Prince George, Prince Rupert and Cariboo Forest Regions

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Note #LTSPS-04

LTSPS RESEARCH NOTE

Nutrient Removals in Woody Biomass:
Preliminary Estimates from the Sub-Boreal Spruce Long-Term Soil Productivity Study

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Introduction

The Long-Term Soil Productivity (LTSP) Study (Ministry of Forests E.P. 1148) seeks to understand the long-term impacts of organic matter removals and soil compaction on tree growth and other ecosystem processes (Powers *et al.*, 1990). The core LTSP experimental design includes 3 levels of organic matter removal:

- OM1: merchantable boles only (Photo 1)
- OM2: merchantable boles + logging slash (Photo 2)
- OM3: merchantable boles + slash + forest floor

The OM1 treatment is comparable to conventional bole-only harvests in which de-limbing occurs at the stump, while the more intensive OM2 treatment simulates whole-tree harvesting (WTH)[2].

Since the early 1970's, numerous studies have considered whether the higher utilization levels involved in WTH are a threat to sustained site productivity (*e.g.* Kimmins, 1977; Weetman and Webber, 1972). The removal of additional biomass components increases the potential site nutrient loss from harvesting because foliage and fine branches have higher nutrient concentrations than the bole. For areas with considerable winter harvesting, this would be a greater concern for evergreen than deciduous species, since the latter would shed their foliage before the winter harvesting season. As noted by Wiensczyk (1992), the likely impact of WTH-related nutrient removals depends on site-specific factors such as natural rates of nutrient replacement (*e.g.* atmospheric deposition, chemical weathering of minerals) and the relative size of other nutrient pools in the forest floor and mineral soil. Other things being equal, sites with thin forest floors and/or coarse-textured parent materials are expected to be much more sensitive.

Using data collected from the LTSP installations in the Sub-Boreal Spruce (SBS) biogeoclimatic zone of central B.C., this note addresses three main questions:

- *What amounts of macronutrients were removed with logging slash in the OM2 and OM3 treatments?*
- *How do these amounts compare to those removed by bole-only harvest?*
- *For both levels of utilization, are the nutrient removals significant in comparison with the nutrient pools in the forest floor and mineral soil?*

FIGURE 1. Long-term Soil Productivity Study research sites in the Sub-Boreal Spruce zone.

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2 *The literature is inconsistent in defining how much of the tree biomass is removed by WTH. This paper will follow the most common usage i.e., only the merchantable bole and its attached branch and top components are removed from the stump. Removal of root systems and stumps is an additional level of utilization not currently practiced in BC.*

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Site Descriptions

The three LTSP installations in the SBS share a climate with severe, snowy winters and relatively warm, moist and short summers (Meidinger and Pojar, 1991). For this zone as a whole, mean annual temperatures range from 1.7 to 5° C, with temperatures below 0° for 4-5 months per year and above 10°C for 2-5 months. Mean annual precipitation can range from 415 to 1650 mm, with snow accounting for approximately 25-50%. The subzones chosen for the LTSP installations represent much of this range (Figure 1, Table 1). These zonal sites have deep, medium-textured soils, derived from morainal deposits. Climax tree species in the SBS are hybrid white spruce (*Picea engelmannii x glauca)* and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt). Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), trembling aspen (*Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh.) are seral species common in maturing climax forests.

PHOTO 1. Post-harvest slash loading, OM1 (bole-only harvest) treatment, Log Lake site (June, 1992).

PHOTO 2. OM2 (whole-tree harvest) treatment, Log Lake site (June, 1992).

Methods

Estimates of the amounts of slash removed by WTH were made by post-harvest fuel load surveys (1994 and 1995) in the bole-only (OM1) treatments, using the line-intercept method (Trowbridge *et al.*, 1986). For chemical analysis, in 1996 we sampled fresh deadfall (Topley, Skulow Lake) or trees felled in early winter (Log Lake) from the adjacent unharvested control areas. The following size classes were sampled from 5 trees per species at each site: < 0.5, 0.6-1.0, 1.1-3.0, 3.1-5.0, 5.1-7.0, and >7.0 cm diameter. The > 7.0 cm class included a range of diameters, up to approximately 15 cm (Skulow Lake), 20 cm (Topley), and 12 cm (Log Lake). At the Log Lake site, 5 disks were also removed at equally spaced intervals from the bole of each sample tree.

