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CLIMATE CHANGE AND C

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1. INTRODUCTION

Canadian foresters rarely get to see the trees they plant reach maturity. From an investment point of view, forest regeneration expenditures appear to reap no direct return for 100 years or more. These points are made because in a mixed discipline seminar like this it is easy to overlook the very long time scales with which forestry, viewed as a "crop type" industry, must deal: it is quantitatively different than other "renewable" resource industries in this regard.

If the environment in which the tree crops grow is thought to be fixed and unchanging, the need to look far into the future is not very pressing: past experience will be a reliable guide to the future. Generally resource decisions can be based on an assumption that "what we had is what we'll get" (Peterson and Apps, 1989). Harvest schedules, resource management practices and land use policies have traditionally taken the renewability of the natural resource for granted. Resource management strategies have thus been heavily influenced by socio-economic imperatives with little need for concern about the environment. This was embraced in the guiding principle of "sustained yield".

In recent years, however, mounting environmental concerns have called this paradigm into question. In particular, the prediction of significant changes in the global climate <u>during the lifetime of the trees now being planted</u>, challenges the assumption of an unchanging, and virtually limitless, forest resource. Moreover, because the predicted climate changes are being driven by changes in atmospheric chemistry due to human activities, there is increasing pressure to ensure that the world's forest resources be managed in such a way as to mitigate, not exacerbate, these changes. The title of this paper reflects this interest by Canadians in the form of a question. The question has the natural corollary: how can we manage the forests of Canada to help solve the global problem?

The old paradigm of "sustained yield" has given way to "sustainable development" which recognises the need for forest management, as with other renewable resource sectors, to go beyond immediate economic considerations, and take into account potential impacts on the larger environment. There is considerable overlap between the two concepts but the new paradigm acknowledges environmental sustainabilty as a fundamental precursor to economic development. Dr. Jag Maini (1990a), ADM Forestry Canada, has interpreted sustainable development to mean <u>environmentally</u> sustainable <u>economic</u> development. Forestry Canada is committed, by the Forestry Act of 1989, to the more enlightened view of sustainable development. The meaning of this concept, in the light of potential climate change, is a thread which will weave throughout this paper.

I will begin with some comments on our current understanding of global warming projections for west central Canada and then briefly review published attempts to understand the expected impacts to the forests of the region. This will lead to a general discussion of the implications of these changes for forest resource management and the challenge to the forest sector to become part of the solution, and not part of the problem of growing global environmental concerns - while remaining economically sustainable. In the closing parts of the paper, part of this role - the regulation of greenhouse gases driving the projected climate change - will be discussed.

2. FORESTRY AND CLIMATE CHANGE

A holistic approach is needed to assess the environmental sustainability of resource management activities in a changing climate. Students, users, and managers of forests have long been aware of the influence of climate on their resource. Their accumulated knowledge is reflected in a myriad of ecosystem classification systems, life-zone schemes, and forest vegetation cover/type maps. One challenge that climate change poses, however, is to understand (and therefore predict) how changes in the climate are manifested in forest ecosystems. A second task is to understand (and predict) how changes in forest ecosystems influence the climate system (e.g. by affecting land-air exchanges of energy, water, and greenhouse gases). Because of the direct and indirect effects of his activities on both the climate system and the forest ecosystems, his attempts to manage them must be included in both these tasks (Figure 1, adapted from Maini 1990b).

