Predicting forest growth and yield under climatic change conditions

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Abstract

According to most general circulation models the climate in west-central Canada is expected to change in the next 50-100 years. We need to consider such changes in our predictions of future growth and yield. The increase of greenhouse gases especially CO_2 will probably cause the temperature to rise and perhaps precipitation to some extent in the higher latitudes of the northern hemisphere. In west-central Canada boreal tree species are expected to be most affected by climate change. Present species ranges are expected to migrate northwards. Palaeobotanical studies indicated that similar climatic warming which occurred in west-central Canada about 6000 years ago resulted in similar shifts in species distribution. Transect studies along latitudinal north-south direction provided evidence of growth and yield variation along climatic gradients. As the most productive forest region in west-central Canada, research into the effects of climatic change on forest productivity in the boreal forest is urgently required. Ecosystem-based dynamic gap models may offer the means to study the effects of climate change induced by CO_2 increase on forest growth and yield.

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Introduction

In the foreseeable future, the air pollution due to anthropogenic effects and climatic change could modify the silvicultural practices in Canada. The effect of air pollution is studied intensively in Europe and eastern North America. These studies have demonstrated the detrimental effects of the air pollution on the functioning and structure of the forest ecosystem and the future forest growth and yield. This could be the case also with climatic change but the effects of the climatic change are much less known than those of the air pollution. It is expected that the climatic change is, in particular, inevitable in the high latitudes of the northern hemisphere which include the most productive forests in Canada. The climatic change at high latitudes is expected to result in higher temperatures with longer growing seasons but precipitation would increase only slightly or remain the same (Mitchell et al. 1990). The future forest growth and yield will be dependent on the structure and functioning of the forest ecosystem and the consequent patterns of silvicultural management. Therefore the interaction between the ecological processes and silvicultural practices is the basis for the analysis of the silvicultural implications of the climatic change. Consequently, the future forest yield is not predictable unless the silvicultural management of the forest ecosystem is outlined at the same time as the effect of climatic change on the structure and functioning of the forest ecosystem. This paper stresses the need to consider an "ecosystem" approach to modelling the future growth and yield in light of the increasing evidence of global warming and climatic change.

CO_2 increase and global warming

Rising CO_2 levels in the US will raise the temperature in US by 3.0 to 5.1 degrees within the next 50 to 100 years based on hypothetical climate change scenario using GCM's and historical climate data (Woodman 1990). Application of these scenarios to several forest succession models resulted in a northward shift in the ranges of northern hardwoods, boreal forest species (Botkin et al. 1989). In western Canada anticipated climate change within the next century, caused by anthropogenic actions (greenhouse gas emissions, etc) would result in a warmer climate with precipitation patterns similar to the present. The CCC GCM, Environment Canada, for example shows temperature changes in the order of +4 to +6 degrees for the region. Table 1 shows the comparison of 6 GCM models for projected global mean temperature and precipitation changes for the 2 X CO_2 or doubling of atmospheric carbon dioxide (occurring probably by 2050). Four of the six models including CCC indicate expected increased summer dryness for mid-continental North America.

Historical data

Interestingly enough, comparable conditions of anticipated climate change existed in western Canada during the post glacial "mid-Holocene" warm-dry period about 6000 years ago (Zoltai and Vitt 1990), then grasslands and aspen parklands occurred far north of their present extent. The anticipated climate change would cause increased drought conditions in the south and longer growing season in the north. For the southern boreal region, we may expect reduced growth rates, higher mortality and higher incidence of insect and disease infestations. The extent of wildfires will probably also increase. In the mid-range, forest tree species would benefit from the extended growing period with increased productivity. In the north, tree species would become more aggressive in extending their ranges.

Transect studies

Maini (1968) reported a strong effect of latitudinal change in the dominant height of mature aspen in Saskatchewan (Figure 1), based on measurements along a 1200 km N-S transect through grassland, grassland-forest , boreal forest, and into the edge of the forest tundra transition. Aspen trees attained maximum height in the main boreal forest but were considerably shorter northward near the tundra and southwards near the grasslands.

