1991

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S.C. Zoltai

T. Singh

M.J. Apps

Recommended Citation

Zoltai, S. C.; Singh, T.; Apps, M. J. 1991. Aspen in a changing climate. S. Navratil and P.B. Chapman (editors). Aspen Management for the 21st Century: Proceedings of a Symposium. Forestry Canada, Northwest Region and Poplar Council of Canada, Edmonton, Alberta.143-152.

ASPEN IN A CHANGING CLIMATE

S.C. Zoltai, T. Singh, and M.J. Apps
Forestry Canada
Edmonton, Alberta

ABSTRACT

In western Canada, aspen attains its best growth potential in the boreal zone under the present climatic conditions. The anticipated climate change within the next century, caused by anthropogenic actions, would result in a warmer climate and precipitation patterns similar to the present. Comparable conditions existed in western Canada during the mid-Holocene warm-dry period (about 6000 years ago), when grasslands and aspen parklands occurred far north of their present extent. The anticipated climate change would cause increased drought conditions in the south and a longer growing season in the north. Under such conditions aspen is expected to respond with generally reduced growth rates, higher mortality, and higher incidences of insect and disease infestations in the south. In the mid-range, aspen would benefit from the extended growing period with increased productivity. In the north, existing aspen stands would become more aggressive in expanding their range.

INTRODUCTION

In recent years, predictions of impending climate change have introduced a new dimension to the management of our forest resources. More than ever, forest managers must consider not only the direct effect of their management interventions, but must also consider the "natural" evolution of the forest ecosystems they attempt to manage, if they are to avoid the future shock that some have suggested will occur (Kimmins 1985). Although all renewable resource sectors will be significantly affected if the climate changes projected under the enhanced greenhouse warming take place, the forest resource sector, by virtue of the longevity of the species involved, has the opportunity to adapt or the potential to be adversely affected. This is because the predicted change will be so rapid that species migration and adaptation may be unable to keep pace. There is a consequent potential for major changes to vast areas of present forests and the possible loss of species (IPPC 1990).

Changes in the socioeconomic forces in a changing climate will also contribute to these ecosystem changes. Public interest increasingly forces forest managers to recognize multiple nontimber values of the forest as well as the traditional economic ones. Environmentally sustainable economic development that would not only prevent the degradation of the environment, but to some measure also enhance it for various multiple uses, is now recognized as an attainable goal (Maini 1990). This concept enters a different dimension, however, when the development has to be sustainable not only under the present environmental conditions, but also under changing climatic conditions.

This paper is an assessment of how western Canada's aspen resource might be affected by the projected climate changes. It is not our purpose to predict or explain what the future climate will be. We instead take the possible scenarios, as provided by the experts in atmospheric sciences, and try to evaluate, on the basis of current understanding, what the impact of these potential climate changes will be on the aspen resource.

CLIMATE CHANGE

The widely publicized concern for global warming arises primarily because of the observed increase in radiatively opaque gases (carbon dioxide, methane, etc.) in the earth's

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atmosphere, resulting in an enhanced "greenhouse" warming. These changes are clearly linked with man's use of fossil fuels and to a lesser extent (20%) with changes in land use, which affect the carbon dynamics role of the vegetation.

Although the changes in the atmosphere are readily documented, the effect of these changes on the climate is less easily substantiated and is an active area of research fraught with uncertainty. Not only is the magnitude and rate of climate change based largely on theory, the manifestation of these changes (extreme events vs. averages) is speculative at this time. Although there remains a small group of scientists who dispute the results of a number of global warming projections as a result of the enhanced greenhouse effect, the world's scientific community generally agrees that there will be a significant, unavoidable climate warming. The Intergovernmental Panel on Climate Change reports reflect this consensus.

Table 1 from Environment Canada (1990) shows a comparison of the results from six independent global circulation models (GCMs) for projected global mean temperature and precipitation changes. The projections are for a period after climatic equilibrium has been reached in an atmosphere with an effectively doubled CO_2 loading. Normally referred to as the $2 \times CO_2$ scenario, this atmospheric loading is expected to be passed sometime towards the middle of the next century. The table also shows that four of the six models, including the Canadian Climate Centre's (CCC) 1990 model, indicate expected increased summer dryness for mid-continental North America.

