Testimony Before the Subcommittee on National Parks, Forests, and Public Lands of the Committee of Natural Resources for an oversight hearing on "The Role of Federal Lands in Combating Climate Change", March 3, 2009.

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Introduction

I am here to represent myself and offer my expertise to the subcommittee. I am a professional scientist, having worked in the area of forest carbon for nearly three decades. During that time I have conducted numerous studies on many aspects of this problem, have published extensively, and provided instruction to numerous students, forest managers, and the general public.

Recently there has been an increasing interest in using forests as a way to remove carbon from the atmosphere and store it over the long-term as part of a greenhouse gas mitigation strategy. US forests currently remove an equivalent of 12% of this nation's carbon dioxide emissions; there is excellent potential to increase and maintain this carbon "offset" as part of a bridging strategy. The following testimony reviews, in terms as simple as possible, how the forest system stores carbon, the issues that need to be addressed when assessing any proposed action, and some common misconceptions that need to be avoided. I conclude by reviewing and assessing some of the more common proposals as well as my general concerns about the forest system as a place to store carbon.

My key points: 1) Forests are leaky carbon buckets, 2) Forests can play an important, but limited roles in sequestering carbon, 3) All carbon pools need to be examined when thinking through the merits of carbon policy, 4) To increase the sequestration of forest carbon, we need to either increase carbon inputs, decrease carbon outputs, or put forest carbon somewhere else, 5) Forests are best seen as a bridging strategy in carbon mitigation, 6) Seemingly "good" forest carbon ideas when examined at the stand level at a point in time dissipate when looked at the forest level over time, and 7) With accelerating climate change, forests may shift from being part of the carbon solution to being part of the carbon problem.

The Basic System: Forests as Leaky Carbon Buckets

Carbon is stored in multiple ways in the forest system: in the forest itself and the carbon harvested from the forest. Living plants store carbon above- and belowground. The longer lived the plants or their parts, the more that they store. This is why forests contain more live carbon than grasslands: their parts have longer lives. When plants or their parts die they start to decompose, but some carbon can be stored as dead biomass. The slower the decomposition rate, the more that will be stored. This is why dead wood in a forest can be an important carbon store. Decomposition of dead plants eventually leads to the formation of soil carbon, which due to its relatively slow decomposition rate can accumulate to high levels. So despite a low live carbon store, grassland can store a great deal of carbon in the soil because it produces many dead roots that end up as soil. Harvest of wood and bark can also store carbon, but as with other parts of the forest system, it is subject to carbon losses, specifically during manufacturing, use, and disposal.

In the case of biomass energy, the harvested carbon is theoretically stored as unused fossil fuel carbon. Given the longevity of carbon dioxide in the atmosphere and the fact that this fossil fuel carbon may be eventually burned, "carbon" biomass energy must delay the use of fossil fuels for many decades to be an effective storage mechanism.

Photosynthesis, respiration, and combustion are the major processes that control how much carbon enters and leaves the forest system. These processes interact to control the carbon store of forest systems. Forests are biological systems and as such are "leaky" with regards to carbon. That is. there is one way in which carbon comes in (photosynthesis) but many ways it goes out (respiration of plants, decomposers, and consumers, combustion, leaching, and erosion). A key concept to understand is that leaky systems can store carbon, but the amount they store is related to the amount that is coming in versus the proportion that is leaking out. By analogy a bucket with leaks can store water, but to do so it needs a constant input of water. However, the larger the leaks the less water that is stored regardless of the amount of flow into the bucket. The same can be said of a bank account; one can spend money and still accumulate wealth as long as money is put into the account. Returning to the forest system, photosynthesis is constantly causing carbon to flow into the bucket or account. Increasing the input of carbon by increasing the rate of photosynthesis will increase the average forest carbon store. Decreasing the respiration rate of plants or decomposers or the losses from combustion will also increase the average forest carbon store. However, regardless of cause these net increases will eventually slow and then cease as the forest system comes to a new balance.

Disturbance, be it natural or human-induced, influences the balance of carbon several ways. Some disturbances, such as fire, directly release carbon to the atmosphere. All disturbances convert living plant biomass into dead biomass, subjecting the forest system to additional respiration losses (essentially more leaks). Disturbance temporarily reduces photosynthesis; which means that the average carbon input to the system is decreased by disturbances because it takes some time to restore the photosynthetic capacity of forests. The effect of disturbance depends on the frequency and the severity (i.e., amount of carbon removed) of the disturbance. The more frequent disturbances appear in forest systems, the more that is removed, and hence less carbon is stored on average. Decreasing the interval between disturbances effectively increases the number of leaks in the bucket. The same effect is true for disturbance severity; the more severe the disturbance is in directly removing carbon, the less stored on average. Increasing disturbance severity effectively increases the size of the leaks in the bucket.

The Effects of Natural Disturbances versus Harvest

Whether trees killed by fire or windstorm are salvaged makes relatively little difference in carbon storage. Whenever there is a natural disturbance it is often suggested that harvesting dead trees will release less carbon than letting them decompose naturally. This is based on the assumption that natural processes will rapidly release carbon and timber harvesting will not. This assumption is not supported by the likely rates of carbon release from these two processes. Setting aside the fact that harvest and transport of wood currently requires carbon-based energy, there is an inevitable release of carbon during the manufacturing and use of forest products. Depending upon the type of wood product produced, the amount of carbon released during manufacturing is equal to 25-50% of the harvested amount. In many cases harvested forests are burned for site preparation, a process that removes approximately 5-10% of the forest's carbon. Combined with manufacturing losses, this means that timber harvest reduces total forest carbon stores by 10-25%. When products are in use, their life-span has a wide range from less than several decades to centuries. This yields a rate of loss of between 1 and 10% per year. While surprising, these values are not that different for natural disturbances. Consider the amount of loss during a fire, the natural disturbance that removes the most carbon. A common assumption is that much of the wood burns in a fire, although if that were true there would be no debates about salvaging wood. Analysis after fire indicate that, while small material can be totally consumed, it is rare that harvest sized wood is consumed. Losses from roots and the soil are minimal. Taking all the carbon stores of a forest into consideration, the range of carbon losses from fire consumption is probably between 5 and 15%, generally lower than range for timber harvest and products manufacturing. After the fire, the newly killed trees decompose. For the US, the range of wood decomposition rates for the size of material harvested is between 1 and 10% per year. That is very similar to that of forest products! Although all these numbers are approximate, they do indicate that salvaging fire-killed trees is not substantially better for carbon storage than simply allowing the trees to decompose, and in certain situations might be considerably less effective in storing carbon.

Things to Consider: Framing the Analysis of Carbon and Forests

There are a number of general things that should be examined whenever an action regarding carbon and forests is considered. Unfortunately this has not always been the case.

1. **All the relevant carbon stores need to be examined.** Many projects are considered from the point of view of just live carbon. This may be quite natural to do as we have the most data and understanding of live trees. However, it must be realized that other important carbon stores in forests do not behave the same as live trees. Dead trees, for example, often reach their highest store after disturbance, whereas live trees reach their lowest store at that point. By only considering live plants it is highly likely that the rate of forest carbon uptake is overestimated, in some cases by substantial amounts. A related issue is that the changes in all the carbon pools need to be considered for a total accounting. For example, harvesting wood does increase stores in the wood products pool, but it also decreases stores in the live and dead wood pool in the forest.

