samples of the same depth and homogenized them to make one sample per depth per site, for a total of 45 soil samples.

Lab analysis:

In the lab, I measured the dry mass of the bulk density soil samples of known volume, to find the density. I ashed 30g of homogenized soil to find the carbon content of the soil at each depth.

A hydrometer analysis was used to find the percent sand, silt and clay. 80g of soil was shaken overnight with 100ml of 50g/L sodium hexametaphosphate solution and deionised water. I transferred the soil solution to a one liter cylinder, took hydrometer readings at 40sec and 2 hours, and recorded the temperature at each reading.

Calculations:

Using the bulk density of each soil and its carbon content, I calculated the soil carbon stock for each vegetation type. Tree carbon stocks were calculated using Whittaker and Woodwell's allometric equations (1968) to convert DBH into Biomass and 50% carbon was assumed to get total carbon. I used the allometric equation for *Pinus rigida* for the evergreen plantations and the *Quercus coccinea* equation for all deciduous trees without their own equation.

Using my hydrometer values for soil texture, I calculated soil water holding capacity and soil water wilting point using Saxton's calculating interface (Saxton).

Model analyses:

I used a water budget model created by Williams et al. (1996). This model calculates actual evapotranspiration and ground water recharge on a daily time step. To operate the model I used temperature, precipitation and solar radiation values from Falmouth weather station for the 2005 water year. I used my late November LAI readings as winter values and estimated daily LAI values for tree oaks from summer values measured by Neill (unpublished) and other vegetation types using a phenology map of Martha's Vineyard to identify leaf out for each tree type (Fisher 2005). My canopy height and soil water holding capacity values were also entered into the model.

The carbon flux model (Williams et al. 1997) used the same inputs to operate as the water budget model, plus a leaf nitrogen value that I assumed was $2gN/m^2$ leaf area for all vegetation types. The carbon flux model generates a daily and yearly value of carbon consumed by vegetation.

The outputs of these models for each vegetation type, and the tree and soil carbon stock values, were applied to the area of Martha's Vineyard occupied by that vegetation type occupies. In this way, I generated a whole island water budget and carbon balance for current conditions.

Management Assessment:

Management questions were then addressed using the model values. Scenarios included a) the implementation of burning, b) the removal of non-native tree plantations and c) the continuation of forest succession. Map areas were adjusted to mimic vegetation changes likely under each scenario and a whole island budget was generated for each scenario. For scenario 'a', I assumed fire would revert the entire outwash plain to scrub oak and recalculated the areas accordingly. In scenario 'b', the area of evergreen plantation was added to the tree oak total area. I reworked the island budget using new areas for scenario 'c' such that all the scrub oak and half the tree oak land was considered deciduous forests and the other half of the tree oak and half the pitch pine area was designated as evergreen plantation trees. The other half of the pitch pine remained pitch pine. I then used vegetation maps for the Correllus State Forest from years 1938, 1952 and 1995, to generate the water and carbon balance for the forest for each year. The areas used to analyze these different questions are given in Table 2.

Results:

Canopy height was very different between different tree species. Scrub oaks have an average canopy height of 1.5m. Tree oaks have a height of 8.9m followed by pitch pine, mixed deciduous trees and finally, at 16.3m, plantation pines (Table 3).

Leaf area values were very low in scrub oak, tree oak and mixed deciduous sites because readings were taken in late fall after most leaves had dropped. Pitch pine and plantation pines had much higher LAI values (Table 3).

Scrub oak soils had higher sand content, 78%, then the other plots and tree oak had much less sand content then all the other sites with an average of 51% sand. Plantation and tree oak sites were fairly consistent across replicate sites, but there was variability in the other sites (Figure 1).

Soil carbon was highest in pitch pine and tree oak sites. And lowest soil carbon was found in scrub oak sites but the variation among sites was not great (Figure 2). Soil carbon is about twice that of tree carbon per metre squared.

Tree density was greatest in evergreen plantation and mixed deciduous tree sites and tree DBH was also greatest in evergreen plantation and mixed deciduous sites (Table 3). Therefore these sites had much higher tree carbon stocks. Though scrub oak grows very densely, it is short and has slender trunks. Therefore its biomass and carbon stock is much less then other tree species (Figure 3).

Model results:

The results of the water budget show that there is little variation among vegetation types. There is slightly more ground water recharged by scrub oak sites, followed by tree oak, mixed deciduous trees, pitch pine and evergreen plantation had the lowest recharge. Evapotransiration is inversely proportional to ground water recharge (Figure 4).

