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Nutrient Budgeting in Canadian Boreal Forests

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Highlights

- Nutrient budgeting is a useful tool for determining the sustainability of current forest management practices insofar as nutrients are concerned.
- Data for inputs of nutrients by precipitation, forest floor and mineral soil nutrient pools, and nutrient outputs via fire and various harvesting regimes are available for boreal forests in Canada.
- Nutrient equations for stemwood, leaves, and branches are available for mixedwood forests[2] but not for other boreal forests. Such equations need to be developed in order to determine how many nutrients are removed when disturbance removes trees from the forest.

Intensive harvesting of **boreal forests** has resulted in increasing public concern about the long-term productivity of these forests. Nutrient budgeting can be a useful tool to determine long-term sustainability of harvesting practices. Nutrient budgets account for the amount of existing nutrients in various pools within the forest (i.e. vegetation, forest floor, mineral soil), the amount of nutrients entering the ecosystem (via rainfall and soil mineral weathering), and the amount of nutrients leaving the ecosystem (via harvesting, fire or leaching). If the incoming amount of any nutrient equals or surpasses the amount leaving the system, nutrient sustainability can be assumed. Unsustainable harvesting occurs when the amount of nutrients leaving the forest outweigh the amount entering it.

Nutrient budgeting can also aid in determining whether specific management goals are being achieved. Emulating natural disturbance patterns has become a goal of forest management throughout much of Canada. Thus, comparing nutrient losses from harvesting with those caused by fire can indicate if emulation of natural disturbance is being achieved.

This note serves as a general primer to nutrient budgeting in Canadian boreal forests. For the purposes of the following discussion, we refer to two harvesting methods—full tree (FT) and tree-length (TL). FT is defined here as the removal of all aboveground tree parts (i.e. stem, leaves, and branches) with no redistribution of roadside slash onto harvested sites. TL refers to harvesting whereby stems are removed but leaves and foliage remain on site to decompose. For our purposes, we did not consider any topping being left on site (as is sometimes done with TL harvesting), and we assumed off ground road transportation (i.e. forwarding), thus eliminating the possibility of nutrient loss and/or redistribution via ground skidding. While all forest harvesting and natural disturbances cause nutrients to be lost from a forest, there is evidence that suggests the amount lost can depend on the type of disturbance. Thus, the type of harvesting method used can be a key determinant in long-term site productivity of boreal stands.

Nutrient pools

Standing biomass

The foliage, twigs, branches, stem wood and bark of boreal trees can represent large nutrient pools. For example, in a 110 year old black spruce forest in northern Ontario, whole trees contained 7% of total N, 3% of total P, 53% of total K, 52% of total Ca, and 35% of total Mg found in the ecosystem.[3] In aspen stands in northern Alberta, whole trees contained 13, 35, 10, 4, and 5% of N, P, K, Ca, and Mg respectively (see the

SFMN Research Note entitled *Nutrient budget for aspen forests on clay soils in west-central Alberta*). It is useful to determine the proportion of total nutrients found in only the trees as well as the portion of the nutrient pool found in separate tree components (foliage, branches, etc…), in order to discern the effects (if any) of leaving foliage and branches on site, as is done with TL harvesting.

Understory vegetation

Another nutrient pool in forested ecosystems lies in the understory vegetation. As with other nutrient pools, the amount of nutrients found in understory vegetation can vary considerably due to the dominant species type (which, in turn, is influenced by climate, as well as soil moisture and nutrient regimes). The influence of this pool may have some significance in nutrient cycling in mixedwood forest but is thought to be insignificant in black spruce forests.

Tree roots

Tree roots represent another nutrient pool in forests. As roots decompose, their nutrients can be used to grow new roots for new trees. This pool can account for 20% of total standing crop biomass in black spruce forests and up to 30% in mixedwood forests.[4] Black spruce roots have been found to hold 7, 11, 7, 20, and 9% of total tree N, P, K, Ca, and Mg. In the same study, mixedwood roots were determined to hold 23, 44, 18, 25, and 26% of total tree N, P, K, Ca, and Mg.[4] We could not find literature referring to nutrient amounts in the roots of jack pine forests. Future studies quantifying such amounts would be useful in order to provide a more complete understanding of nutrient budgets in these forests.

Forest floor and mineral soil

Both the forest floor and mineral soil can contain large reserves of nutrients. Total forest floor N can range from 392 kg/ha in jack pine forests to 884 kg/ha in black spruce and 2425 kg/ha in mixedwood stands.[6] Total P ranges from 38 (jack pine) to 624 (mixedwood) kg/ha; K from 60 to 818 kg/ha; Ca from 239 to 1775 kg/ha; and Mg from 47 to 1088 kg/ha.[6] Amounts of these nutrients found in black spruce forests lies somewhere between jack pine and mixedwood.

It is paramount to keep in mind that total nutrient content differs dramatically from the amount of nutrients actually available for plant uptake. Total nutrients may be bound up in forms unusable to plants for many years. Table 1 illustrates the difference in total and available nutrients in the mineral soils of three boreal forest types.

As can be seen from Table 1, the proportion of total nutrients present in the mineral soil that are actually available for plant usage can be quite small. When evaluating nutrient budgets, then, it is important to remember that for management purposes available or exchangeable nutrient content is probably a more useful number than total nutrient content.

	Form	Jack Pine	Black Spruce	Mixedwood
N	Total	1174	1143	1797
	Avail.	36	6	36
P	Total	261 (mg/kg)	172	1042
	Avail.	19 (mg/kg)	13	181
K	Total	*	2760	289
	Exch.	64	54	232
Ca	Total	*	2155	2327
	Exch.	633	213	1641
Mg	Total	*	621	670
	Exch.	53	37	187

Table 1. Comparison of total vs. available (or exchangeable for K, Ca, and Mg) nutrients (kg/ha) in the mineral soil of 3 boreal forest types. Data represents means of means for studies conducted across the boreal forest and was obtained from comprehensive databases.[6] *Indicates no available data.

