

SOME VEGETATION INDICATIONS OF CLIMATE WARMING AS
DETECTED ON THE FOREST-TUNDRA BORDER IN THE
CONTINENTAL CANADIAN ARCTIC

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Abstract: A pilot forest survey on the arctic/alpine timberline in northernmost continental Canada showed increasing forest biomass in the past 150 years. This increase in forest biomass growth resulted from an increase in stem density due to successively colonizing younger generations of white spruce (*Picea glauca*) rather than from growth enhancement in existing individual trees. Two tentative conclusions can be drawn from this result. 1) Considering the expanse of the circumpolar forest/tundra ecotone, increased forest growth in this region, if established globally, may account for a considerable part of the “missing sink of carbon dioxide”. 2) Of the two possible effects of increasing carbon dioxide on vegetation, *i.e.*, CO₂ fertilization and climate warming, the latter is showing itself more strongly than the former on the forest/tundra ecotone.

1. Introduction

Since TANS *et al.* (1990) suggested the impracticability of the oceans absorbing all the excess CO₂ other than that contributing to increases in atmospheric loading, inferences suggesting increased CO₂ sequestering by terrestrial ecosystems (ROTMANS and DEN ELZEN, 1993; MELILLO *et al.*, 1993) as regrowth in plantation and secondary forests in the temperate region and growth enhancement in boreal forests due to CO₂ fertilization and/or climate warming is accumulating. However, the evidence in support of increased terrestrial carbon sequestration is rather circumstantial resulting more from isotopic measurement of ¹³C/¹⁴C ratios (NAKAZAWA *et al.*, 1993; ENTING *et al.*, 1995) or from analysis of variation in atmospheric CO₂ (KEELING *et al.*, 1995) than from large-scale field measurements of terrestrial carbon stock. One of the major factors which makes the direct measurement difficult is the enormous complexity and heterogeneity of terrestrial ecosystems, which in turn defies simple extrapolation of measurement to large spatial scales. Another factor, which is often overlooked, is the competition among trees in closed forest communities. More specifically, in a closed forest, where trees are growing tightly together forming a continuous canopy, increased growth in individual trees can be easily offset by increased natural thinning resulting from the increased competition, or conversely decreasing growth in individual trees can be offset by increasing stem density of the forest communities, making it difficult to relate growth of individual trees to that of the stand or forest community as a whole. This difficulty, however, is not the case with timberline woodland communities where trees are widely scattered and increased growth in individual trees does not necessarily result in increase in competi-

tion and death of suppressed individuals. In other words, growth measurement in a limited number of sample trees directly indicates the community growth trend in the timberline woodland. The objective of this work was to examine, on a preliminary basis, the growth of such a timberline forest in terms of population dynamics and individual tree growth to find any increasing trend in forest biomass as well as to identify the mechanism behind such biomass increase.

2. Materials and Methods

The samples were collected in August 1994 from the latitudinal/altitudinal timberline at 439 m above sea level, and $67^{\circ}15'N$ and $135^{\circ}10'W$ on the east slope of the Richardson Mountains, Northwest Territories, Canada (Fig. 1). Two increment cores were bored at breast height (1.3 m above ground) from each of 12 dominant individual trees in a small grove of white spruce (*Picea glauca*). More or less protected in a groove along a stream, the 7–8 m high grove constitutes the last stand of trees on a slope where dwarf (1–2 m in height) white spruce was growing sparsely scattered in a barren tundra of Labrador tea (*Ledum* spp.) and other Ericaceous shrubs. Beside those sampled, there were many smaller trees in and around the grove, but they were not sampled in this work primarily because they were either below breast height, or if not, the stems were too thin and soft to bore increment cores at breast height.

In the laboratory the cores were crossdated and then the ring-widths were measured to a resolution of 0.01 mm. The mean radial growth for each tree was obtained by averaging the two core ring-width series from a given tree and is shown in Fig. 2. Using these raw tree chronologies, the standard ring-width index (RWI) and basal area for the