The carbon fluxes for each vegetation type, generated by the model, varied substantially among types. Evergreen plantation trees sequester three times as much carbon yearly as scrub oak trees (Figure 5).

Management scenarios:

The reversion back to a scrub oak dominated landscape by fire increased ground water recharge and reduced evapotranspiration. The Annual carbon flux to the system diminished and tree carbon stocks dropped by 33%. Soil carbon also decreased slightly. The same effects were seen in carbon with the replacement of evergreen plantations with native tree oaks, but to a lesser extent. This scenario, however, had no effect on the water budget (Table 4).

The continuing succession scenario had the opposite results. Ground water recharge diminished. But the annual carbon flux increased by 22% and tree carbon stocks increased by 64% (Table 4).

The same successional trend can be seen in the historical changes in the Correllus State Forest. As time proceeded, the total carbon flux to the state forest increased and the carbon stocks of the forest increased six fold. The decrease in ground water recharge was negligible (Table 5).

Discussion:

Model inputs:

I was able to construct a water and carbon budget for Martha's Vineyard using soil and vegetation structure measurements specific to the five most dominate vegetation types. The carbon flux model is predominantly controlled by leaf area. There is a strong correlation between increasing leaf area and increasing annual carbon uptake by vegetation. Photosynthesis, the process by which plants take up carbon from the atmosphere, is driven by solar radiation, which the plant receives through its leaves. The greater a plants leaf area, the more solar radiation it can receive, the more photosynthesis it can perform and the more carbon it will sequester. The major difference among the vegetational types I studies was their phenology. Both the evergreen plantation trees and the pitch pines have leaves throughout the year. The three oak and mixed deciduous trees leaf out in mid May and loose their leaves in late September. Scrub oaks were found to leaf out considerably later, about 45 days, in the summer then most species (Fisher 2005). This greatly limits scrub oak's ability to photosynthesize and grow. Soil water holding capacity also controls the model because photosynthesis is hampered by water limitations.

The water budget was also influenced by the leaf area of the tree species. Species with a greater leaf area are able to photosynthesize more. But trees require water during photosynthesis as well. So species with greater leaf area take up more water and limit the amount of rain water that passes through the soil to enter ground water. Scrub oak's delayed phenology limits the trees water demand. Using the water budget model, I found that scrub oaks only felt water stress 31 days out of the year; whereas evergreen plantation trees felt water stress 63 days out of the year (Figure 6). Larger stature forests are more likely to become water stressed. Not only does this mean plantation trees reduce the water entering the ground water, it means plantation trees will dry out faster. In times of drought these trees will not survive and they are more prone to forest fires because their water content is already depleted.

Soil carbon stocks didn't vary much among vegetation type. The tree oak and deciduous sites had the highest soil carbon because they produce more litter. The evergreen trees retain their leaves longer, usually two to three years, and therefore don't produce as much litter. Scrub oak soil have the lowest soil carbon, probably because their short stature doesn't allow for the production of as many leaves as other trees.

Tree carbon content varied greatly among vegetation types. The evergreen plantations and deciduous forests were the densest forests and had the largest trees; therefore they stored the most carbon. Scrub oaks, which have very thin trunks and branches and are only about 1.5 metres tall, could only store minimal carbon. Location on the island may also influence a forests ability to store carbon. The mixed deciduous forests have oak trees in them, some areas were predominantly oak; yet the carbon storage of deciduous plots is more then twice that of exclusively tree oak sites. This could be a function of their location: the tree oak sites were on the outwash plain, whereas the mixed deciduous forests only grow on the northwest moraine.

Soil texture determines a soils water holding capacity. I found interesting differences not only between vegetation types but between sites within the same type. Soil structure does not seem strongly correlated with vegetation type; instead I think it varies with topography and the glacial history of an area. Tree oak and scrub oak are the predominate vegetation in on the outwash plain. The tree oaks prefer higher elevation, where as the scrub oaks are primarily found in depressional areas and spring sapping valleys, though they grow right next to each other. In my soil survey, scrub oak soils had a very high percent of sand and gravel and tree oaks had the lowest sand content of all the soils I surveyed. This is curious because the sites were in close proximity to each other. Among the three scrub oak soils I noticed a difference. Two of the sites had very high sand contents, around 86%, and the third site had a percent sand of 64%, similar to the tree oak values (Figure 7). These sites also varied in elevation, the first two are in spring sapping valleys but the third site is level with surrounding areas. More research is necessary to examine any correlation between elevation and soil texture. If there is such a correlation, carbon and water budgets could more accurately be estimated by applying soil texture information based on a soil's map rather then a vegetation map.