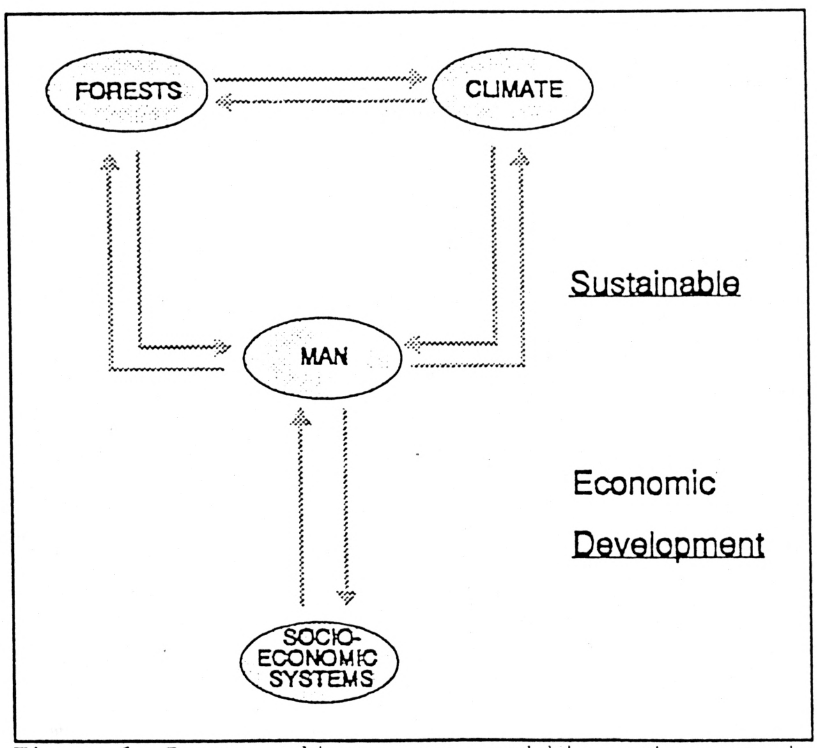

Figure 1. Forest, climate, man and his socio-economic systems are interconnected. Sustaining the environment must be part of economic development.

However, man's decisions are influenced not only by the state of the physical world (top part of figure 1), but also by socio-economic forces which drive much of modern man's activities. These socio-economic forces arise because man is able, to some extent, to foresee and therefore influence the course of future events. Indeed resource management boils down to the making of a conscious choice in order to bring about a particular set of desired (future) conditions. A "sustained yield" paradigm tends to focus the choices on economic values (e.g. wood supply) and related social values (e.g. jobs) - i.e. on the bottom part of figure 1. It also tends to focus attention on immediate, short-term issues related to these values; a focus enhanced and supported by a view of an unchanging (or at least easily renewable) and extensive forest resource. In contrast, "sustainable development" provides, in principle, a mechanism to encompass non-economic, "environmental" forest values in the decision criterion (as indicated by figure 1). A sustainable development paradigm explicitly requires that the longer-term consequences be addressed so as to achieve "economic development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Maini, 1990a).

How will Canadian forests respond to climate change? How do Canadian forests affect the climate? What can forest managers do to meet challenge of sustainable development in a changing climate? These are the critical questions to be addressed if we are to meet the challenges of "Our Common Future" as set out by the Brundtland Commission Report (World Commission on the Environment and Development, 1987). We are well aware of the influence climate has on forests, rather less knowledgable about how changes in climate are manifested in forests, and only starting to ask how forests influence the climate system itself.

3. CLIMATE CHANGE IN THE FOREST REGIONS OF WEST-CENTRAL CANADA

The most sophisticated projections of future climatic conditions in an human-enhanced greenhouse world come from global circulation models (GCMs). These computer models simulate water and energy exchanges between the atmosphere and the surface of planet earth and include somewhat crude representations of transport processes in the atmosphere and oceans.

Scientists at the Canadian Climate Center have recently completed a "second generation" GCM which has been particularly adapted for North American conditions (Blanchet 1990). Environment Canada (1990) has recently published a comparison of the Canadian Climate Centre results with the other 5 world-class GCMs which shows that both elevated temperatures and likely increased summer soil dryness can be expected on a global scale. For central North America, these global averages will probably be significantly exceeded: the Canadian GCM, for example, indicates a "bullseye" for climate changes in mid-continent, just south of Manitoba. Annual T increases range from +4 to +6 C over much of the forested estate of western Canada (Environment Canada, 1990). The other GCMs show similar spatial characteristics (Kellogg and Zhao, 199*, Stewart and Teissen, 1990).

For forest productivity, soil moisture is an extremely important factor. The projected drying trend arises from the increased evapotranspiration associated with the warming, despite the uncertain but positive increase in projected precipitation. Both the response of forests and their regulatory role in the hydrological cycle is important on a regional and a global scale and is believed to have a major influence on the atmospheric circulation pattern (e.g. the Sudan - Sahel - Sahara interactions in north Africa).

Despite their sophistication, GCM projections must be treated be with some caution. The uncertainty in process understanding, initial conditions, and the stochastic nature of the climate system itself all result in a lack of confidence in the specific projections for specific locations or areas on the earth's surface. This does not, however, mean that there is lack of confidence in the generalised findings of the models and the Intergovernmental Panel on Climate Change (IPCC, 1990) has summarised the consensus of the world's leading scientists' confidence in the GCM results.

