Formerly Oregon Natural Resources Council (ONRC)
PO Box 11648 | Eugene OR 97440 | 541-344-0675 | fax 541-343-0996
dh@oregonwild.org | http://www.oregonwild.org/

Version 1.6 – April 19, 2011

The straight facts on forests, carbon, and global warming.


A significant portion of the "extra" carbon in the atmosphere is due to deforestation and forest mismanagement.

This report is available electronically at: http://tinyurl.com/2n96m5

Executive Summary

The Intergovernmental Panel on Climate Change (IPCC), made up over 1,000 scientists, from over 100 countries around the world is releasing in four installments this year its latest report on global warming. The IPCC summary for policy makers includes the strongest statement to date linking human activities to global warming. The IPCC finds that it is "very likely" (defined as 90% probability) that human activities are the main cause of global warming and highlights the need for action today to address this extremely serious global problem that will affect our climate, ecosystems, and the institutions that support humanity.

More than any other issue, humanity's response to climate change will define our times. To preserve options for future generations it is prudent to both mitigate impacts and begin preparing for anticipated changes. Significant reforms are necessary to address climate change in a comprehensive way, including changes in energy policy, transportation policy, land use, urban design, agriculture, etc. This report focuses on a subset of the problem — how climate change will affect forests and how sound forest conservation can play a role in mitigating climate change.

Predictions of specific climate changes at any given place and time are highly uncertain, yet scientists can confidently predict a few notable large-scale trends, such as general climate warming, altered patterns of precipitation, rising sea level, and significant disruptions of terrestrial and aquatic ecosystems.

Forests are the most significant terrestrial stores of living carbon and their destruction and mismanagement over the last century has contributed significantly to the carbon dioxide (CO_2) pollution that threatens our climate. In the future, we need to manage forest to (a) make forests more resilient to the anticipated changes brought by climate change, and (b) manage forests to help mitigate climate change by allowing forests to achieve their full potential for storing carbon in living systems.

To make forests more resilient to climate change we need to <u>protect the full diversity of life</u> in our forests. Every species and each biotic community is a record of successful adaptation to past changes. Even though the future may not mirror the past, the diversity of life that exists currently represents the full catalog of successful adaptations that are available for the profound restructuring of ecosystems to come. We should not be throwing tools out of the toolbox by allowing species to go extinct.

Since ecosystems are expected to shift toward the poles and toward higher elevations in response to warming climate, we need to <u>expand our existing system of protected areas</u> to give forest ecosystems enough room to migrate via natural processes of disturbance, dispersal, and regeneration.

To help forests store more carbon we need to <u>let our forests grow</u>. Photosynthesis is the mechanism plants use to capture CO_2 and convert it to plant matter that feeds the base of the entire planetary food chain. Old-growth trees store massive amounts of carbon in their trunks as well as in the soil. Logging stops photosynthesis and initiates decay processes that transfer much of the carbon in the trees and soil back to the atmosphere. Forest conservation allows forests to grow large and complex, which not only helps mitigate climate change but also enhances water quality, wildlife habitat, recreation, and quality of life.

Background: What determines global temperature and climate?

Global temperature and climate are largely determined by the balance of incoming energy from the sun, minus outgoing radiation. Incoming light radiation from the sun has short-wavelengths and can readily pass through the atmosphere, but after being absorbed and re-radiated from Earth's surfaces the out-going infra-red radiation has longer wave-lengths and is less able to pass through the atmosphere. The so-called "greenhouse gases" absorb and re-radiate a portion of the outgoing long-wave radiation back toward earth, acting like a heat-trapping blanket. Though greenhouse gasses make up less than 1% of Earth's atmosphere, our global climate is quite sensitive to changes in their concentration. Even slight changes in the ratio of incoming and outgoing solar energy have significant influence on our global climate system.

Ice-core data from Greenland and Antarctica tells us that atmospheric levels of CO_2 vary somewhat predictably with cycles of ice ages and warm inter-glacial periods. The ice cores also show that atmospheric CO_2 is increasing almost 100 times faster today than during past climate cycles, and that current concentrations of CO_2 are higher than at any time in at least the last 800,000 years. Given the difficulty of rapidly changing our resource-intensive lifestyles, we'll be lucky if global atmospheric CO_2 concentration merely doubles. More likely it will go much higher before we control our appetite for fossil fuels and land exploitation.

While CO_2 is of primary concern among greenhouse gasses, there are others such as methane (CH_4) that contribute to global warming.[1] CO_2 is unique in that is has a very long, approximately 100 year, "residence time" in the atmosphere.[2] Concentrations of

---

[1] Water vapor also has a significant influence on climate, but it has a very short residence time in the atmosphere so it is better thought of as a "feedback" than a "forcing." http://www.realclimate.org/index.php?p=142 Warming is expected to increase water vapor in the atmosphere but the effects on climate are very complex and remain unclear. Water vapor can act as both a greenhouse gas with a warming influence (positive feedback), and it can have a cooling influence via cloud formation and increased albedo (negative feedback). Scientists are keenly interested in this issue and continue to study the role of water vapor and clouds in future climate scenarios.

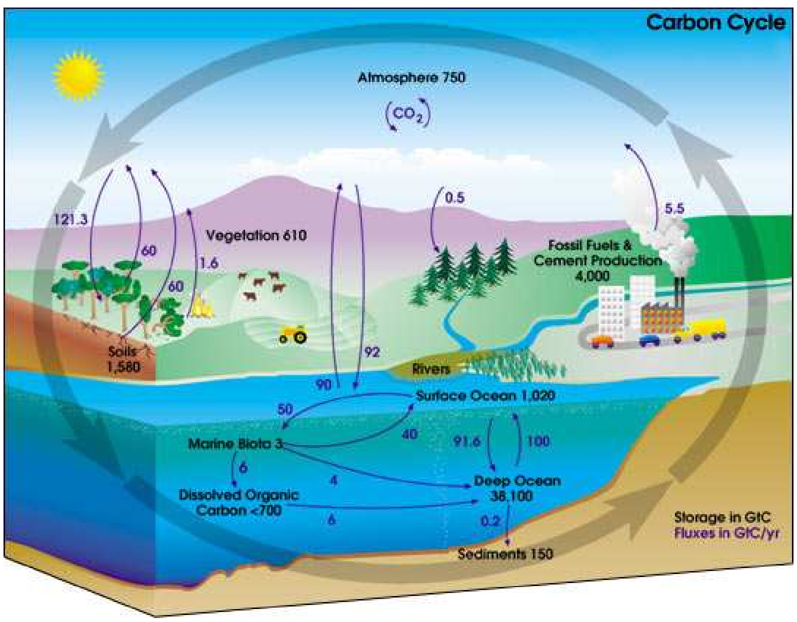
[2] Water vapor has a mean residence time in the atmosphere on the order of days; methane about 10-12 years. Estimating the residence time of carbon dioxide is complex because of the many different types of "sinks" but "it is now generally believed that a substantial fraction of the excess CO_2 in the atmosphere will

CO_2 in the atmosphere will likely remain far above "normal" for centuries, because millions of tons of CO_2 released to the atmosphere during the agricultural revolution, the industrial revolution, and the automobile revolution will not reach a new equilibrium until biological and geophysical processes (in the oceans and on land) have a chance to capture and store the "extra" carbon that has been transferred to the atmosphere.

We have a moral obligation to leave future generations with choices and opportunities for survival. We must avoid irreversible harm to the planet's life support systems including a livable climate and functioning ecosystems that sustain life.

How does carbon move in and out of the atmosphere?

There is a fixed amount of carbon on planet earth which is distributed among several carbon reservoirs or pools in the atmosphere, biosphere (e.g., forests, grasslands, and sea life), hydrosphere (e.g., dissolved in the oceans), and lithosphere (e.g., coal, oil, limestone). In the grand scheme, carbon is neither created nor destroyed but continually moves between these various pools owing to the operation of natural and human-induced processes. The root cause of global climate change is human activity that has shifted massive quantities of carbon to the atmosphere from forests, soil, and fossil deposits.



"Diagram of the carbon cycle. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for GigaTons of Carbon). The blue numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ~70 million GtC of carbonate rock and kerogen."[3]

---

remain in the atmosphere for decades to centuries, and about 15-30% will remain for thousands of years. … [I]f the sinks that now remove CO_2 from the atmosphere get saturated in the future, the residence time (of CO_2) will increase…" Tamara S. Ledley, Eric T. Sundquist, Stephen E. Schwartz, Dorothy K. Hall, Jack D. Fellows, and Timothy L. Killeen. EOS Electronic Supplement to AGU Vol. 80, No. 39, September 28, 1999, p. 453. Climate Change and Greenhouse Gases http://www.agu.org/eos_elec/99148e.html

[3] Carbon cycle, From Wikipedia, the free encyclopedia http://en.wikipedia.org/wiki/Carbon_cycle Kerogen is a mixture of organic chemical compounds that make up a portion of the organic matter in sedimentary rocks. Examples include bitumen, and oil shale.