A recent paper by Kellogg and Zhao (1988) compares five of the current GCM projections in some detail and provides comparisons of their North American projections in the form of maps. The Canadian GCM shows a qualitatively similar pattern. What is particularly striking is that in nearly all the projections the "bull's-eye" of change is focused on the mid-continent. The zones of largest temperature changes, which encompass most of the current aspen resource, are considerably higher than the global averages in Table 1. The CCC GCM, for example, shows temperature changes in the order of +4°C to +6°C for the region.

The $2 \times CO_2$ projections shown in Table 1 indicate the direction and approximate magnitude of the expected changes in a greenhouse-enhanced world. They do not, however, indicate the dynamics of the change. Some unusual weather patterns associated with the change may have severe consequences on the aspen resource (increased drought frequency, violent storms, deep wet snow, late spring frost, etc.), but such manifestations of the climate change are not readily predictable.

The point is that future climate projections currently indicate significant changes in primary factors (temperature and moisture) affecting forest processes. If these projections prove true, the forests being planted now will "mature and decline in a climate to which they are increasingly poorly adapted" (IPPC 1990). While we may be concerned about the lack of spatial and temporal precision in projections of the climate variables and be even more critical of their uncertain accuracy, we can use the current GCM results to explore the sensitivity of the forest resources to the possible changes that may occur. Using this approach, in this paper we explore the effect on the aspen resource if the climate were to shift towards the equilibrium $2 \times CO_2$ projections over the next century.

ECOLOGICAL BASIS FOR IMPACT ANALYSIS

There are several approaches to analyze the possible effects of a changing climate on aspen ecosystems. One approach is to compare the forests of an area to a region that has the anticipated climate according to the climatic change scenario. This would give an indication of the expected forests if a vegetative-ecosystem equilibrium could be reached under the changed climate. As this is not likely to happen, at best this approach gives an indication of the direction of vegetation change from the present to the anticipated climatic conditions at a certain time in the future.

Examination of vegetation dynamics on topographically induced local climate can give useful information. Slopes of southerly exposure are usually warmer and drier than the rest of the area, even though they share the same regional climatic regime. Conditions on such slopes may

Table 1. Experiment results from 2 × CO_2 and 1 × CO_2 global circulation models[a]

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

[a]Environment Canada 1990.

resemble the expected changed regional climate, with vegetation that is adapted to these conditions.

To evaluate the pace and magnitude of vegetational changes in specific regions, the climate-related characteristics of the forest ecosystems are examined. The effects of extreme climatic events that have occurred in the past, and may be expected in the future, can be used to indicate possible ecosystem responses. Documented effects of prolonged or severe droughts on aspen ecosystems can give indications of the expected response to increased droughty conditions. The distribution of aspen forests during a warmer and drier period up to 6000 years ago can give indications of ecosystem response to a different climatic regime. The results of such analyses have to be used with caution, as we do not know to what extent the expected climate change will approximate the past climates.

In addition to the uncertainties of the predicted climate change, the impact of the changing climate on the vegetation is also theoretical and unproven, as the anticipated climate change is unprecedented in its scale and rate. We have no clear previous experience on which to base our evaluation. The following account is therefore largely based on inferences derived from some knowledge of relevant environment-vegetation relationships.

PRESENT ASPEN PRODUCTIVITY

Biomass productivity of aspen stands varies with physiographic-edaphic conditions, stand density, genetic differences between stands, and their clonal structure. Regional productivity differences are notable and can be related to broad climatic differences, whether expressed on a forest region basis (Fig. 1) or as ecoclimatic regions (Ecoregions Working Group 1989). Thus, grove-type stands of the aspen-grassland ecotone have different productivity than the main boreal forest in west-central Canada.

Maini (1968) reported a strong effect of latitudinal change in the dominant height of mature aspen in Saskatchewan (Fig. 2). Measurements were made along a 1200-km north-south transect through the grassland, grassland-forest transition (ecotone), boreal forest, and into the edge of the forest-tundra transition. Aspen trees attained maximum height in the main boreal forest but were of considerably shorter heights northwards near the forest-tundra ecotone and southwards in the forest-grassland ecotone and in the grasslands.