2. **The starting conditions are key and yet are often ignored.** The starting and end points need to be specified. Often a proposed action gives the end point, but not the starting point. This would be similar to describing a trip by only giving the destination. One will have no idea of the direction or the distance to be traveled. For example, if one is planning on establishing a short-rotation forest plantation on agricultural land, then more carbon will be stored. Establishing the same type of plantation by converting an old-growth forest will result in a net loss of carbon to the atmosphere.

3. **Our actions to increase carbon stores can take decades to have a positive effect.** Not every action in forests leads to an "instantaneous" response. It takes time to implement policy actions because the area involved is quite large. This means that the effect of any proposed policy needs to consider the long-term: many decades to centuries. Once treated forests take many years to

adjust to any action that is imposed. For example, it takes years to decades for a planted forest to establish full photosynthetic capacity. It also takes years to decades for the dead material created by a disturbance caused by nature or humans to decompose away. This means that temporal lags can be expected in any projected gains. Thus, it may be eventually possible to gain carbon by converting an older forest to a younger biomass energy plantation, but it may take many decades or even centuries for this to occur. This is time we do not have.

4. **Forests are potentially renewable, but this is not a fixed property of forests.** It is generally assumed that forest related carbon in the form of wood and biofuels are renewable. There is logic to this in that trees can be harvested and can regrow. Resources that can regrow are potentially renewable, but a resource is not renewable automatically because it is grows or is a tree. To determine if a resource is renewable we need to compare the regeneration and removal rate. We also need to understand that removal of trees can and does affect carbon pools other than trees and these can decline when trees are harvested. Given we are considering the entire forest carbon system, this mean that harvesting a renewable resource such as trees leads to an non-renewable loss elsewhere in the carbon system.

5. **Forests are systems that have feedbacks which can strongly influence carbon effects of actions**. For example, increasing the growth rate of trees can lead to higher carbon stores in forests, but a larger live tree store also means that more plant material will die during the course of forest growth or harvest. More dead plant material means more losses via decomposition or combustion if there is a fire or harvest. This means that the gains from increases in forest growth feedbacks to result in decreased net carbon increases in time. As another example, it has been stated that forest fire frequency and severity will increase in the future. That may be the case, but it also should be noted that it is generally difficult to increase the severity and frequency of fires for any length of time, in part because more frequent fires eventually lower the fuel level, and fuel level is related to fire severity.

6. **Estimating carbon effects of policies need to look at whole forests over time, not single stands at a point in time.** The way a forest system behaves depends on how large an area that is considered and how long a time period it is considered. Perhaps no other issue, termed scale by ecologists, has lead to so much confusion and frankly wrong-headed notions in terms of forest carbon management. It is perfectly true that young forests of a certain age do remove more carbon in a course of a year than an older forest. This would be useful information if forests never changed their ages. The high rate of uptake of some young forest occurs because even younger forests have lost carbon. Since one can not have a young forest without have an even younger forest, comparing the just one year in the forest's life is completely misleading. Recall that when forests are disturbed by nature or humans the forest initially loses carbon. Over a long time period forests gain carbon and eventually lose some of it when disturbed again. If the average carbon stores of a young forest is compared to that of an older forest, then one finds that the older forest stores a good deal more carbon. Therefore one is unlikely to gain carbon from the forest site if one converts from an older to a younger forest system. When one considers a small plot of land, the carbon balance seems to moving from losing to gaining to losing carbon over time. However, when one considers many plots of land that are going through these cycles at different times, then one sees a relatively steady store of carbon. This is analogous to a bank in which one person puts in funds and another removes them. As long as there is not a run on the

bank, the amount of funds is relatively constant (at least that is the hope). This is quite relevant in terms of carbon policy, because small land owners will see boom and bust cycles in their carbon stores and this may make buying their carbon credits very unappealing. If many small land owners aggregate their carbon projects, then it is possible for the buyer to see a steady store or supply of carbon.

Using Forests to Sequester Carbon from the Atmosphere: increase carbon inputs, decrease carbon outputs, or put forest carbon somewhere else

US forests are currently removing carbon from the atmosphere and are likely to remain doing this for some time, perhaps decades. Eventually, as in all leaky systems, the rate of carbon removal is likely to slow and eventually cease. At this point the forest will be in rough balance with the amount coming in about equal to the amount going out. This "saturation" behavior is one reason forests are considered a bridging strategy and not a lasting solution to the problem of reducing greenhouse gas emissions.

To continue and enhance the removal of carbon by forests, it will be necessary to take direct actions. Put simply, to remove more carbon from the atmosphere with forests it will be necessary to increase the average amount of carbon that forests store or increase the efficiency or manufacture of wood products and the length of their storage in use. As stated above, the average carbon store as well as the carbon balance of any forest is controlled by the amount input via photosynthesis versus the amount lost via respiration (e.g., plants and other organisms such as decomposers) and the amount lost via combustion. Both the average carbon store and the carbon balance vary over time, in part, because the factors controlling photosynthesis, respiration, and combustion vary over time. Therefore it is useful to distinguish between short-term and relatively minor variations in forest carbon caused by yearly variations in climate versus those caused by changes in policy or long-term changes in climate. It is the latter two that will change the balance and store of carbon in the long-term.

Before presenting the range of possible management options **it is worth reminding ourselves that carbon is not the only reason we manage forests.** Forests provide humans clean water, habitat for many animals, plants, and other organisms, harvested goods of all sorts, recreation, and many intangible benefits. Not all these objectives will be compatible with maximizing carbon stores in forests. Moreover, there are certain management actions such as thinning certain forest types (e.g., Ponderosa pine) that may be necessary to maintain these forests despite the fact that carbon stores will be decreased. We can not be so single minded about carbon that we create a host of other problems.

There are many proposed steps and multiple viable strategies and that can be taken with regard to increasing forest carbon. Admittedly this can be confusing for those looking for a "one-size fits all" approach. On the other hand it does offer flexibility that will allow one to tailor approaches with specific situations on the ground. **Essentially one can increase carbon stores of a forest by increasing the input to the forest, decreasing the output from the forest, putting the carbon from the forest somewhere else, or some combination of these.** The following reviews specific approaches that have been proposed recently:

1. **Slowing that rate of deforestation (i.e., the permanent removal of forests) will definitely slow the release of carbon to the atmosphere.** Depending upon the period examined, deforestation is estimated to have added 20-30% of the increased carbon dioxide in the atmosphere since the dawn of the industrial revolution. While deforestation for agricultural purposes is generally low in the US, considerable forest land is being converted to housing and industrial use, which can have the same effect as deforestation, particularly if clearing is extensive.

2. **Planting new forests is generally a good practice to increase carbon stores, particularly on lands that once held forest many years ago.** Much of our nation's current forest-related carbon removal from the atmosphere is associated with the reestablishment of forests in the eastern US after agricultural abandonment. The best opportunities are on marginal agricultural lands as the impact on food production is reduced. Planting forests on degraded agricultural land can increase the store of carbon both above- and belowground (i.e., soils). Forests can also be reestablished on lands with low stocking of trees after regeneration failures. Planting trees on what have been traditionally grassland systems can lead to reductions in soil carbon stores, in part because trees do not produce as many dead roots as grasses. Care needs to be taken in assuring that these losses belowground do not exceed those gained aboveground.