In the atmosphere carbon is stored as CO_2 , methane (CH_4), and other organic compounds. Carbon moves *into* the atmosphere from decomposition of organic matter, respiration by living organisms, combustion, volcanic activity, burning fossil fuels, degassing of waterbodies, etc. Carbon moves *out of* the atmosphere via photosynthesis, rock weathering, dissolution in water, etc. All plants, including forests and many micro-organisms, use photosynthesis which takes CO_2 out of the air to build sugars that can be used by the cell to make sugars and build cellulose and other complex carbon molecules that comprise plant biomass. This process is called "primary production" and it represents the foundation of the global food chain. Virtually all life on earth, including humans, relies directly or indirectly on photosynthesis. Most terrestrial plants share a significant portion of their photosynthate with soil organisms, a cooperative relationship that builds a large and complex underground ecosystem that also stores carbon. Plants shed dead leaves and wood which also builds carbon stores in the soil.[4]

In the hydrosphere (e.g. rivers and oceans) carbon is stored mostly as dissolved CO_2 and other dissolved organic compounds that originated in some photosynthetic life form. Carbon moves *into* the ocean from the atmosphere and biosphere via dissolving gaseous CO_2 in cold seas, dissolving calcium carbonate shells of live or dead organisms, leaching from soil, and input of organic matter from river systems and the biosphere. Carbon moves *out of* the ocean primarily via photosynthesis by phytoplankton and cyanobacteria, degassing of warm seas, and deposition in marine sediments.[5]

In the biosphere carbon is stored as live or recently dead plants, animals, and micro-organisms both in the ocean and on land (e.g., forests and soils). Forests dominate the terrestrial carbon cycle, harboring 86% of the planet's above-ground carbon and 73% of the planet's soil carbon.[6] Carbon enters the biomass pool via photosynthesis, then becomes entrained and cycled through the entire global food chain. Carbon moves *out of* the biomass pool through decomposition and respiration, combustion (forest fires), or through deposition in long-term storage in soil, marine sediments, or geologic deposits.

---

[4] "[A]ging forests were long perceived to be in a state of decay that releases as much carbon dioxide as it captures. But it turns out that the soils in undisturbed tropical rain forests, Siberian woods and some German national parks contain enormous amounts of carbon derived from fallen leaves, twigs and buried roots that can bind to soil particles and remain there for 1,000 years or more. When such forests are cut, the trees' roots decay and soil is disrupted, releasing the carbon dioxide. Centuries would have to pass until newly planted trees built up such a reservoir underground." World Rainforest Movement. Climate Change Convention: Sinks that stink. New scientific findings: tree plantations may accelerate global warming. October 2000. http://www.wrm.org.uy/actors/CCC/sinks4.html

[5] There is an inverse relationship between temperature and the solubility of CO_2, so we observe that cold seas tend to absorb CO_2 while warm seas tend to release CO_2. As the polar oceans warm we expect their ability to capture and store CO_2 will decrease, and as the tropical oceans warm they will more readily release CO_2. Increased ocean stratification and expected changes in carbonate buffering will also likely reduce the ability of the oceans to absorb CO_2. Irina Marinov & Jorge L. Sarmiento. "The Role Of The Oceans In The Global Carbon Cycle: An Overview." Ocean Carbon Cycle and Climate, NATO ASI volume, 251-295, ed. M. Follows and T. Oguz, Kluwer Academic Publishers, 2004. http://ocean.mit.edu/~imarinov/08-Marinov.pdf

[6] Sedjo, Roger.1993. The Carbon Cycle and Global Forest Ecosystem. Water, Air, and Soil Pollution 70, 295-307.

In fossil deposits, the carbon from long-dead plants and animals are stored as coal, oil, “natural gas,” or kerogen. These can be thought of as both “ancient sunlight” and “ancient atmosphere.” Carbon moves *into* the fossil pool via deposition and storage in low-oxygen conditions.[7] Carbon moves *out of* fossil pool mostly via industrial exploitation and combustion.

In the non-fossil lithosphere carbon is stored in carbonate rocks such as limestone and chalk. Carbon moves *into* these geologic structures mostly through ocean deposition. A portion of the oceanic carbon is taken up to make the shells of marine organisms that fall to the deep ocean floor where they may be subducted beneath the earth’s crust and end up in long-term geologic storage, e.g. the Cliffs of Dover. Carbon moves *out of* the lithosphere mostly via volcanic activity and human industry such as the manufacture of cement which heats limestone and releases significant quantities of CO_2.[8]

The advent and diversity of life on earth has had a profound impact on the global carbon cycle and now plays a fundamental role in determining whether or not we have a livable climate. The abiotic carbon cycle that existed before the proliferation of life was less stable than the carbon cycle that developed after marine organisms started to make calcium carbonate shells and deposit carbon in deep storage which helped buffer CO_2 extremes over long time scales.[9] Scientists have found a correlation between biodiversity and levels of atmospheric CO_2 over the last 370 million years.[10]

Human activity, mostly in just the recent era, has dramatically reallocated global carbon stores from the other carbon reservoirs into the atmosphere where it can influence our climate. For example, burning fossil fuels and heating limestone to make cement move carbon from long-term fossil and geologic storage into the atmosphere. Logging kills trees - stops carbon-uptake via photosynthesis, and moves carbon from living forests and soil into the atmosphere. Land uses such as agriculture, livestock grazing, and draining swamps move carbon from the soil to the atmosphere.

How Will Climate Change Affect the Pacific Northwest?

While predicting the local *weather* is an uncertain science, c*limate* prediction is actually more accurate because the focus is on large-scale trends rather than local details. We know that the planet as a whole is almost certain to become warmer on average, and scientists expect an acceleration of the hydrologic cycle as warmer temperatures lead to

---

[7] Surprisingly, there is still some debate about the actual origin of fossil fuels.

[8] The Relationship between Plate Tectonics and the Carbon Cycle. http://dilu.bol.ucla.edu/

[9] Andy Ridgwell, Richard E. Zeebe. The role of the global carbonate cycle in the regulation and evolution of the Earth system. http://tracer.env.uea.ac.uk/e114/publications/manuscript_ridgwell_and_zeebe.pdf

[10] Rothman, Daniel H. 2001. Global biodiversity and the ancient carbon cycle. Proceedings of the National Academy of Sciences. v. 98, no. 8, pp 4305-4310. April 10, 2001. http://www.pnas.org/cgi/content/full/98/8/4305 (“Surprising correlations exist between paleontological records of biodiversity and the carbon isotope fractionation evident in the sedimentary record for the last 370 million years. … Consequently, CO2 levels decreased as biodiversity increased. These conclusions imply that fluctuations of CO2 levels have been driven primarily by changes within the biosphere and only secondarily by purely geologic and geophysical processes.”)

increased evaporation from the oceans and more transpiration from plants. However, the effects of climate change will not be uniform around the globe. Significant uncertainty remains about how global trends will express themselves regionally. Future climate in the Pacific Northwest is also uncertain because of complex topography and uncertain changes in precipitation.

The Pacific Northwest should expect continued climate variability. Existing cycles of cool-wet winters and warm-dry summers will likely continue, though they will be superimposed on a warmer average climate. Both floods and droughts have been part of our past and will almost certainly be part of our future, and both will likely get worse, but we don't know if these climate extremes will be expressed with more frequency or more intensity, or both. Our close proximity to the moderating influence of the Pacific Ocean may offer a slight buffer from extreme warming, but it also puts us in the direct path of more wet winter storms.

It is reasonable to expect more precipitation, mostly during our existing wet seasons. More of our winter precipitation will fall as rain instead of snow, so storage of water in snowpacks will likely decrease (on average). We should expect milder winter temperatures, earlier melting of snow packs, earlier spring run-off, longer periods of summer low stream flow, and more drought.[11]

Importantly, earth's biogeochemical systems are complex and not at equilibrium. There are many feedbacks that lead to non-linear behavior, so we should NOT expect climate changes to be slow and predictable. Small changes in CO_2 and global temperature can lead to large and/or rapid changes in climate and ecosystems.[12] Accordingly, the rate of current and future global changes may be unprecedented, chaotic, and highly disruptive.

How will climate change affect ecosystems, forests, and trees?

Some ecological effects of climate change can already be seen. There is evidence that some trees are leafing out earlier and forbs are flowering earlier. Also, some birds are migrating earlier, and seasonal peaks in some insect populations are occurring earlier.[13] "[C]limate change is not something that will happen in the future but is already in progress."[14]

We should expect shifting "isoclimes" (zones of similar climate). Forest communities will shift toward the poles and toward higher elevations, but the climate may change faster

---

[11] Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest http://inr.oregonstate.edu/download/climate_change_consensus_statement_final.pdf

[12] José A. Rial, Rogera. Pielke Sr., Martin Beniston, Martin Claussen, Josep Canadell, Peter Cox, Hermann Held, Nathalie De Noblet-Ducoudré, Ronald Prinn, James F. Reynolds And José D. Salas. 2004. Nonlinearities, Feedbacks And Critical Thresholds Within The Earth's Climate System. Climatic Change 65: 11–38, 2004. http://pielkeclimatesci.files.wordpress.com/2009/10/r-260.pdf

[13] Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.R., Hoegh-Guldberg, O., Bairlein, O., 2002. Ecological responses to recent climate change. Nature 416, 389–395.

