The soil nutrient state of an ecological restoration area compared to natural regeneration on Galiano Island, BC, Canada

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Abstract

In a restoration area on Galiano Island, BC, Canada, a 25 year old Douglas-fir plantation is being thinned. The effects of thinning on the soil nutrient status was investigated by determining the pH, exchangeable aluminum, organic matter content, the extractable ammonium and nitrate, the available phosphorus, CEC and exchangeable bases (Mg, Ca, Na and K) of both the restoration area, the original plantation a mature forest and a natural regenerated alder forest.

Most interesting results are a strong decrease in nitrate and available phosphorus in the restoration area compared to the plantation. Furthermore all sites are oversaturated with Al^{3+}, organic matter content is the same in all sites, the pH is lower in the alder forest, the CEC is higher in the plantation and the exchangeable bases are higher in the mature forest and the plantation.

The CN ratio of the mature forest shows that it is nitrogen limited, for all the other sites it shows a nitrogen excess.

The data indicate that the restoration area has experienced a loss of nutrient through the uptake by plants. Moreover the soil seems more active in mineralizing organic matter. The study thus reveals that the restoration work in the plantation leads to a more healthy soil system and a more rapid natural regeneration, as was already observed in the increased vegetation growth.

Key words: ecological restoration, Douglas-fir (*Pseudotsuga menziessi* ssp. *Menziessi*) plantation, red alder (*Alnus rubra)*, soil nutrients, natural regeneration.

Introduction

The Galiano Conservancy Association on Galiano Island, B.C., Canada (48°56'N, 123°29'W), one of B.C.'s first land trusts, protects several environmentally sensitive properties on Galiano Island. One of their projects is an ecological restoration, which focuses on a 25 year old monoculture Douglas-fir (*Pseudotsuga menziessi* ssp. *Menziessi*) plantation.

The approximately 70 hectare site is located in the mid-island, in district lot 63. In the 1970's this section of the island was logged. Before replanting the area in 1980, the site was windrowed (all coarse woody debris and the organic topsoil were scraped away and deposited in heaps) and the windrows partially burned. The Conservancy started a restoration project two years ago (2003) and developed methods to thin the forest

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and move coarse woody debris (CWD) without the use of heavy machinery. (For more on the methods see Scholz et al., 2004) Another unique feature of their approach is that all the woody material that is thinned is not removed from the forest. Thinning is done by pulling trees out, girdling and topping of trees. The pulled out trees remain in the stand and simulate the natural dynamics of trees blown over by wind; this results in a hummocky soil surface and the natural decay of the logs. Coarse woody debris is pulled from the windrows and distributed over the plot. Some of the larger logs from the windrows are erected to provide wildlife with snags. Woodpeckers have been observed to locate right after a snag was erected, and other wildlife has been reported to become abundant (Scholz and Millard Galiano Conservancy, personal communication).

Over the two years wildlife has increased, and the vegetation cover has changed dramatically. Instead of the dark monoculture Douglas-fir plantation with almost no other species growing, *Gaultheria shallon* (salal), *Mahonia nervosa* (oregon grape), *Polystichum munitum* (swordfern), *Alnus rubra* (red alder), *Acer macrophyllum* (big leaf maple) and more are now invading the understory, or closing their canopy in the case of the trees. The Conservancy also plants native species, such as *Thuja plicata* (western red cedar), *Abies grandis* (grand fir), maple and different berry shrubs.

Since the vegetation cover in the restoration area has changed so dramatically, it was considered important to learn more about the soil properties and how these are affected by the restoration work. It is generally known that clearcutting has a negative effect on soil nutrient status through leaching, and that monoculture stands cannot mimic the soil dynamics of a mature forest stand (e.g. Antos et al. 2003). But little is known about the effects of a restoration project like this one on soil properties. Therefore this study was set up in order to compare soils from the area along a regeneration transect that included a mature forest, a natural regeneration of alder, both the 40 and the 25 year old plantations and the restoration area. In this article the focus will be on the restoration site compared to the 25 year old plantation, since the differences between those two will tell whether the restoration treatment is changing soil properties.

