



Plain Language Summary

Increasing net ecosystem biomass production of
Canada's boreal and temperate forests despite
decline in dry climates

Pacific Institute for Climate Solutions

Overview

This study investigated changes in forest productivity by compiling thousands of historical observations collected by forest resource management agencies across Canada. Using carefully-designed statistical models, the study was able to look past all the other complex processes that affect forest productivity and isolate the specific impacts of warming, droughts, and changing atmospheric composition. By considering an unprecedented amount of data, and focusing on a spatial scale that is meaningful to forest management policies, and spanning a wide range of natural conditions, the study provides a big-picture view of the evidence of changes in forest productivity in boreal and temperate climates. The observation-based study builds on previous indirect or incomplete indicators of change. The evidence suggests that environmental changes are causing a wide range of responses in forest productivity of Canada's boreal and temperate forests, ranging from moderate decline in dry climates, to strong increase in wet climates.

Forest Productivity and Climate Change

Forest productivity refers to how fast a stand regenerates following a disturbance event. Under cold or dry conditions, forests grow back slowly, while under warmer and wetter conditions, forests grow back fast. We can see quite clearly how growing conditions affect forest productivity across *spatial* gradients in climate, for example comparing the fast regeneration of Douglas-fir on the outskirts of Victoria with the much slower regeneration of Douglas-fir in the Okanagan Valley, but seeing the impact of subtle changes in climate over *time* is far more tricky. In addition to climatic influences, humans have dramatically altered levels of carbon dioxide and nitrogen in the atmosphere, both of which can affect the growth rate of trees.

Timber supply and climate change mitigation strategies in the forest sector are dependent on rates of forest productivity and how they will be affected by climate change. Granted the magnitude of environment-related changes that are already being observed across the forest sector, it is not safe to assume that future forest productivity will be the same as historical levels. Subtle decreases in forest productivity due to increasing severity of droughts could have profound consequences for timber supply and climate mitigation plans in Canada, including dry regions found across all major ecozones of British Columbia. Conversely, there may be significant increases in forest productivity elsewhere, effectively increasing the return on climate

change mitigation projects. Not knowing exactly how regional forest productivity will respond to continued environmental change is, therefore, a major risk factor in plans to reduce greenhouse gas fluxes through forest sector mitigation activities.

Observations of Forest Productivity

Directly measuring forest productivity is conceptually easy, but logistically very challenging and costly. Most of what we know about changes in forest productivity, therefore, comes from studies that addressed the question indirectly, relying on physiological model simulations, or reading tree rings, or satellite observations of surface reflectance (i.e, vegetation greenness), or relating site index – a common expression of productivity in forestry – to climate data. All these approaches provide important lines of evidence, yet they also have important limitations. For all practical purposes, physiological model simulations have 100 percent uncertainty. Tree rings only record the growth of trees, whereas forest productivity is ultimately controlled by the balance between growth *and* mortality of trees. Like many other approaches, site index corrections rely on productivity-climate relationships that are constructed across spatial climate gradients and, therefore, make an inherent assumption that relationships across space are also representative of relationships across time (known among scientists as the space-for-time substitution problem).

Despite challenges in directly observing forest productivity, forest resource agencies across Canada do in fact directly monitor forest productivity at field plots. This consists of identifying an area, say 10 by 10 m, and then taking a census of trees, recording the diameter and height of each tree. Several years later, the crew revisits the plot and takes a second census. There is elegant simplicity then in calculating how many trees were born, how many died, and how fast survivors grew. Across Canada, crews have historically made over 41,358 revisits, constituting an investment reproduction cost likely exceeding 400 million dollars. This study went to extensive efforts to request and compile those observations across Canada to produce a big-picture view of historical changes in productivity.

What is Net Ecosystem Biomass Production?