[14] An Interview with Dr. Gian-Reto Walther. ESI Special Topics: October 2006. http://esi-topics.com/gwarm2006/interviews/Gian-RetoWalther.html

than species' natural capacity to migrate. Species are not expected to shift together as intact communities because of differing capacities for dispersal, migration, establishment, and tolerance of climate change. As a result, forest community composition will likely change. Climate change will disrupt co-evolved relationships between predators and their prey, plants and their pollinators, migration timing and flowering, etc. [15] During the tumultuous period of shifting biomes, opportunistic "weedy" species will readily replace native species that are displaced by climate change.[16]

Expected decreases in streamflow and increases in stream temperatures will place additional stress on cold-water fish such as salmon and trout. Forests may consequently be deprived of large quantities of marine-derived nutrients that for millennia have been conveyed by salmon from the ocean to continental ecosystems.[17]

The following trends in forest ecosystems should be expected as a result of climate change. Forest disturbances such as fire and insect outbreaks will likely increase, causing a reduction in the average age of trees (although old-growth forests will persist because of natural refugia, ecological inertia, and stochastic variation). Forests may become simplified due to the ascendancy of weedy species. The movement of existing forest types northward and toward higher elevations will likely cause extirpation of species where natural or human-induced habitat bottlenecks are encountered.[18]

There are significant feedbacks between climate and forests. Increasing temperatures can lead to longer growing seasons and more plant growth which can store more carbon or provide more fuel for fires. Longer fire seasons will likely occur due to earlier drying of fuels. Milder winters (more frost-free days) and warmer summers will allow insect populations to increase.[19] Warmer temperatures will also increase rates of respiration and

---

[15] Sherry, A., X. Zhou, S. Gu, J. A. Amone III, D. S. Schimel, P. S. Verburg, L. L. Wallace, and Y. Luo. 2007. Divergence of reproductive phenology under climate warming. PNAS, 104: 198-202. http://bomi.ou.edu/luo/pdf/Sherry%20et%20al.%202007%20PNAS.pdf

[16] Hansen, Neilson, Dale, Flather, Iverson, Currie, Shafer, Cook, and Bartlein. 2001. Global Change in Forests: Responses of Species, Communities, and Biomes. BioScience vol 51, no. 9, pp 765-779. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone5.pdf

[17] Naiman, R.J., R.E. Bilby, D.E. Schindler, and J.M. Helfield. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. Ecosystems. 5:399–417. http://www.fish.washington.edu/people/naiman/CV/reprints/naiman_ecosys_salmon_2002.pdf. Helfield, J.M., and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology 82(9) : 2403-2409. http://www.fish.washington.edu/people/naiman/CV/reprints/helfield_naiman_2001.pdf

[18] Nigel Dudley. 1998. Forests And Climate Change. Forest Innovations – a joint project of IUCN, GTZ and WWF. http://www.equilibriumconsultants.com/publications/docs/climatechangeandforests.pdf

[19] Insects' "short life cycles, mobility, reproductive potential, and physiological sensitivity to temperature" lead to a conclusion that small changes in climate can lead to large changes in the distribution and abundance of insects. Ayers & Lombardero. 2000. Assessing the Consequences for Global Change for Forest Disturbance from Herbivores and Pathogens. The Science of the Total Environment 262 (2000) 263-286. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/forests7.pdf

"Shortened winters, increasing summer temperatures, and fewer late-spring frosts correlate to increased insect feeding, faster growth rates, and rapid reproduction. … Drought creates many conditions that are favorable to increased insect reproduction. … Attempts at intervention [to control insects] are proving decomposition which release CO_2 to the atmosphere, yet this effect might be partially countered by drying of soil surface layers which limits soil respiration.[20]

Changes in forest disturbance regimes will likely be tightly coupled with the changes described above and may overshadow the direct physiological effects of climate change on plants and trees.[21] It is reasonable to anticipate increased disturbances from wildfire, flooding, wind and storm damage, insect damage, and invasive species. Disturbance typically disrupts photosynthesis and favors respiration/decomposition processes thereby liberating CO_2.

Plants will likely face increased seasonal drought stress. Higher temperatures will increase evaporative losses from soils and increase transpiration from plants. "Forests at upper (cold) and lower (dry and/or hot) timberlines are most likely to show strong direct effects of climatic variation on tree growth, since they are closer to their physiological limits and, therefore, more prone to stress at these locations."[22] Interestingly, "[s]hade-tolerant trees show greater growth responses to CO_2 than do shade-intolerant species because of more efficient use of light, water, and nutrients."[23] This could account in part for the proliferation of shade tolerant ladder fuels in our forests.

It is important to remember that trees "breathe" — both inhaling and exhaling. During the day plants engage in *photosynthesis* that captures CO_2 to build sugars while releasing oxygen, but plants (like animals) also engage in *respiration* to build and repair tissue, a process that uses some of the sugars produced during photosynthesis, consumes oxygen, and returns CO_2 to the atmosphere. Plant growth is a result of a net imbalance between photosynthesis and respiration. In trees, some of the extra carbon is turned into wood which results in plant growth and long-term carbon storage.

Experiments reveal significant variability in plants' response to elevated CO_2 concentrations, but studies show several consistent results including: increased rates of photosynthesis, increased concentration of non-structural carbohydrates, enhanced

---

mostly negligible. " Dunn, David, Crutchfield, James. 2006. Insects, Trees, and Climate: The Bioacoustic Ecology of Deforestation and Entomogenic Climate Change. Santa Fe Institute Working Paper. Arxiv.org. However, reduced snow cover might lead to increased winter mortality for some insects that rely on a blanket of snow for winter cover.

[20] Hanson & Weltzin. 2000. Drought Disturbance from Climate Change: Response of United States Forests. The Science of the Total Environment 262 (2000) 205-220. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/forests2.pdf

[21] Flannigan, Stocks & Wotton. 2000. Climate Change and Forest Fires. The Science of the Total Environment 262 (2000) 221-229. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/forests5.pdf

[22] Climate Impacts Group. Climate Impacts on Pacific Northwest Forests. University of Washington. http://www.cses.washington.edu/cig/pnwc/pnwforests.shtml.

[23] John Aber, Ronald P. Neilson, Steve Mcnulty, James M. Lenihan, Dominique Bachelet, And Raymond J. Drapek. 2001. Forest Processes and Global Environmental Change: Predicting the Effects of Individual and Multiple Stressors. BioScience vol 51, no. 9, pp735-751. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone3.pdf

efficiency of water use and nitrogen use, and decreased plant nutrient concentration.[24] Elevated CO_2 may increase growth at the expense of other aspects of plant health and could degrade the quality of the resulting plant material as food and fiber.

Plants grow better when night-time temperatures are about 5 degrees C cooler than day-time temperatures, because lower night time respiration reduces the use of carbohydrates and allows more carbohydrates to be stored or used for growth. If climate change reduces the temperature difference between day and night, plants may suffer because night-time respiration will increase *more than* day-time photosynthesis.

Plants' reaction to drought may be complicated, especially in an enriched CO_2 atmosphere. Trees obtain CO_2 from the atmosphere by opening stomatal pores on their leaves, but they unavoidably lose water in the process. Some plant species may react to CO_2 enrichment by actively closing their stomata and by reducing the number of stomata on new leaves, both of which will reduce water loss, thereby increasing water use efficiency and partly mitigating drought stress.[25] Constricted stomata may also reduce plants' exposure to damaging ozone pollution. These intriguing plant responses to warming and CO_2 enrichment are likely species-specific and more research is needed. These mitigating benefits of CO_2 appear to manifest themselves more during times of stress than during periods of peak plant growth.[26]

Complex interactions among all the geophysical and biological responses to climate change will certainly lead to non-linear dynamics, threshold behavior, and rapid phase transitions that are difficult to model.[27] "Many disturbances are cascading. … [W]hen ecosystems experience more than one disturbance, the compounded effects can lead to new domains or surprises."[28] For instance, increased herbivory of above-ground vegetation by insects could shift the normally favorable below-ground relationship between fungi and tree roots. Mutualistic mycorrhizal fungi could be replaced by competitive or parasitic organisms, thereby harming trees and increasing liberation of CO_2.[29] Also, the migration of species toward the poles will likely be facilitated by

[24] Luo YQ, Reynolds J,Wang YP. 1999. A search for predictive understanding of plant responses to elevated [CO2]. Global Change Biol. 5:143–56 http://face.env.duke.edu/PDF/gcb5-99a.pdf.

[25] Since less than 1 percent of the water taken up by plants is used in photosynthesis (the remainder being lost to transpiration), stomatal control could have an enhanced effect on soil moisture during times of water limitation. However, the reduced transpiration could also adversely affect cloud formation, potentially reducing the albedo effect of clouds and increasing warming.