Management scenarios:

I was able to apply models and create flux estimates based on realistic land use change scenarios. Using the fluxes and stocks specific to vegetation type, I scaled up to find the ground water recharge, evapotranspiration, carbon flux, tree carbon stock and soil carbon stock of Martha's Vineyard under current conditions. To address questions of how these budgets are likely to change as the vegetation on Martha's vineyard changes, these findings were applied to vegetation change scenarios.

The forest management has considered the value of reimplementing forest fires. Scrub oak recolonizes after a burn and used to be the single dominate species. However, without fire, other species have out competed the scrub oak and drastically changed the plant makeup of the island. If fire were to be reintroduced, it would reset succession and favor the domination of the scrub oak, returning the vegetation to a more historically natural state. To mimic such an event I changed the areas to which the model values were applied and recalculated the total island budgets. Ground water recharge increased slightly and evapostransporation decreased slightly. The carbon flux and both carbon stocks dropped as the result of the change in vegetation. Because of scrub oaks limited phenology and leaf area, the carbon flux dropped; because of scrub oaks small stature the tree carbon stock for the island dropped; and because of the scrub oaks small leaf area the soil carbon decreased.

Correllus state forest management has proposed converting the non-native evergreen plantations back to native species. This land use change should have a similar but less drastic effect as the burning scenario. Under this plantation removal scenario, there was no difference in the water balance from that of current conditions. However the carbon flux and stocks diminished, though not the extent they did in the fire scenario. The plantations make up a tiny part of the islands area, but because they are such an important carbon store, their demise would make a difference in the carbon stocks of the island.

For my third scenario, I asked what would happen if no mitigation was implemented and succession preceded as it has been? If the system is not interrupted by fire or some other disturbance I would expect larger stature trees to out compete not only the scrub oaks but the tree oaks and pitch pines as well. A mix of hardwoods would probably accumulate in the outwash plain. The larger evergreen trees could spread and easily shade out native species. As expected this scenario had the opposite effect as the fire. Ground water recharge decreased and the carbon stocks increased. Tree carbon tripled, yet soil carbon's increase was negligible. Later successional species, including non-native species, store more carbon and are able to sequester more carbon form the atmosphere.

Finally I used the model values to look at the historical changes that have occurred in the Correllus State Forest due to vegetation changes over the past 60 years. Using sequential vegetation maps for 1938, 1052 and 1995, I calculated the water and carbon budget for the state forest for each year. I found that over the past 60 years, with the loss of scrub oak and the invasion of evergreen plantations and tree oak, the annual carbon flux to the forest has almost doubled and the tree carbon stock has increased six fold. However the water budget changed minimally and the soil carbon stocks increased only slightly, suggesting that vegetational changes have a strong influence on tree carbon and carbon flux, but not much of an influence on the water budget.

Conclusion:

From the scenarios I ran, it appears that larger stature and later successional tree species are able to sequester and store more carbon without having a drastic effect on ground water recharge. Though, I did find evidence that these species are more likely to become water stressed and are probably more susceptible to drought and fire then other species. The water budget of an ecosystem is only minimally affected by land use changes. This suggests that ground water recharge is a major ecosystem serves but should not drive restoration decisions. However it is important to calculate the ground water recharge required to sustain the ground water in order to assess the situation accurately. Even a slight decline in recharge might make the groundwater unsustainable.

Models were a useful tool for assessing management propositions and historical changes. More refined sampling could be conducted to hone in on nuances and generate a more accurate model. Soil composition appears to be fairly independent of vegetation type. A more complete soil survey could be conducted to more accurately apply values to areas on a soils map. It could be that certain vegetation types are not adapted to grow under particular conditions found on the island. For example some trees may have trouble growing along the shore or at low elevations. Knowing such information would allow more realistic scenarios to be analyzed.

Literature Cited:

Fletcher, P.C. and R.J. Roffinoli. 1986. Soil Survey of Dukes County, Massachusetts. United States Department of Agriculture, Soil Conservation Service.

Forester, D.R., G. Motzkin. 1999. Historical Influences on the Landscape of Martha's Vineyard: Perspectives on the Management of the Manuel F. Correllus State Forest. Harvard Forest, Harvard University, Petersham MA.

Uchupi, E. and R.N. Oldale. 1993. Spring sapping origin of the enigmatic relict valleys of Cape Cod and Martha's Vineyard and Nantucket Islands, Massachusetts. Geomorphology 9:83-95.