Similar trends were found in total biomass production (Johnstone and Peterson 1980) when stands from the grassland-forest transition, the main boreal zone and montane regions were examined. The montane stands were all from high elevation >1300 m above sea level, where climates are similar to a more northern forest-grassland ecotone location. Tree biomass components from stands of comparable age were always greater in the main boreal zone than in either the montane or aspen-grassland ecotone (Figure 2). Other productivity indicators including height, diameter at breast height, crown dimensions and leaf areas showed similar highly significant ($p<0.01$) differences.

These data indicate that aspen (and probably for other species), growth and productivity is sensitive to a climate gradient as reflected in regional latitudinal differences. Optimum conditions for aspen, and other boreal species for that matter, exist within the main boreal zone, with less suitable conditions near the southern and northern ecotones in response to climate-related environmental stresses. Should the projected climate changes occur the optimum conditions for aspen and other tree species will shift accordingly.

Ecoclimatic regions

Anthropogenic changes are expected to exceed natural climatic fluctuations by the end of

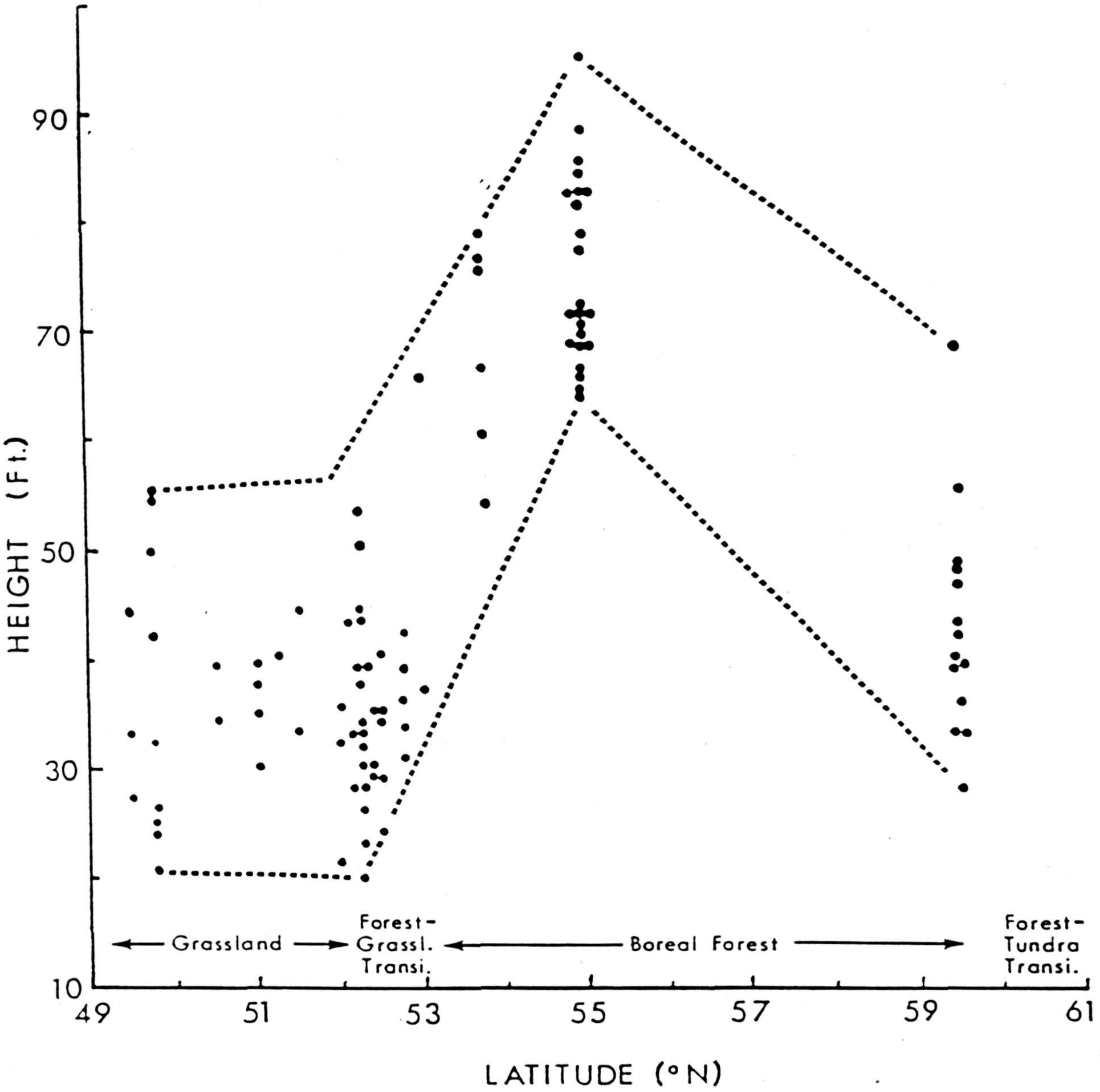

Figure 1. Height growth of mature aspen stands along a 1200 km N-S transect in Saskatchewan (Maini 1968)

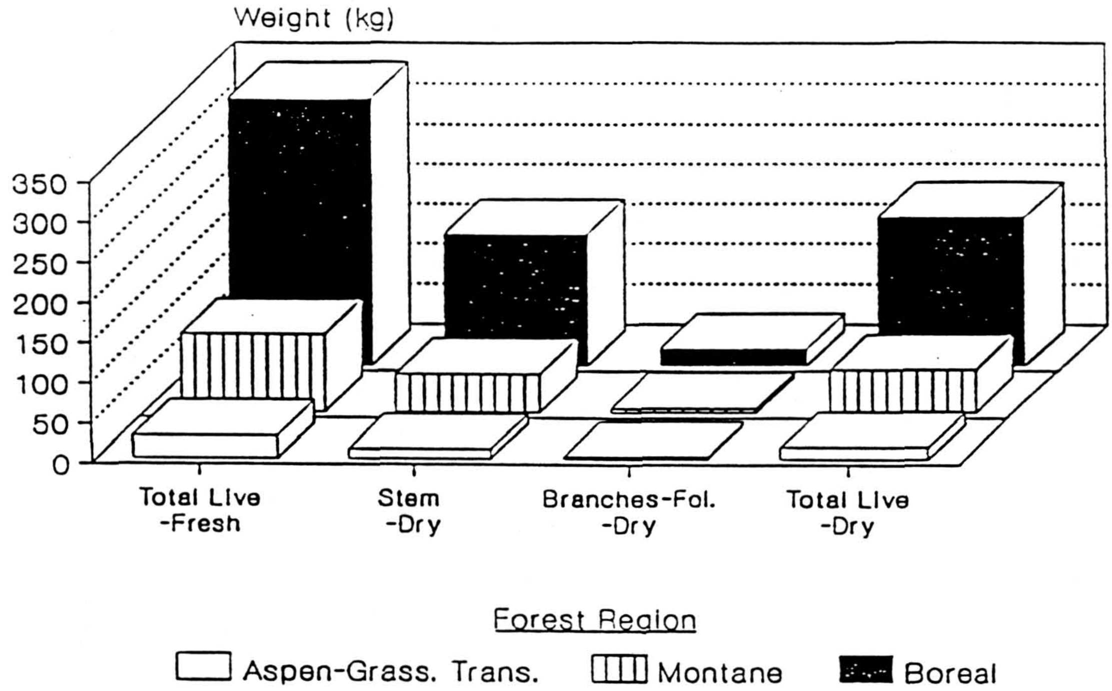

Figure 2. Growth parameters of aspen in different forest regions in Alberta (recalculated from Johnstone and Peterson 1980)

Model	Temperature Change (°C)	Precipitation Change (%)	Summer Dryness
GFDL (1989)	4.0	8.7	yes
CISS (1984)	4.2	11.0	no
NCAR (1984)	4.0	7.1	no
UKMO (1987+)	1.9-5.2	4 - 15	yes
OSU (1987)	2.8	7.8	yes
CCC (1990)	3.5	3.8	yes