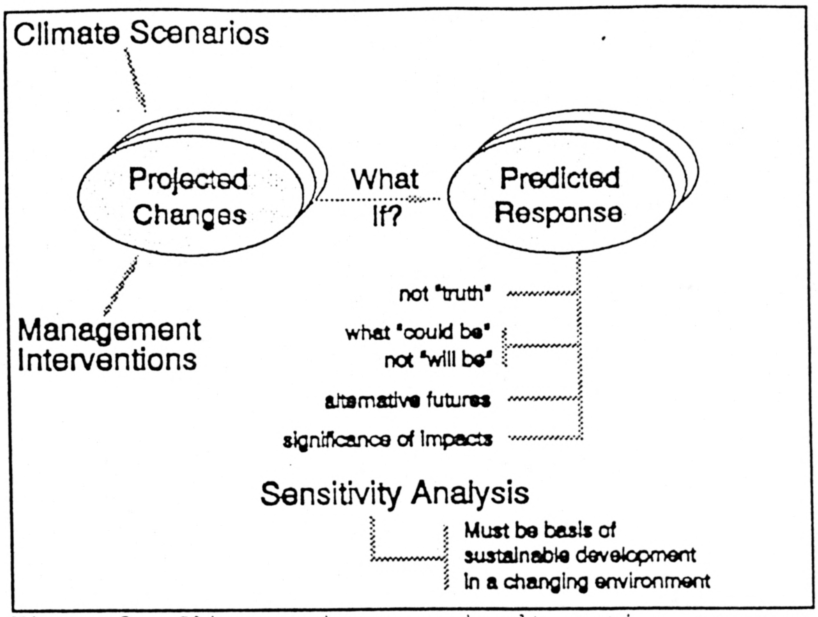

Figure 2. Climate change and alternative resource managment options are treated as scenarios to evaluate the sensitivity of forests (and derived benefits) to choices.

A conservative approach is to regard the GCM projections as alternative scenarios of future climate (rather than absolute predictions) and to evaluate the sensitivity of the forest response to these scenarios (figure 2). This is consistent with the policy makers need to evaluate alternative scenarios of forest management practices.

4. EFFECTS OF CLIMATE CHANGE ON CANADIAN FORESTS

A number of different approaches have been used to try to predict the effect of a given climate change scenario on forested ecosystems. All of these studies should be regarded as "sensitivity analyses" - indications of the types and magnitudes of the changes that could occur not necessarily what will occur (figure 2).

To assess the implications for forest management strategies, we must distinguish between studies of equilibrium response and transient response analysis. Broadly speaking, equilibrium analysis gives a picture of the possible future end-states of alternative climate scenarios but is limited in its ability to shed light on the dynamics of change. Transient response, on the other hand, attempts to evaluate the effects of changes as they occur and is therefore generally more process oriented (in biological terms). Both approaches have important messages for resource managers attempting to implement "sustainable development" practices.

4.1 Equilibrium based approaches

Equilibrium response analyses generally assume:

1) the climate stabilises at some steady-state condition (such as at a doubled effective CO_2 concentration - the $2xCO_2$ scenario),
2) the vegetation and associated ecosystems have more or less adapted to these conditions,

3) the currently observed correlation between climate variables and vegetation associations will also prevail under the changed conditions.

4) the processes of terrestrial ecosystem evolution are predictably deterministic[1].

Despite the obvious unreality of these assumptions, considerable insight into the sensitivity of forest ecosystems to different climate change scenarios has been gained by this approach.

Basing their projections on an analysis of vegetation associations under current climatic conditions (Ecoregions Working Group, 1989), Zoltai (1988) and Rizzo (1988) have independently attempted to project the distribution of vegetation associations under a projected 2xCO2 scenario climate. The findings of both these studies have major implications for forestry in west-central Canada in that both predict that the structure and composition of what is now predominantly boreal forest in the region would be dramatically changed (Figure 3). Grasslands can be expected to extend well to the north of the current ecotone (boundary), while in the north, climate conditions would favour ingress by boreal forest species into the tundra.

In an earlier work, Singh (1988) focused on the increasing temperature (expressed by the parameter "growing degree days") to conclude that over some parts of the region, forest productivity would be enhanced. Increased disturbance regimes (particularly fire), however, could greatly limit the ability of the forest sector to realise these productivity gains, pointing out the need for risk assessment tools (Singh, person. commun.).