The constructed database presents all sorts of unique advantages that arise from a new ability to analyze Net Ecosystem Biomass Production (NEBP). NEBP is the difference between growth

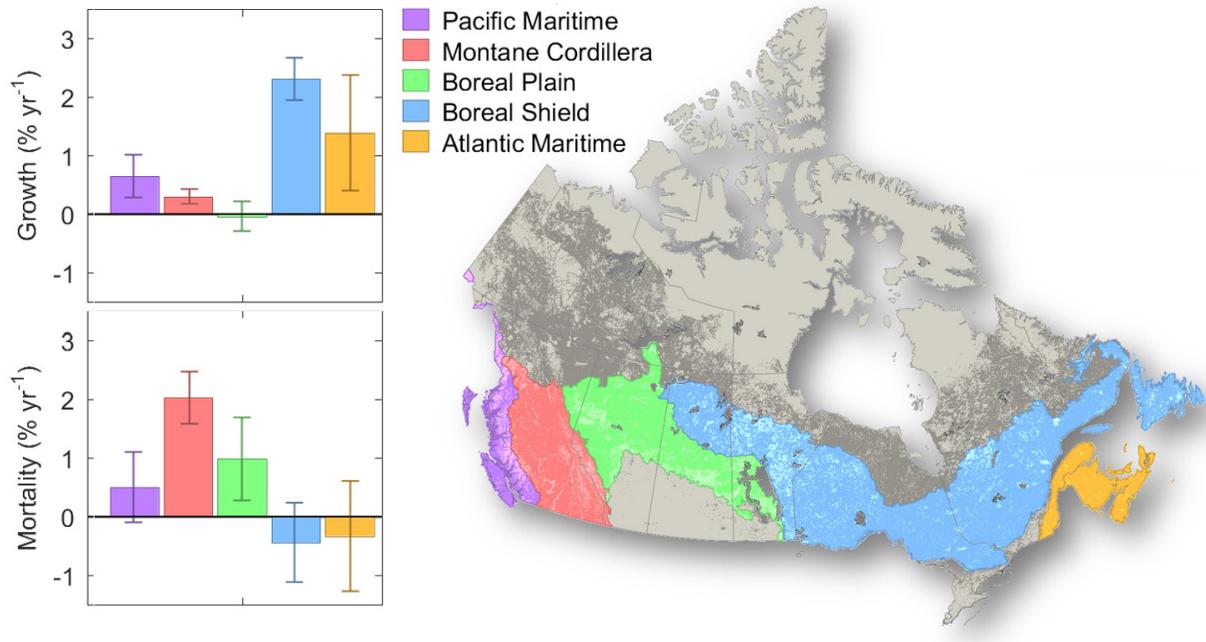
and mortality. It sounds very technical for important reasons that help us to conceptually define and appropriately interpret the scope of what we are analyzing:

- The “BP” in NEBP signifies that it measures the transfer (flux) of carbon associated with the production of biomass, which is an important distinction because carbon stored in tree biomass is far more meaningful to climate change mitigation planning than most other common indicators of productivity.
- The “net” in NEBP signifies that it refers to the balance between growth and mortality, which is an important distinction from the majority of previous studies that were only able to focus on growth.
- The “ecosystem” in NEBP signifies that it is a flux of carbon measured over a specified area of undisturbed forest, which is an important distinction for two reasons. First, it gives us assurance that relationships between productivity and climate are representative of real-world conditions where individual trees are battling for access to resources within stands. Second, because it isolates the relationship between productivity and climate specifically during the period of stand regeneration (i.e., intentionally omitting the impact of disturbance events), we know that the relationships are not contaminated by the influence of disturbances, which likely have completely different relationships with climate. Hence, separating regeneration periods from disturbance periods gives us greater confidence that we understand and accurately predict the environmental impacts on regeneration.

Is forest productivity changing?