[26] R.A. Houghton. 2007. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 2007. 35:313–47.

[27] Burkett, V.R.; Wilcox, D.A.; Stottlemyer, R.; Barrow, W.; Fagre, D.; Baron, J.; Price, J.; Nielsen, J.L.; Allen, C.D.; Peterson, D.L.; Ruggerone, G.; Doyle, T. 2005. Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. Ecological Complexity. 2: 357–394. http://www.fs.fed.us/psw/cirmount/wkgrps/ecosys_resp/postings/pdf/Burkett2005EcoCom357.pdf

[28] Virginia H. Dale, Linda A. Joyce, Steve Mcnulty, Ronald P. Neilson, Matthew P. Ayres, Michael D. Flannigan, Paul J. Hanson, Lloyd C. Irland, Ariel E. Lugo, Chris J. Peterson, Daniel Simberloff, Frederick J. Swanson, Brian J. Stocks, And B. Michael Wotton. 2001. Climate Change and Forest Disturbances. BioScience vol 51, no. 9, pp723-734. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone2.pdf.

[29] Ayers & Lombardero (2000).

disturbance because (relative to intact forests) disturbed sites will be more readily colonized by new arrivals from the south.[30]

It gets even more complex. Since forests are dark green, they tend to absorb rather than reflect sunlight, so the local albedo[31] effect of forests tends to counteract forests' carbon sequestration effects. Loss of forest cover tends to increase albedo thereby reflecting more of the sun's energy back into space. The effect can be temporary or long-term depending on how snowy the region is and how quickly forests regrow. On the other hand, new forests growing on warmer, formerly treeless landscapes will lower albedo, thereby absorbing more of the sun's energy. As the northern treeline moves north into the tundra the value of the carbon stored in the new forest may be more than off-set by reduced albedo.[32] Another complexity — evapotranspiration from forests, combined with forests' natural release of organic aerosols that act as "cloud condensation nuclei" are credited with increasing albedo by enhancing cloud formation and increasing the reflectance and longevity of clouds, further highlighting forests' significant and varied influence on our global climate.[33]

Will Future Forests Become Carbon Sources or Carbon Sinks?

Just to put the terrestrial biosphere in perspective, there is about ten times more carbon contained in all land plants and soil than all the "extra" anthropogenic carbon currently in the atmosphere. Most of the terrestrial carbon is contained in forests which have been significantly depleted by mismanagement. An important question is whether forests are more likely to store or release carbon under a changing climate.

The coupled processes of photosynthesis and respiration/decomposition mirror each other at a global scale to help regulate CO_2 levels and our climate.[34] Photosynthesis captures water and CO_2 and liberates oxygen to create biomass, while respiration consumes biomass and oxygen to liberate CO_2 and water. Depending on temperature and

---

[30] Neilson, Ronald P.; Pitelka, Louis F.; Solomon, Allen M.; Nathan, Ran; Midgley, Guy F.; Fragoso, Jóse M.; Lischke, Heike; Thompson, Ken 2005. Forecasting regional to global plant migration in response to climate change. Bioscience, Vol. 55(9): 749-759. http://www.treesearch.fs.fed.us/pubs/24527

[31] "Albedo" is a measure of the reflectivity of surfaces. Light colored surfaces (e.g. snow and deserts) reflect more sunlight back to space, while dark surfaces (e.g. forests and oceans) tend to absorb more of the sun's energy and contribute to global warming. Large-scale changes in the extent of arctic ice and the composition of vegetation play a significant role in the climate models.

[32] Catherine Brahic. 2006. Location is key for trees to fight global warming. NewScientist.com. 15 December 2006. http://environment.newscientist.com/article/dn10811-location-is-key-for-trees-to-fight-global-warming.html. G. Bala, K. Caldeira, M. Wickett, T. J. Phillips, D. B. Lobell, C. Delire, & A. Mirin. Combined Climate and Carbon-Cycle Effects of Large-Scale Deforestation. [pre-publication draft]

[33] Gregory C. Roberts, and Meinrat O. Andreae, Jingchuan Zhou, Paulo Artaxo. 2001. Cloud condensation nuclei in the Amazon Basin: "Marine" conditions over a continent? Geophysical Research Letters, Vol. 28, No. 14, Pages 2807-2810, July 15, 2001.
http://www.mpch-mainz.mpg.de/~biogeo/Roberts-CCN-CLAIRE-2001.pdf

Tunved, P., Hansson, H.-C., Kerminen, V.-M., Strom, J., Dal Maso, M., Lihavainen, H., Viisanen, Y., Aalto, P.P., Komppula, M. and Kulmala, M. 2006. High natural aerosol loading over boreal forests. Science 312: 261-263. Summarized here:
http://www.co2science.org/scripts/CO2ScienceB2C/articles/V9/N25/C2.jsp

[34] Christopher B. Field. 2001. Plant Physiology of the "Missing" Carbon Sink. Plant Physiol, January 2001, Vol. 125, pp. 25-28. http://www.plantphysiol.org/cgi/content/full/125/1/25

moisture conditions, among other factors, photosynthesis sometimes dominates leading to net carbon uptake. At other times respiration/decomposition dominate leading to net carbon release.[35] Whether our forests ultimately become net carbon sources or net carbon sinks under the future climate of the depends on factors that remain uncertain, such as the amount of summer precipitation vs. drought stress, the effects of future climate on fuels and fire hazard, the effects of CO_2 enrichment and climate change on plant physiology, whether forests geographically expand or contract, and whether forests are exploited or protected.[36]

The good news is that slight to moderate warming may increase our forests' ability to store carbon through increased growth and geographic expansion. Pacific Northwest forests might become significant carbon sinks and help mitigate climate change if growing conditions remain favorable and disturbances like fire do not significantly increase. Under warm-wet conditions growing seasons will lengthen, and forest or woodland communities could expand into current rangelands, thus raising the possibility that northwest forests could absorb more CO_2 and become a significant net carbon sink.[37]

The bad news is that there is likely a warming *threshold* above which forests will likely decline due to drought stress and increased disturbances.[38] Drought stress limits the potential photosynthetic benefits of longer growing seasons and CO_2 enrichment. Increasing temperature also increases rates of respiration and decomposition, so under a future climate scenario like this, northwest forests could wither, succumb to fire, recede geographically, and become a significant net carbon source. The IPCC tells us that some warming has already occurred and that existing levels of CO_2 already commit us to some additional warming. There is considerable uncertainty about when we may cross the sink to source threshold.[39]

El Niño/Southern Oscillation (ENSO) is a prominent source of multi-year variability in weather and climate around the world. The main signature of ENSO is a periodic

[35] The seasonal uptake and release of CO_2 by plants in the northern hemisphere is evident at a global scale in the ground-breaking measurements of CO_2 taken at Mauna Loa in Hawaii starting in 1958. The planet essentially inhales CO_2 in the spring and summer and exhales in the fall and winter. See http://en.wikipedia.org/wiki/Mauna_Loa_Observatory and http://www.cmdl.noaa.gov/ccgg/trends/co2_data_mlo.php

[36] A study conducted at the Wind River Canopy Crane revealed that "[s]easonal to interannual variability in precipitation and consequent water balance appears to influence the timing of this switch from photosynthesis-dominance to respiration-dominance, ultimately determining whether the forest will be a net carbon sink or source." Matthias Falk, K. T. Paw U, S. Wharton, and M. Schroeder. Interannual variability of water use efficiency in an old-growth forest under drought conditions. http://ams.confex.com/ams/pdfpapers/110964.pdf

[37] Geographic expansion of forests might be good news from carbon standpoint, but not from the standpoint of rangeland ecosystems and the species that depend upon them such as pronghorn and sage grouse.

[38] Marko Scholze, Wolfgang Knorr, Nigel W. Arnell, and I. Colin Prentice. A climate-change risk analysis for world ecosystems. Proceedings of the National Academy of Science. PNAS vol. 103 no. 35. published online Aug 21, 2006. http://www.pnas.org/cgi/reprint/0601816103v1.pdf

[39] Even if we may already have crossed the threshold from sink to source, forest conservation remains a valuable tool for climate mitigation, because failure to conserve forests will only make a bad situation worse.

(~every 3-8 years) reduction in winds moving westward across the Pacific ocean. This allows warm water to move eastward across the tropical Pacific Ocean. ENSO has strong impacts on ocean nutrient cycling and associated fish populations and birds. ENSO has repercussions far beyond the Pacific ocean, including periodic wide-scale drought in many regions of the world. Scientists have found a correlation between periodic phenomena like ENSO and years with anomalous global increases in CO_2 which appear to be linked to CO_2 releases from plants, soil, and fire.[40] While there remains debate about this, some have predicted that ENSO may become more frequent and sustained under global warming which could cause a positive feedback favoring respiration over photosynthesis on a global scale.[41]

The source/sink differences could also manifest themselves differently across geography and time periods. "In regions where drought stress is not important because of high levels of precipitation, or if increases in CO_2 concentration increase water use efficiency and thus reduce water stress, longer growing seasons could result in increased growth. Where drought stress is important, a longer growing season may mean only that plant respiration exceeds photosynthesis for a longer time, which would result in reduced growth."[42] So, it is conceivable that moist forests west of the Cascades might remain net carbon sinks, while the dryer forests east of the Cascades might become net sources.