Van Wilgen, B.W., R.M. Cowling and C.J. Burgers. 1996. Valuation of ecosystem services: a case study from South Africa fynbos ecosystem 46: 184-189.

Whittaker, R.H., F.H. Bormann, G.E. Likens, and T.G. Siccama. 1974. The Hubbard Brook ecosystem study: forest biomass and production. Ecological Monographs 44: 233-252.

Whittaker, R.H. and G.M. Woodwell. 1968. Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. The Journal of Ecology 56: 1-25.

Williams, M. E.B. Rasstetter, D.N. Fernades, M.L.Goulden, G.R. Shaver, and L.C. Johnson. 1997. Predicting gross primary productivity in terrestrial ecosystems. Ecological Applications 7: 882-894.

Table 1. the five dominant vegetation types on Martha's Vineyard with geological setting, dominant species and area occupied on the island.

Forest Type	Geological setting	Dominant vegetation	Area on Martha's Vineyard (ha)
Scrub oak	Outwash plain	*Quercus ilicifolia*	784
Tree oak	Outwash plain, northeast moraine	*Q. alba*	8847
Mixed deciduous	Northwest moraine	*Q. velutina,* *Sassafras albidum,* *Q. alba,* *Q. coccinea,* *Fugus grandifolia,* *Q. rubra,*	1487
Pitch pine	Outwash plain, northeast moraine	*Pinus rigida*	3261
Evergreen plantation	Outwash plain, northeast moraine	*P. strobus,* *P. sylvestris,* *P. resinosa,* *Q. alba*	259

Table 2. Areas used to scale up to Martha's Vineyard and Corellus State Forest for each scenario.

	Current	Scenario a: burn	Scenario b: no plantation	Scenario c: succession	1995	1952	1938
	ha	ha	ha	ha	ha	ha	ha
scrub oak	784	7097	784	39	807	1215	1881
tree oak	8847	4424	9106	0	698	524	70
deciduous	1487	1487	1487	6655	0	0	0
pitch pine	3261	1631	3261	1631	83	62	62
plantation	259	0	0	6313	424	212	0
total	14638	14638	14638	14638	2013	2013	2013

Table 3. Canopy height varies among vegetation types. LAI values were used as winter values. Tree density and average DBH is greatest in deciduous and evergreen plantation forests.

	Canopy ht	Winter LAI	tree density	average DBH
	m		tree/m2	cm
Scrub Oak	1.5	0	3.3	1.7
Tree Oak	8.9	0.42	0.054	14.7
Deciduous	16.0	0.64	0.084	19.3
Pitch Pine	12.2	2.1	0.051	17.3
Plantation	16.3	2.9	0.13	20.3

Figure 1. Scrub oak contains the greatest percent sand. Tree oak is only 51% sand.