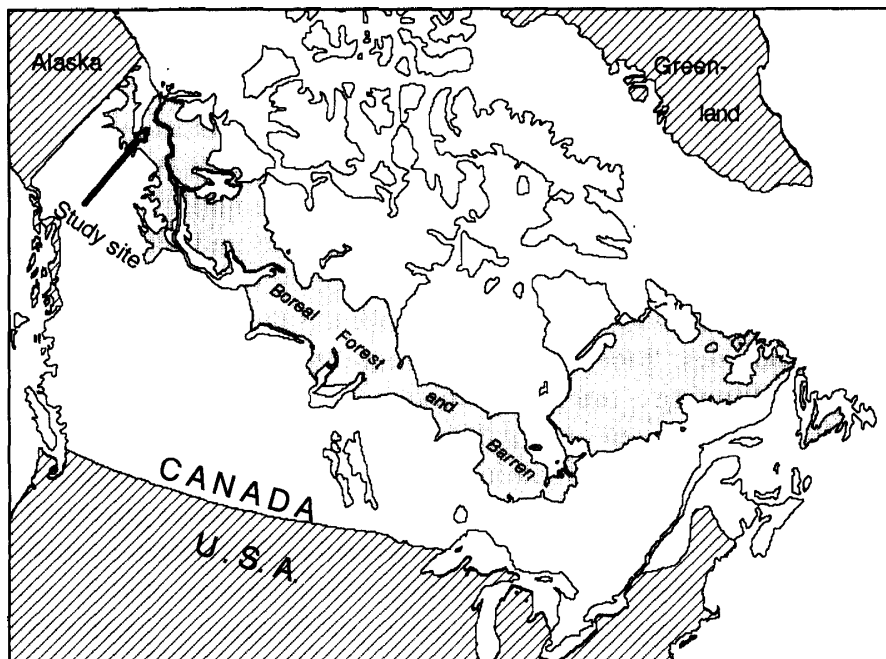


Fig. 1. Study site (base map after Forestry Canada, 1992).

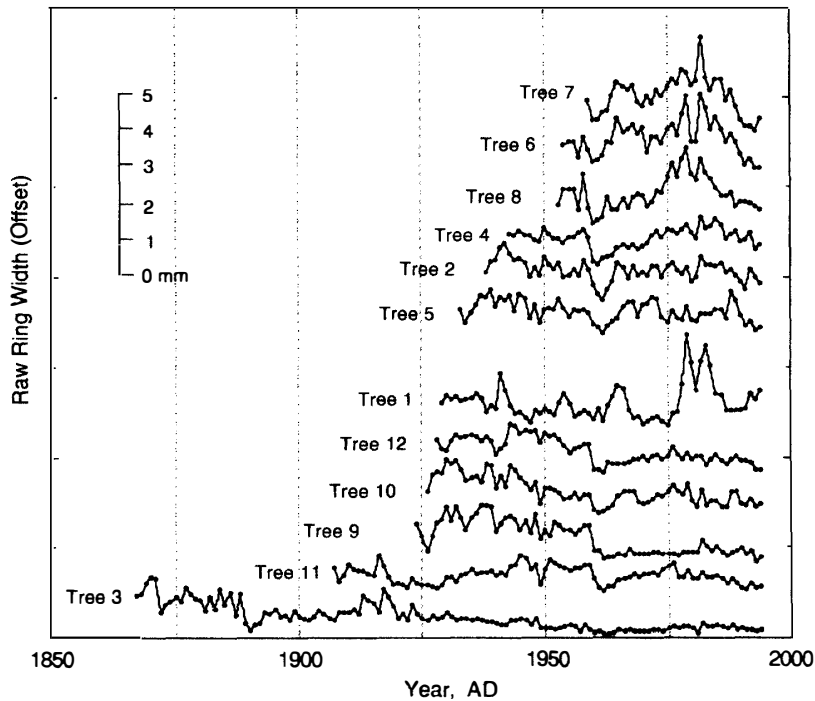


Fig. 2. Ring-width pattern of individual trees.

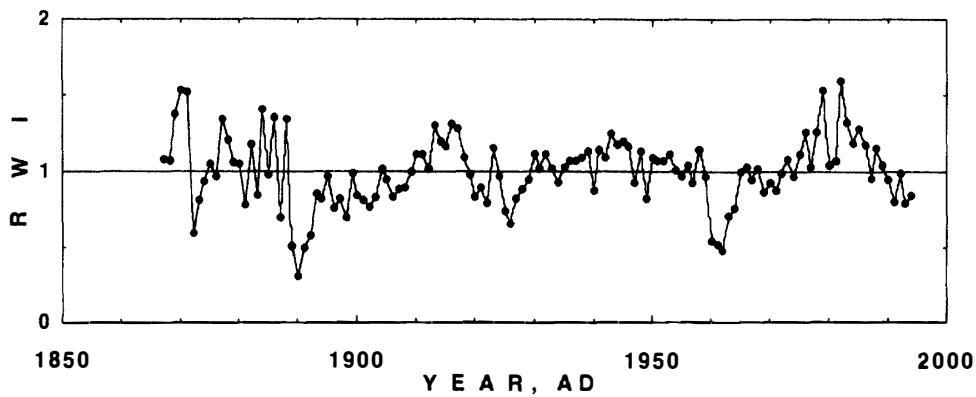


Fig. 3. Standard ring-width index (RWI) chronology.

sampling site were calculated as indicators of individual tree growth and stand biomass growth, respectively.