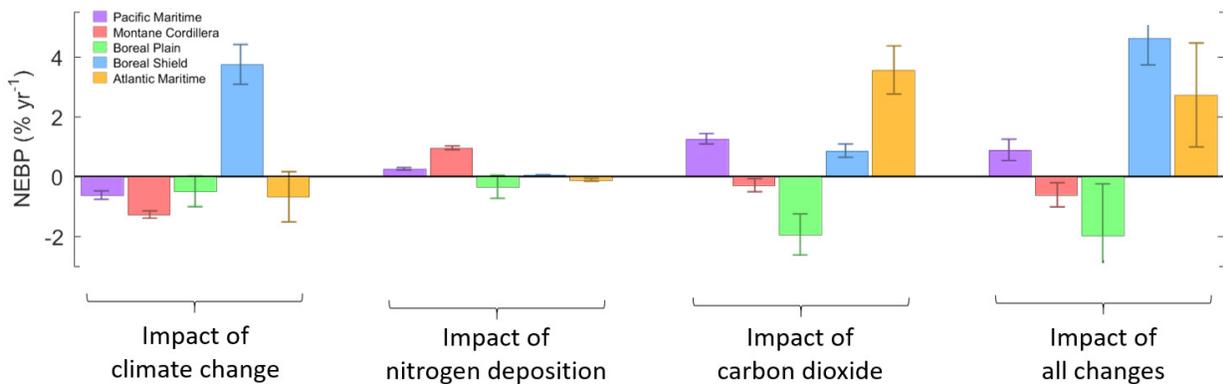
Because the physiological processes at work differ, it is necessary to break NEBP down into its individual components, growth and mortality. By applying statistical models to growth and mortality data, we were able to assess whether relationships between forest productivity and environmental variables led to trends over time. This involved controlling for many other factors, including natural changes in productivity that occur with aging. We found that the growth of trees was significantly increasing in the Pacific Maritime ecozone, in the Montane Cordillera ecozone, the Boreal Shield, and the Atlantic Maritime ecozone. For example, we estimate that growth in the Pacific Maritime ecozone increased by 0.6 % per year. Accumulating this rate over a 50 year period translates into a growth enhancement of 30 %. Consistent with recent concerns,

we also found that the rate of tree mortality was also increasing in the Montane Cordillera and Boreal Plain ecozones.



Trends in growth and mortality of forest stands differ among ecozones of southern Canada.

Ultimately, the enhancement of growth in four of the five ecozones only translated into significant positive trends in NEBP in the Pacific Maritime ecozone, the Boreal Shield, and the Atlantic Maritime ecozone. NEBP significantly decreased in the Montane Cordillera and Boreal Plain ecozones.



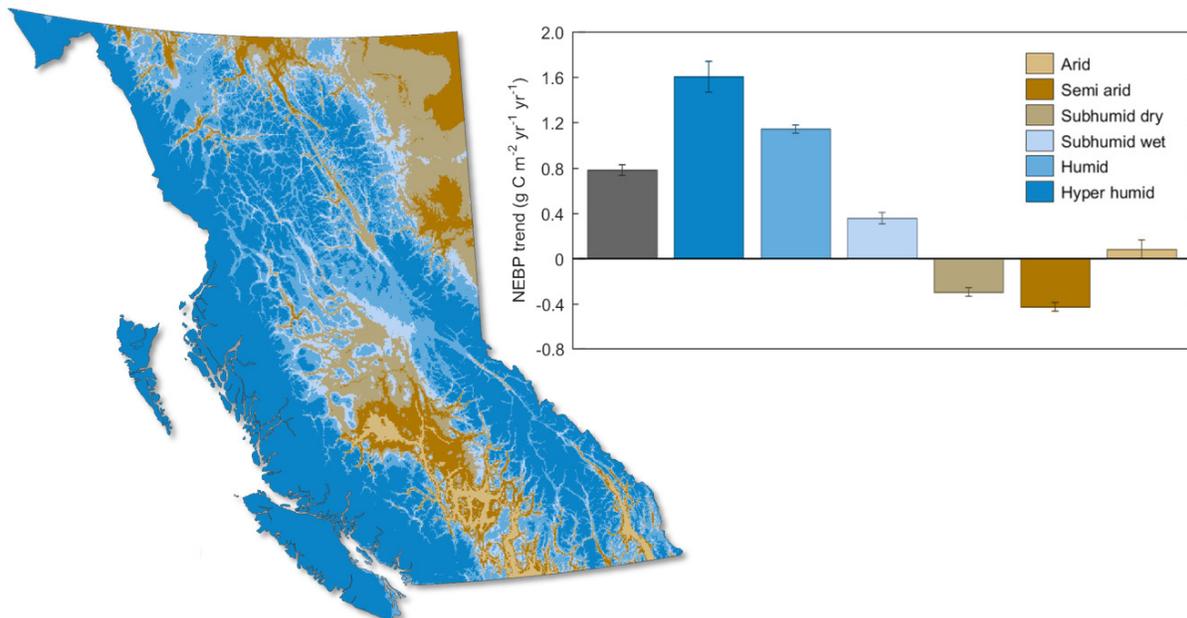
Trends in net ecosystem biomass production (NEBP) depend on the combined impact of climate change, nitrogen deposition, and carbon dioxide concentration.