At the present time these equilibrium scenario analyses probably provide the best scientific estimate of "what-if" outcomes that we have but they do not explicitly tell us how these end states will be achieved. They can be used, however, to gauge the magnitude and direction of the changes that may occur. This approach has been recently been put into practice with my coauthors Zoltai and Singh by treating the changes in equilibrium vegetation distributions as indicators of changes in ecosystem stress. Figure 4, adapted from Zoltai et. al. (1991), shows the expected response of aspen, an increasingly important commercial species for the region. Such analysis can help forest managers in their resource planning by identifying areas of expected increased stress (and risk) and increased productivity (opportunity).

Even in this analysis however, the implicit assumption is made that the same forces affecting past dynamics play the same role in the future. It largely ignores the influence that man can play in this ecosystem evolution. Whether for good or bad, man is a new ecological force which must be taken into account in projecting the forests of the future (Figure 1).

4.2 Transient response approaches

Transient response analyses attempt to use the understanding of forest ecosystem processes

[1] This last assumption is not generally recognised and has only recently surfaced in developments in the theory of highly non-linear processes (chaos theory).

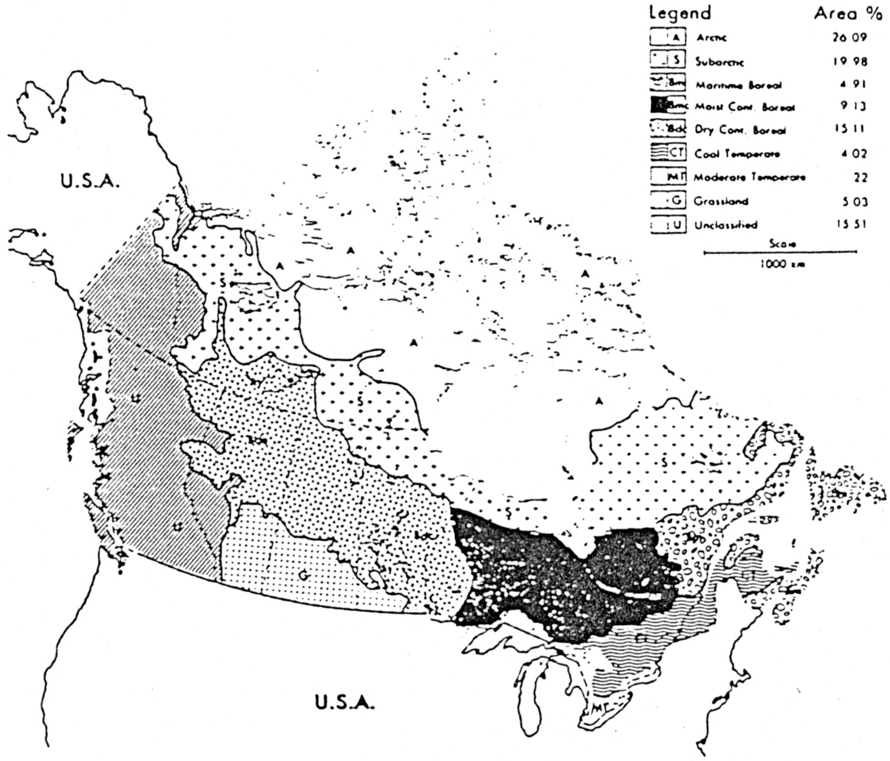

Figure 3a. Distribution of ecoclimatic provinces under current atmospheric conditions (from Rizzo, 1988)