To obtain the RWI series each raw tree chronology was standardized to detrend the long term individual growth pattern while retaining short term fluctuations as much as possible. The standardization was conducted by fitting either a negative exponential curve or a straight line to the observed ring-width chronologies tree by tree, and subsequently by dividing the raw ring-width series by the theoretical counterpart calculated from the fitted curve or straight line. Finally, the standard ring-width index series for the site (Fig. 3) was obtained by averaging the ring-width index series thus calculated for each tree.

The basal area is the cross-sectional area of a stem or a group of stems in a given area as measured at breast height. It is used here as an indicator of stand biomass since it is strongly correlated with stem volume and stand biomass yet is much easier to measure or to calculate. It increases as diameters of constituent trees increase. It also increases when the number of constituent trees increases as new individuals colonize a site. In calculating the basal area in this work, it was assumed that stems are round.

3. Results

Of the 24 cores sampled, seven hit the pith directly, while the rest nearly did so. Thus the ring count on the cores approximates the breast-height age of the sample trees. They ranged from 36 to 128 years with three sample trees in a range of 30–50 years, seven in 50–80 years and two over 80 years as shown in Fig. 2. This unevenness in tree age shows that these trees have been colonizing the site at more or less equal intervals of five to ten years since the early 1900s. Allowing for the time required for the trees to reach breast height after germination, the colonization process took place some 20 years earlier than it appears in Fig. 2. Considering smaller trees which were excluded from the present sampling, it would be reasonable to judge that the colonization is still continuing up to the present.

Figure 2 also shows the growth patterns of individual trees. The overall mean and standard deviation of the raw ring-widths were 0.834 and 0.223 mm, respectively. The rings of 1960 through '62 were markedly narrow, while those of '79 and '82 were remarkably wide in most of the trees. Generally speaking, tree growth declines more or less exponentially with age. This general trend is more pronounced in older trees, especially in the oldest (Tree 3). Younger trees showed a somewhat strange pattern with gradually increasing growth culminating in the early 1980s followed by growth decline thereafter. This rather abnormal pattern of growth in the majority of the samples indicates some environmental change in the early 1980s though it was not identified in this work.

This increasing trend of growth from the early 1960s until the early '80s followed by growth decline continuing up to the present is retained in the standard ring-width index series shown in Fig. 3. In spite of this and other decadal-long ups and downs, however, the standard RWI series as a whole does not show any long term trend of growth enhancement nor decline, indicating no significant long-term environmental change such as a fertilization effect of increasing carbon dioxide or resultant climate warming.

On the other hand, the basal area series in Fig. 4 shows a definite increasing trend, signifying a definite increase in the biomass of the site. As mentioned earlier the increase in basal area results from the growth of individual trees as well as from an increase in the number of trees in a given area. To discount the former effect, the total basal area was divided by the individual basal area of Tree 3 as shown in Fig. 5. The fact that the increasing trend is still maintained in this normalized basal area, indicates that the increase in community basal area has resulted mainly from an increasing number of trees. This may not be the case with closed forests where colonization by younger generations of trees is generally difficult due to shading by older trees, and, even if success-

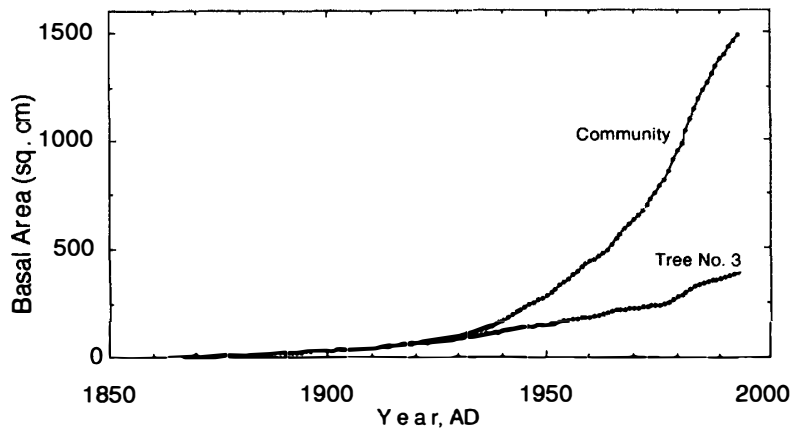


Fig. 4. Basal area increase, the oldest individual vs community.