Similar trends were detected in the total biomass production of aspen (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 elevations (>1370 m ASL), with climates similar to a more northern forest-grassland ecotone location. Tree

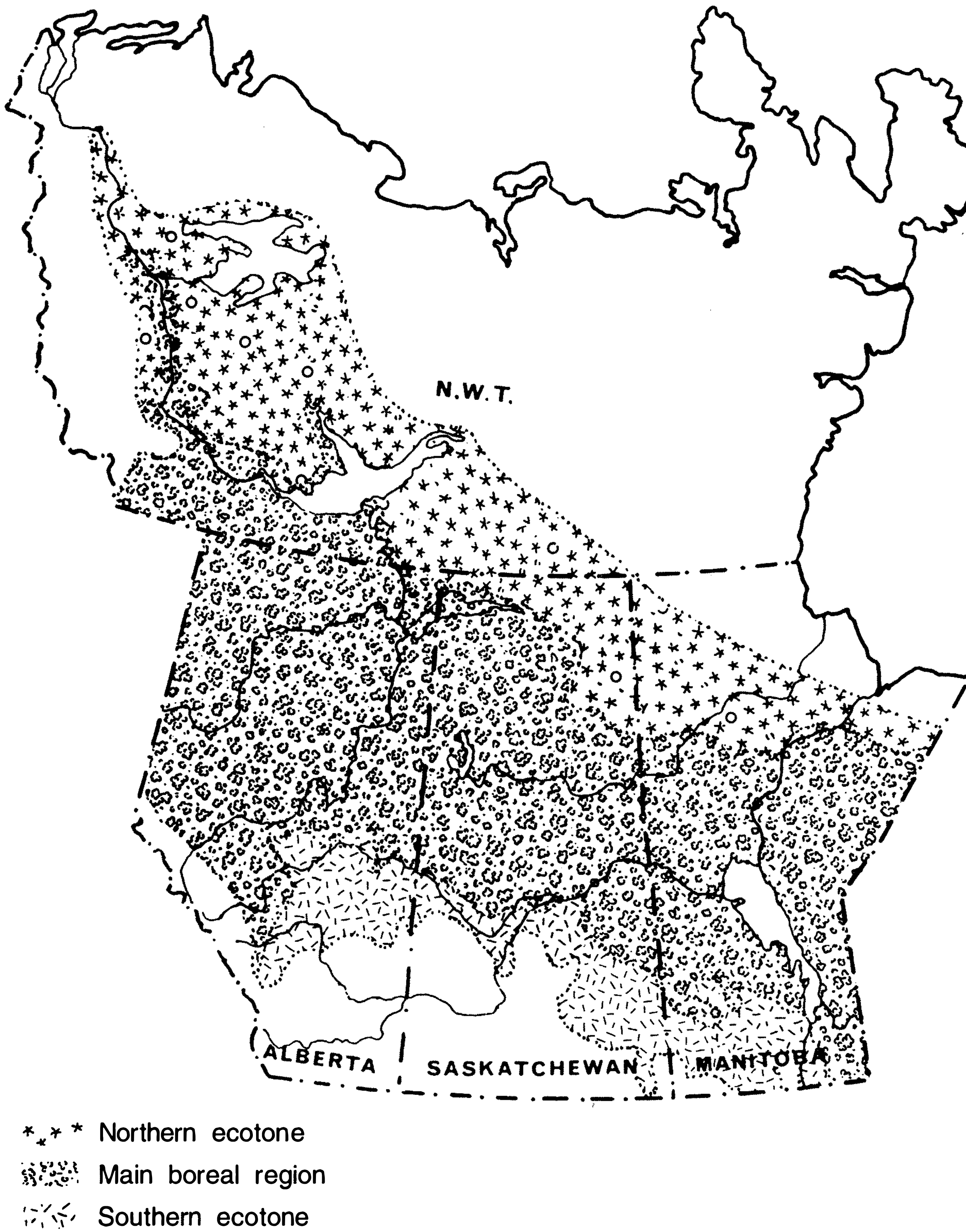

Figure 1. Main forest zones of west-central Canada (Rowe 1972).