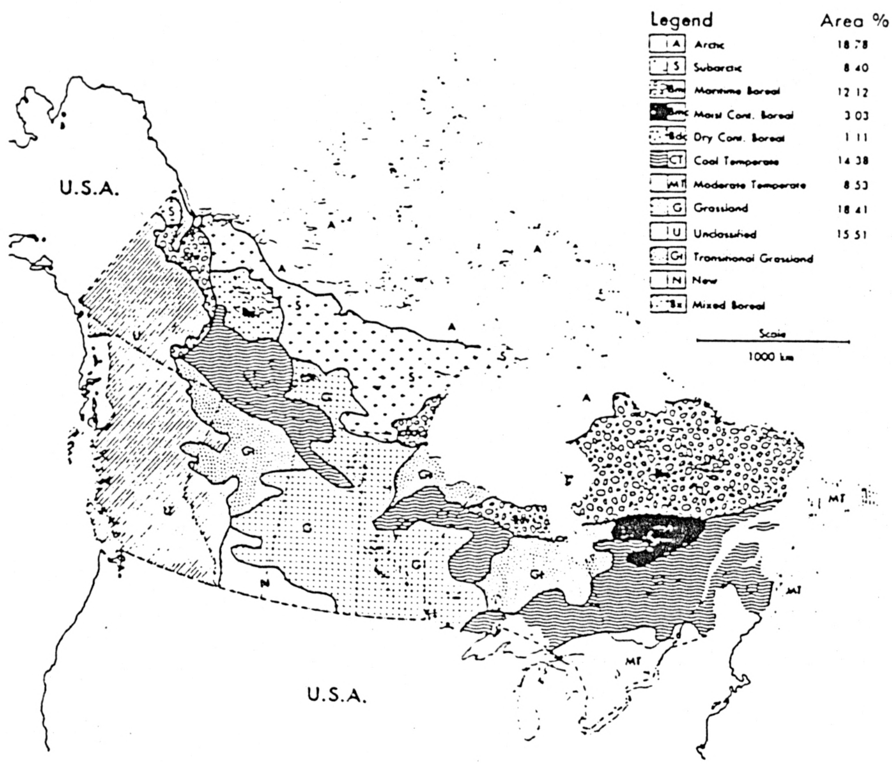

Figure 3b. Predicted distribution of ecoclimatic provinces of Canada in a $2xCO_2$ climate (from Rizzo, 1988)

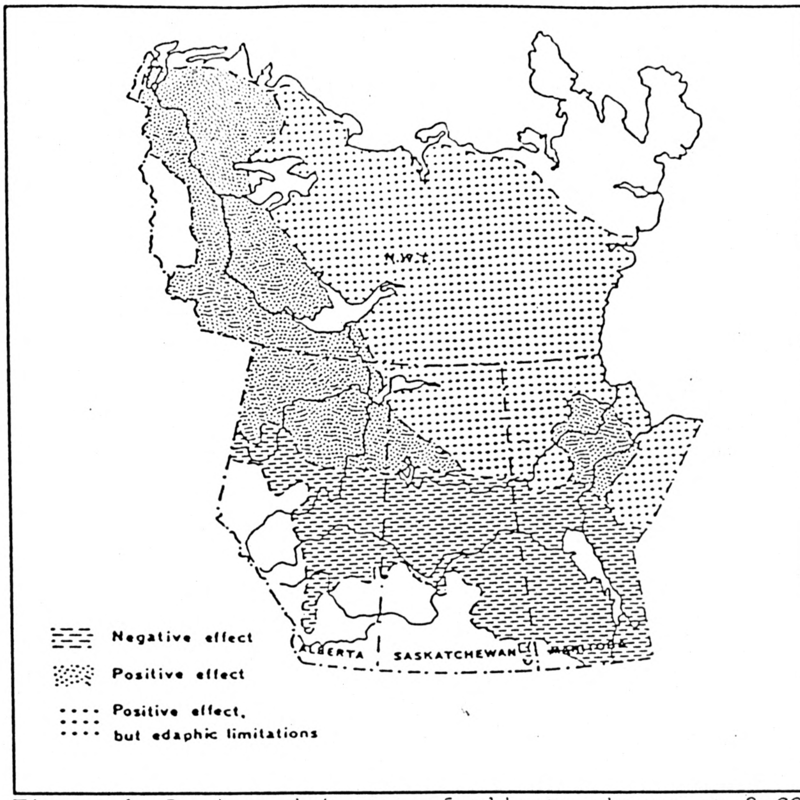

Figure 4. Projected impact of climate change at $2xCO_2$ levels on aspen growth in west-central Canada (from Zoltai et al., 1991)

to relate cause (climate change) and effect (forest changes). The most successful attempts have been built on a theory of forest succession (Shugart, 1984) implemented in computer simulation models. The underlying concept of these models is that the structural changes in a forest plot (typically 1/12 ha) are dominated by competition of the potential biota for available resources. Each plant modifies the environment in which it lives and competes and it is the relative success of the different biota in capturing the resources that determines the forest plot dynamics. The evolution of the forest vegetation communities under a changing climate is simulated by factoring in species-specific relative response to climate variables (e.g. temperature, moisture). Although this procedure has shortcomings, it does provide good insight into the possible structural and productivity changes that might be expected as climatic conditions change.