All samples from all sites were ground for chemical analysis with the bark attached. Needles were included in the conifer samples from the finest size class at all sites. For deciduous species, the leaves were either absent at the time of sampling, or were removed by hand. For the Log Lake bole disks, the subsamples for chemical analysis were taken in the form of pie-slice wedges, ensuring that all components of the stem were included in their correct proportions.[3]

We did not estimate biomass of either understorey vegetation or roots, nor were these components sampled for chemical analysis.

Results and Discussion

(1) Nutrient removals in slash

On average, about 30 Mg/ha of slash remained on the OM1 treatments (Table 2). The much higher levels at Log Lake reflect the large numbers of small-diameter subalpine fir, as well as a greater abundance of non-merchantable deciduous species (birch, aspen). At all sites, the > 7.0 cm diameter class accounted for the largest proportion of the slash mass.

When the estimated species composition of the residues, the chemical analyses and the fuel loading data

3 *Additional details on methods and analytical data, and a fuller discussion of the assumptions involved in some of the estimates, are contained in an internal report available from the first author.*

are combined, potential nutrient losses via slash removals can be estimated (Table 3). Comparing Tables 2 and 3 it is apparent that the coarse (> 7.0 cm diameter) materials contribute less as a proportion of slash macronutrient pools than in terms of biomass. For example, at Skulow Lake the coarse materials comprised 2/3 of the slash mass, but contained only about half or less of the total macronutrient content. This reflects a consistent decrease in nutrient concentration with increased slash diameter class, observed for all species at all sites.

Between-site differences in nutrient mass are even more pronounced than those for slash biomass. For example, total masses of Ca and P are 3 x higher in the Topley slash than at Skulow Lake. These differences primarily reflect tree species composition, with the Skulow Lake site almost completely occupied by lodgepole pine, in contrast to the more diverse stand at Topley (42% pine, 23% spruce, 35% subalpine fir). At the latter site, subalpine fir had consistently higher concentrations of most macronutrients than did pine, across almost all size classes.

(2) Nutrient removals in boles

The potential additional nutrient removal from WTH has to be compared to the unavoidable losses involved in bole-only harvest. This could only be done for the Log Lake installation, because only at this site were samples obtained from boles with diameters representative of the original stand. (Compared to > 7.0 cm diameter slash, bole nutrient concentrations were consistently lower for almost all elements and species, so using data for the coarse slash components would considerably overestimate nutrient removals from bole-only harvest.) Harvested bole biomass was estimated as the product of net merchantable volumes (from the cruise summary) and wood density data (provided by the fuel loading calculation program). This estimate was combined with mean bole nutrient concentrations to yield estimated nutrient removals for each species (Table 4).

For most elements, the additional nutrient removal involved in WTH represents about a 50% increase over bole-only harvest; for P, the loss is 75% higher (Tables 3 and 4; Figure 2). These differences are generally similar to those reported by Kimmins (1977) for other temperate-zone coniferous stands and by Wei *et al.* (1997) for less-productive lodgepole pine stands in the Cariboo Forest Region.

(3) How do these removals compare with total site nutrient capital?

To assess the significance of harvesting-related nutrient removals, these amounts need to be compared to the rest of site nutrient capital. In addition, natural processes that replace nutrients in these ecosystems would need to be considered. Unfortunately, the scope of our study does not include measurement of important processes such as atmospheric deposition, N-fixation, or nutrient release from chemical weathering of soil minerals. For that reason, we are unable to estimate recovery times for nutrient removals associated with forest harvesting.

The pattern of distribution of nutrients among various pools varies with the individual element. For example, in comparing nitrogen and sulphur, the forest floor would appear to be relatively more important as a reservoir of S. At all three SBS sites, removal of slash would include 4 kg/ha of S, compared with 84 kg S/ha in the forest floor (Figure 2). This 21-fold difference in pool sizes for S contrasts with a ratio of only 14 in the case of N. The implication of this is that forest floor conservation will make much more of a difference than slash retention, but that this will be particularly true for S. This concern is reinforced when forest floor nutrient reserves are compared with those in the surface (0-20 cm) mineral soil. On an area basis, the forest