Study area

Located on Galiano Island, on the West coast of Canada, the study site belongs to the coastal Douglas-fir biogeoclimatic zone (Krajina, 1969). Although the Island belongs to the moist maritime climate, it lies in a rainshadow and has dry summers. Parent material is sandstone, sometimes overlaid by glacial deposits. General soil type is brunisol (Canadian soil classification) or arenosol (FAO classification). (Green et al. 1989)

Methods

From each forest site (mature, alder, plantation and the restoration area) 5 samples of the top mineral soil were taken (A horizon), and these were analyzed at the soil lab of the University of British Columbia. A horizons were chosen over LFH horizons, because nutrient state of the LFH is influenced by different litter types and by treatment (all four forests have different LFH properties). A horizons are more stable and thus better comparable.

Table 1: chemical properties per forest type, average and standard deviation of 5 samples.

	Mature		Alder		Plantation		Restoration	
	Average	Stdev	Average	Stdev	Average	Stdev	Average	Stdev
pH [H_2O]	6.29a	0.25	4.99b	0.16	5.90c	0.11	5.86c	0.07
pH [$CaCl_2$]	5.38a	0.45	3.94b	0.09	5.06c	0.24	4.83c	0.05
pH [KCl]	5.33a	0.49	3.95b	0.05	4.99c	0.33	4.72c	0.07
LOI [%]	14.61	6.88	21.63	3.52	20.29	6.55	17.89	4.22
bases [meq/100g]	6.58a	2.49	2.27b	0.42	4.81ac	1.76	3.27c	0.61
CEC [meq/100g]	24.47a	8.14	32.00ab	6.92	39.08b	6.36	33.82ab	4.10
NH_4 [ppm]	8.61	5.00	8.49	1.93	8.38	3.31	8.25	2.40
NO_3 [ppm]	0.40a	0.12	17.19b	4.36	12.97b	4.48	4.56c	1.44
P [ppm]	4.54a	0.88	7.78b	1.99	95.00c	31.64	17.87d	2.65

T test significant differences ($\alpha = 0.05$) indicated with letters; different letters = significant difference, same/no letter = no significant difference.

Analyses performed on air dry 2 mm sieved material are: pH (in H_2O, KCl and $CaCl_2$), exchangeable aluminum by titration, organic matter (loss on ignition), total carbon and nitrogen (Leco CN analyzer, with ground soil), available phosphorus (Bray method), extractable ammonium and nitrate (colorimetrically), cation exchange capacity (colorimetrically) and exchangeable bases (ICP). All analyses followed standard procedures as described in Page et al. (1982), as modified for the UBC Pedology Laboratory by Lavkulich (1978).

Results

In table 1 the chemical properties that are determined are summarized. Significant differences are indicated, if present, with different letters. Figure 1 shows the CN ratio and table 2 gives the median and range of exchangeable aluminum (median and range were used because of high variability between samples of the same site).

The pH (table 1) in water averages 6, and is significantly lower (about 1 pH unit) in the alder stand and in the plantation and restoration area (0.5 pH units) compared to the mature forest. pH in $CaCl_2$ and KCl are close to each other and are 0.5 to 1 pH unit lower than pH in water.

Table 2: exchangeable Aluminum median and range.

		Al [meq/100g]	pK
Mature forest	Median	2,4	-16,82
(N = 5)	Range	69	3,38
Alder forest	Median	102	-13,87
(N = 5)	Range	112,32	0,32
25 yr plantation	Median	85,92	-16,88
(N = 5)	Range	122,88	1,61
Restoration area	Median	92,28	-16,11
(N = 5)	Range	57,12	0,74

pK = pAl-3pH (Matzner et al., 1998)

Exchangeable aluminum (table 2) is significantly lower in the mature forest and very high in the other sites. The pK value (= pAl-3pH, indicator of Al^{3+} saturation of the soil, defined by Matzner et al. (1998)) is low for all sites. This will be explained in the discussion.

There are no differences in organic matter (LOI, average 18.61%) between the four forest sites observed (table 1). Exchangeable bases (table 1) are significantly higher in the mature forest

and the plantation, with lowest values in the alder site (average 2.27 meq/100g). No significant difference is observed between the plantation and the restoration area.
CEC (table 1) is significantly lower in the mature forest compared to the plantation.
Extractable ammonium is average 8.43 ppm and the same in all sites.
Extractable nitrate (table 1) is significantly different between the mature forest, the alder forest and the plantation, and the restoration area. It is highest in the alder forest and the plantation, around 15 ppm and lowest in the mature forest. The restoration has significant lower nitrate than the plantation and the alder sites, but higher than the mature forest.