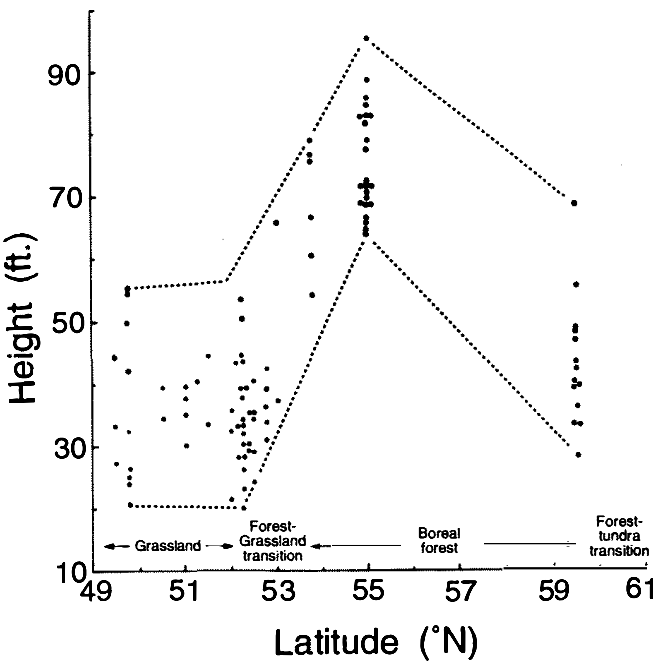

Figure 2. Height growth of mature aspen stands along a 1200-km north-south transect in Saskatchewan (Maini 1968).

component biomass from stands of comparable age were always greater in the main boreal zone than in either the montane or aspen-grassland ecotone (Fig. 3). Other productivity indicators, including height, diameter at breast height, crown dimensions, and leaf areas showed similar highly significant ($p < 0.01$) differences (Fig. 4).

These data indicate that aspen growth and productivity is sensitive to a climate gradient as reflected in regional latitudinal differences. Optimum conditions for aspen growth exist within the main boreal zone. Less suitable conditions exist near the southern and northern ecotones, apparently in response to climate-related environmental stresses. Should the projected climate changes occur, the optimum conditions for aspen growth will shift accordingly. In the southern (grassland-forest) ecotonal areas, aspen will be subjected to increasing stress and will be adversely affected, while in the northern (forest-tundra) ecotone, the direct climatic stresses should be reduced.

PROJECTED SOUTHERN ECOTONE

Projected climate change scenarios for the southern ecotone indicate warmer temperatures, especially during the winter. This would result in a higher number of growing degree days and a longer growing season. Precipitation predictions, although very uncertain, appear to be marginally higher than at present; however, the higher temperatures would result in increased evapotranspiration and thereby result in a reduction of ecologically effective moisture.

These conditions would favor the expansion of the grasslands at the expense of aspen. If conditions were stabilized at the 2 × CO_2 scenario, the likely response would be for the arid grasslands to advance north of Edmonton and Prince Albert and for the aspen parkland to extend north of Churchill River in Saskatchewan (Zoltai 1988). This would approximate the position of the boreal forest boundary about 6500 years ago, as determined from tree pollen (Ritchie 1976) and peat formation (Zoltai and Vitt 1990).

The distribution of aspen in the southern ecotone appears to be controlled by recurring severe droughts. The drought of 1961 resulted in up to 100% mortality in aspen groves in the southern Saskatchewan and Manitoba portions of the ecotone. Some trees were killed outright, while others succumbed to the weakly parasitic fungus, *Cytospora chrysosperma* that attacked the weakened trees in the years following the drought (Department of Forestry 1961, 1962, 1963).

The drier climate would result in more forest fires that would burn larger areas than at present. This would further facilitate the spreading of grasslands into formerly treed areas.