Another study looked at the effects of CO_2 enrichment and climate change on vegetation in the mid- and high-latitudes of the northern hemisphere and found opposing effects in spring and summer. CO_2 uptake was apparently enhanced during warm wet spring season, but looking over the entire growing season, including the dryer summer, CO_2 uptake did not increase.[43] Another paper estimated that western forests might increase in spatial extent while decreasing in their carbon density, i.e., more forested acres, but fewer trees per acre.[44]

---

[40] Knorr, W., N. Gobron, M. Scholze, T. Kaminski, R. Schnur, and B. Pinty (2007), Impact of terrestrial biosphere carbon exchanges on the anomalous CO2 increase in 2002–2003, Geophys. Res. Lett., 34. . http://www.fastopt.com/papers/knorral07.pdf

[41] William J. Merryfield. 2006. Changes to ENSO under CO2 Doubling in a Multimodel Ensemble. Journal of Climate. Volume 19, pp 409-427. http://www.ocgy.ubc.ca/~yzq/books/paper5_IPCC_revised/Merryfield2006.pdf. Michael W. Wara, Ana Christina Ravelo, Margaret L. Delaney. Permanent El Niño-Like Conditions During the Pliocene Warm Period. Science 29 July 2005: Vol. 309. no. 5735, pp. 758 – 761. Gabriel A. Vecchi, Brian J. Soden. 2007. Global Warming and the Weakening of the Tropical Circulation. Journal of Climate. 2007. http://www.gfdl.noaa.gov/~gav/REPRINTS/VS_07_GWnCIRC.final.pdf

[42] John Aber, Ronald P. Neilson, Steve Mcnulty, James M. Lenihan, Dominique Bachelet, And Raymond J. Drapek. 2001. Forest Processes and Global Environmental Change: Predicting the Effects of Individual and Multiple Stressors. BioScience vol 51, no. 9, pp735-751. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone3.pdf

[43] A. Angert, S. Biraud, C. Bonfils, C. C. Henning, W. Buermann, J. Pinzon, C. J. Tucker, and I. Fung. 2005. Drier summers cancel out the CO2 uptake enhancement induced by warmer springs. Proceedings of the National Academy of Sciences of the United States of America, 2005 (Vol. 102) (No. 31) 10823-10827. http://www.pnas.org/cgi/reprint/0501647102v1.pdf

[44] Dominique Bachelet, Ronald P. Neilson, James M. Lenihan, and Raymond J. Drapek. 2001. Climate Change Effects on Vegetation Distribution and Carbon Budget in the United States. Ecosystems (2001) 4: 164–185. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/Ecosystems2%20Bachelet.pdf. ("[S]imulation results suggest the possibility for an early green-up in response to a moderate warming,

The bottom line is that if we carefully conserve our forests, they can play a substantial role in mitigating our current carbon predicament. Even if forests shift from becoming a carbon sink to a carbon source, continued forest conservation will help mitigate the consequences. To manage forests for resilience, they must be allowed time to grow and accumulate carbon while natural disturbance processes are allowed to self-regulate, thus ensuring that live vegetation is maintained below the water-limited carrying capacity and fuels will be maintained below the threshold for uncharacteristic fire.

What Can We do to Protect Forests from the Perils of Climate Change?

Jerry Franklin points out that "forest management can either exacerbate or reduce the effects of climatic change on the productivity and biological diversity of northwest forestscapes."[45] To increase the chances that we will continue to enjoy the diverse benefits we receive from northwest forests, we must maintain and enhance their ability to respond to change. The key components of such a strategy are:

- Maintain biodiversity in all its dimensions. Genetic diversity is like a library of possibilities that have worked well during past climate variability, representing the sum of "tools" available for adapting to the future.[46]

---

followed later by vegetation density declines due to temperature-induced droughts … [In the model] precipitation exhibits considerable interdecadal variability, which can override the simplified trajectory implied by the hypothesis.

… The fate of the western coniferous forests under warmer climates is less clear. MC1 [a dynamic climate model] simulates a large expansion of the coniferous forests across the western states under CGCM1 [a climate change scenario], even though it simulates a decrease in their [carbon] density over the area of their current distribution.") See also, National Forest Assessment Group. 2001. Forests: The Potential Consequences of Climate Variability and Change. USDA, DOE, NASA. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/forest.pdf, USDA Forest Service. 2002. Is Carbon Storage Enough? Can Plants Adapt? New Questions in Climate Change Research. Science Findings #44. May 2002. Sherri Richardson Dodge, ed. http://www.fs.fed.us/pnw/sciencef/scifi44.pdf and Climate Impacts Group. Climate Impacts on Pacific Northwest Forests. University of Washington. http://www.cses.washington.edu/cig/pnwc/pnwforests.shtml

[45] Dudley, Nigel. 1998. Forests And Climate Change - A report for WWF International November 1998. http://www.equilibriumresearch.com/upload/document/climatechangeandforests.pdf *citing* Franklin, J.F., F.J. Swanson, M.E. Harmon, D.A. Perry, T.A. Spies, V.H. Dale, A. McKee, W.K. Ferrell, J.E. Means, S.V. Gregory, J.D. Lattin, T.D. Scholwalter and D. Larsen (1992) ; Effects of Global Warming on Forests in Northwestern America; The Northwest Environmental Journal; 7:233-254.

[46] Respected conservation biologist Reed Noss notes — "Among the land-use and management practices likely to maintain forest biodiversity and ecological functions during climate change are (1) representing forest types across environmental gradients in reserves; (2) protecting climatic refugia at multiple scales; (3) protecting primary forests; (4) avoiding fragmentation and providing connectivity, especially parallel to climatic gradients; (5) providing buffer zones for adjustment of reserve boundaries; (6) practicing low-intensity forestry and preventing conversion of natural forests to plantations; (7) maintaining natural fire regimes; (8) maintaining diverse gene pools; and (9) identifying and protecting functional groups and keystone species. Good forest management in a time of rapidly changing climate differs little from good forest management under more static conditions, but there is increased emphasis on protecting climatic refugia and providing connectivity." Reed F. Noss (2001) Beyond Kyoto: Forest Management in a Time of Rapid Climate Change. Conservation Biology 15 (3), 578–590. See also, Nigel Dudley. 1998. Forests And Climate Change. Forest Innovations – a joint project of IUCN, GTZ and WWF. http://www.equilibriumresearch.com/upload/document/climatechangeandforests.pdf Others urge that we

- Protect intact native ecosystems where species relations have stood the test of time and remain robust;
- Provide refugia and allow species to migrate. Buffer and expand protected areas to provide connectivity along climatic gradients. Manage the entire landscape to be amenable to dispersal of native species.
- Protect streams. Cold water fish are particularly vulnerable to climate change because of increased winter flooding, reduced summer stream flow, and increased stream temperature. To mitigate expected effects on fish we should provide generous riparian buffers to help shade streams and maintain lower stream temperatures. To render streams more resilient to hydrologic extremes, such as flooding, we should manage whole watersheds to improve their ability to absorb, store, and slowly release water. This can be accomplished in part by reducing disturbance of vegetation and soils, reducing road densities, and retaining abundant woody debris.

Logging Releases Significant Amounts of Carbon.

Not surprisingly, logging accelerates the transfer of carbon to the atmosphere by killing trees that would otherwise continue to capture and store carbon through photosynthesis and growth. Killing trees also stops them from pumping carbon into the soil where much of the carbon in forests is stored.[47] Logging actually accelerates the rate of decomposition of wood via several mechanisms. By removing the forest canopy and exposing the soil to more sunlight, logging raises soil temperature which increases the decay rate of forest litter and debris. Logging also breaks up woody material in the forest thereby decreasing the average piece size and increasing the surface area exposed to microbial decomposition. Finally, logging debris is often burned on site or as part of an industrial process.

Traditional logging also increases the risk of disturbances. Logging increases wind damage by creating exposed edges and increasing wind speeds within forest stands. Logging often increases the wildfire hazard by making the stand hotter, dryer, and windier; by moving the most flammable small fuels from the forest canopy to the forest floor where they are more available for combustion (i.e. creating logging slash); and by initiating the establishment of dense stands of young trees with interlocking branches close to the ground which represent a significant fire hazard. Logging roads also increase the risk of human-caused fire ignitions and spread tree diseases like Port Orford cedar root disease that kill trees and release carbon.

---

recognize that historic landscapes may not be a good model and recommend that we prepare ecosystems for climate change by being adaptive, proactive, value genetic diversity, and attempt to build resilient systems. James A. Harris, Richard J. Hobbs, Eric Higgs, and James Aronson. 2006. Ecological Restoration and Global Climate Change. Restoration Ecology Vol. 14, No. 2, pp. 170–176 JUNE 2006.

