GLOBAL CLIMATE CHANGE: SOME IMPLICATIONS, OPPORTUNITIES, AND CHALLENGES FOR U.S. FORESTRY

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Abstract.--It is widely agreed that the concentration of greenhouse gases in the earth's atmosphere is increasing, that this increase is a consequence of man's activities, and that there is significant risk that this will lead to changes in the earth's climate. The question is now being discussed what, if anything, we should be doing to minimize and/or adapt to changes in climate. Virtually every statement on this matter; from the U.S. Office of Technology Assessment, to the National Academy of Science, to the Nairobi Declaration on Climatic Change, includes some recommendation for planting and protecting forests. In fact, forestry is intimately involved in the climate change debate for several reasons: changing climate patterns will affect existing forests, tropical deforestation is one of the major sources of greenhouse gases to the atmosphere, reforestation projects could remove additional carbon dioxide from the atmosphere, and there is renewed interest in wood-based or other renewable fuels to replace fossil fuels. Part of the enthusiasm for forestry-related strategies in a greenhouse context is the perception that forests not only provide greenhouse benefits but also serve other desirable social objectives. This discussion will explore the current range of thinking in this area and try to stimulate additional thinking on the rationality of the forestry-based approaches and the challenges posed for U.S. forestry.

Keywords: Climate Change, Carbon Dioxide, Reforestation

On June 23, 1988, with the U.S. in the midst of a major East Coast drought, Jim Hansen of the National Aeronautics and Space Agency went before a Senate Committee and stated that he was 99% sure that the global climate was changing and that the change could be attributed to the increasing concentration of greenhouse gases in the atmosphere (Hansen 1988). Since that day global climate change has been an increasingly important political issue in the U.S. and around the world. Within 7 months we saw bills in the U.S. Congress like Senate Bill 201, which asserted "The Congress finds that the Earth is a fragile planet with a thin blanket of air, a thinner film of water, and the thinnest veneer of soil to support a web of life", and proposed a host of remedies to slow global climate change. Carl Sagan has referred to this particular assertion as "one of the most important findings of the Congress in 200 years" (Sagan 1989) but the political will is not yet firmed to pass such sweeping legislation in the face of continuing uncertainty about the magnitude and impact of global climate change. Nonetheless, there has been continuing debate, both domestic and international, on what, if any, actions should be pursued, and forestry is a central component of most action proposals. I would like to take a minute to dramatize the political perception of forestry's role and then back up and look at the essence of the climate change issue and the challenges and opportunities it offers for U.S. forestry.

This is a sampling of the smorgasbord of observations and declarations now in the international literature. From the America the Beautiful Plan to plant trees in the U.S.

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(U.S. Department of Agriculture 1990). "President Bush is proposing a major new initiative, called America the Beautiful, that provides an environmental legacy, enhances existing natural and recreational resources, and addresses mounting public concern about the buildup of atmospheric carbon dioxide". From the Noordwijk Declaration, a 67-country ministerial declaration (1989), "...agrees to pursue a global balance between deforestation on the one hand and sound forest management and afforestation on the other. A world net forest growth of 12 million hectares a year in the beginning of the next century should be considered as a provisional aim." From the Nairobi Declaration on Climatic Change (1990), "Governments of African countries are called upon to adopt and implement policies which...initiate and promote afforestation and reforestation activities." From the U.S. Congress' Office of Technology Assessment (1991), "OTA also identified an energy conservation, energy supply, and forest management package that can achieve a 20 to 35 percent emissions reduction." From Shell Oil Company (Elliott and Booth 1990), "Biomass based power generation appears to have considerable potential both in the developed and developing world...The present indications are that such systems could be competitive in certain circumstances with today's price system." From the U.S. National Academy of Sciences (1991), "Action should be initiated now to slow and eventually halt tropical deforestation...Reforestation offers the potential of off-setting a large amount of CO_2 emissions." And, in a statement issued on behalf of President Bush to the first session of the U.N. International Negotiating Committee on Climate Change (1991), "Implementation of the President's Comprehensive Climate Change Strategy will result in United States greenhouse gas emissions in the year 2000 being equal to or below 1987 levels. The specific actions which will contribute to this result include...initiating a program to plant a billion trees a year and to make other forest improvements". Even McDonald's now has a corporate policy on tropical forests and climate change/forestry is fair and frequent game for political cartoonists.