TABLE 1. Site properties for the Sub-Boreal Spruce zone LTSP installations

Site	Log Lake	Skulow Lake	Topley
Subzone	SBSwk1 (wet, cool)	SBSdw2 (dry, warm)	SBSmc1 (moist, cold)
Lat./Long.	54°21'N, 122°37'W	52°20'N, 121°55'W	54°37'N, 126°18'W
Site series	01/Spruce-Oak fern	01/Spruce-Douglas-fir-Pine grass	01 Spruce-Huckleberry
Elevation (m)	785	1050	1100
Slope	0-3%	Level	2-12%
Dominant soil subgroups	Gleyed Humo-Ferric Podzol, Gleyed Eluviated Dystric Brunisol	Orthic Gray Luvisol Gray Luvisol	Orthic or Gleyed
Texture*	SiL over L	L	L to CL
Coarse frag*	37-41%	30-39%	21-40%
Forest floor (classification, thickness)	Hemimor, 6.7 cm	Hemimor, 5.2 cm	Hemimor, 6.6 cm
Dominant pre-harvest tree spp.	*Abies lasiocarpa, Pseudotsuga menziesii, Picea glauca x engelmannii*	*Pinus contorta, Picea glauca x engelmannii*	*Pinus contorta, Abies lasiocarpa, Picea glauca x engelmannii*
Age (years)	140	112	140
Site index (m@50/yrs)	*Picea* – 18.5 *Pseudotsuga* – 19.2	*Pinus* – 17.9	*Picea* – 16.1 *Pinus* – 15.7
Gross vol. (m^3/ha)	437	161	424

* 0 to 20 cm

floor contains approximately half as much total N as the mineral soil, but this proportion rises to over 70% in the case of S. Any losses of N may eventually be replaced by a combination of natural atmospheric deposition and biological N-fixation. In contrast, the potential for S replenishment is much more limited — atmospheric sources are minor at these relatively unpolluted, inland locations, and the background S levels in soil parent materials are very low throughout the central interior, leading to widespread S deficiencies in conifer plantations (Brockley, 1996).

For phosphorus, the significance of either bole-only harvest or WTH is difficult to evaluate. Extraction methods for assessing available P do not directly measure the long-term P-supplying potential of either forest floors or mineral soils. For example, analysis of an unfertilized forest floor in a young SBSwk1 lodgepole pine stand found that available P comprised only 6% of the total P content[4]. Most of this total P likely exists in organic forms, but it is not known how much would ultimately become available to plants, or at what rate.

For Ca, Mg, and K, our forest floor and soils data (Figure 2) are only for exchangeable forms. For the forest floors, this may not be a serious problem, since other data from the SBS indicate that exchangeable Ca, Mg, and K comprise between 60 and 100% of the total amounts of these elements.[5] For both Ca and Mg, the amounts potentially removed with slash in WTH amount to about 20% of the forest floor exchangeable pools at all 3 sites. In the case of K, this proportion rises to over 50% (Figure 2), suggesting that the long-term availability of this element may be more sensitive to harvesting practices. Furthermore, when exchangeable pools in the surface mineral soil are also considered, K reserves appear to be much more concentrated in the biomass and forest floor than are those for Ca or Mg.

In contrast to the forest floors, the mineral soils have only a very small proportion of Ca, Mg, and K in exchangable forms. In these geologically young soils, which still contain a high proportion of their original primary minerals, there are substantial reserves of nutrients that are slowly being released by chemical weathering. For example, at Log Lake the dominant Ca-containing mineral in the surface soil is Ca-feldspar (anorthite), which comprises 3% of the sand fractions (Arocena and Sanborn, 1999). Although this appears to be a small proportion, it provides a Ca reserve of over 2000 kg/ha, an amount that at least doubles when the mineralogically similar silt fraction is also considered.

A similar story can be told for K, which occurs in both sand- and silt-sized feldspars, as well as much finer micaceous minerals in the clay fractions. At Log Lake, K-feldspar in the sand fraction of the 0-20 cm mineral

TABLE 2. Post-harvest fuel loads (Mg/ha) on OM1 treatments at Sub-Boreal Spruce LTSP installations.