These transient analyses are in their infancy in Canada, particularly in Western Canada. Several important general features of ecosystem dynamics can be gleaned from the published results of studies carried out in various parts of North America. One of the most important is the tendency of existing systems to resist displacement. Once established on a site, a species has a distinct advantage over other would-be invaders. Shugart and West (1980) used the FORET model to illustrate the hysteresis that appears in the simulated density of a given species when the climate is changed in one direction and then reversed. This biological inertia - or resistance to rapid change - must not be overlooked when considering the changes in forest structure, particulary at ecotonal boundaries. In a rapidly changing climate, species which reproduce annually (such as grasses), and therefore adapt more quickly, may prevent (or at least delay) the establishment of longer-lived, but less adaptable species such as trees. On the other hand, long-lived species, although poorly adapted to the changed climate, may continue to occupy the site and prevent ingress by more productive species.

The second feature highlighted by transient response analysis is the extremely important role that disturbances (such as fire) have on the evolution of forest structure. Such disturbances effectively speed up the process of adaptation by providing "growing space" for the species better adapted to the new conditions. Studies by Overpeck et. al.(1990)

with the FORENA model for a mixed conifer-hardwood forest in Wisconsin and the southern boreal forest of Quebec showed that vegetation changes closely tracked simulated changes in climate up to $2XCO_2$ conditions using expected increased disturbance (fire) rates. In contrast, when forest disturbances were switched off (in the computer simulation) vegetation composition lagged behind climate changes by 50-100 years and when the climate conditions were stabilised at $2xCO_2$ conditions, it took a further 200-250 years for the vegetation to stabilise.

Pastor and Post (1988) studied the transient response of eastern North American forests to a ramping-up of climatic conditions to a $2xCO_2$ scenario over a 100 year period. Using a model (LINKAGES) which includes an explicit representation of nutrient dynamics, they concluded that productivity is strongly coupled to both soil-moisture conditions and to nutrient limitations. In particular, they found that net primary production (reflected in biomass productivity) is strongly limited by soil nitrogen availability, which in turn is partially controlled by decomposing litter in the soil. They concluded that interactions between vegetation and water and nutrient availabilities may produce a bifurcation in the forest ecosystem response, that is, increased production where soil water is not limiting and nitrogen availability is enhanced, and decreased productivity where water and nitrogen become limiting.

5. THE RESOURCE MANAGEMENT CHALLENGE

The current understanding of forest response to climate change as reviewed above, have subtle implications for forest resource management strategies. In the absence of disturbances or human intervention, poorly adapted growing stock may, once established, "hang on" and result in lower yields than could be obtained with stock better suited to the new environmental conditions. In order to capitalise on potential increase in future forest productivity, the appropriate species must be in place, and the appropriate management practices be undertaken. This requires great foresight in today's planting and silvicultural programs. Changes in specific site productivity depend on a number of ecological factors, many of which (e.g. soil moisture and nutrient availability) are at least partially controlled by climatic conditions but can be directly or indirectly influenced by management. Models like FORCYTE-11 (Kimmins et. al. 1990) provide insight into the human intervention, but so far do not explicitly represent climate change-driven processes.

Analyses of climate response have not yet included, at least in any systematic way, the possible interventions by man - planting appropriate (low risk) species, thoughtful management of fires and other risks, and regulation of nutrient regimes through direct fertilisation, or using multiple-species ecosystem management techniques (Apps and MacIsaac, 1990) - which can clearly have a direct impact on the ecosystem response and ability to capture increasing productivity opportunities.

In the spirit of environmentally sustainable economic development there is an additional important consideration to be factored into forest resource management decisions: how much can these decisions influence the environment, for better or worse? The physical climate system not only affects forest growth processes but also is regulated, to some extent, by these forest systems (Figure 1). The feedback mechanisms can be both positive (enhancing the climate change) and negative (reducing the change).

Quantification of the role of global forests in the water, energy and gas exchange with the atmosphere (and thus the physical climate system) is a major international scientific task. Forestry activities can affect these ecosystem processes to mitigate or deepen the environmental changes. It is important to understand how alternative forestry and land-use practices influence surface albedo, surface energy and momentum exchanges, and the small- and large-scale hydrologic cycle.

Understanding the processes at work is, however, not enough: the knowledge must be worked into a structure to assist and guide resource management decisions. These structures must provide the information for balancing of socio-economic concerns with environmental ones required by the principles of sustainable development.