With that somewhat eclectic introduction, let's take a quick look at the concerns about global climate change.

In 1958 David Keeling initiated a program of monitoring the atmospheric concentration of carbon dioxide in the earth's atmosphere. His measurements at Mauna Loa Observatory in Hawaii now provide us with a record that unambiguously documents a CO_2 increase from 315 ppm to 355 ppm over the ensuing 32 years (Keeling 1990). The Keeling record is supported by shorter time series from other stations, and measurements on tiny air bubbles extracted from drill cores in the polar ice sheets reveal that prior to the industrial revolution, the concentration was near 280 ppm (Barnola et al. 1987). During the last two centuries mankind has increasingly capitalized on the store of energy available in the earth as chemically reduced carbon in coal, oil, and natural gas. We now release to the atmosphere as CO_2 some 6 billion metric tons of carbon per year. Additional carbon is released, perhaps 1.5 billion metric tons per year, as forests are cleared and burned to provide agricultural land and living space for people (Dale et al. 1991). Patterns of CO_2 emissions and growth plus measurements of the stable isotopes of carbon strongly support the conclusion that the observed 25% growth in atmospheric CO_2 is indeed a consequence of man's activities on Earth (Watson et al. 1990).

We should not forget that very large quantities of carbon cycle continuously through terrestrial systems. Carbon is removed from the atmosphere by photosynthesis, returned to the atmosphere by plant and animal respiration, exchanged between the atmosphere and the surface ocean, etc. Figure 1 gives some idea of the magnitude and complexity of annual flows which are part of the natural carbon cycle and the relative magnitude of the perturbation caused by man. Although man's contribution is still small by comparison, and will be damped out over the aeons, it is large enough to disturb the system over time scales of concern to us.

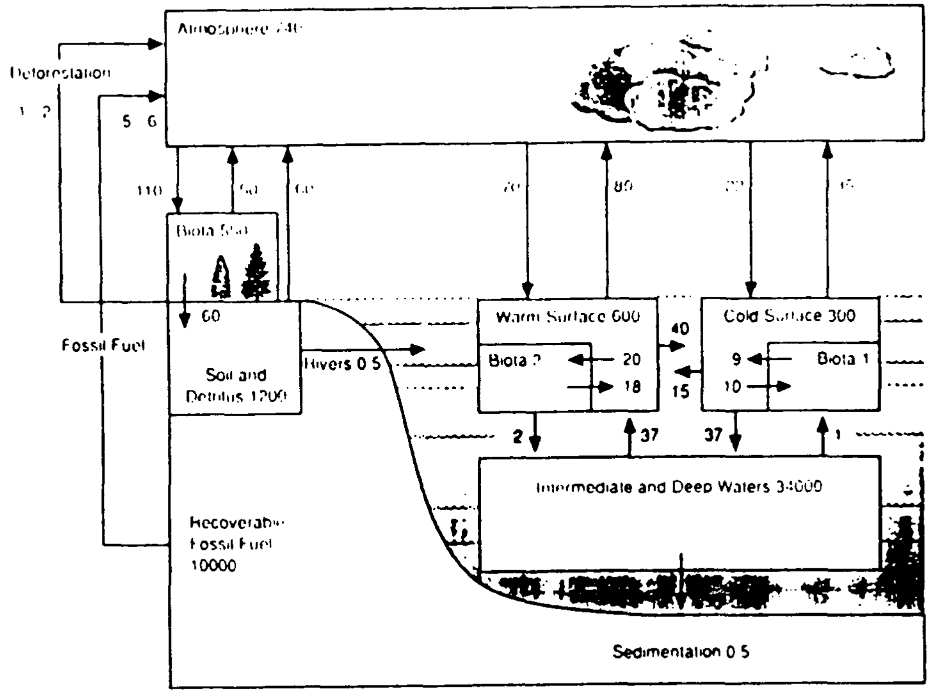

Figure 1: Schematic representation of the mass of carbon in major components of the global carbon cycle and the annual fluxes between components. All units are in 10^9 metric tons of carbon. (Adapted from Moore 1985 and Moore and Bolin 1986.)