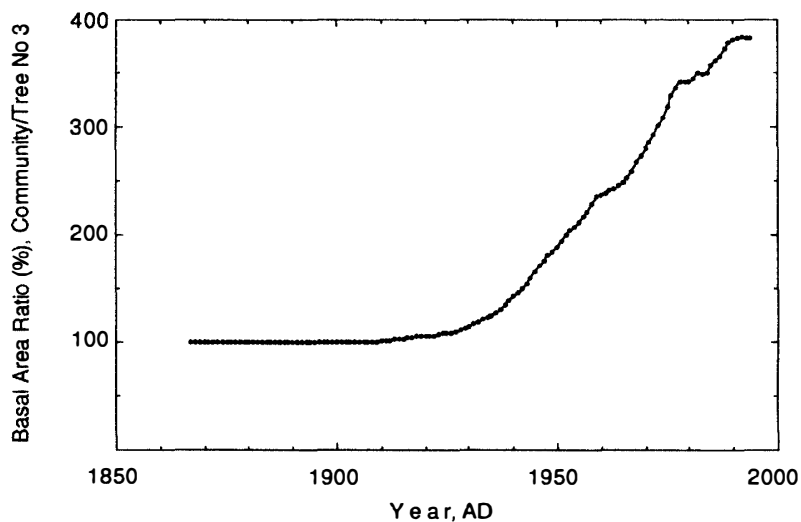


Fig. 5. Community basal area as normalized by the oldest individual tree.

ful, it inevitably increases competition among them which slows growth in every member of the community.

4. Discussion and Conclusions

The results show that the community basal area is definitely increasing since early 1900s largely due to colonization by younger generations of trees rather than from growth enhancement in individual trees. An increase in basal area means increase in biomass, which signifies some significant environmental change in favor of tree growth. The possibilities include the fertilization effect of increasing atmospheric carbon dioxide and possible climate warming also resulting from increasing carbon dioxide. The question now is which is more responsible for the present results.

The scattered trees on the forest-tundra border signifies that they can survive only at sites where the microclimate is more favorable than in the rest of the area where the

short growing period due to cold climate limits tree growth and a minute difference in micro environment dictates successful germination and subsequent growth. It is reasonable then to consider that the continued colonization by younger generations of trees signifies climate warming which may well provide more micro sites habitable for germinating seedlings.

On the other hand, the fertilization effect of increasing atmospheric carbon dioxide should benefit both older and younger generations. However, no such trend can be found either in individual tree growth in Fig. 2 or in the standard ring-width index series in Fig. 3. Two reasons can be considered for this; *i.e.* the short temporal span of the present dendrochronology and competition among trees.

Many long term dendrochronologies from arctic-subarctic and alpine-subalpine regions of the world (LAMARCHE, 1974; JACOBY and D'ARRIGO, 1989; SWEDA, 1993; BRIFFA *et al.*, 1994) show growth enhancement since the early 1800s, probably in response to increasing atmospheric carbon dioxide and/or resultant climate warming. Detection of growth enhancement in these chronologies may well have been made possible by their coverage of much longer time span than the present chronology, which made pre- and industrial eras comparison possible. No such comparison was possible with the present chronology covering only the latter half of the industrial era. Furthermore, even if growth enhancement is occurring it is detrended in the process of standardization and may not be detected. To make this point clear, establishment of a longer chronology, either by extending the present chronology with snags and subfossil trees or with older trees found on the less harsh side of the forest-tundra ecotone, is highly recommended.

Another reason why growth enhancement was not detected in the present chronology may be due to underground competition for mineral nutrients among the existing older trees and colonizing younger trees. Observation in the field shows that the colonization occurs in clusters rather than in even spatial distribution. This is partly because climatic amelioration expands more or less in a concentric manner from spots where microclimate is already favorable and thus older trees already exist. In addition, the prior existence of tall trees itself induces amelioration of microclimate by absorbing more solar energy in spring when the adjacent shrubby vegetation around is still covered by snow scattering precious sunlight back to the space. Although no visible competition is found above ground, there is a possibility of underground competition especially for mineral nutrients in peaty soil.

A mention has to be made on the possibility of the forest fire. It is one of the major ecological agents in boreal forest and tundra ecosystems, and dictates population dynamics considerably by destroying the existing tree population and inducing colonization by younger generations. In the present case, however, the establishment of younger trees does not seem to be such a direct outcome of forest fires for the following two reasons. First, vegetation recovery after fire in the boreal forest-tundra region is generally characterized by simultaneous regeneration of even-aged forest stands. This was not the case at the present study site. As seen in Fig. 2, younger trees have settled in the area at more or less equal intervals for the past 100 years. Second, no obvious evidence of past fires such as macro charcoal or charred snags were witnessed in the search for the best sampling site.

Although the case is limited and sample is very small, these results illustrate what

can be expected in a forest-tundra border when increasing atmospheric carbon dioxide fertilizes vegetation as well as warms climate. To confirm the finding of the present work, it is important to extend works of similar nature and strategy with more sample trees from a given site as well as placing study sites in more extensive locations of different climatic, topographic and edaphic environments over the circumpolar forest-tundra ecotone.

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