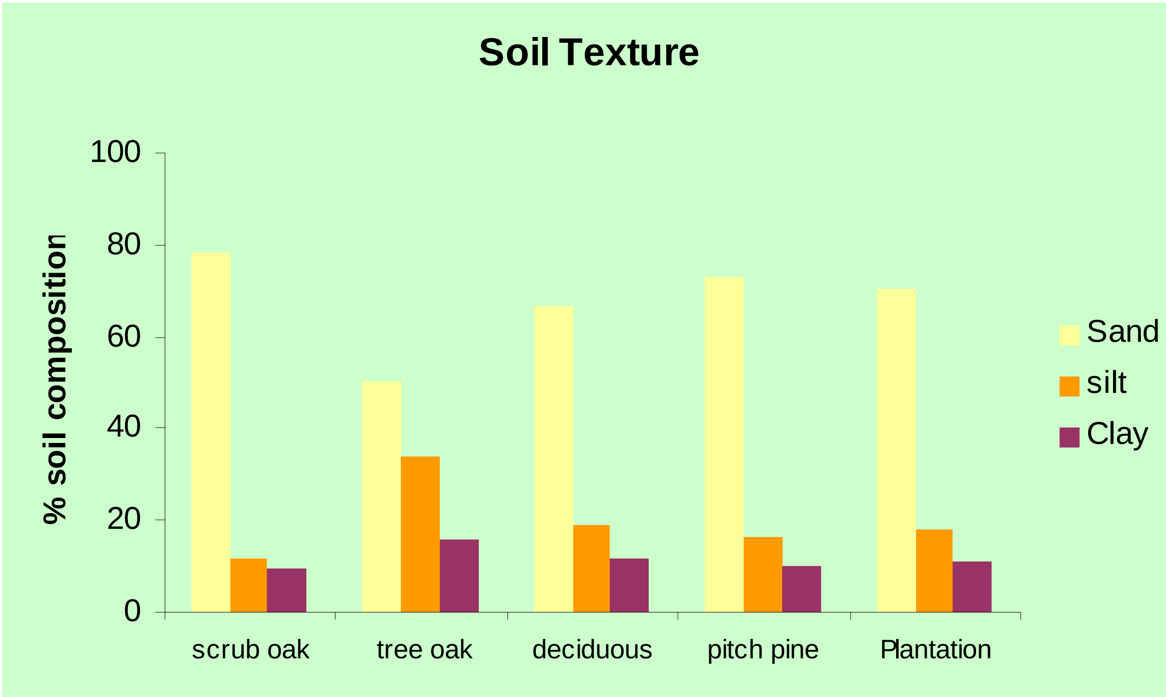


Figure 2. Soil carbon stocks do not vary much among forest types.

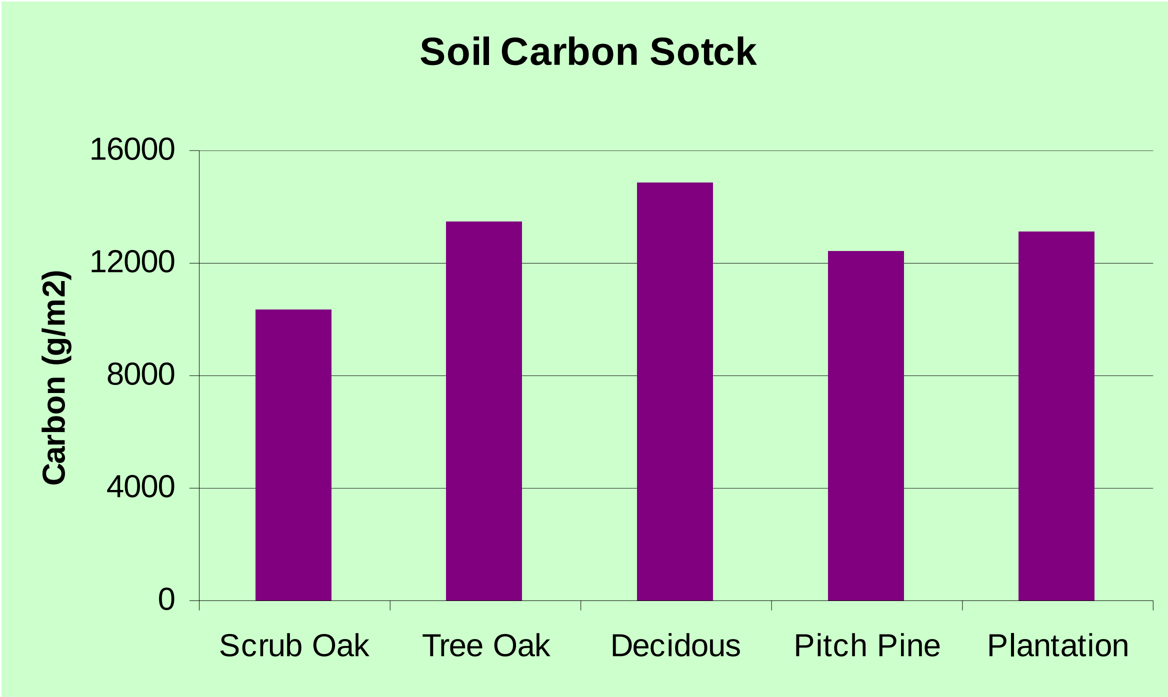


Figure 3. Tree carbon is about half of soil carbon. Tree carbon stocks vary with forest type. Denser forests and large stature trees, such as mixed deciduous and evergreen plantation trees, have greater carbon storage.