The reason we worry about modest changes in the atmospheric concentration of a gas which occurs in the atmosphere at part-per-million levels has to do with its optical properties. The carbon dioxide molecule is inactive, and hence transparent, in the visible wavelengths at which the sun radiates to the earth, but has molecular vibration-rotation transitions in the infrared wavelengths at which the Earth radiates to space. The consequence of this is that increasing the CO_2 concentration causes an imbalance in the Earth's radiation budget and the build up of heat in the lower atmosphere. The "greenhouse effect" is real and well understood and explains why the mean Earth-surface temperature is near 15 ° C rather than at the calculated black-body temperature of -18 ° C. The question which confronts us now is the extent to which a change in the concentration of atmospheric greenhouse gases will change the Earth's climate system. A good part of the uncertainty has to do with the behavior of the Earth's hydrologic cycle. Very simply stated, increased heat at the Earth's surface can be expected to change the rate of evaporation and water is an important greenhouse gas. Also, once evaporation is increased, we have to be concerned with the effect on cloud cover. Clouds are very important to the Earth's radiation balance and their effect is dependent on cloud type and on their vertical and regional distribution. It is a complex system and our anticipation of the climatic impact of changes in atmospheric chemistry is thus dependent on mathematical models that try to simulate the climate system.

Detailed models of the Earth's climate system generally agree that an increase in atmospheric greenhouse gases will lead to an increase in the mean Earth-surface temperature. As an indication of scale, most models predict that a doubling of atmospheric CO_2 concentration would result in an increase in mean surface-air temperature of between 1.9 and 5.2 ° C (Mitchell et al. 1990). These models have a very coarse grid size, typically on the order of 5 degrees of latitude and longitude, and have a difficult time predicting how temperature will change on a regional basis. The models have an even more difficult time predicting changes in other manifestations of climate, e.g. precipitation, and there are some very significant differences between models with respect to regional predictions (Grotch 1988). We are thus left with a general consensus that climate will change but with little useful information on how rapidly it will change or how these changes will be manifest at a specific locale. I may overstate this slightly to make a point (we do have some broad agreement on drying of continental interiors and greater change at higher latitude) but the point is that the parameters of greatest interest to farmers and foresters are the least reliably predicted.

Examination of historical records of climate may help some but it is very difficult to clearly establish cause and effect. In their recent assessment of the science, the Intergovernmental Panel on Climate Change (IPCC 1990) was willing to conclude that there has been a long-term increase in Earth-surface temperature, but they were unable to conclude that it was a consequence of greenhouse gas emissions: "Our judgement is that...global mean surface air temperature has increased by 0.3 to 0.6 ° C over the last 100 years...The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability." The recent National Academy of Sciences study (1991) struggled with the same problems and concluded, "Despite the great uncertainties, warming is a potential threat sufficient to justify action now."

This discussion has focused, and will continue to focus, on CO_2 although there are a number of other gasses with increasing atmospheric concentrations and absorption spectra in the infrared wavelengths at which the Earth radiates energy to space. Methane, nitrous oxide, and the chlorofluorocarbons, for example, are of concern, although CO_2 is the most abundant and most important of the greenhouse gases. These gases vary in importance because of differences in absorption spectra, atmospheric lifetime, and ease with which their atmospheric increase might be controlled (see, for example, Shine et al. 1990). For changes in atmospheric chemistry which occurred during the decade of the 1980s, about half of the total potential to affect the Earth's radiation balance is attributable to the CO_2 (Ramanathan et al. 1987). Also, of course, CO_2 is the one greenhouse gas intimately linked with forests.