The rate of vegetation change due to the changing conditions will depend on disturbance regimes (Overpeck et al. 1990), which in turn depend on the weather patterns in the changing climate. If severe droughts occur at frequent intervals, aspen ecosystems could be destroyed rapidly by the drought and attendant insect and disease attacks. This would cause the most immediate changes in the southern fringe of the ecotone. In the rest of the area, some aspen

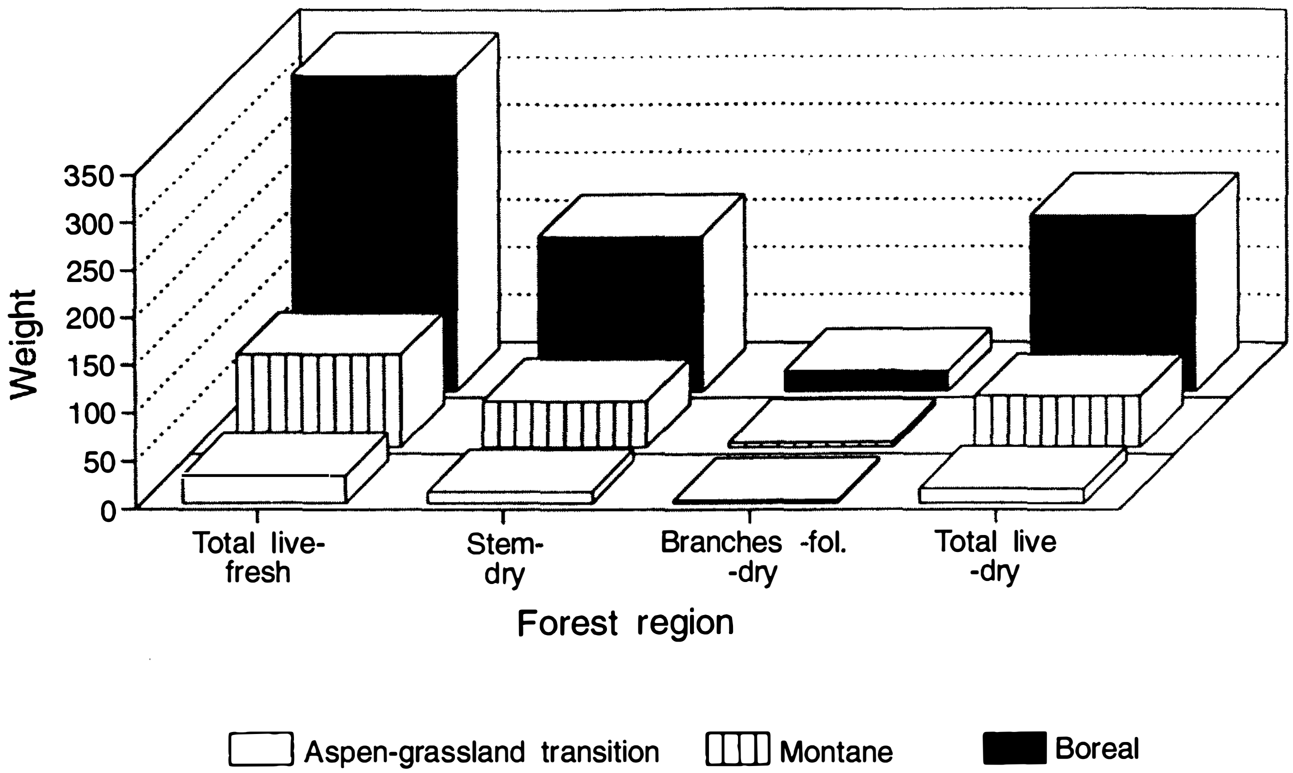

Figure 3. Aboveground biomass of aspen in different forest regions in Alberta (recalculated from Johnstone and Peterson 1980).