3. **Biomass energy has the potential to offset fossil fuel use and hence reduce carbon release to the atmosphere under certain conditions.** However, there are several factors that must be considered before this potential is realized. Biomass energy is not necessarily renewable; it is only renewable when the resource is allowed to fully regenerate. Forests, by their very long-term nature, take years to regenerate their biomass and one can not assume that all forest practices lead to a renewable resource. When using biomass energy, it must be borne in mind that one is substituting energy and not carbon. Because biomass contains less energy per unit carbon than fossil fuels, some fossil fuels are required to produce the same amount of energy, and so removal of one unit of carbon from the forest results in less than one unit of fossil carbon from being unused or stored. It therefore may take several cycles for carbon benefits to accumulate to the point that they offset losses in the forest. This is why the carbon benefits of biomass energy can be delayed if natural forests storing a more carbon are converted to plantations that store less carbon. This suggests that if biomass energy is to be part of a forest strategy, it is best employed with afforestation efforts or in forests that are already young. Although it is usually assumed that fossil fuel use is decreased when biomass energy is used, this is not necessarily true. Given the lifespan of carbon in the atmosphere, the delay in fossil fuel use has to be substantial to be effective. Simply delaying the use a few years does little to reduce the rate of overall carbon emissions. The argument that the increase in fossil fuel related carbon would have been worse without biomass fuels would have merit if the issue was to just slow the increase in these releases. However, the issue that confronts us is how to decrease the current release rate of fossil fuel carbon.

4. **Converting older forests to younger forests rarely stores more carbon. S**uch action increases the leakiness of the forest bucket (recall major losses discussed above in site preparation, manufacturing losses, and the increased frequency of disturbance). An exception is when a frequent natural disturbance is replaced by a less frequent harvest (which by the way rarely happens). Another is when an inherently very slowly growing natural forest is replaced by

a much faster growing plantation. That too is fairly rare. Two of the best ways to store more carbon in forests is to extend the interval between harvests or take less per harvest. Basically both actions make the forest bucket less leaky. Depending on the length of the rotation or the amount of harvest, one can either enhance or reduce the store in forest products. While longer rotations can lower the average amount that is harvested, the material that is harvested tends to be more suitable for long-term use and hence may store more as wood products.

5. **It is possible to increase forest system carbon stores by increasing the growth rate of trees.** Depending on the forest, this can be achieved by using superior genetic stock, planting faster growing species, fertilization, irrigation, or speeding the rate of tree regeneration. In most cases the increases in tree growth do not offset the losses from converting older natural forests, and in all cases it may take several harvest intervals before gains are fully realized in wood products stores. Usually the goal of increasing the growth rate of trees is to shorten the interval between harvests. If this practice is followed, then the gains of carbon in the forest itself will be minimal. On the other hand it may result in increased wood products stores, but that depends on the types of products produced. It should also be noted that thinning of forests does not increase the rate carbon is added to forests. It does allow the remaining trees to grow faster and become larger faster, but one must remember that it does this for fewer trees. The claim that thinning increases forest production is really based on the amount harvested, not the amount of carbon entering the forest: these are two completely different things.

6. **Reducing fuels in forests have few benefits from a carbon storage standpoint.** Recently it has been proposed that reducing fuels in forests would reduce fire severity to the point that more carbon would be stored in forests than allowing them to burn untreated. This practice can have benefits for ecosystem restoration in some forest types (for example, Ponderosa pine), but there appear to be few benefits from a carbon storage perspective. There are many reasons for this result. First, to reduce fuels one needs to reduce carbon stores, so there would have to be major changes in fire severity and size to offset these losses. Second, the difference in the effects of severity on carbon stores is less dramatic than generally imagined. As indicated above, a very light fire might results in forest losses on the order of 5% of total carbon in a forest, whereas for an extremely severe fire these losses might be on the order of 15%. Third, one can not anticipate where fires will occur, so a large proportion of the forest area needs to be treated. In contrast, a small proportion of the forest area may burn in the next few decades, which results in more losses from the treatment than the fires (bear in mind the total effect depends on both the area involved and the average loss per area). The most likely case where removal of fuels will result in a long-term carbon benefit would be if, without fuel treatment, the fire severity increases to the point that tree regeneration is greatly delayed. However, this regeneration delay has to be substantial to have much of an effect.

7. **Forest products do store carbon; whether they actually increase the forest system carbon stores is a more complicated issue.** Given that the basic material of forest products, wood, is approximately 50% carbon, harvesting wood and placing it into forest products can definitely store carbon. However, this gain is at the expense of storing carbon in the forest, and it is completely possible there will be no net gain in the total forest system carbon stores. Harvest of wood removes carbon from the forest which means the parts of the forest that depended on that carbon will decrease in stores. Manufacturing of wood into products results in a loss of carbon as

does the use and disposal of wood products. Overall, the effect of harvesting carbon is to make the overall forest system leakier. If wood products are to be used to store carbon, then the efficiency of converting wood into long-lived products needs to be increased, and the life-span of these products needs to be lengthened considerably (see above). There have been proposals to harvest wood from forests and store it in a location where it can not decompose by burial on land or sinking it into oceans or lakes. I suppose this would be the "ultimate" wood product in terms of carbon storage. Assuring that there is no decomposition may prove challenging: wood is decomposed quite quickly in oceans, for example, organisms such as shipworms readily eat wood as any naval historian can attest. Wood is not the most concentrated form of carbon and the sheer volume to be stored would likely dwarf those of current landfills and interfere with other land-uses. Also it may not prove particularly popular. Finally, the harvest of wood causes other parts of the forest to temporally lose carbon which would introduce time lags into the gains offered by this scheme.

8. **Substitution of wood for more energy intensive materials has the potential to decrease fossil fuel carbon releases, but how much of this potential will be realized is difficult to quantify.** It has been proposed that substitution of wood for more energy intensive materials will reduce the rate that fossil fuel carbon is released into the atmosphere. While wood is generally less energy intensive than many alternative materials, the difference between materials has been decreasing and not all the energy for these is supplied via fossil fuels. Currently, steel and concrete utilize three times the energy of wood. However, most buildings are mixtures of wood and other materials, so the energy savings of a building primarily constructed of wood is 30% relative to those primarily made of other materials. As noted above, harvest results in the release of carbon from the forest and while not fossil fuel-related, these losses need to be deducted from any gains. Many homes and small commercial building already utilize wood to a high degree. It is therefore not clear how large the substitution effect can become in the US. Finally, although it has been stated by some that the substitution-related carbon offset never decreases and accrues each harvest. However, there are reasons to suspect this claim. This would only be true if wooden buildings lasted forever or the supply of buildings increased without limit. It is far more likely that buildings will have a finite life-span and need to be replaced, which also means wooden buildings can not increase without limits. Since that is true, then in time harvests are maintaining the store in buildings and there is no net gain in this form of carbon offset. So depending on how much carbon is actually offset, this might be part of a bridging strategy.

Concerns

Despite the reality that US forests are currently removing carbon from the atmosphere and the great potential for forests to play a role in offsetting greenhouse gas emissions, I do have several concerns.