As noted earlier, the principal human activity responsible for current increases in atmospheric CO_2 is the burning of carbon-based fossil fuels. When fossil fuels are burned, carbon which has been long stored in the earth is released to the atmosphere. The burning of wood releases more CO_2 per unit of useful energy than does the burning of fossil fuels, but the implications for atmospheric CO_2 are fundamentally different. When wood is burned, carbon which was recently removed from the atmosphere via photosynthesis is simply returned to the atmosphere. So long as the tree is replaced by another tree, i.e. it is grown in a sustained-yield system, there is no net release of CO_2 to the atmosphere. To the extent that the tree is not replaced, there will be a net release of CO_2 from the biosphere, and herein lies our concern with forest clearing. We recognize, though, that when mature forest is harvested and replaced with young forest it may take a very long time to regain the carbon storage (Harmon et al. 1990). We should not conclude that there is no net CO_2 release from biomass fuel systems. For a current wood-fired power plant, for example, fossil fuels are used to plant, manage, harvest, and transport wood. Oxidation of these fuel "supplements" should be counted as CO_2 emissions required to operate the wood-fired system, even when there is no net emission from the wood combustion itself. As an example, Anthony Turhollow and I have examined the full accounts for producing ethanol from corn. We find that by the time corn is planted, fertilized, harvested, and converted into ethanol; the oxidation of fossil fuel supplements has yielded CO_2 emissions equivalent to about 80% of the emissions from simply burning a quantity of gasoline of equal energy content (Marland and Turhollow 1991).

The total quantity of CO_2 released to the atmosphere from fossil fuel burning has now (1989) reached 5.97 billion metric tons of carbon per year, up from 1.64 billion tons in 1950. The U.S. share of this is 1.33 billion tons, approximately 5.4 tons of carbon per person per year (Marland 1990).

With broad agreement that the chemistry of the atmosphere is changing, that it is changing because of man's activities (particularly fossil fuel burning), and that this change bears some significant (but as yet poorly specified) risk of global and regional changes in climate; what, if anything, should we do? The current aphorism, especially in the U.S., is to pursue "no-regrets policies". The concept of no-regrets policies is that there are actions which have merit on other criteria, that we might responsibly pursue anyway, that would slow the rate of growth of greenhouse gases in the atmosphere. These are actions for which we would have no retrospective regrets even if the risks of climate change turn out to have been overstated. Some of the proposed measures would seek to limit the magnitude or rate of climate change while others would simply try to anticipate and accommodate the changes which occur. It is in this context that we return to the issues of forestry. Forests are perceived as being fundamentally "good" and most plans to confront global climate change include some effort to maintain and/or increase the amount of carbon which is stored in forests.

There are actually four basic questions for forestry in a global climate change context. First, if climate changes, how will it affect forests? Second, can we reduce CO_2 emissions by reducing the rate of destruction of forests, especially in the tropics? Third, can we remove carbon from the atmosphere and store it by increasing the area and/or carbon storage density in forests? And, fourth, can wood-based fuels from sustained-yield systems substitute for a significant fraction of fossil fuel usage? I don't wish to belabor details but perhaps I can provoke some useful thinking by bringing a variety of ideas together here.

Consider, first, the effect of climate change on forests. To begin with, we know that climate is but one of a number of stresses confronting forests. These stresses include ozone, acid precipitation, heavy metal deposition, and even the potentially beneficial direct effects of increasing ambient CO_2. We have data on tree seedlings to suggest that growth rate, drought tolerance, reproductive success, and other properties can be affected by increasing ambient CO_2 but there is little evidence to indicate how these will apply over the life of a tree or to complete ecosystems. It is species, not in-tact ecosystems, that will respond to climate change. The ability of trees to adapt to changes is different than for agricultural crops, for example, because of their longevity and long juvenile period (Brubaker 1986), and because of the intensity of management. On the other hand, trees are able to survive long periods of adverse conditions and they have a large genetic base for adaptation. Trees can also migrate under the pressure of changing climatic conditions. Evidence from the Holocene of eastern North America shows that tree species succeeded in migrating at 300 - 1000 meters per year as climate warmed behind retreating glaciers (Shugart et al. 1986). On the current earth, however, a distinct lack of ecosystem continuity could severely limit such migrations. Modeling studies by Al Solomon and his colleagues (e.g. Solomon 1986) suggest that the response to climate change in the Eastern United States will be a northward shift of forest zones, with expansion of forests into tundra areas in the north and losses of forest to non-forest vegetation on the southern and western margins. In his Mitchell Prize-winning essay, Daniel Botkin (1991), "project(s) that global warming will lead to rapid and severe changes in forests of the Great Lakes States, with some areas suffering major die-backs during the first decades of the twenty-first century and some becoming deforested and unable to support trees by the end of that century." Botkin goes on to argue that the natural state of forests is, in fact, one of change and that we err in "believing that the natural condition is one of uniformity and constancy." As we discuss the options and opportunities below, we have to wonder how much the possibilities are amplified or constrained by the issues raised in this paragraph.