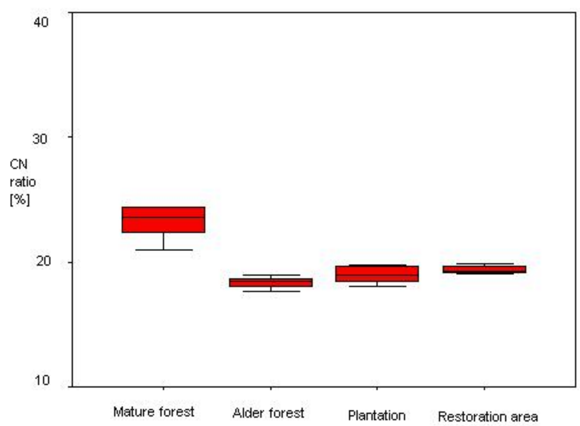

Figure 1: CN ratios of the four sample sites, averages with standard deviation.

The CN ratio (figure 1) is significantly highest in the mature forest (above 20). The other three sites are all the same; around 18.
Available phosphorus (table 1) is significantly different between all sites. It is highest in the plantation, followed by the restoration area, the alder forest and the mature forest has lowest available phosphorus.

Discussion
The pH of all the sites is rather low, which can have impact on the soil processes that take place (McBride, 1994). These will be discussed later. The reason for the low pH lies probably in the poor parent material. In the case of the alder forest the lowest pH is linked with the fixing of nitrogen by alder and the *Frankia* bacteria that are associated with alder (Hart et al., 1997, Rojas et al., 2001). With the nitrification of N tot nitrate the amount of H^+ ions increases.

The Al^{3+} saturation of the soil, defined by Matzner et al. (1998) as pAl^{3+} - 3 pH, is in all samples less than -8.99 which is considered to be over saturated with respect to synthetic gibbsite. This suggests that disturbance has disrupted not only the younger forest types, but also the natural equilibrium of the mature forest.

The organic matter content of all sites are similar since the mineral soil was sampled, and in the mineral soil the amount of organic matter is less variable than in the organic soil horizons. According to Lavkulich (UBC soils department, personal communication) less than 30% organic matter is standard for the A horizons of this soil type.

Exchangeable base quantities (the sum of exchangeable Ca, K, Mg and Na) are mainly controlled by exchangeable calcium that has the highest proportions of all exchangeable bases. Alder forests have generally lower exchangeable Ca due to more rapid absorption of Ca by alders or through leaching of Ca after its replacement of H^+ ions (from H^+ released after nitrification) (Bollen and Lu, 1967) This is why the pH of the alder stands is lower than the other stands.

The CEC is low for all sites because the parent material is mostly sand. Significant differences between the mature forest and the plantation may be due to slight differences in parent material; in some places more clayey glacial material is present. CEC is positive correlated to organic matter, which is found by most researchers (e.g. Heilman, 1981, Franklin et al., 1968)

Nitrogen in soil is controlled by organic matter microbial dynamics. At neutral conditions, bacteria are prevalent, and they favour nitrate for their energy. At lower pH values, fungi take over the decomposition of organic material because they can use ammonium (Killham, 1994). The fact that there are no significant differences between ammonium contents, indicates that in all sites bacteria are decomposing most.
Thomas and Prescott (2000) observed that a 25 year old Douglas-fir plantation mineralizes more N than other coniferous species and as a result has higher ammonium concentrations. Thomas and Prescott's results suggest that a component of Douglas-fir in a coniferous stand may improve N availability in coniferous forest soils. This might be one of the reasons why the plantation with monoculture Douglas-fir has such high nitrate availability, although the high available phosphorus concentration in the plantation may indicate fertilizing with N and P. This is strongly doubted by the Conservancy though, and it is known that for the last 15 years no fertilizers have been added.
A reason why the restoration site has less nitrate than the 25 year old plantation may be that the opening of the closed canopy enhances understory growth and the vegetation takes up more nitrate from the soil than the plantation. Antos et al. (2003) observed a negative correlation between extractable nitrogen and plant biomass, which indicates that N availability is reduced by plant growth. On the other hand canopy openings in a forest can contribute to N mineralization through increased soil temperature and higher soil moisture content that both favor microbial activity (Hope et al., 2003) This is not observed in the study area; the restoration has lower ammonium and nitrate available than the plantation itself.
Nitrate can also have leached from the soil as a result of thinning, when less trees are available to hold the nitrate on to the soil. Most likely the decrease in nitrate in the restoration area compared to the 25 year old plantation is a combination of increased uptake by plants and some leaching. Leaching is less likely because the organic matter content in the restoration area is not lower in the restoration than in the 25 year plantation. Nitrogen dynamics are closely related to organic matter (Heilman, 1981, Franklin et al., 1968), so it can be assumed that the nitrogen that was in the organic matter is now incorporated into the increased biomass and has not leached from the soil. In addition exchangeable base concentrations are not lower in the restoration plot, had leaching taken place this would have been the case.