[47] Forests store massive amounts of carbon in the soil in the form of live and dead roots, woody debris, charcoal, and the vast below-ground ecosystem supported by photosynthate received from trees. Logging cuts off the food supply for the below-ground ecosystem which rapidly dies and decomposes.

Scientists estimate that a large fraction of all the carbon transferred to the atmosphere by humans has been released due to forest exploitation.[48] In recent decades CO_2 emissions resulting from human-induced changes to forests exceed CO_2 emissions from all motor vehicle sources combined, but forest releases are less than total emissions from all uses of fossil fuels.[49] After an old-growth forest is logged, the site remains a net source of carbon for more than 20 years, and depending on the conditions, the site does not rebuild pre-logging carbon stores for a century or more. As a result of widespread clearcutting and aggressive slash burning, the Pacific Northwest has contributed huge quantities of carbon to the atmosphere.[50]

What Can We Do To Increase Carbon Storage in Forests?

Here in the Pacific Northwest we live in the midst of a globally significant carbon pool that should be nurtured and conserved to help keep carbon out of the atmosphere.[51] Temperate old-growth forests of the Pacific Northwest contain some of the highest amounts of biomass per acre measured anywhere in the world. About half of the dry weight of forest biomass is comprised of carbon. The latest IPCC Mitigation Report notes that "Forest-related mitigation activities can considerably reduce emissions from sources and increase CO_2 removals by sinks at low costs…"[52] The IPCC also states that more than 1/3 of the potential mitigation available from forests is located outside the tropics and half of the forest mitigation will come from changes in forest practices, rather than simply preventing deforestation.

The objectives of forest management with respect to mitigating climate change should be two-fold effort to *protect* and *restore* forests —

- Minimize the release of additional forest carbon into the atmosphere. The best way to *retain* carbon in existing forests is to protect mature and old-growth forests and roadless areas.
- Rebuild depleted carbon stores within forested landscapes. Probably the best way to *rebuild* forest carbon stores in forests is to allow forests that were previously logged or burned to regrow and become mature and old-growth forests.

---

[48] G. M. Woodwell, J. E. Hobbie, R. A. Houghton, J. M. Melillo, B. Moore, B. J. Peterson, and G. R. Shaver. 1983. Global Deforestation: Contribution to Atmospheric Carbon Dioxide. Science 9 December 1983: Vol. 222. no. 4628, pp. 1081 – 1086. http://www.sciencemag.org/cgi/content/abstract/222/4628/1081

[49] The Scottish Forest Alliance. Factsheet: Human influences on forest carbon flows. July 2002. http://www.scottishforestalliance.org.uk/carbon/fs_human_influences.pdf

[50] "Mass balance calculations indicate that the conversion of 5×10^6 hectares of old growth forests to younger plantations in western Oregon and Washington in the last 100 years has added 1.5×10^9 to 1.8×10^9 megagrams of carbon to the atmosphere." Harmon, M., Ferrell, W., and J. Franklin. 1990. Effects on Carbon Storage of Conversion of Old-Growth to Young Forests. Science. 9 February 1990.

Warren B. Cohen, Mark E. Harmon, David 0. Wallin, and Maria Fiorella. 1996. Two Decades of Carbon Flux from Forests of the Pacific Northwest - Estimates from a new modeling strategy. BioScience 46(11):836-844. http://www.humboldt.edu/~storage/pdfmill/Batch%203/carbonflux.pdf

[51] Smithwick, E. A., M. E. Harmon, S. M. Remillard, S. A. Acker and J. F. Franklin. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest. Ecological Applications 12:1303-1317.

[52] IPCC Working Group III. 2007. Climate Change 2007: Mitigation of Climate Change. Summary for Policymakers. IPCC Fourth Assessment Report. May 2007. http://www.ipcc.ch/SPM040507.pdf

There are significant complementary benefits of managing forests for carbon storage to ameliorate global climate change. If done carefully, forests managed to provide public services such as clean water, habitat for fish and wildlife, soil conservation, and an enhanced amenity-based economy will also store large amounts of carbon over time.[53]

Forests exhibit a quality known as "ecological inertia" which recognizes that established forests are generally long-lived, resilient to disturbance, and help create conditions suitable for their own survival.[54] This means that our northwest forests may be able to persist through some climate changes and continue to store carbon and provide other benefits, as long as they are not clearcut or severely disturbed. This implies that if we want continued carbon storage in forests that are at the edges of their suitable range we should avoid stand-replacing logging methods (such as clearcutting) and, where ecologically appropriate, we may need to strategically reduce fuels to reduce the risk of stand-replacing fire. Such fuel reduction must be done carefully however, because excessive removal of vegetation not only compromises carbon storage in both plants and soil, but can also increase fuel loads and fire hazard. Recent fire/fuel models indicate that forest fire hazard can be managed reasonably well by treating about 20-30 percent of the landscape in strategic locations.[55] Treating fuel on every acre is neither needed or desired. Logging need not be the primary tool for accomplishing fuel reduction, because non-commercial techniques, such as low-intensity prescribed fire, are available and effective.

Forest Management Recommendations

Private forestlands: Short-rotation clearcutting typically practiced by private industrial forest land-owners is probably the worst possible way to manage forests for carbon storage, because the young forests never develop large carbon stores; significant soil carbon is lost during and after clearcutting, slash disposal, and site preparation; and the resulting wood products produced have limited longevity. Where logging is expected to continue, scientists recommend that carbon release can be mitigated if forest managers will:[56]

---

[53] Krankina, O.N., & M.E. Harmon. 2007. Forest Management Strategies for Carbon Storage. In OFRI 2007. Forests, Carbon and Climate Change: A Synthesis of Science Findings. Pp 27-28. http://www.oregonforests.org/media/pdf/CarbonRptFinal.pdf

[54] Mazza, Patrick. 1998. Case Study — Global Warming and the Pacific Northwest: Perpetual El Niño. ("'Responses will be slow and muted especially for older forests, because they are relatively tolerant to change and adapt somewhat to new environments,' [Jerry] Franklin reports.")

[55] Alan Ager, Mark Finney, and Andrew McMahan. 2006. A Wildfire Risk Modeling System for Evaluating Landscape Fuel Treatment Strategies. USDA Forest Service Proceedings RMRS-P-41. 2006. http://www.fs.fed.us/rm/pubs/rmrs_p041/rmrs_p041_149_162.pdf Josh McDaniel. SPLATS, SPOTS, and the Future of Fuels Treatment. http://www.wildfirelessons.net/Additional.aspx?Page=57

[56] Final Workshop Summary and Scientific Conclusions *in* Climate Change, Carbon, and Forestry in Northwestern North America: Proceedings of a Workshop. November 14 - 15, 2001 Orcas Island, Washington. PNW-GTR-614. April 2004 http://www.fs.fed.us/pnw/pubs/pnw_gtr614.pdf (p 117).
Ross W. Gorte. 2007. Carbon Sequestration in Forests. CRS Report for Congress. Updated March 29, 2007. http://www.ncseonline.org/NLE/CRSreports/07Apr/RL31432.pdf
Spies, Adams, Harmon, Johnson, & Reeves. Project A5. Assess the Scientific Basis for Standards/Practices at the Stand, Management Unit, Landscape and Regional Level: Oregon Coast Range.

- Allow trees to grow much longer before harvest (i.e., longer rotations),
- Retain more live trees on every acre during harvest (i.e., thin instead of clearcut),
- Retain more dead wood after harvest (e.g. protect snags, practice less intensive slash disposal and site preparation), and
- Take steps to reduce road systems and prevent soil erosion, which would help store more carbon in forest soils.

Public lands: Federal forests can help mitigate climate change if they are restored to their natural-sustainable level of biomass and biodiversity. Large stores of carbon exist within roadless areas and mature and old-growth forests on federal lands. These should be protected from harvest, while previously logged younger forests should be carefully restored to a mature and old-growth condition that has optimal biomass storage. This management approach luckily complements other highly sought-after forest values that are currently under-represented in our forests. Careful management of forests for carbon storage can help resolve ongoing controversies over forestry's impact on water quality, old-growth, roadless areas, fish & wildlife habitat, and scenic values.

Market Solutions: Given humanity's slow response to the growing evidence of human-induced climate change and its consequences, aggressive approaches such as market intervention are now needed. The debate continues on whether a carbon tax or cap-and-trade system is better, but either is better than nothing. A carbon tax system establishes the price of carbon and the market determines how much is sequestered and not emitted. In a cap-and-trade carbon market, government would determine how much total carbon can be emitted from all sources and the market would determine who is allowed to emit the carbon and at what price.

Under current international climate protocols it is possible that forest owners of the Pacific Northwest might seek compensation for storing "extra" carbon. This would reward forest managers for storing carbon that would otherwise be transferred to the atmosphere and help off-set some of the economic costs of managing forests for carbon storage. However, there are unresolved issues about how to account for the full carbon consequences of proposed forest management activities.[57] For instance, the Kyoto Protocol has some "perverse incentives" that could reward carbon-poor young forests at the expense of carbon-rich old forests, though this is not scientifically supported.