Table 1. Comparison of CGM "$2xCO_2$" -"$1xCO_2$" experiment results (reproduced from Environment Canada 1990)

Boundary	Degree days
Arctic/Subarctic	500
Subarctic/Boreal	900
Boreal/Grassland	1350(west)-1600(east)
Arid Grassland/ Transitional Grassland	1500(west)-1900(east)
Boreal/Cool Temperate	1500
Cool Temperate/ Moderate Temperate	2250

Table 2. Approximate annual degree days (5 degree C base) at present boundaries of ecoclimatic provinces

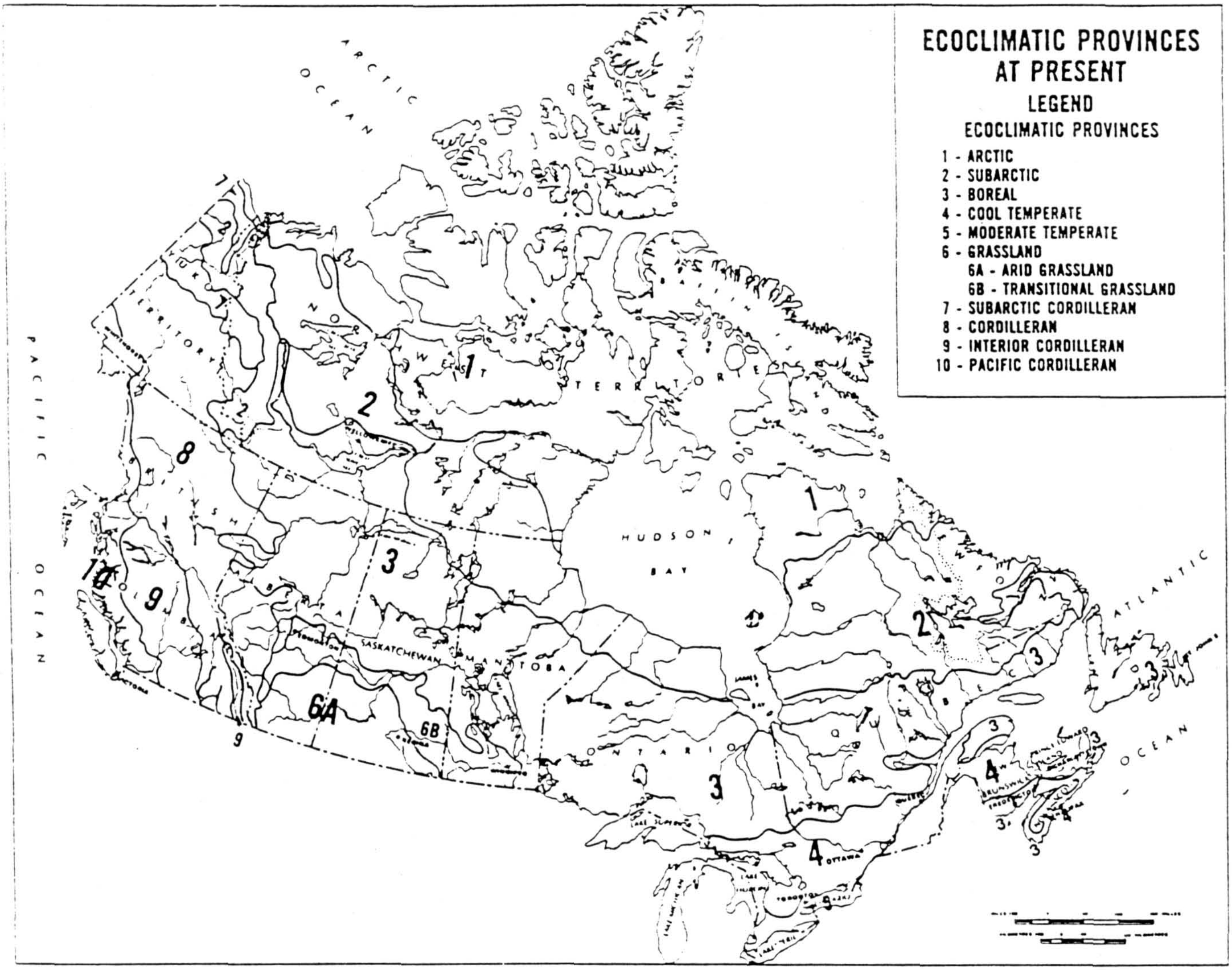

Figure 3. Ecoclimatic provinces at present