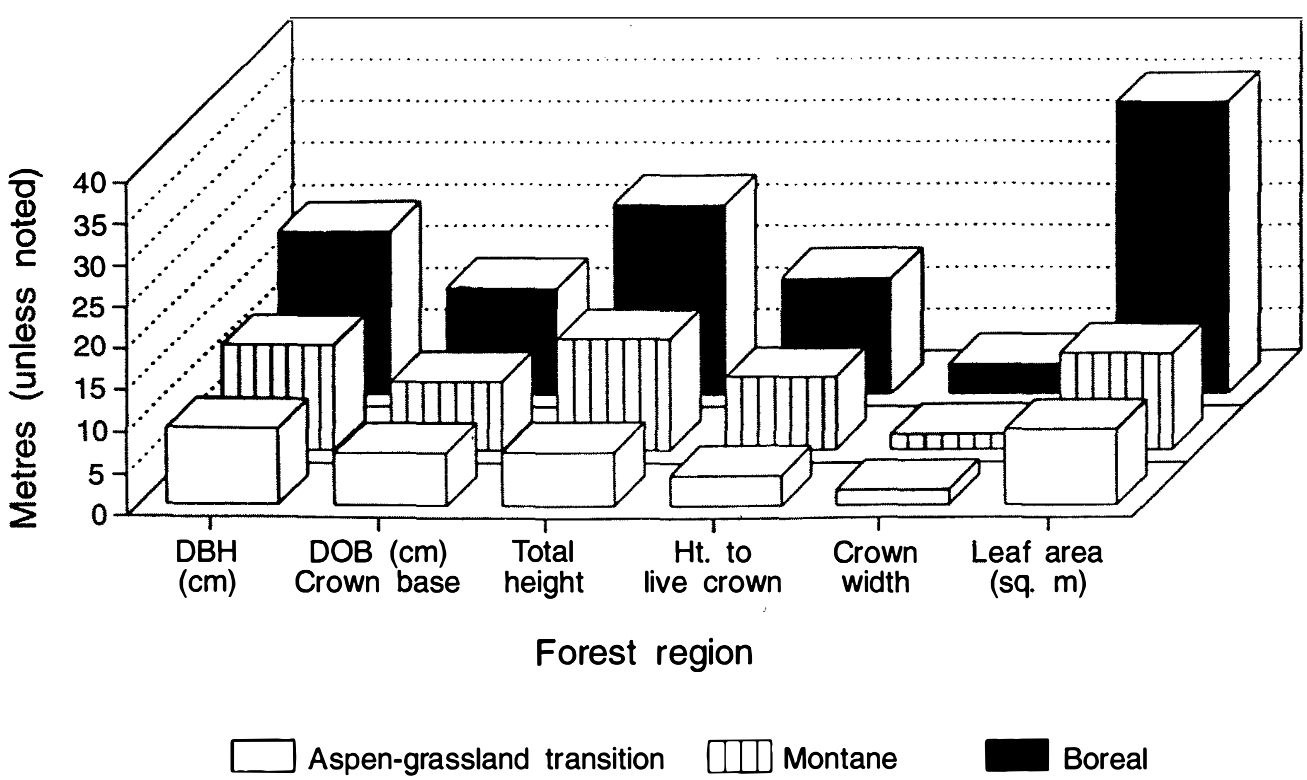

Figure 4. Growth parameters of aspen in different forest regions in Alberta (recalculated from Johnstone and Peterson 1980).

stands might reach maturity, but their productivity and rate of growth would be reduced by moisture stress. Regeneration will suffer from frequent droughts, fires, and vigorous competition from grasses and forbs. The combined effect is that sustained aspen production is not likely to be successful in this area, although aspen may remain present in favorable localities.

PROJECTED MAIN BOREAL

Aspen is now widely distributed within the main boreal zone. The anticipated increase in air temperatures, coupled with a possible slight increase in precipitation, should result in a positive effect on aspen productivity in the central and northern portions of this zone. Higher amounts of radiant energy, a longer growing season, and less extreme winter temperatures should result in faster, more vigorous growth, at least during the present rotation. Aspen can be expected to retain its competitive edge by producing seedlings of both vegetative and seed origin after cutting or fires.

The southern fringe of this zone is expected to be adversely affected by the climate change. Here, the progressively drier climate will cause aspen regeneration to fail on the droughtier soils and on south-facing slopes. Grasses and forbs, better adapted to low levels of soil moisture and frequent droughts, will dominate instead of aspen or conifers. Although good aspen growth will be possible on lower slopes and moister sites, on other sites aspen growth will be slower due to moisture stress and insect and disease infestations of the weakened trees.