I don't want to devote much time here to a discussion of tropical forests except to note that the current annual clearing of tropical forests has been estimated to exceed the area of the state of Tennessee (e.g., Houghton et al. 1987; Myers 1990). The contribution to global CO_2 emissions is probably on the order of 25% of the total. With an integrated global economy, a well-mixed atmosphere, and one global pool of genetic material, we in the U.S. are immune from neither damage nor responsibility for what is happening in developing tropical nations. The area of U.S. forests decreased by 21 million hectares between 1953 and 1987 with loss of an additional 7 million hectares anticipated by 2010 (U.S. Congress 1991).

To illustrate the magnitude of the problem of offsetting fossil fuel related CO_2 emissions, consider the possibility of offsetting all 6 billion tons of carbon emissions with new forest. If we could establish new, fast-growing tree plantations on land that did not previously contain trees, and achieve a productivity of about 30 cubic meters equivalent in total biomass per hectare per year (i.e. a carbon uptake of 7.5 kg C per hectare per year), it would require 800 million hectares to accomplish a full offset. This is slightly smaller than the land area of Brazil. To offset emissions from a single coal-fired power plant operating at 38% thermal efficiency and with a capacity factor of 70% would require about 200 hectares of these plantations per megawatt of capacity. These rough calculations do not make allowance for the energy required to establish and maintain the plantation and they do not suggest what happens when the trees begin to mature and the growth rate drops off. They suggest that planting trees cannot solve the whole problem or even provide a permanent offset for a single fossil-fuel power plant. Trees could, however, provide a way to slow the growth of atmospheric CO_2 while we endeavor to either develop a more friendly energy system or establish a better understanding of the risks of climate change.

To contemplate tree-planting a little more broadly, consider Figure 2. The figure shows cumulative net emissions of CO_2 from a power plant as a function of time and suggests 4 scenarios. In scenario A, the current path, fossil fuels are being burned and there is a continuing increase in the cumulative amount of CO_2 discharged. In scenario B we envision that new forest is established so that growth of the forest is initially able to sequester an amount of carbon equivalent to that discharged by the power plant. As the forest matures, however, the rate of carbon uptake decreases until there is no net carbon uptake. Curve B then becomes parallel to curve A but offset from it by a quantity, a-b in the figure, equal to the amount of carbon stored in the mature forest. In scenario C, there is envisioned to be no fossil fuel burning and the power plant is fueled instead by harvesting from a mature forest. As mature forest is harvested, it is replaced by plantation forest which continues to provide fuel for the power plant. In the early stages, net CO_2 emissions closely track those from the coal-fired plant, but ultimately the rate of net emissions falls to zero as the plantation achieves a steady state of standing biomass. The carbon shown as c-o in the figure represents the difference in standing crop between the mature forest and the plantation forest. In scenario D, we envision that when construction of the power plant is initiated, there is simultaneous establishment of a plantation forest where forest did not previously exist. This plantation forest then provides fuel for the power plant and some modest amount of carbon storage in standing biomass, d-o in the figure. Note that in the figure (c-o) + (d-o) = (a-b).