Liquidation of forest carbon stores can be the potential unintended consequence of carbon policy. To have forests play a greater role than they do currently, we will have to do something different than business as usual. We must assure that additional carbon is stored due to new actions, a concept usually called "additionality." Despite the need for this concept, it must be acknowledged that it means those with practices that have lead to the lowest carbon stores have the most to benefit from changing their practices. The role of those that have already changed practices or have always managed in a manner to keep carbon stores high has to be recognized and encouraged. Little will be gained if the only way to have carbon store increases counted is to first lower carbon stores. Given the time lags inherent in the forest system, this will be totally counterproductive.

Making sure carbon stores are real: the need for a national accounting, verification, and monitoring system. We must make sure that any gains in forest carbon stores are real, which means they will have to be monitored and verified. This needs to be done at two levels. The first would be at the level of specific projects. The second would be at a national level, which would involve more than simply adding up all the projects, in part because there will be many forest areas without carbon projects that need to be considered in the national balance sheet. The often stated claim that methods do not exist to monitor changes in forest carbon is completely puzzling given that scientists developed these methods decades ago. There are many existing methods and systems that can be modified to achieve the goal of monitoring and verification. They could be substantially improved with further investments, but are sufficient to start the process now. National guidelines or protocols, similar to those developed by California, would greatly aid in assuring monitoring and verification is trustworthy. At least at the project level, where the goal is to support a carbon credits market, these protocols can be flexible as long as there are discounts or deductions for uncertainty about how much additional carbon is being stored. That way the project managers can decide the tradeoff between the gain in carbon by lowering uncertainty versus the cost of a more expensive and comprehensive measurement program. It should also be noted that these estimates of carbon gains need to be conservative, because failing to count storage will do far less environmental harm than over-counting. Another possible role for the government would be to support detailed studies of proposed projects to fully understand the carbon impacts of the most commonly proposed projects. While there is a great deal of scientific research in this realm, it has not generally been of an applied nature. It is unlikely that all forest projects will be able to afford detailed measurements of all the carbon pools and processes. These studies would allow others to more fully anticipate the likely carbon gains and costs of proposed projects and in fact streamline the verification process because certain practices would have been proven to work under certain conditions. Finally, it is important that a system be established to rank the quality of the carbon as opposed to the quantity of carbon. This might be similar to that used for rating bonds; however, as we have all just learned to work this system needs to be independent of those buying and selling carbon credits.

Despite the potential for forests to contribute to the challenge of reducing our nation's greenhouse gas emissions, I do believe that the forest system's limits have to be fully recognized. Even if we could double the current rate that forest's are removing atmospheric carbon, it would amount to approximately 20% of the current fossil fuel release of carbon dioxide. This is quite important, especially since it can be achieved with largely with today's technology. But clearly forests can not be used to solve the entire problem.

My greatest concern: with continued warming forests can shift from being part of the carbon solution to being part of the carbon problem. Forests cannot continue to accumulate carbon forever, so it can be part of a bridging strategy, but we need to use the time it buys us wisely. This brings me to my greatest concern which involves the role forests will play if the climate continues to warm as projected under a business as usual scenario. If we do not act soon to reduce the rate the carbon dioxide and other greenhouse gases are released, we may create a climate that will make forests start a net release of carbon to the atmosphere. This could come about in several ways, but many of the effects are likely to be caused indirectly by increased drying of forests. This will mean that wildfires become more extensive and more severe, that insect outbreaks become more extensive and more severe, and that even trees in so-called “undisturbed” forests start to die at faster rates. If this starts to happen then the leaks from the forest carbon system will increase and eventually less will be stored. Not all the carbon will be released all at once as is often implied, it will happen gradually, but if forests reach this point then they will start to contribute to the problem we are trying to solve. Further, it may also become part of a vicious cycle in which more trees die which releases more carbon which warms the climate even more which causes more drying, which causes more trees to die, etc. Forests are not the only part of the natural world that may act in this manner; thawing currently frozen soils in the north could cause yet another vicious carbon release cycle to begin. To assure that this does not happen we need to act on a number of fronts and to decrease carbon dioxide and other greenhouse gas concentrations in the atmosphere as fast as we possibly can.

Summary

Forests are currently storing considerable carbon in the US and are currently offsetting approximately 10% of the nation’s carbon dioxide emissions. Forest systems can be managed in a wide range of manners to sustain and perhaps even increase their ability to remove carbon from the atmosphere. Some of the actions being proposed will definitely not store more carbon in forests, but there are many that will. To assure that forest projects in fact remove atmospheric carbon, it is essential that the actions conform to rigorous scientific principles, that increases of stores be monitored and verified. Forest systems can be a good share of the nation’s solution to decreasing the accumulation of carbon dioxide in the atmosphere, but they can not be used alone. It is highly likely that unless other steps are taken that the positive role that forest could play will become diminished and even switch to a negative one. We must also make sure that actions taken to increase the role of forest as carbon stores does not create other problems in terms of what we expect forests to do for us.

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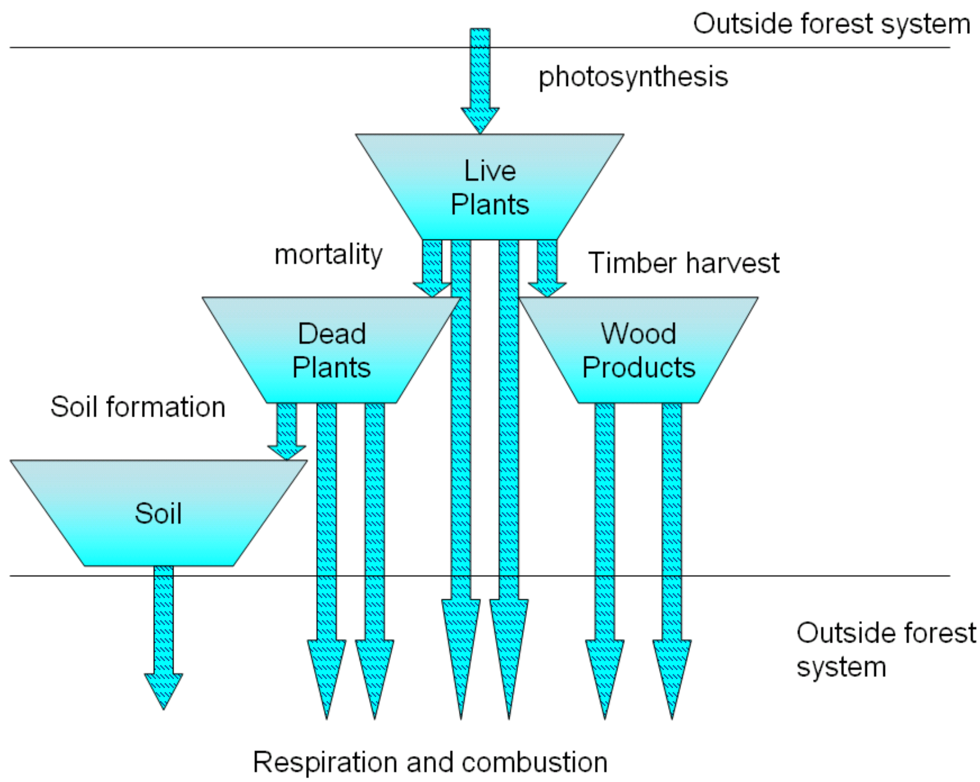

Figure 1.The forest carbon system can be envisioned as a series of leaky buckets. The amount stored in each bucket depends on the amount coming in versus the proportion leaking out. Carbon enters the forest systems via photosynthesis. Carbon leaks out via many processes, but the main ones are respiration and combustion.