A progressively warmer climate will certainly increase the incidence of forest fires throughout the main boreal zone. A dramatic increase in burned area has been observed to accompany the warming and drying trend of the late 1970s and early 1980s (Van Wagner 1988). In 1980 and 1981 records were set and reset with the average burned area varying from a low of 0.9 M ha in 1968 to 4.8 M ha in 1980 and 5.4 M ha in 1981, much of which was in west-central Canada. In 1989 at least 6.4 M ha burned (Stocks, in press), including large areas in Manitoba. The fires may affect the growing aspen stock, but aspen regeneration, especially through suckering, should result in adequate regrowth in the burned aspen or mixedwood stands. Indeed, the rapid early growth of aspen will give it a strong competitive advantage under such highly disturbed conditions.

The rate of change in the main boreal zone will be less obvious than in either of the ecotones. The existing stands, growing at a faster rate than at present, should reach maturity before further changes in the climate will be noticeable. If atmospheric CO_2 accumulation continues beyond the double present levels, however, aspen productivity in the main boreal zone will be progressively negatively affected. Plans beyond the next rotation should include growing short rotation aspen crops and hybrid species mixes in anticipation of this possibility.

PROJECTED NORTHERN ECOTONE

The changed climatic regimes indicate substantially higher temperatures and more precipitation than at present. Aspen already growing in this area should respond with increased growth to the generally warmer climate and longer growing seasons. An increasingly milder climate would also allow aspen to extend its range beyond its current limits, provided other factors do not limit the migration.

Warmer summer temperatures are expected to cause extensive thawing of permafrost. In highly icy permafrost areas this will induce uneven subsidence and mudflows. When stabilized by eventual desiccation, such disturbed surfaces can serve as seedbeds for aspen. Although aspen reproduces readily from suckers, sexual reproduction does take place from seeds produced annually in copious amounts and widely dispersed by wind (McDonough 1985). Paleobotanical studies in the northern Yukon (Delorme et al. 1977) indicated that *Populus* was an early pioneer on lands recently vacated by the continental ice sheet.

It is expected that conditions for aspen growth will improve in the present northern ecotone in response to the milder climate. Aspen may not benefit from the more favorable climate in all of this area, however. A large part of this area is on the Canadian Shield, where the soils are sandy and shallow over bedrock. Aspen would not grow well on such sites due to poor rooting depth, lack of soil moisture, and low nutrient status. Here, aspen has good growth potential only in valleys and on lower slopes where the soils are deeper and contain more moisture.

CONCLUSIONS

Our confidence in the changes outlined above, which are based on our current understanding of projected global warming and vegetation interactions, is increased by observations of the paleoecological record. Persistent warmer climates during the Holocene, similar to those expected during a 2 × CO_2 scenario, resulted in a large extension of grasslands into the present boreal forests (Ritchie 1976) and a northward displacement of the tree line (Nichols 1976). This indicates that the ecotonal regions of western Canada are sensitive to persistent climate shifts.

If greenhouse gases could be stabilized at the 2 × CO_2 level and the vegetation allowed to reach an equilibrium with the changed climate, the ecological zonation in western Canada would be shifted considerable distances northward (Fig. 5). Aspen would lose some ground in the south, but on the whole would benefit from increased productivity and extended range in the central and northwestern portion.

This presents both a challenge and an opportunity for forestry. The challenge is to recognize the changing ecological conditions in response to the changing environment. The forest manager has to think not only in terms of today's conditions, but also in terms of change that is not likely to occur until today's seedlings reach merchantable size. Past experience at any one site will not necessarily be a reliable guide to the future crop, as the site conditions will change during the life of the crop.

The projected climate change offers an opportunity to maximize aspen production in areas where aspen is expected to benefit from the changing climate. The rapid initial growth of aspen and its ability to reproduce vegetatively make aspen a prime candidate for management under the changing conditions. The introduction of superior clones or hybrids would allow even shorter rotations, making aspen less vulnerable to further unfavorable changes in the climate.