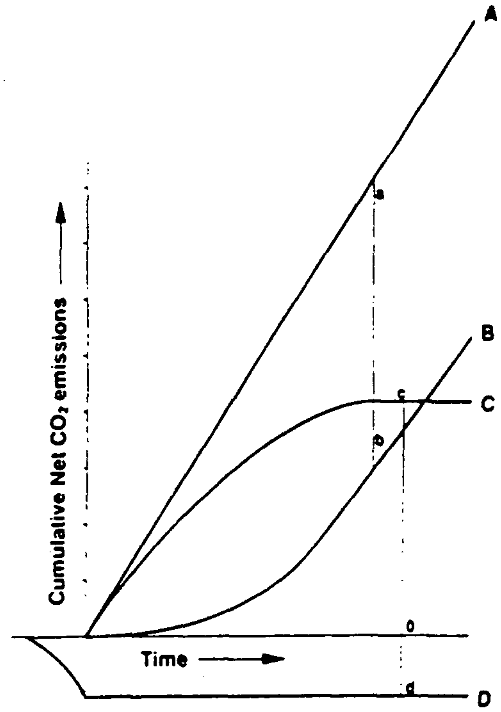

Figure 2: Qualitative representation of the net cumulative CO_2 emissions for a coal-fired power plant and associated forest. See text for a discussion of the four scenarios represented.

It is clear that the cartoon of Figure 2 leaves many unanswered questions because without quantification it tells us nothing about time, land area, productivity, standing crop, energy conversion efficiency, or cost. It doesn't distinguish between total and harvestable biomass. It does provide a framework for beginning to think seriously about these, and other, important variables. Whereas the figure suggests that the most attractive option, on net-CO_2-emissions criteria, should be the establishment of energy plantations where forest does not now exist, we know that the viability of energy plantations will depend on high yields, low energy inputs, low harvest costs, and high conversion efficiency. For biomass to provide a reasonable alternative to fossil fuels it is going to have to provide modern fuels (i.e. electricity or liquid transportation fuels) at reasonable cost. And, if biomass fuels are going to be advanced on environmental (global climate change) grounds, they are going to have to offer good environmental credentials on all fronts: habitat, soil loss, chemical inputs, nutrient cycling, combustion emissions, etc.

Scenario C above has not been a real possibility because we have not been able to burn wood with the same output of electricity per unit of carbon emitted as we can for coal. Recent work by Bob Williams (1990) and David Ostlie (1989) hold out the promise for highly efficient wood-combustion systems and work at the Solar Energy Research Institute and elsewhere is pursuing promising technologies for production of ethanol from cellulosic materials. I should emphasize, as an aside, that there may be advantages for woody crops, but at this point it is not clear why scenario D above should not be based, at least at some sites, on high-yield herbaceous crops rather than on trees.

Let me close with a brief quantitative summation of 3 recent studies and what they envision as possible or likely. Bob Moulton and Ken Richards (1990) of the U.S. Forest Service suggest that the U.S. could offset 56.4% of current CO_2 emissions with tree planting on "economically and environmentally marginal pasture and crop land and non-federal forest land." This would involve 140 million hectares, of which 30 million hectares are already forest land. The National Academy of Sciences (1991) takes a conservative approach in evaluating the Moulton and Richards data and suggests that a reasonable initial objective would be a 10% offset of current U.S. CO_2 emissions on 28.7 million hectares. The NAS study also considers replacing 2.4 quads (2.5×10^{18} joules) of fossil-fuel-fired electric power with biomass. The Office of Technology Assessment (U.S. Congress 1991) estimates that through a combination of planting trees on Conservation Reserve lands, increasing productivity, planting urban trees, general afforestation, and biomass energy the U.S. "might be able to offset about 2% of U.S. 1987 carbon emissions...in the year 2000 and 7.5% in 2015". They envision that economic opportunities for tree planting may exist on about 30 million hectares.

My conclusion is that where we can combine high yields with efficient harvest and conversion, energy crops should offer an attractive long-term contribution to reducing global emissions of CO_2. Where yields are lower and/or harvest more difficult, increasing forest area or improving forest management could provide a temporary brake on the growth in CO_2 emissions. In other areas, carbon storage may provide an added incentive to protect and preserve mature forests. The distinctions will depend on relative values of standing crop, achievable yield, and harvest cost. We are just beginning to get a realistic view of the possible magnitude of the contribution. The challenge is how to incorporate carbon fixation and storage as a management objective while maintaining a balance among other forestry management objectives.

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