Size Class (cm)	Log L.	Skulow L.	Topley
0.1 - 0.5	0.31	0.26	0.89
0.6 - 1.0	0.61	0.70	1.17
1.1 - 3.0	2.77	1.91	3.91
3.1 - 5.0	2.84	1.99	1.27
5.1 - 7.0	2.83	1.64	2.21
> 7.0	36.24	12.96	17.38
0.1 - 7.0	9.34	6.51	9.45
Total	45.58	19.48	26.82

TABLE 3. Mass of macronutrients (kg/ha) in post-harvest fuels at Sub-Boreal Spruce LTSP installations.

Site	Size Class(cm)	Ca	K	Mg	N	P	S
Skulow Lake	<7.0	13.4	6.3	4.8	13.2	1.3	1.0
	>7.0	16.7	8.6	6.2	12.4	1.1	0.8
Topley	<7.0	41.3	17.4	4.9	26.9	4.4	2.3
	>7.0	48.8	23.9	6.2	25.4	3.2	2.0
Log Lake	<7.0	39.7	15.0	3.7	27.7	3.7	2.0
	>7.0	85.0	53.1	10.9	68.9	8.1	4.2
All	<7.0	31.5	12.8	4.4	22.5	3.2	1.8
	>7.0	50.1	28.6	7.7	35.6	4.2	2.4

4 *Unpublished data for Ministry of Forests E.P. 886.13, Kenneth Creek installation, Prince George Forest District.*

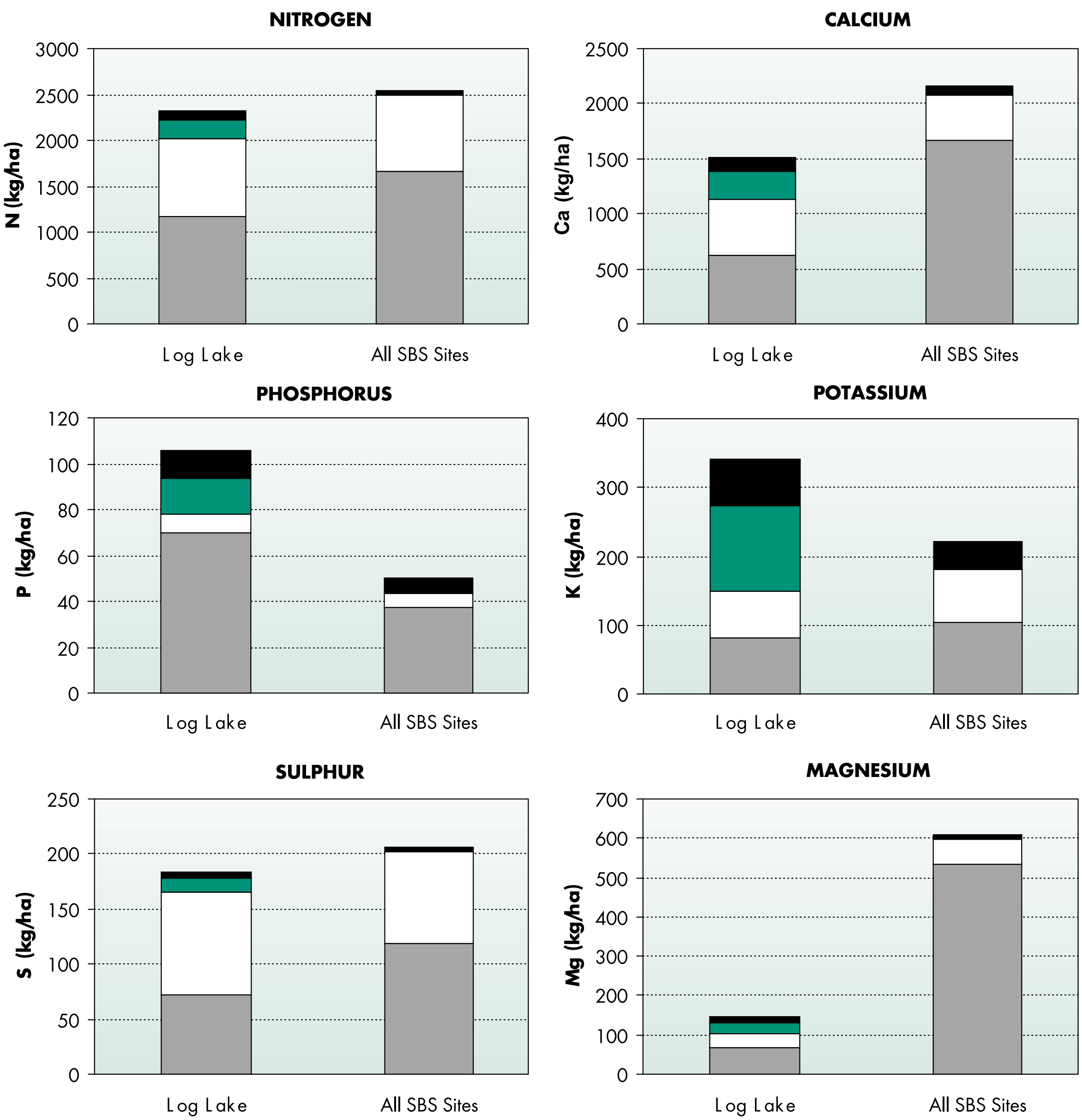
5 *Unpublished data for Ministry of Forests E.P. 886.13, Kenneth Creek installation, Prince George Forest District, and Kimmins (1974).*