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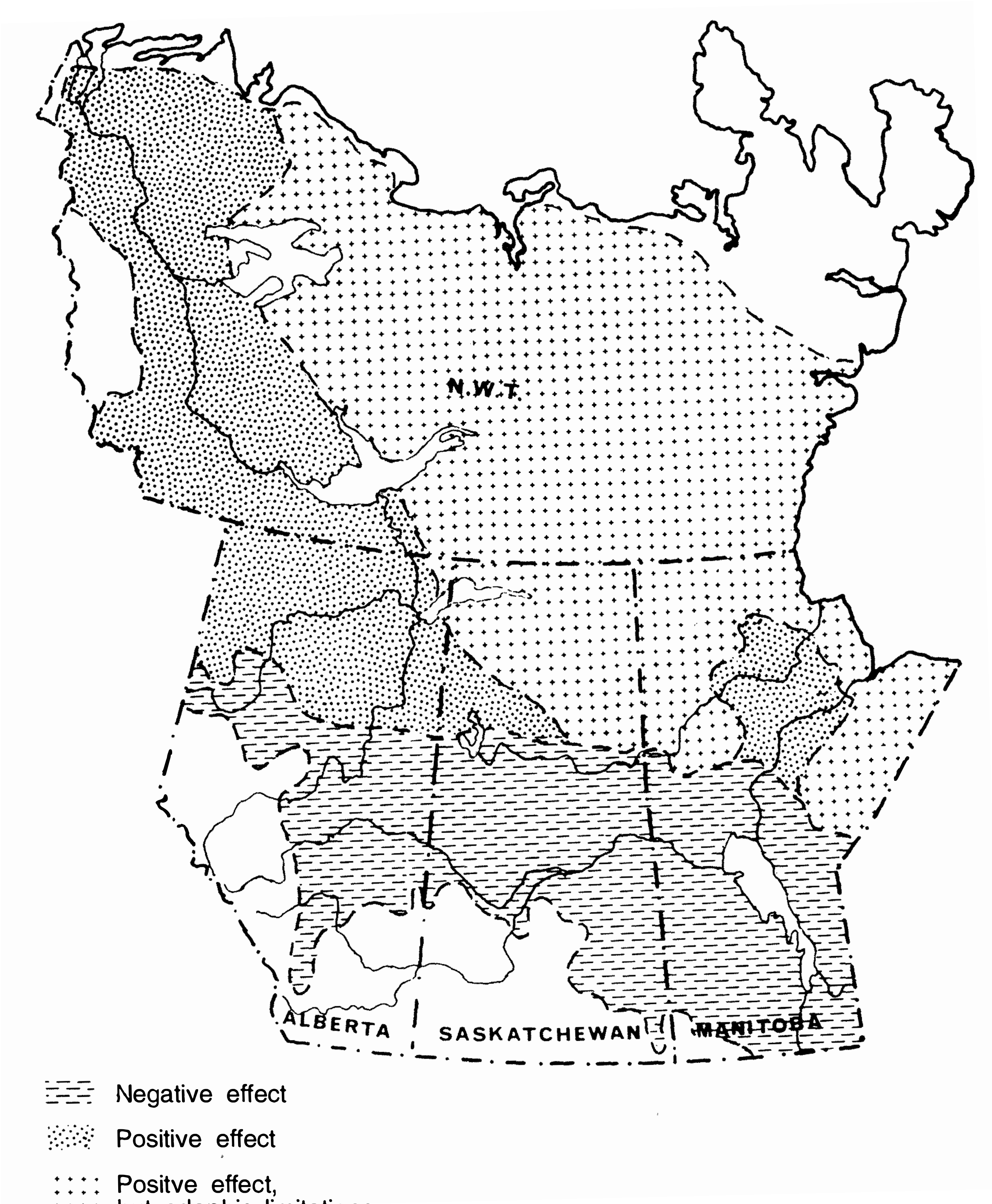

Figure 5. Projected impact of climate change at 2 × CO_2 levels on aspen growth in west-central Canada.

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