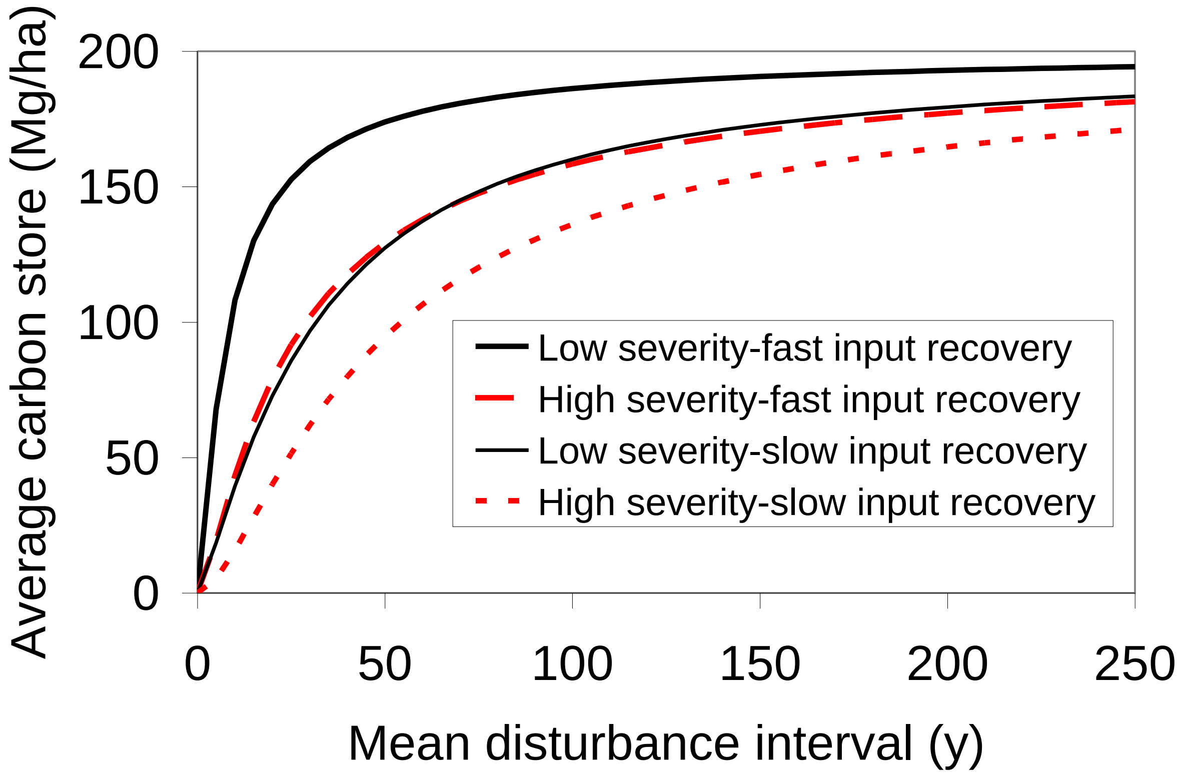

Figure 2. One can store carbon in forests even when there are disturbances. This figure shows the average amount of carbon that can be stored given various combinations of disturbance interval and severity. The low severity disturbances remove 5% of the carbon and the high severity disturbances remove 50%. This model also accounts for that fact that disturbance reduces the input of carbon via photosynthesis for a time period. Fast recovery of carbon input occurs in 5 years and slow recovery in 50 years. Notice that a low severity disturbance with a slow input recovery has about the same response to disturbance interval as a high severity disturbance with fast input recovery. Also note that as the interval of disturbance increases disturbance severity and input recovery have diminishing effects. To increase carbon stores there are multiple options: one could decrease the severity, increase the interval between disturbances, or increase the rate that carbon input recovers.

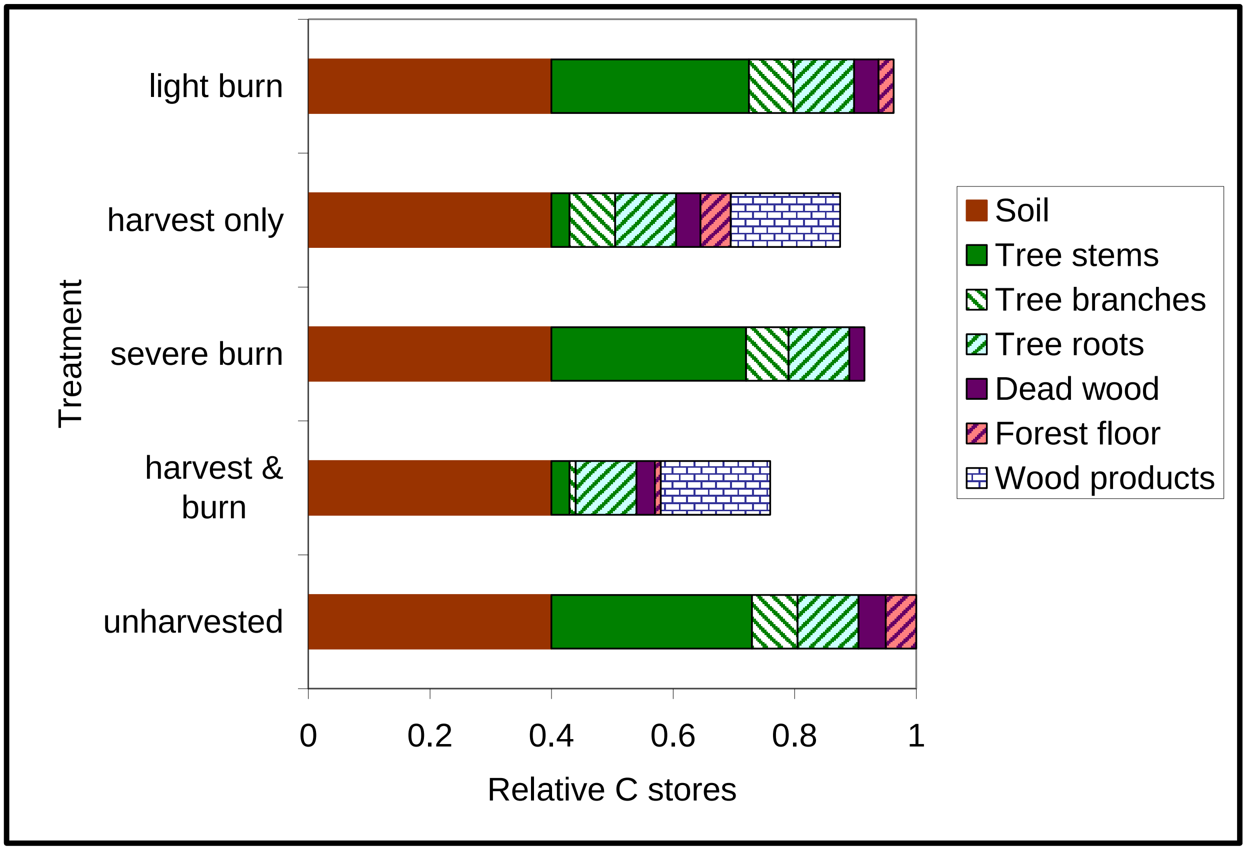

Figure 3. Hypothetical stores in forest system after wildfires and timber harvest with and without site preparation fires. None of these treatments is assumed to influence carbon stores belowground. The conversion rate from harvested carbon to wood products carbon is assumed to be 60%. Severe wildfires are assumed to consume the entire forest floor and 45% of the dead wood. Light wildfires are assumed to consume 50% the forest floor and 10% of the dead wood. Fires associated with site preparation are assumed to be intermediate in their effects on these pools.