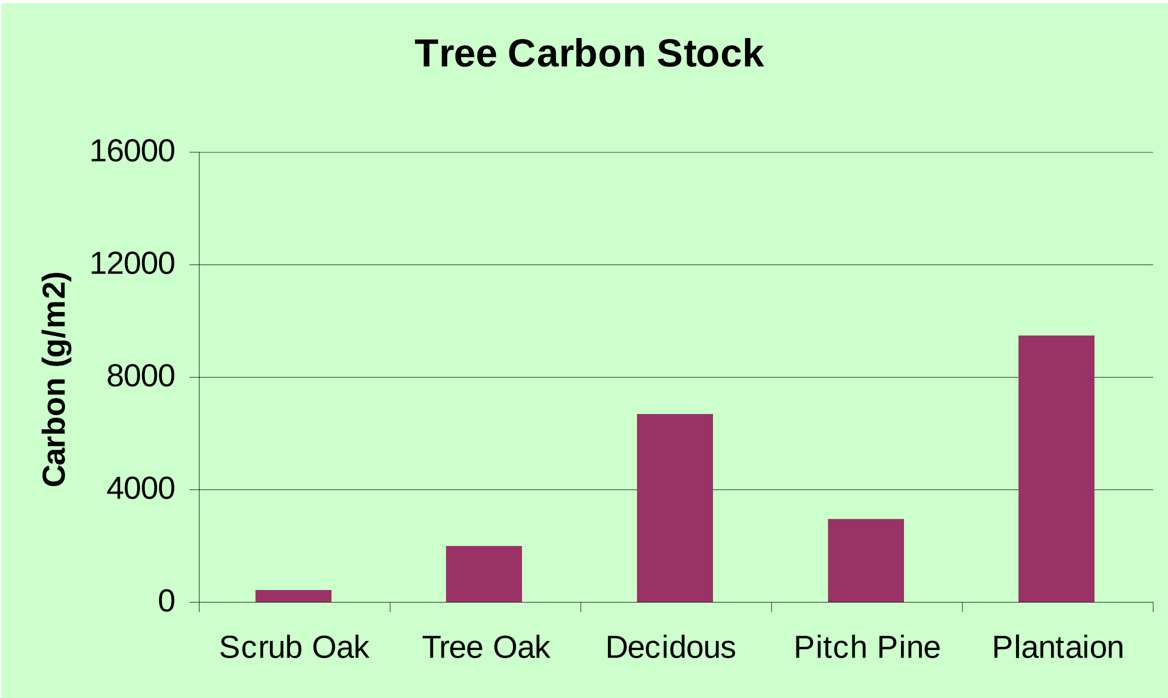


Figure 4. Annual ground water recharge is greatest at scrub oak sites. Evapotranspiration is low at scrub oak sites, and much higher in plantation. Ground water recharge decreases and evapotranspiration increases with leaf area.