Final Report To National Commission on Science for Sustainable Forestry. January 23, 2004. http://www.ncseonline.org/ewebeditpro/items/O62F3833.pdf

R. JANDL, K. RASMUSSEN , M. TOMÉ and D.W. JOHNSON. 2006. The Role of Forests in Carbon Cycles, Sequestration, and Storage. Issue 4. Forest Management and Carbon Sequestration. http://www.iufro.org/download/file/1629/3754/issue4_jan06.pdf

Johnson, Sherri. Applying knowledge of biological legacies to forest management. Powerpoint. http://intranet.lternet.edu/archives/documents/presentations/2004_lter_nsf_symposium/JohnsonLTERTalk2004/index.html

Colombo, Parker, Dang, & Luckai. Intensive Forest Management and Carbon Sequestration http://flash.lakeheadu.ca/~carbon/

[57] American Lands, and Center for International Environmental Law. Saving Forests and Cooling the Planet – Goals and Standards for Forest Sequestration. January 2000.

> In contrast to the sink management proposed in the Kyoto protocol, which favors young forest stands, we argue that preservation of natural old-growth forests may have a larger effect on the carbon cycle than promotion of regrowth. ... [I]ncreasing life-span of the stand, proportionally more carbon can be transferred into a permanent pool of soil carbon (passive soil organic matter or black carbon)... [R]eplacing unmanaged old-growth forest by young Kyoto stands ... will lead to massive carbon losses to the atmosphere mainly by replacing a large pool with a minute pool of regrowth and by reducing the flux into a permanent pool of soil organic matter.[58]

Carbon stored in wood products generally do not last as long as they would if left safe inside a mature tree, but we can improve the carbon storage equation by using less wood and by increasing the lifespan of wood products. It's not just American's big cars and SUVs that are a problem; it's also their increasingly large houses. We should consider policies to help reverse the national trend toward larger houses, and we should build houses that last for centuries instead of just decades.

What about Forest Fires?

We cannot avoid the fundamentally dynamic nature of forests. Fire is an unavoidable part of life in western forests and we must stop fighting a losing battle against the inevitable. Most western forests are in some ways *dependent* upon disturbances such as fire, and past fire suppression has exacerbated rather than solved the problem of fire. Our goal should not be to prevent all damage from fires, insects, etc. Fire should be allowed to operate within natural bounds, as long as it doesn't threaten public safety. Communities and property owners in forest settings must take responsibility for becoming fire resilient or fire permeable.[59]

We should maintain healthy forest habitat by allowing natural disturbance processes to operate and expect forest carbon stores to ebb and flow, while also allowing forests to grow for long periods (and store lots of carbon) in between these natural disturbances. We must take a long-term and landscape view, so that we *optimize* carbon storage at any given point in space and time in order to *maximize* carbon storage over large landscapes and long time frames.

Fuels could be reduced in forests that are significantly outside the natural range of variability, but this must be done in a strategic and limited way that protects all large fire resilient trees and spatially disconnects large expanses of excessive fuels, while retaining as much biomass as sustainably possible. Current enthusiasm for fuel reduction must be tempered with a realization that removing too much fuel makes forests hotter, dryer, and windier which increases fire hazard and increases decomposition rates, both of which

[58] Ernst-Detlef Schulze, Christian Wirth, Martin Heimann. CLIMATE CHANGE: Managing Forests After Kyoto. Science 22 September 2000: Vol. 289. no. 5487, pp. 2058 - 2059. http://academic.engr.arizona.edu/HWR/Brooks/GC572-2004/readings/schulze.pdf

[59] FUSEE. Frontline Home Safety Practices for protecting homes and property from wildfire. http://www.fusee.org/safety/frontline_content.html Darling, J. 2005. Safer in the Sticks. Medford Mail-Tribune. September 24, 2005. http://archive.mailtribune.com/archive/2005/0924/life/stories/01life.htm

counter carbon storage and other objectives. After fire, the goal should be to retain carbon on site and allow the recovering forest to grow into a mature and old-growth condition. Aggressive replanting as recommended by the timber industry[60] is unsupported because it establishes a dense fuel-laden condition that is susceptible to drought and is soon ripe for another fire. Natural regeneration of forests leads to more diverse and less dense forests, which is preferable from a climate change perspective because the resulting habitat diversity and spatial discontinuity are more resilient to future hazards.

Conclusion

The best way to think of the carbon potential of forests is not as carbon sponges, but as carbon reservoirs; not to think of just the carbon in the trees but also the carbon in forest soils and the full diversity of forest life; and not to think of the carbon in forests at any single point in time, but strive to maintain a high average amount of carbon stored over long periods of time and across large forest landscapes. Old-growth forests are one of the most secure forms of carbon storage, while converting old-growth to plantations causes a significant net loss of carbon to the atmosphere.

A reality check: We are very likely past the "point of no return." Significant climate change is almost certainly unavoidable at this point because there is already so much CO_2 in the atmosphere, carbon has such a long residence time in the atmosphere, fossil fuel consumption and land use continue to release such vast quantities of CO_2, and so far, we are not changing our habits fast enough to make a real difference. Forests can sequester *some* carbon but not nearly enough to allow us to maintain business as usual. Current levels of fossil fuel use is already overwhelming the biosphere's ability to absorb carbon and climate change will likely further inhibit the biosphere's capacity to function as a carbon sink.[61] A comprehensive policy approach to climate change will require far-reaching changes in energy policy, land use, transportation, urban design, and protection of native ecosystems. Even then we will need to *adapt* to the unavoidable changes that are coming. Forest conservation can play a valuable role in a comprehensive climate change policy.

---

[60] OFRI. 2007. Forests, Carbon, and Climate Change – Exploring the Role of Trees in Reducing Atmospheric Carbon. A Special Report of the Oregon Forest Resources Institute. http://www.oregonforests.org/media/pdf/CarbonRptFinal.pdf

[61] A. Angert, S. Biraud, C. Bonfils, C. C. Henning, W. Buermann, J. Pinzon, C. J. Tucker, and I. Fung. 2005. Drier summers cancel out the CO2 uptake enhancement induced by warmer springs. Proceedings of the National Academy of Sciences of the United States of America, 2005 (Vol. 102) (No. 31) 10823-10827. http://www.pnas.org/cgi/reprint/0501647102v1.pdf

Appendix: Myths & Facts about Forests and Global Warming

Myth: Fast-growing young forests are better carbon stores than slow-growing old forests.

Fact: An honest accounting reveals that logging and industrial forestry release vast amounts of carbon that is not captured and stored in wood products. Young forests continue to release carbon for decades after harvest due to the decomposition of rich carbon stores maintained by the previous stand.[62] Scientists discovered that old forests continue to absorb CO_2 even after tree growth appears to have slowed. This may be explained in part by the fact that old-growth trees are sending a lot of carbon into the soil to support the below-ground ecosystem that helps sustain them (e.g. symbiotic relation between old growth trees and mycorrhizal fungi).[63] Also, traditional tree farming models breakdown because they fail to view old forests as complete ecosystems, instead of just old trees. Old forest ecosystems continue to absorb and store carbon because they harbor a diversity of plants and because these well-developed ecosystems constantly recruit new

---

[62] "[C]onversion of old-growth forest to younger forests … has added and will continue to add C to the atmosphere. This conclusion is likely to hold in most forests in which the age of harvest is less than that required to reach the old-growth stage of succession. The amount of C added by conversion will vary among forests, depending on their maximum storage capacity and the difference between the timber rotation age and the age of the old-growth state within the given ecosystem." Harmon, Mark E; Ferrell, William K; Franklin, Jerry F. 1990. Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. Science; Feb 9, 1990; pg. 699 http://academic.evergreen.edu/curricular/ftts/downloadsw/harmonetal1990.pdf

[63] "Long-held theory, according to Knohl et al. (2003), maintains that assimilation is 'balanced by respiration as a forest stand reaches an 'advanced' stage of development.' Quite to the contrary, however, a number of newer studies are finding this supposition to be as poor a representation of reality as were the early evolutionary theories of aging in animals.

"In a recent biomass inventory, for example, Cary et al. (2001) found much larger than expected net primary production in multi-species subalpine forest stands ranging in age from 67 to 458 years, while similar results have been obtained by Hollinger et al. (1994) for a 300-year-old Nothofagus site in New Zealand, by Law et al. (2001) for a 250-year-old ponderosa pine site in the northwestern United States, by Falk et al. (2002) for a 450-year-old Douglas fir/western hemlock site in the same general area, and by Knohl et al. (2003) for a 250-year-old deciduous forest in Germany." "It's Never Too Late" to "Live Long and Prosper" CO_2 Science, Volume 7, Number 23: 9 June 2004. http://www.co2science.org/scripts/CO2ScienceB2C/articles/V7/N23/EDIT.jsp

http://www.co2science.org/scripts/CO2ScienceB2C/articles/V5/N6/COM.jsp

Stauth, Winner. Old-growth trees still soaking up CO2, study shows. OSU News. Dec 1997. http://oregonstate.edu/dept/ncs/newsarch/1997/December97/old.htm

Paw U, K.T., Falk, M., Suchanek, T.H., Ustin, S.L., Chen, J., Park, Y.-S., Winner, W.E., Thomas, S.C., Hsiao, T.C., Shaw, R.H., King, T.S., Pyles, R.D., Schroeder, M. and Matista, A.A. 2004. Carbon dioxide exchange between an old-growth forest and the atmosphere. Ecosystems 7: 513-524.