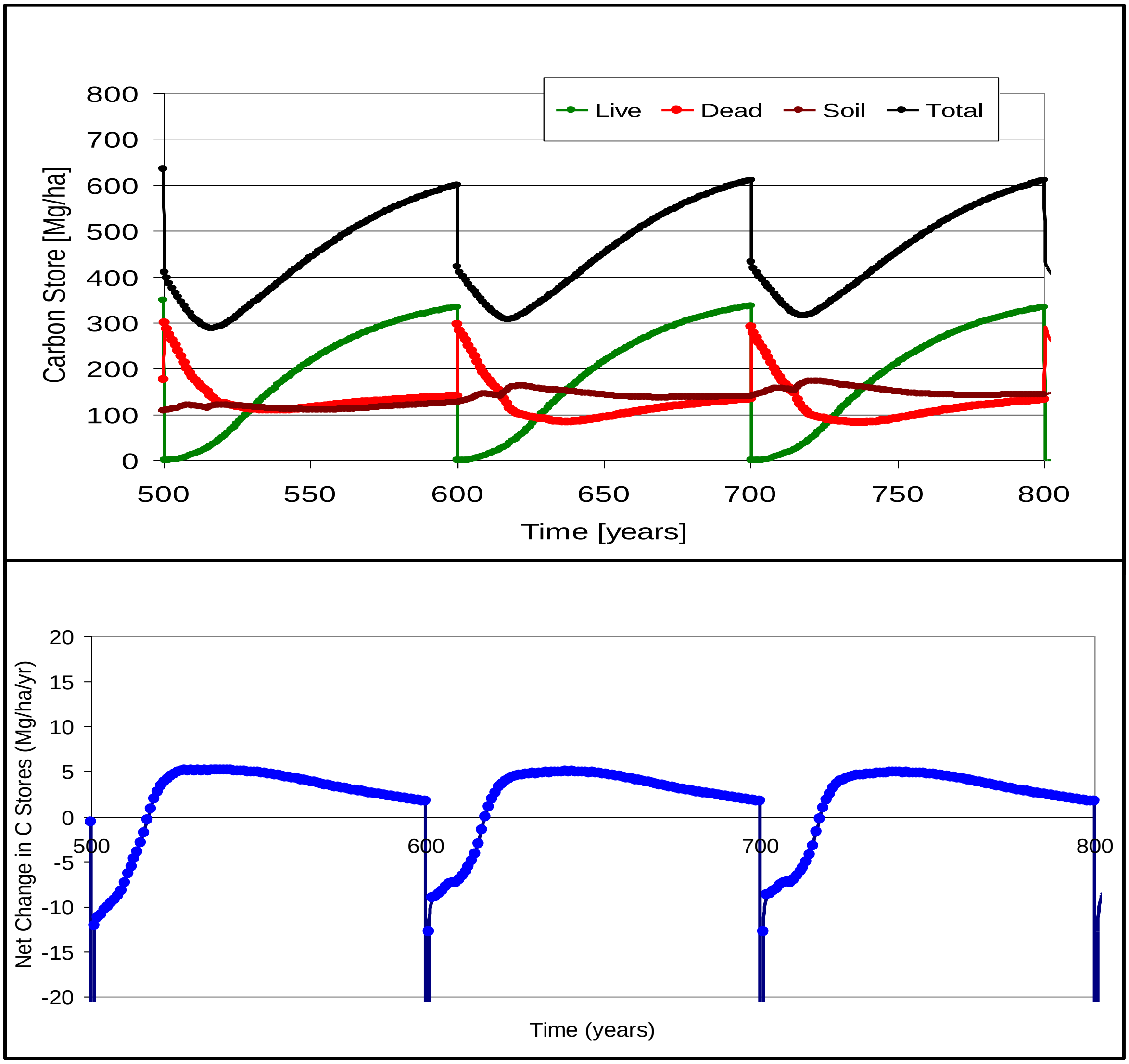

Figure 4. The divergent dynamics of live trees and dead plant material is the key to understanding distinction between optimal management for timber production and the optimal management for carbon stores on forest land. This figure shows the change in carbon stores following a hypothetical timber harvest (upper panel). The live carbon drops to 0 once the trees are cut, then increases. The rate of live carbon accumulation slows in part because more and more carbon is to replacing trees and tree parts that die. The other major stores not change in sync with tree biomass. Dead biomass receives an input of material following harvest. This dead store loses carbon gradually over many years and decades; the dead store increases again as dead plant inputs from the new stand exceed losses from respiration. The Soil carbon pool changes over time as well, but those changes are relatively minor and its peaks lag behind the dead pools which form its source. The total carbon stores decline for about 20 years following disturbance; this means that the forest is a source of carbon even as a new generation of trees actively accumulates carbon. The net change in all the carbon stores in the forest over time changes from a source to the atmosphere (negative sign) to a sink (positive sign) from the atmosphere (lower panel).