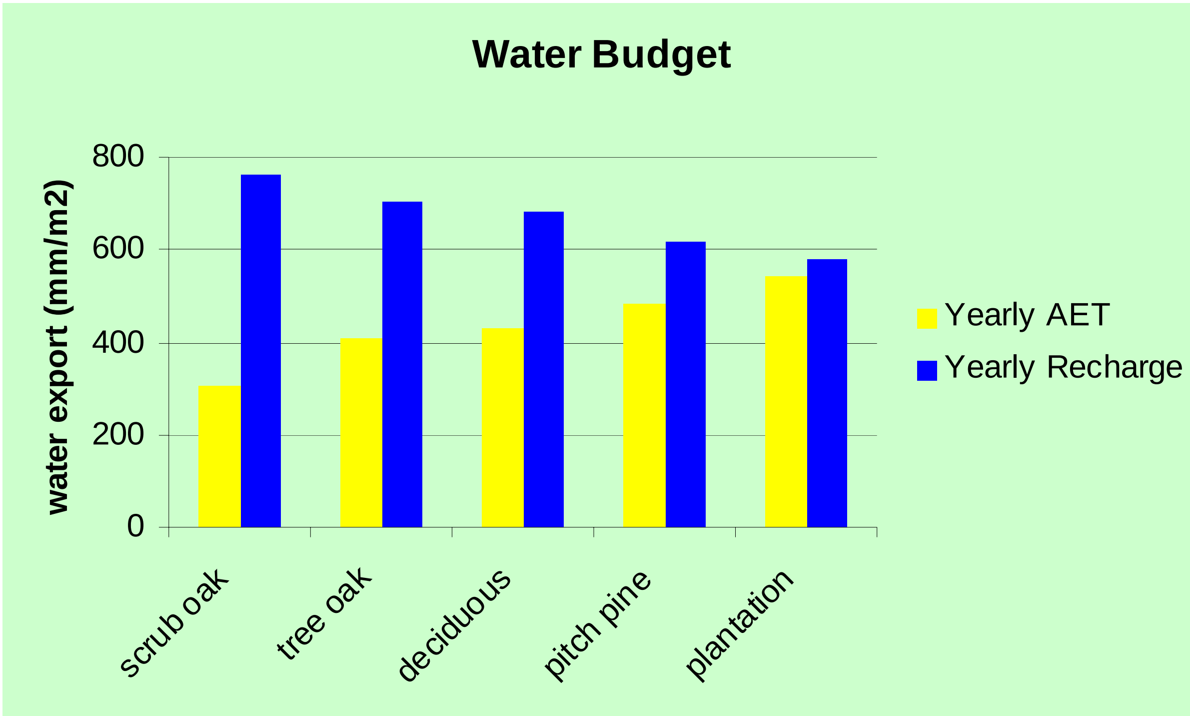
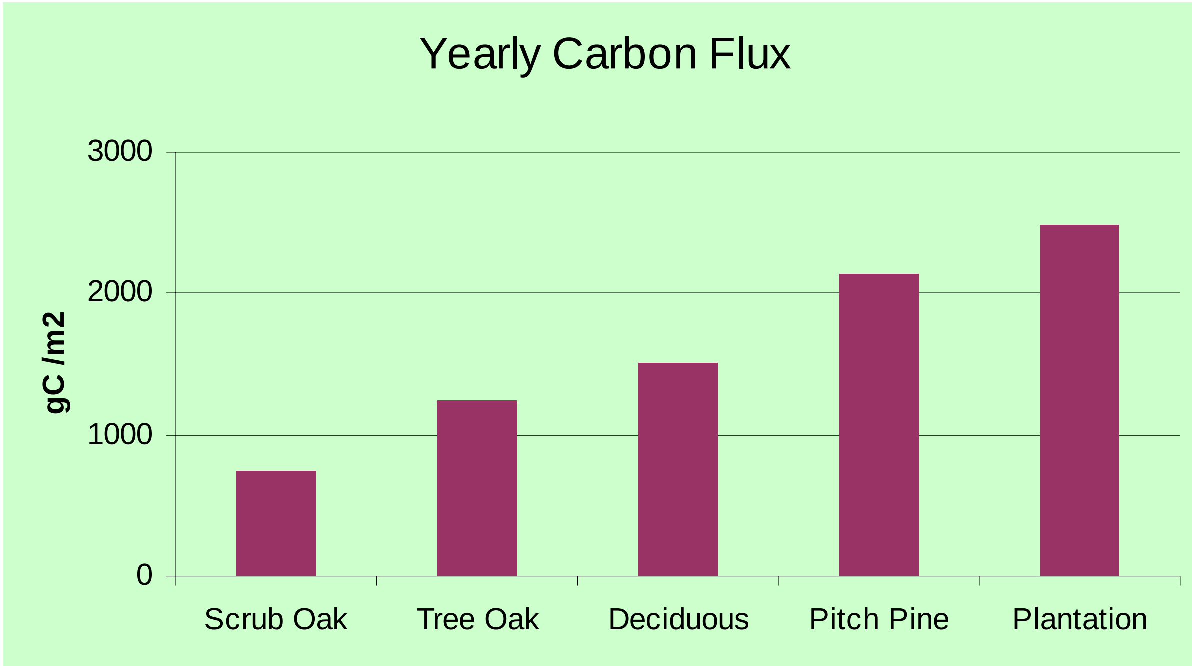


Figure 5. Annual carbon flux is correlated with leaf area. Scrub oaks have low carbon sequestration rates. Pitch pine forests and evergreen plantations can remove three times as much carbon from the atmosphere as scrub oaks can.



	Annual Carbon Flux gC/m2
Scrub Oak	742
Tree Oak	1251
Deciduous	1503
Pitch Pine	2143
Plantation	2491

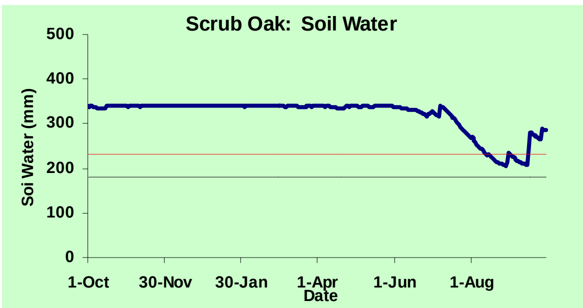
Table 4. Island wide annual water budget and carbon balance. Scanario a and b decreased carbon flux and carbon storage, but had little effect on the water budget. Scenario c decreased ground water recharge and increased the carbon budget. Tree carbon tripled with succession.