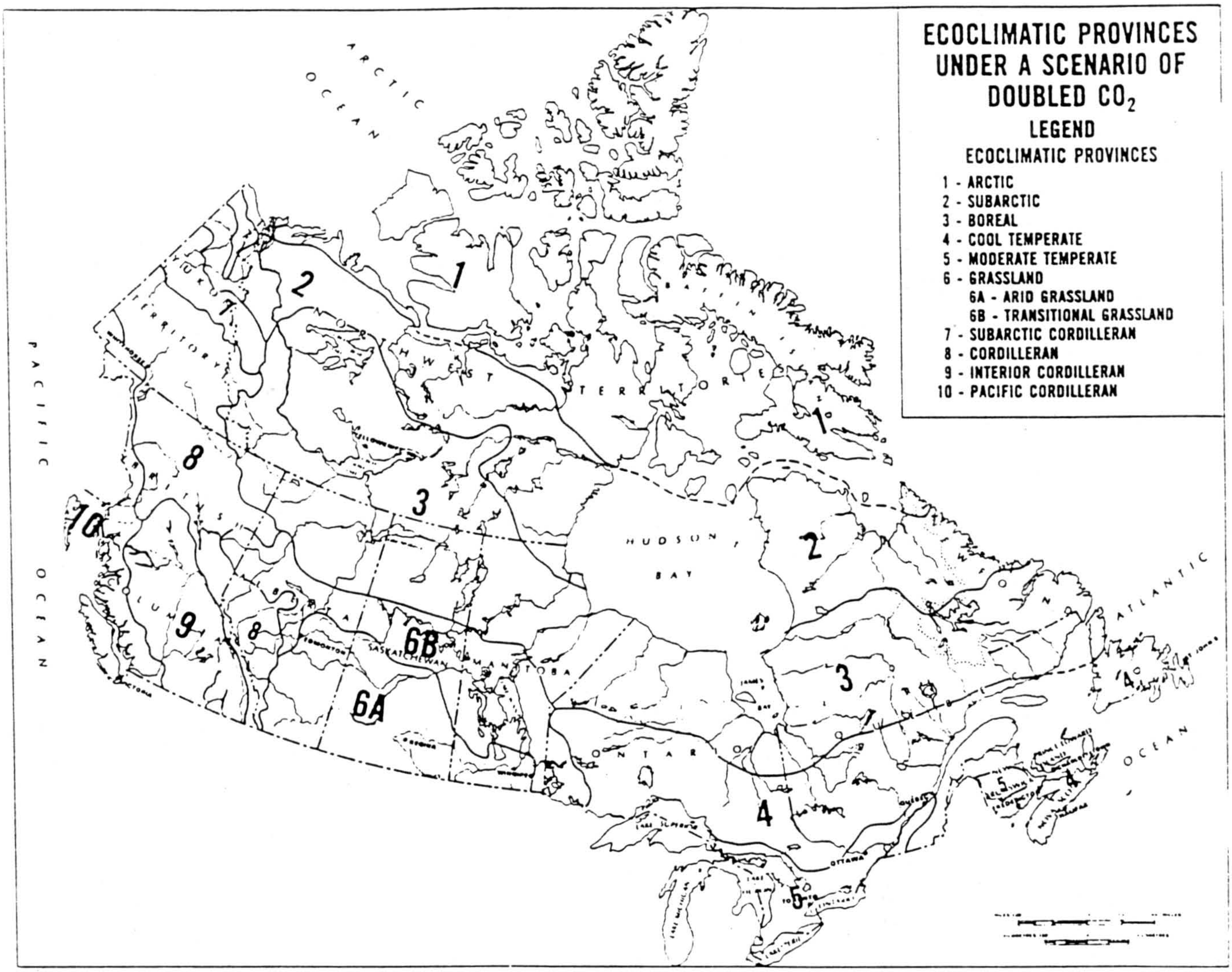

Figure 4. Ecoclimatic provinces under a scenario of doubled CO_2

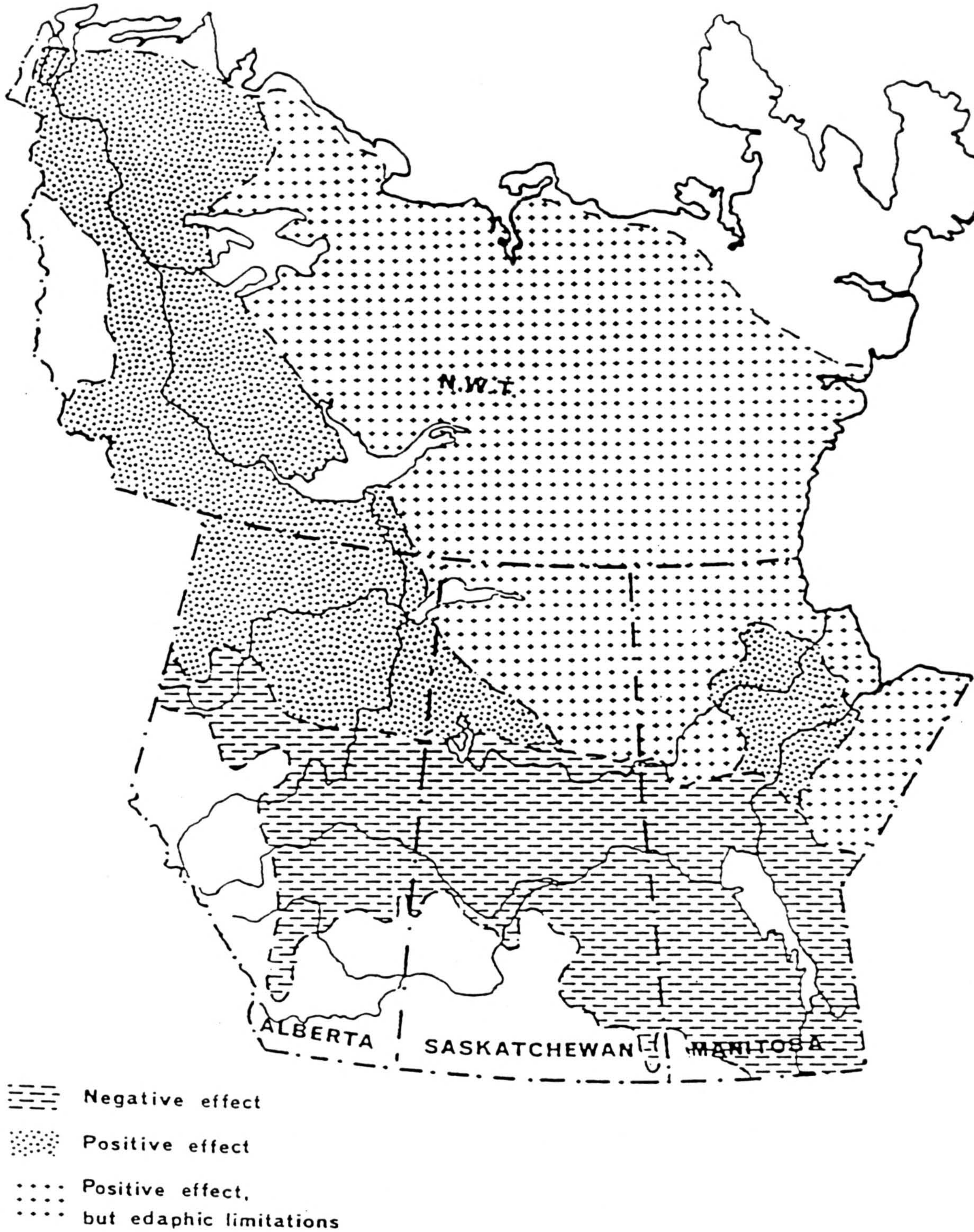

Figure 5. Projected impact of climate change at $2xCO_2$ levels on aspen growth in west-central Canada