Confounding the issue of total vs. available nutrients is the lack of consistency with what exactly "available" is measuring. Available nitrogen, for example, can refer either to nitrate (NO_3^-) or Ammonium (NH_4^+) or both. The way in which measurements were taken varies considerably and, as a result, considerable variation between amounts is seen in the literature. Exchangeable nutrients—most often used for cations (Ca, K, Mg)—is a more reliable number because there is a much more standardized method of obtaining nutrient amounts. Suffice to say that, when using nutrient budgets to make management decisions, it is important to consider that much of the total nutrient content will take long periods of time before becoming available to plants. Thus, available nutrient content can give some indication of how much of a given nutrient is available to plants within one rotation length.

Nutrient inputs: gaining from nature

Forests obtain nutrients from natural processes such as precipitation, atmospheric fixation, fire and mineral weathering. Quantities of nutrients obtained from these processes vary widely and are affected by local climatic conditions, soil type, type of bedrock and forest age.

Atmospheric deposition

Precipitation in the form of rain or snow adds nutrients to forest ecosystems. Deposition amounts depend on several factors including the level of industrialization in surrounding areas (which affects the amount of various elements being released into the atmosphere) and wind patterns (which can influence the distance elements are carried from the source which emitted them). In northwestern Alberta, yearly atmospheric input amounts were estimated to be 0.5 kg N/ha, 0.01 kg P/ha, 0.3 kg K/ha, 1 kg Ca/ha, and 0.12 kg Mg/ha.[1] Data from collection sites in somewhat polluted areas in Ontario reveal yearly deposition amounts of 17.8 kg N/ha, 0.3 kg K/ha, 1.6 kg Ca/ha, and 0.3 kg Mg/ha (P was not measured at these sites.[1] In less polluted areas in Ontario, yearly precipitation amounts were calculated as being 5 kg N/ha, 0.2 kg P/ha, 0.5 kg K/ha, 1.1 kg Ca/ha, and 0.1 kg Mg/ha.[4]

Fire

Fire can add nutrients to forests through several means. First, nutrients can be added via ash that is deposited on the forest floor during a fire. Second, fire can raise soil temperatures, stimulating biological decomposition and, thus, transforming essential nutrients such as nitrogen and phosphorus from unusable to available forms for plant uptake. Lastly, fire has been found to increase the availability of base-forming cations such as calcium and magnesium.

Mineral weathering

The rate at which nutrients such as potassium and calcium are weathered from underlying bedrock influences the availability of these nutrients to the vegetation above. Weathering represents the primary avenue through which all nutrients except for N are added to the forest system (N is added primarily through precipitation input). Nutrient inputs via mineral weathering are extremely difficult to measure due to the slow nature of the weathering process. As a result, estimations of nutrient inputs to forested ecosystems--especially for phosphorus which already occurs in such small quantities in the forest that the amount input through weathering is thought to be significant--will most likely be underestimated. It is unknown at this time if the amount of underestimation would be significant or not. On thin soils in mixedwood, jack pine, and black spruce stands across Quebec, average yearly weathering inputs were estimated to be ~0.21 kg P/ha, 1.02 kg K/ha, 2.19 kg Ca/ha, and 0.32 kg Mg/ha.[5] Other studies documenting weathering inputs would be helpful in order to support these findings and aid in nutrient budgeting.

Nutrient removal: leaching, harvesting, and fire

Nutrients can be removed from boreal forests via three primary avenues: leaching, harvesting, and fire. Of the three, leaching most often removes the least amount of nutrients. This is especially true in clay soils where leaching is minimized by the high nutrient and water holding capacity of clay. However, in coarse-textured sands (i.e. many of those found under jack pine forests), leaching can occur more readily due to larger pore size and a lower water retention capacity.

Tree harvesting can remove a significant portion of forest nutrient reserves. The amount of nutrients exported depends on the harvesting method employed—simply put, FT harvesting will always remove more nutrients than TL harvesting. In black spruce forests in Quebec, for example, the amount of N lost via TL harvesting (0.08-4.12 kg/ha/yr) was less than half that lost via FT harvesting (0.36-9.21 kg/ha/yr).[5] Similarly, a nutrient budget that we conducted for an immature black spruce stand in northern Ontario revealed that FT harvesting removed 41% more N; 31% more P; 38% more K; 27% more Ca; and 31% more Mg than TL harvesting (see the SFMN Research Note entitled *Nutrient Accounting for Black Spruce Plantations in Northern Ontario*).

While fire can add nutrients to forested ecosystems, it can also result in a net loss of nutrients to the ecosystem. For a more detailed description of the effects of fire on forest nutrient cycling, please refer to the SFMN Research Note entitled *Fire and Stand Nutrition in Boreal Forests of Canada*. Insofar as nutrient budgeting is concerned, it is useful to compare the nutrient losses and/or gains due to each disturbance type in order to determine whether management practices (i.e. harvesting) are effectively emulating natural disturbance (i.e. fire) patterns.

Take home message

Nutrient budgeting can be a useful tool to aid in determining if harvesting practices are sustainable. Budgeting can also help determine whether forest management is effectively emulating natural disturbance patterns. In order to make an accurate nutrient accounting, existing nutrient pools, nutrient inputs, and nutrient outputs all need to be considered. There is room for error--especially when accounting for nutrient input via mineral soil weathering and precipitation (wet vs. dry sampling). Nevertheless, nutrient budgets can give fairly accurate estimations of forest nutritional status and can point to forested sites that will be negatively impacted by harvesting.

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