	Current	Scenario a: Fire	Scenario b: Replace Plantation	Scenario c: Succession
Annual Ground Water Recharge:	$1.0x10^8m^3$	$1.1x10^8m^3$	$1.0x10^8m^3$	$9.2x10^7m^3$
Annual Evapotranspiration:	$6.2x10^7m^3$	$5.4x10^7m^3$	$6.2x10^7m^3$	$7.1x10^7m^3$
Annual Carbon Flux:	$2.2x10^{11}g$	$1.7x10^{11}g$	$2.1x10^{11}g$	$2.9x10^{11}g$
Tree Carbon Stock:	$4.0x10^{11}g$	$2.7x10^{11}g$	$3.8x10^{11}g$	$1.1x10^{12}g$
Soil Carbon Stock:	$1.9x10^{12}g$	$1.8x10^{12}g$	$1.9x10^{12}g$	$2.010^{12}g$

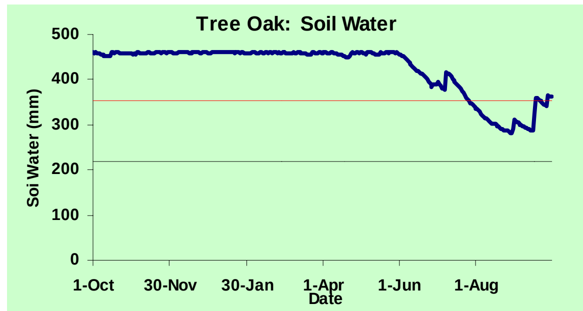
Table 5. Corellus State Forest carbon and water budget history. Over 60 years tree carbon stocks have increased six fold and the annual carbon flux has nearly doubled. The water budget was barley affected.

	1938	1952	1995
Annual Ground Water Recharge:	1.5x107m3	1.5x107m3	1.4x107m3
Annual Evapotranspiration:	6.5x106m3	7.4x106m3	8.0x106m3
Annual Carbon Flux:	1.6x1010g	2.2x1010g	2.7x1010g
Tree Carbon Stock:	1.1x1010g	3.8x1010g	6.0x1010g
Soil Carbon Stock:	2.1x1011g	2.3x1011g	2.4x1011g

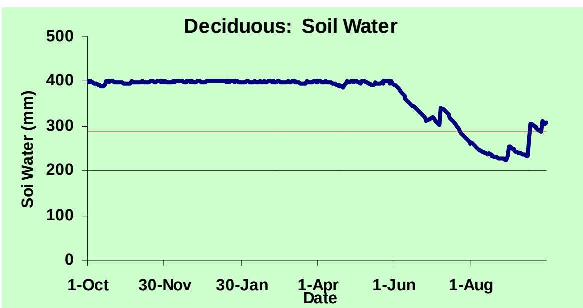
Figure 6. The blue line is soil water over the course of a year. the red line is the point at which water becomes limiting and plants begin to feel water stress. The black line is the soil water level at which water is no longer accessible to plants, it is called the wilting point. Scrub oaks (A) only feel water stress for 31 days out of the year. The other trees experience much more water stress. The evergreen plantation trees (E) are water stressed for 63 days of the year and draw the water down very close to the wilting point.



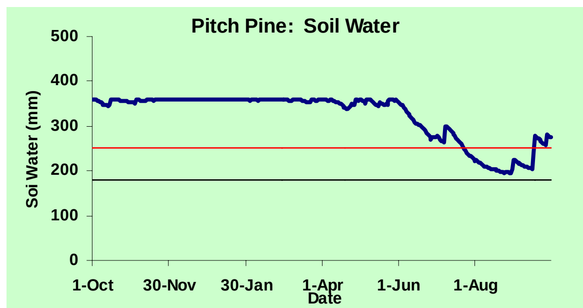
A.



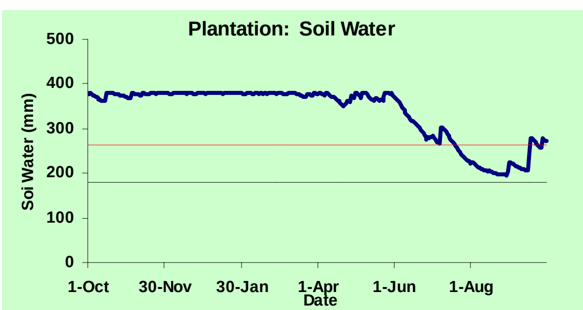
B.



C.



D.



E.

Figure 7. Soil texture among scrub oak sites is not consistent. The variation may be related to location: deep bottom and willow tree are located in depressional areas. The old county rd site is in a level area.