the century. Table 2 shows the approximate annual degree days (5 degree C base) at the present boundaries of ecoclimatic provinces. Using degree days to locate the generalized position of ecotones shows promise. Zoltai (1988) used this approach to produce a map of Ecoclimatic Provinces of Canada (Figure 3) under current climate. The Goddard Institute for Space Sciences (GISS)'s model was used to predict climatic conditions under doubled CO_2 conditions. This general circulation model predicts mean monthly temperature and precipitation for points located every 5 deg longitude and 4 deg latitude apart. Using these projections Zoltai (1988) produces an ecoclimatic provinces map under a scenario of doubled CO_2 (Figure 4). Of particular interest to our region, the conditions favourable for coniferous boreal forests will exist some 300-450 km farther north than at the present. However, boreal forest conditions will be displaced along the southern boundary by about the same amount. Increase in sea level due to the melting of polar ice caps may flood large areas around Hudson and James bays. Figure 5 shows the likelihood of climatic change at 2 X CO_2 on aspen growth in west-central Canada (Zoltai et al. 1991).

The LINKAGES model

The challenge of predicting growth and yield, forest productivity under climatic change conditions forces us to look into new approaches of modelling our ecosystem relationships. We cannot simply look at a site and assume productivity to remain the same in the future. Processes such as carbon and nitrogen cycles, temperature (degree days) and water availability must be examined and projections made for the expected changing conditions. Admittedly it is difficult to include these complex relationships, however, we can no longer assume that climate will remain the same. Ecosystem dynamic gap models such as