Guoyi Zhou, Shuguang Liu, Zhian Li, Deqiang Zhang, Xuli Tang, Chuanyan Zhou, Junhua Yan, Jiangming Mo. 2006. Old-Growth Forests Can Accumulate Carbon in Soils. Science 1 December 2006:Vol. 314. no. 5804, p. 1417.

A. Knohl et al. Large carbon uptake by an unmanaged 250-year-old deciduous forest in Central Germany. Agricultural and Forest Meteorology 118 (2003) 151–167.

plants that help maintain, on an ecosystem basis, a productive ratio of leaf area (where photosynthesis occurs) to sapwood (where respiration occurs).[64]

Myth: Wood products store carbon. Some argue that logging is helpful because carbon is sequestered in wood products.

Fact: It turns out that well-conserved forests, on average, store carbon more securely than our *throw-away* culture does. First, only a small fraction of the carbon removed from logged forests end up as durable goods and buildings - most ends up as slash, sawdust, waste/trim, hog fuel, and non-durable goods like paper.[65] Second, wood products have short "life spans" compared to forests that are well-protected from logging. Most wood products are essentially *disposable.* Wood products which can reasonably be considered *durable* (e.g. buildings) may in fact be less durable than the wood retained safely inside an old-growth tree that could live to be hundreds of years old.

Myth: Forest fires release carbon stored in forests so forests are not good places to store carbon. Managing forests for carbon storage requires that we continue to practice aggressive fire suppression.

Fact: Forest fires do release CO_2 to the atmosphere, but taking a long-term view, forest fires represent a temporary localized dip in the landscape carbon pool that should eventually return to high levels with proper management. When evaluating the carbon consequences of fire we must also account for the decades and sometimes centuries between fires when photosynthesis and carbon uptake dominate the system. Also, when fires burn, only a small fraction of the total forest biomass is converted to greenhouse gases and lost to the atmosphere. Due to the incomplete combustion of large wood, 70-80 percent of the carbon in tree stems may remain after forest fires, and globally, 23 times more carbon is captured by photosynthesis than is emitted by fires.[66] Even after a forest fire, most of the carbon remains in the forest and contributes to carbon sequestration.[67] So called "salvage logging" would tend to exacerbate the carbon released by the fire because it would (a) disturb soils and release soil carbon, (b) convert the largest, longest-lasting logs into short-lived wood products, and (c) reduce the piece-size of the remaining material resulting in higher rates of decomposition. Aggressive fire suppression is not wise because it will only make future fires more severe and exacerbate future emissions

---

[64] Carey, E.V., Sala, A., Keane, R. and Callaway, R.M. 2001. Are old forests underestimated as global carbon sinks? Global Change Biology 7: 339-344. http://www.firelab.org/media/gcb_carey_2001.pdf

[65] Of the 1,692 Tg of carbon harvested in Oregon and Washington from 1900 to 1992, only 23% is contained in forest products (including landfills), the other 77% has been released to the atmosphere, so, for every ton of carbon in our houses and landfills, there is another 3 tons in the atmosphere. Also, the carbon store in landfills is growing faster than that stored in buildings. Harmon, Harmon, Ferrell and Brooks. Modeling Carbon Stores in Oregon and Washington Forest Products 1900-1992. Climate Change 33:521-550 (1996). http://www.springerlink.com/content/u51867621j8307m7/

[66] Guido van der Werf. 2006. Quantifying Global Biomass Burning Emissions Using Satellite Data and Biogeochemical Modeling. *PhD Thesis*, Vrije Universiteit, Amsterdam. http://www.geo.vu.nl/users/gwerf/pubs/VanderWerf2006Thesis.pdf

[67] Wayburn, L.A., J.F. Franklin, J.C. Gordon, C.S. Binkley, D.J. Mladenoff, and N.L. Christensen, Jr. 2000. Forest Carbon in the United States: Opportunities & Options for Private Lands. Pacific Forest Trust, Santa Rosa, CA, USA. http://landscape.forest.wisc.edu/pdf/Wayburn_etal2000_PFT.pdf

of GHGs. The goal should be to reestablish natural and resilient disturbance regimes. In many areas this will mean large trees with thick bark and high canopies that store lots of carbon while remaining resistant to fire.

Myth: Tropical forests are most important. Forests outside the tropics do not contribute significantly to global carbon storage.

Fact: Because of their high biomass and continuous growing season tropical forests are one of the most significant living terrestrial stores of carbon. However, tropical forests are being lost at an alarming rate while temperate forest are expanding.[68] In developing countries tropical forests are too often used for firewood which results in the immediate release of stored carbon. It is true that many temperate and boreal forests have shorter growing seasons, lower biomass per acre, and lower evapotranspiration. However, our northwest "seasonal rainforests" compare favorably to tropical forests. The northwest's low-elevation old-growth forests have long growing seasons due to the maritime influence of the Pacific Ocean, and they can store more carbon per acre than many tropical forests, so they too play a significant role in global carbon storage. Because they occupy such large geographic areas, other boreal and temperate forests cannot be dismissed (e.g., Canada, Russia, Scandinavia).

Myth: Forests tend to exacerbate global warming because they have low reflectance and absorb the sun's energy.

Fact: A recent modeling study looked at the combined effects on global climate of biological carbon storage and albedo under hypothetical scenarios of complete planetary deforestation or afforestation.[69] Not surprisingly, the model revealed that forests in relatively snow-free latitudes such as the tropics help cool the planet by storing carbon and the model showed that the absence of forests in the polar and boreal regions helps to cool the planet because it allows snow to reflect energy back into space. The implications are that expansion of forests toward the poles (which is expected to occur as the climate warms) may exacerbate climate change because the carbon storage benefit of the "new" forest is more than offset by the warming that will result from reduced albedo when highly reflective snow fields are converted to dark absorptive forests. Where snow is less prevalent and albedo is already low, such as forested areas of the tropics and mild temperate regions, carbon storage in forests is expected to contribute to cooling. Another recent study showed that the loss of carbon in boreal forests (expected due to increased fire occurrence) may not significantly contribute to warming because the loss of carbon is

---

[68] The UN Food and Agriculture Organization estimates that 79 million acres of forest are lost (deforested) in the tropics each year, while 35 million acres are gained (afforested) in the temperate regions. Salwasser, H. 2007. Introduction: Forests, Carbon, and Climate — Continual Change and Many Possibilities. OFRI Forest, Carbon, & Climate Synthesis *citing* UN FAO 2005. Global Forest Resource Assessment 2005: Progress Toward Sustainable Forest Management. ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E00.pdf

[69] G. Bala, K. Caldeira, M. Wickett, T. J. Phillips, D. B. Lobell, C. Delire, and A. Mirin. Combined climate and carbon-cycle effects of large-scale deforestation. PNAS | April 17, 2007 | vol. 104 | no. 16 | 6550-6555. http://www.pnas.org/cgi/content/abstract/104/16/6550.

offset by the increase in albedo from snow.[70] Since maritime NW forests do not have long snowy winters and are already “dark” from an albedo standpoint, it is reasonable to assume that forests are a good place to mitigate climate change with carbon storage.

Myth: Timber industry representatives are experts on forests and provide reliable information on the effects of logging on climate change.

Fact: The timber industry appears to be advancing a public relations campaign intended to convince policy-makers and the public that “business-as-usual” forestry is good for the climate.[71] For instance, the timber industry likes to say that fast young forests are better at sequestering carbon than old forests, when the exact opposite is true, and they leave out important factors such as the loss of soil carbon after logging and the carbon value of retaining old-growth forests. The timber industry needs a lesson in honest accounting. Industry emphasizes forests’ role as a carbon sink, but the industry over-states the role of wood products in carbon storage, glosses over the fact that logging causes forests to become a net carbon source, and ignores old forests’ potential as a long-term carbon store. Industry’s analyses make assumptions that are favorable to wood products and biased against alternative building materials.

[70] Randerson, J.T., Liu H, Flanner MG, et al. 2006. The Impact of Boreal Forest Fire on Climate Warming. SCIENCE. 314(5802):1130-2. Nov 17, 2006. http://www.sciencemag.org/cgi/content/abstract/314/5802/1130

[71] For instance see “California Forests, Volume 10, No. 1. http://www.calforests.org/California_Forests-502-Winter_2006.htm. CORRIM, the Consortium for Research on Renewable Industrial Materials is a wood products promotion group, producing ostensibly scientific reports that are in fact biased in favor of short-rotation forestry.