It is generally assumed that a C/N ratio around 20 represents soil equilibrium; for mineralization of N this is the optimal ratio in a forest soil. If the ratio is above 20, nitrogen becomes limited, such as in the mature forest. For all the other sites the CN ratio is slightly under

20, which indicates an abundance of nitrogen over carbon so that the nitrogen can be used for plant growth. And although the alder forest, the plantation and the restoration area do not differ significantly it can be noted that the restoration area has the highest CN ratio and thus has used more nitrogen lately to increase the biomass of the stand.

Apart from the changed nitrate concentration in the restoration area, available phosphorus has also dramatically decreased compared to the plantation. For all samples the available phosphorus is higher than was expected on basis of the pH. At pH (KCl) values lower than 5 available phosphorus will be bonded to Al^{3+} $\{Al(PO_4)_3\}$ and thus become unavailable to plants . The pH in KCl is generally lower than or around 5, indicating that at least some of the P has become attached to aluminum. This indicates there should be correlation between P and pH and P and exchangeable Al, but this is not observed. The assumed fertilizing can not be the cause for this since even when those samples are left out there is no correlation. Perhaps the bindings to Al^{3+} are the reason.

Giardina et al. (1995) studied the P dynamics in a pure Douglas-fir stand and a mixed red alder/Douglas fir stand (comparable to the restoration area where red alder grows) and found that there is an increased P availability in stands with alder. In mixed alder stands there is an increased cycling of P, root turnover, increased microbial activity and more effective mycorrhizal associations. The high need for P from alder may still limit the P availability in soil though. However, if the alders eventually die and give way to other species, the P from alder litter and wood may be valuable.

Conclusions

The restoration work as performed by the Galiano Conservancy is not only enhancing vegetation regeneration and wildlife habitats; it is also supporting the natural soil system by means of an active nutrient cycling. The observed vegetation increase (both species diversity increase and canopy broadening by older trees) has indeed activated the soil: the uptake by plants of the available nutrients will enhance the soil microbes to recycle the nutrients that fall on the ground as litter. The data found in this study strongly suggest that restoration work done by the Conservancy increases microbial activity, creating a healthy soil system that will eventually turn into a natural mature forest system. The restoration area is different from the plantation in the most essential elements nitrogen and phosphorus. It is not yet the same as the mature forest, this will take decades as the forest matures and the nutrient balance settles in. It is hard to compare the natural regenerated alder forest and the restoration area, since the alder trees influence the soil largely by fixing nitrogen. It shows though that it is an advantage there is alder trees in the restoration area, where they can help other species with their supply of nitrogen.

Still it should be noted that this was a preliminary study and that repetitive sampling is needed to fully support the hypothesis that the restoration work helps the soil. More sampling at different sites of the restoration area and monitoring of easy to measure soil parameters should be continued in the future. The restoration work is still taking place and since it only started two years ago more soil research is definitely needed.

Implications for practice

- Soil research is necessary for restoration practices: a healthy soil is the basis for any successful restoration
- Soil health can be improved by thinning: more light increases plant growth, plant growth increases litter decomposition
- A more diverse forest creates a more dynamic soil: different litter types attract different soil animals
- A decrease in soil nutrients is not bad as long as there is an equilibrium between input of litter and uptake by plants
- Thinning by hand (without electrical machinery and heavy soil compacting trucks) gives the opportunity of observing wildlife during the work

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