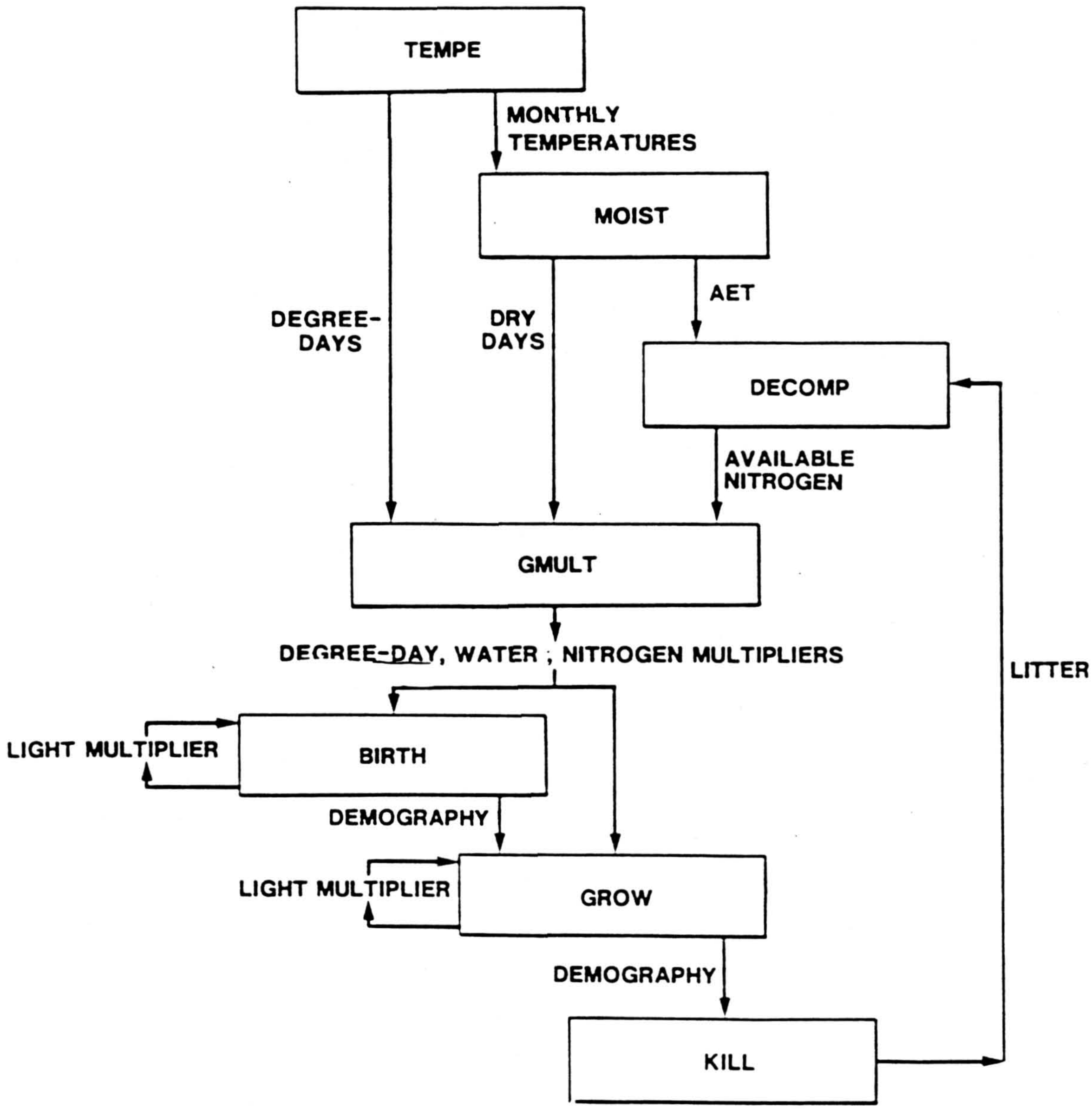

Figure 6. Structural and functional relationships in the forest ecosystem and the effects of climatic factors on productivity of the forest ecosystem according to Pastor and Post (1985)

LINKAGES (Pastor and Post 1985) are required to answer such questions as productivity changes under climatic change conditions. Figure 6 presents a schematic diagram of the hypothesis of the model. The ecosystem model considers the establishment and growth of individual trees in a 1/12 ha plot and their responses to degree days, soil water deficits, soil nitrogen availability, and light. The maximum and minimum growing season degree days a species can tolerate are assumed to coincide with the southern and northern limits of its range. Species are assumed to be either shade tolerant or intolerant and are assigned to appropriate photosynthetic response curves accordingly. The growth of each tree is limited by degree days, water deficits, light or nitrogen, whichever is most limiting in a given year. Different species in turn influence nitrogen availability through the chemical quality of their litter and influence light availability in all smaller trees through shading (Pastor and Post 1985). The assumption is made that the probability of mortality increases from about 10% to 30% upon two consecutive years of slow growth due to stress. In the model, changes in temperature affect tree growth directly through the degree-day response curves; indirectly through the increased evapotranspiration and hence drought stress; and through changes in decomposition rates, and hence nitrogen availability. Species biomass, total biomass, number of live stems, leaf area, and total woody production are calculated for the output interval. These, along with humus C:N, soil CO_2 evolution, soil organic matter, available nitrogen, and average evapotranspiration, are considered in the ecosystem simulation model.

Conclusion

Sceptics may say that the climate will not change but only fluctuates slightly. However palaeobotanical studies have shown that the range of boreal forests have shifted significantly in the past due to climate warming, it can happen again in the future. Increasingly we are seeing evidences from global warming that it will happen. We are driven to explore a more "global" approach to predicting (modelling) forest growth and yield that considers all the components of the ecosystem in an explicit manner. Forests take a long time to mature: in 80 years the climate is expected to undergo significant changes. It is to our benefit to anticipate the response of the forests, to take advantage of the changes, or at least to minimize the detrimental impact.

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