It should be clear that resource managers will require considerable new foresight if they are to rise to the challenges of Brundtland Commission Report (World Commission on Environment and Development, 1987) in a changing global environment. There is a pressing need to develop new predictive capability for assessing possible resource management options which take into account: 1) the potential changes in environment and; 2) their effect on these changes. Without such predictive capability to guide resource decisions, policy makers have been likened (Maini, 1990a) to drivers of

"accelerating cars at night on a road with curves, and must take care not to over-drive our headlights"

This poses a dilemma for science and for policy makers alike because all facts are about the past, but decisions must be made for the future where the facts are not yet known (Apps and MacIsaac, 1990). Although decision-makers are used to dealing with uncertainty, the threat of climate change poses a particular crisis for them because the implications of the changes are beyond the realm of human experience. They, along with the general public, must rely on the predictions of scientists and this presents an even more urgent challenge to the scientific community who are called upon to offer scientific judgements often before adequate data can be collected. As Kimmins (1985) points out relying on historical data alone can lead to a form of future shock: we must avoid

attempting to steer the car using only the rear view mirror!

6. FORESTS AND THE CARBON CYCLE

Recent newspaper headlines such as "Revenge of the Killer Trees - is World Vegetation Becoming a Giant Carbon-dioxide Pump?" have focused public attention on the role of forest vegetation in the global carbon cycle. These, together with concerns about tropical deforestation, clearly establish a perceived connection in the public mind between management of the forest resource and the issues of global warming. As a result forest management practices of the future will surely be under increasing pressure to demonstrate they result in positive contributions to the global carbon budget. For resource managers to assume such responsibility is consistent with acceptance of the principles of sustainable development as stated earlier. While drawing upon the economic benefits associated with being one of the world's trade leaders in forest products, Canadians also recognise that they are custodians of some 10% of the world's forested area and are anxious to see it be a positive factor in maintaining the global environment.

There are good scientific reasons for interest in the contribution of forests in general, and northern forest in particular, to the sustainability of the global environment - especially with respect to the carbon cycle. Global warming concerns are driven by human induced increases in atmospheric greenhouse gases of which carbon dioxide is the most important. In the role they play in the global carbon cycle, the world's forests have been likened to the lungs of the planet; on a global scale the carbon in the atmosphere is effectively passed through the earth's terrestrial biota every seven years. This fact together with the observation that forests, and their soils, represent huge and changing storage pools of carbon, ties the issues of changing climate and forest dynamics tightly together.

Furthermore, Houghton (19**) and others have documented the contribution that deforestation has made increases in atmospheric greenhouse gases. Although these studies have largely focused on land-use changes in the tropics, recent research (e.g. Tans et. al., 1990) has led to considerable interest in the role that temperate and northern forests play in the carbon cycle.

7. THE CARBON BUDGET OF THE CANADIAN FOREST SECTOR

A major part of the answer to the question posed in the title of this paper has to do with the role of Canadian forests and forestry practices in the global carbon cycle. The question has three parts: how much carbon is currently stored in Canadian forests, how much do they currently contribute to the atmospheric budget, and how will these carbon storage pools and exchanges change in the future as a consequence of climate change and forest management?

To address these questions, a three phase study of national scope was initiated in 1988 as a joint project between ESSA Environmental and Social Systems Analysts Ltd. (Principal Investigator, Werner Kurz) and Forestry Canada (Project leader, Mike Apps). The study has the following objectives:

- Phase 1 - assessment of the current carbon budget using best available data;
- Phase 2 - evaluation of the likely/possible consequences of alternative forest resource management strategies on future carbon budgets; and
- Phase 3 - evaluation of the likely/possible consequences of alternative climate change assumptions on future climate budgets.

7.1 Phase 1 carbon budget: a modelling framework and snapshot of 1986

A conceptual model, analytical framework and computer simulation model were developed by drawing upon the expertise of a large group of scientists in Forestry Canada, the University community and forest industry. The results obtained reflect the efforts of all these individuals and they are sincerely acknowledged (Kurz et.al. 1991). The model includes the contribution of standing biomass, the associated soils and peatlands, as well as the residual carbon in forest product materials previously harvested from the forest. Year-specific, event-driven processes are used to drive simulated transfers of carbon between pools (e.g. transfers of standing biomass carbon to the soil pool and forest products through harvesting) and fluxes of carbon to the atmosphere from these pools through decomposition and decay processes as well as through direct release by fire.