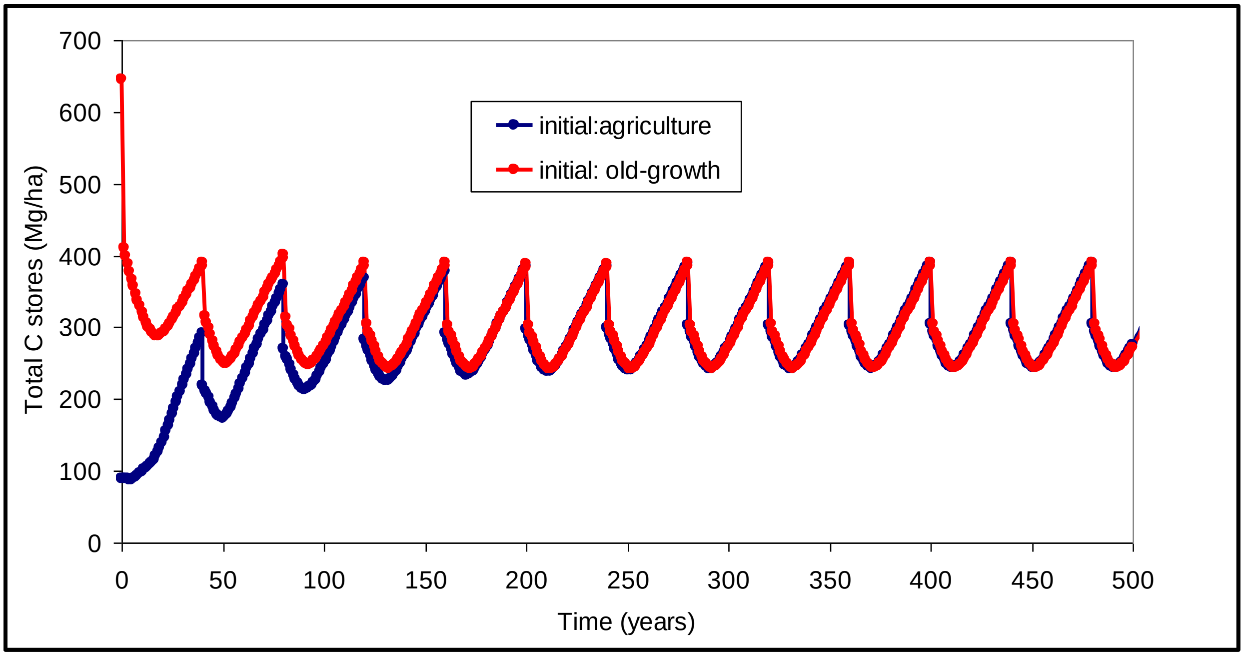

Figure 5. It is important to consider the starting as well as the end point when evaluating policies. In both cases above there is conversion to a plantation forest that is harvested every 40 years. Starting from an agricultural field there is a net gain carbon. Starting from an old-growth forest there is a net loss of carbon. Notice that in time the plantation forest is the same regardless of the starting point.

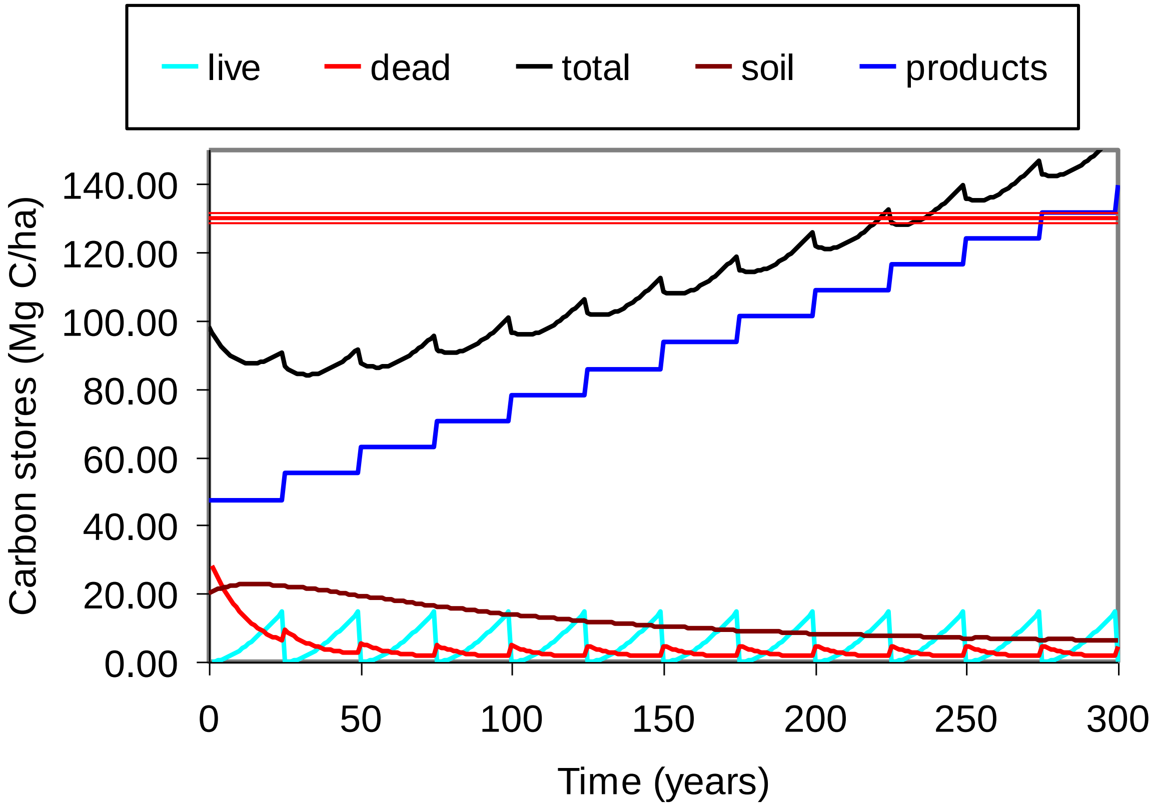

Figure 6. Forests can be slow to respond to changes in management. In this example, the gains from biomass energy harvesting may not be immediate for several reasons. When biomass energy offsets are being claimed, one needs to be aware that energy and not carbon is being substituted. In this hypothetical case an older forest was converted to a biomass plantation with a 25 year harvest interval. It is assumed that 80% of the live carbon is harvested, and none of the dead biomass is harvested. The energy content of wood is assumed to be 2/3rds that of fossil fuels. The horizontal red line indicates the starting store that was contained within the old-growth forest. Note that it could take hundreds of years before there is a net gain. If the net energy content of biomass fuels is lower, it will take even more time.