TABLE 4. Estimated nutrient removals from bole-only harvest at Log Lake LTSP site.

	kg/ha					
Species	Ca	K	Mg	N	P	S
At	3.1	1.6	0.4	2.0	0.2	0.1
Bl	65.9	53.1	8.3	45.6	5.6	2.8
Ep	20.4	15.5	4.0	18.2	1.1	0.9
Fd	59.7	22.1	4.7	73.3	5.5	4.0
Pl	22.1	6.4	4.1	14.3	0.6	0.9
Sx	88.6	26.5	7.0	47.7	2.9	2.7
Total	259.8	125.1	28.5	201.1	15.9	11.6

At = Populus tremuloides; Bl = Abies lasiocarpa; Ep = Betula papyrifera; Fd = Pseudotsuga menziesii; Pl = Pinus contorta; Sx = Picea glauca x englemannii

FIGURE 2. Nutrient pools in biomass and soil components, Sub-Boreal Spruce LTSP sites (bole nutrient data obtained only for the Log Lake site.)



soil contains almost 4000 kg K/ha, with a similar amount likely occurring in the silt fraction. Clay-sized micas contribute an additional 5000 kg K/ha, and due to their substantial surface area, are potentially much more affected by soil weathering processes. Considerable evidence (*e.g.* Arocena *et al.*, 1999) indicates that release of K from primary minerals is strongly stimulated by biological processes in the rooting zone of forest soils. Other recent research suggests that the difficulties of measuring soil chemical weathering rates have generally resulted in considerable underestimation of its contribution to tree nutrition (Bormann *et al.*, 1998). For medium-textured soils with substantial amounts of primary minerals in silt and clay fractions, chemical weathering is likely a significant source of Ca, Mg, and K, and perhaps P.

Although these observations tend to de-emphasize the importance of woody residue retention for the maintenance of soil fertility and productivity, only gross site nutrient balances have been considered. Woody residues, both fine and coarse, have a multitude of biological, chemical, and physical functions in our forests

(Stevens, 1997). For example, coarse woody debris provides an important setting for N-fixation by asymbiotic processes (Wei and Kimmins, 1998), as well as in association with certain mycorrhizal fungi.[6] These roles are still very poorly understood, so a prudent approach would be to avoid unnecessary removals of these materials.

Conclusions

(1) Whole-tree harvesting increases potential nutrient removals by 50% or more, compared to bole-only harvesting at mesic sites in the SBS with medium-textured soils.

(2) For these sites, conservation of forest floors likely has greater immediate significance for maintaining site fertility than does the intensity of biomass removal during harvesting. Forest floors have particular importance as a reserve of S, which has endemically low concentrations in mineral soils across much of the central interior.

(3) Ca, Mg, and K reserves in slash and tree boles are comparable to the exchangeable amounts of these nutrients in forest floors and mineral soils, but their significance appears to be much smaller when the total elemental content of mineral soils are considered. Although nutrient release through weathering of soil minerals is difficult to measure, recent research suggests that nutrient release from primary minerals may make a major contribution to forest nutrition on geologically young soils.

(4) Removal of woody residues during harvesting may have limited short-term significance for nutrient budgets, but these materials have many ecological roles that contribute in poorly-understood ways to site productivity. Therefore, it would be prudent to minimize unnecessary removal of these materials during forest management.

6 *L. Paul, UBC, Ph.D. thesis in progress.*

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