The existing forest sector carbon inventory (pool sizes) and budget (changes in pools and atmospheric transfers) were simulated for the reference year 1986. Biomass dynamics (growth) are derived from Canada's forest resource inventory by applying ecosystem-and species-specific factors to account for additional biomass components (such as understorey and roots, which are not explicitly in the database), converting biomass to carbon units, and summing over all of Canada's forest eco-regions (Ecoregions Working Group, 1989). Soil pool dynamics are calculated on the same site-specific basis using a three compartment sub-model which incorporates world soil data (Oak Ridge National Laboratories) and couples to the dynamics of the overlying vegetation. Peatland pool growth was estimated using published accumulation rates (Gorham, 19**) and unpublished data (Zoltai, pers. commun.). The state of the forest product pool was simulated using a submodel which tracked all carbon of biomass origin from the time of its removal from the forest to its eventual decomposition and return to the atmosphere.

At the time of this seminar, phase 1 results are being prepared for publication and formal review, but to give a taste of the findings, a few of the salient features are provided in Table 1 (carbon inventory) and Table 2 (carbon budget for 1986). Our preliminary results indicate that, at least for 1986, Canadian forests and forest sector activities appear to play a positive role in addressing the global problem of atmospheric carbon dioxide. However, it should be noted that the budget figures are of the order of 0.1% of the pool sizes.

It must also emphasised that these are preliminary results and are subject to change during the review process. In particular, I will not provide estimates of either the precision or confidence we have in the accuracy of these results here except to comment that a number of assumptions and expert estimations had to be made in the absence of available hard data. In the report under preparation analysis of the sensitivity of the model results to some of these data is examined.

7.2 Phase 2 and 3: exploring alternative futures

Although the forest sector budget for 1986 indicates a positive contribution, it can be improved. Even a cursory study of the two tables suggests that by improving forest growth and decreasing losses - through aggressive afforestation programs, fire suppression programs, alternative harvest and silvicultural practices and similar resource management options - it is possible to enhance Canadian forests' contribution to the solution of a global problem.

Basic good forest resource management practices will provide the necessary advancements. All that is needed is the subtle shift in our attitudes towards forest values mentioned in the opening sections of this paper - a shift which accommodates environmental sustainability while supporting economic development. In phase 2 of the carbon budget project, we will use the modelling framework to help assess the influence of alternative forest sector management on the future carbon budgets.

Good forestry practices will not be enough, however, if the possibility of global warming becomes the reality. To predict whether the Canadian forests and sector activities continue to be a sink or become a source of atmospheric carbon is a hugely difficult scientific challenge requiring the inclusion of the transient response analysis discussed in section 4.

If the threatened climate change does come about it will be due, in large measure to man's seemingly insatiable thirst for energy and his willingness to slake that thirst with fossil fuels. In considering the forest sector's role in such a changing world, it will become increasingly relevant to consider factors such as energy usage - and the potential for renewable substitution of fossil fuel with bioenergy plantations. These considerations are being included in the ongoing development of carbon budget model.

In addition, forestry management practices and land-use policies can be expected to play a major role in the forest's response to climate change. The extent to which such decisions can influence the "bottom line" of the carbon budget in a changing climate is the significant challenge for the future.

8. CONCLUSIONS

Forest species have a lifetime scale comparable to that of the changes in climate projected to result from the enhancement of the greenhouse effect by human industrialisation. They are thus both particularly affected by such potential change, and may have a significant role to play in the change itself. Forests, too, are under the direct control of humans over large parts of the world and in some areas, such as the tropics, the wholesale changes wrought by man are significantly contributing to global change. In Canada, forests provide important social and economic benefits while also providing "existence value" in which Canadians take pride. To meet the challenge of the principles of sustainable development, the potential for change in the forest resource must be understood and taken into account in resource management strategies. Going beyond the "sustained yield" paradigm which it replaces, "sustainable development" requires a balance between environmental sustainability and economic development. This suggests that forest management strategies should be examined for their potential to contribute positively to the solution of the global problem and not merely avoid being part of the problem. With respect to their contribution to the atmospheric carbon dioxide (the main greenhouse gas) burden, Canadian forests and forest activities appear to be on the right side of the equation, at least for 1986. Whether they will continue to be part of the solution depends on whether climate change actually occurs, how they respond to the changes as and if they occur, and how we choose to manage them. This is, I believe, the challenge of sustainable development.

ACKNOWLEDGEMENTS

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CONTENTS