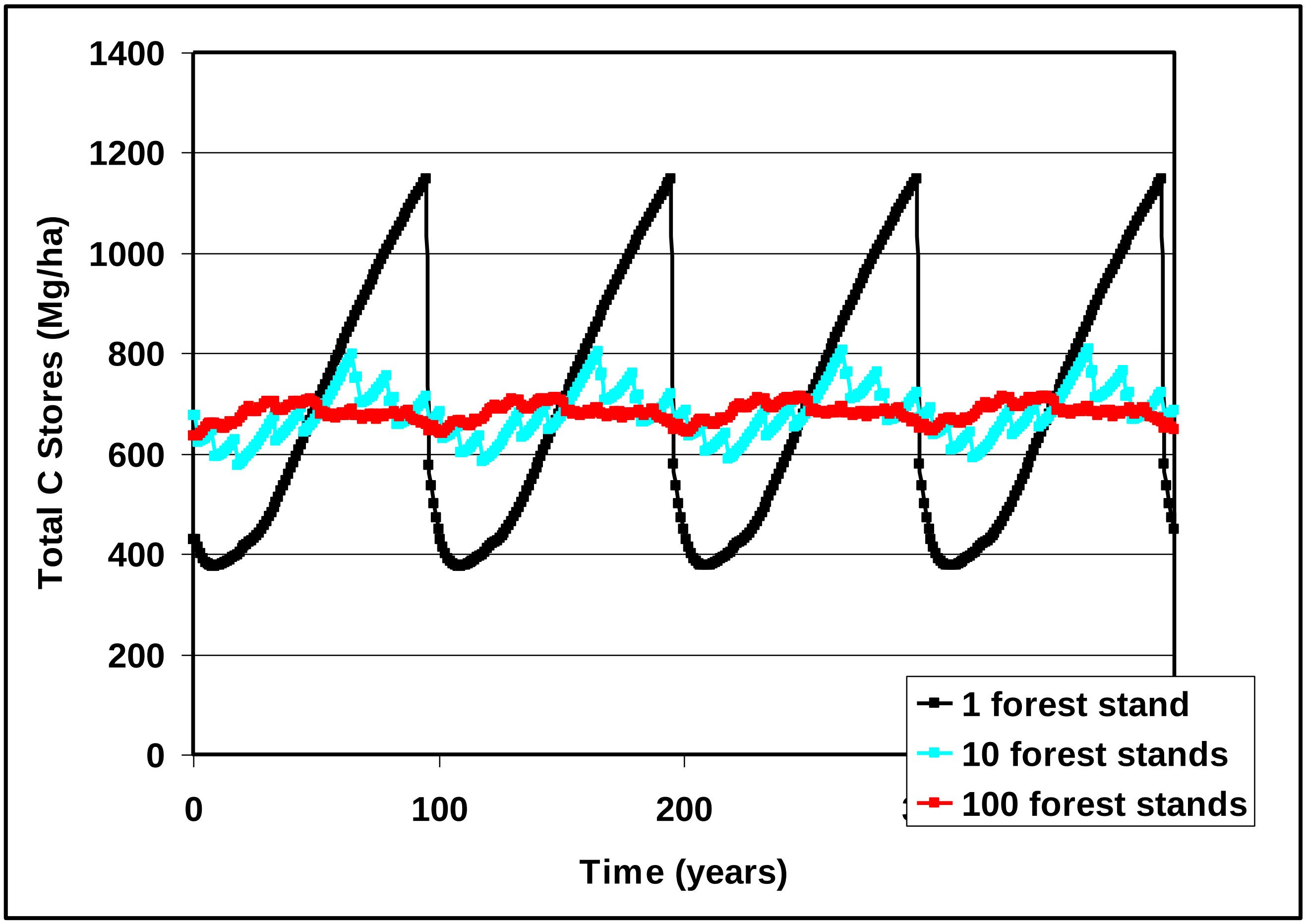

Figure 7. It is essential to examine management actions at the relevant time period and areal extent. This illustrates how the behavior of carbon stores changes as one includes more stands in the analysis; essentially increasing the area of forest being considered. As the number of stands increases, the gains in one stand tend to be offset by losses in another and hence the flatter the carbon stores curve becomes. The average carbon store with a large number of stands is controlled by the interval and severity of disturbances as shown in Figure 2. That is, the more frequent and severe the disturbances, the lower the average becomes.

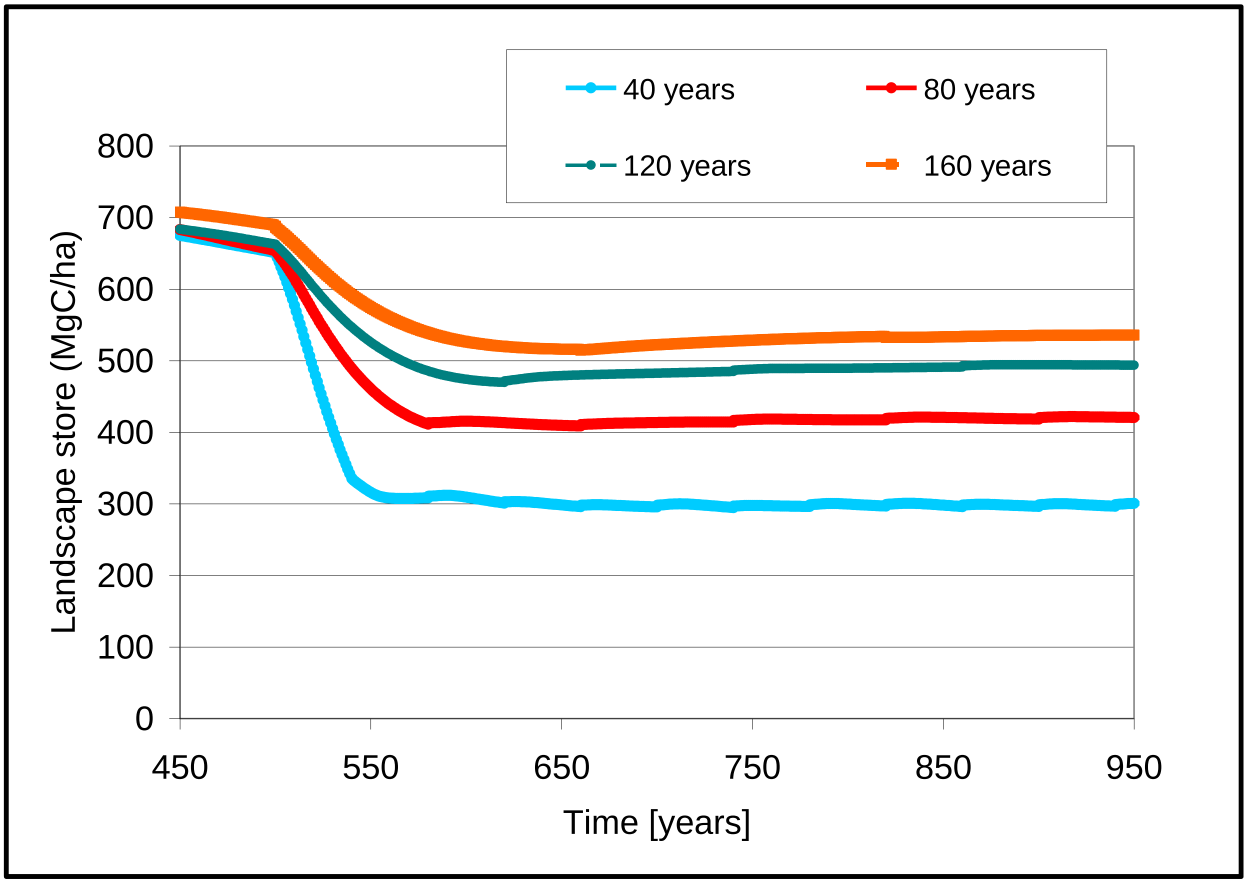

Figure 8. Converting old-growth forests in productive forests such as those in the Pacific Northwest is highly unlikely to result in the forest storing more carbon. In this series of simulations old-growth forest landscapes are converted to plantation forest landscapes with differing intervals between harvests. As the interval between harvests is shortened, the lower the carbon store becomes. The gains in wood products stores do not fully offset this loss.

Table 1. Summary of possible actions to increase carbon stores in forests. For those actions with large ranges, the underlying factor causing the range is noted.

Action	*Odds of Positive Result*	*Potential Area Involved*	*Pairs Best with*	*Trades off with*
1. Slow deforestation	High	Low to Moderate	3, 4	7, 8, 9
2. Afforestation on former forest lands	High	Moderate	7, 8, 9	6
3. Lengthen interval between harvest	Moderate to High Depends on time added	Moderate to High	1, 2, 4	7, 8, 9
4. Reduce amount harvested	Moderate to High Depends on degree	Moderate to High	1, 2, 3	7, 8, 9
5. Increase growth of trees	High	High	3, 4, 7, 8, 9	
6. Fuel reduction on wildlands	Low	Moderate	7	3, 4
7. Wood-based Biomass energy	Low to High Depends on starting point	Moderate	2, 5	1, 3, 4
8. Wood products	Low to High Depends on starting point	Moderate	2, 5, 9	1, 3, 4
9. Substitution of wood for other materials	Uncertain	Moderate	2, 5	3, 4