One definitely gets the sense from ecozone averages that trends in NEBP are associated with the hydrology of the ecozone. For instance, enhancement of NEBP was found in relatively wet ecozones, decline was found in dry ecozones of western Canada.

Running the statistical models across a continuous grid over Canada allowed us to explore this generalization in more detail from alternative perspectives. We found that trends in NEBP indeed varied strongly with Thornthwaite's hydrological classification system, ranging from enhancement in hyper humid, humid and subhumid wet climates and decline in subhumid dry and semi-arid climates.

Because British Columbia spans the entire spectrum of Thornthwaite's hydrological classification system, we can expect a mix of areas where forest productivity is increasing and where it is decreasing.

We interpret these results to mean that the benefits of warming and increasing carbon dioxide for plants is overwhelmingly restricted to regions where water is not a major limiting factor. In dry climates, trees struggle to remain hydrated and accelerating growth simply leads to unsustainable use of water.



Net ecosystem biomass production is strongly increasing in hyper humid, humid and subhumid wet climates and moderately decreasing in subhumid dry and semi-arid climates.

Are forests reaching production capacity?

At a certain point, the benefits of increasing carbon dioxide and warming in wet climates should start to level off as other factors become limiting. For example, there is only so much space to grow in a dense forest and at a certain point there is just not enough sunlight and soil nutrients to sustain further growth. An interesting dimension to this study was the attention we placed on trying to assess whether competition was intensifying as a result of growth enhancement and whether this might someday cause Canada's forests to reach a production capacity.

As a combination of warming and increasing carbon dioxide enhance the growth of trees, we hypothesize that it should lead to greater use of resources, principally including water and nutrients. This phenomenon constitutes what system modellers call a negative feedback mechanism. This was addressed in the study by taking into account the negative dependence of growth on the amount of biomass in forest stands. What we found was that as growth enhancement in wet climates led to higher forest biomass, this did indeed *feedback* negatively by causing a decrease in growth and an increase in mortality. However, the magnitude of this feedback was not enough to compensate for the initial enhancement. Hence, although we found evidence to suggest that environmental change is partially compensated by an increase on the premium for resources, we did not find any evidence to suggest that this is preventing forests from growing faster. Interestingly, the same negative feedback mechanism causes the opposite effect in dry climates, acting to alleviate the negative impacts of drought.

Conclusions

- This study emphasizes that, with minor amendments to the way we monitor forest productivity and a coordinated effort to integrate data from provincial forest resource agencies, we can directly observe the impacts of environmental changes with much stronger confidence.
- This line of evidence suggests that a combination of warming and increasing carbon dioxide concentration accelerated the rate at which biomass accumulates in intact forest stands across southern ecozones of Canada by 90 % over 1951–2012.
- This anthropogenic biomass sink was confined to wet regions where a combination of warming and increasing carbon dioxide concentration drove enhancement of growth and

suppression of mortality. To date, there is no indication that warming and carbon dioxide are causing forests to reach capacity.

- In dry climates of western Canada, low water supply appears to prevent growth enhancement from occurring, while increasing mortality is associated with increasing severity of droughts and increasing carbon dioxide.
- Even though the overall average response was positive, large expanses of boreal and temperate forest biomes, historically located at the boundary between wet and dry climates, may be at high risk of decline under continued increases in evaporative demand.
- This information has important implications for carbon cycle model predictions used in national greenhouse gas emission accounting and climate change mitigation plans in the forest sector.

References

Hember, R. A., W. A. Kurz, and N. C. Coops. 2017. Increasing net ecosystem biomass production of Canada's boreal and temperate forests despite decline in dry climates. *Global Biogeochemical Cycles*:2016GB005459, doi:10.1002/2016GB005459.

