MASTER'S THESIS

Geochemistry of Wildfires

Klas Fahlgren
2015

Master of Science in Engineering Technology
Natural Resources Engineering

Luleå University of Technology
Department of Civil, Environmental and Natural Resources Engineering

Geochemistry of Wildfires 1
Introduction 3

Part I 4
  Effects of wildfires 4
  pH 7
N 8
P 9
K 9
  Effects on the organic matter and carbon 10

Part II 10
Site description 10
Sampling, measurement and analyses 13
  Tot N and Tot P 13
  Conductivity and pH 13
  K 13
Result 14
  ph 14
  Conductivity 15
  N-tot 17
  Tot-P 19
  K 21
Discussion 23
  pH 23
  Conductivity 24
  N 24
  P 24
  K 25
Future studies 25

Introduction

From the beginning of the 20th century wildfires have been successfully supressed in Sweden and Scandinavian. Wildfires are a natural process and some living organisms are dependent on wildfires to survive. Nowadays there are different types of certifications that advocating a sustainable and a responsible forestry. In Sweden there are two types, PEFC and FSC and both are favouring forest burning. To maintain the FSC and the PEFC standards you have to burn a minimum 5% of the productive forestland area to maintain or promote the natural biological diversity of the habitat.

In the summer of 2006, after a few dry weeks, a fire spread in northern Sweden and about 1628 ha of boreal forest burnt down. The burnt area lies in the boreal region that comprises around 29 % of the world's forest area (Sjörs, 1999). The boreal zone is also called "circumpolar" when the boreal zone circles (Brandt, 2009) the northern hemisphere typically between 45 and 70° north latitude (Larsen, 1980) Scandinavian countries contain about 4 % of the world's boreal zone, Russia is home to 60% and Canada 29% (Brandt, 2009). The Boreal zone is home of coniferous trees such as pine, larch, spruce and fir but also of deciduous trees like birch and aspen.

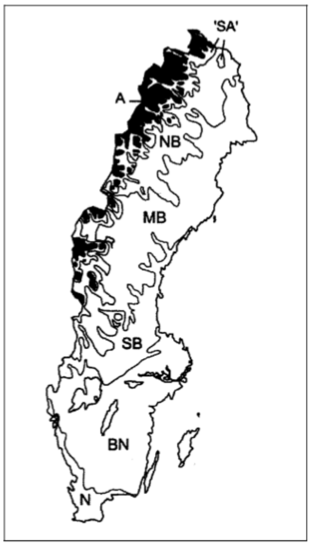


Figure 1 Boreal zones in Sweden from (Sjörs, 1999)

There are plenty of works about effects on the soil after fire but most have been made in north America (e g references in Smith (2011), (Lucas et al. 2011) and Bayley & Schindler (1991)) and little have been done in Scandinavian and the effect that the fire has on the groundwater (e g Lydersen et al., 2014, Nordblad 2011 and Eriksson, Edberg, & Borg, 2003).
This master thesis aims to present how fire affects forest soils **(Part I)** and to illustrate how measurements of stream water geochemical data can be used to deduce the fire-induced processes **(Part II).**

Part I

Effects of wildfires

A fire can start by the most common nonanthropogenic way, eg. by lightning, or by anthropogenic, human interference that can be accidental or nonaccidental *(DeBano et al., 1998).*

In a complete combustion model of biomass burning the assumption is that H_2O, CO_2 and minerals in ash is the ending product. The biggest challenge in that simplified model is that it requires O_2 through the whole process for a complete combustion. In reality the combustion will be incomplete and instead we will get an incomplete combustion where CO, CH_4 and a variety of pyrolysis including hydrocarbons and particulate organic matter can be the outcome (Cofer et al., 1997*)*. The newly formed C species that can be created do not naturally exist in the ecosystem (Gonzales et al., 2004)

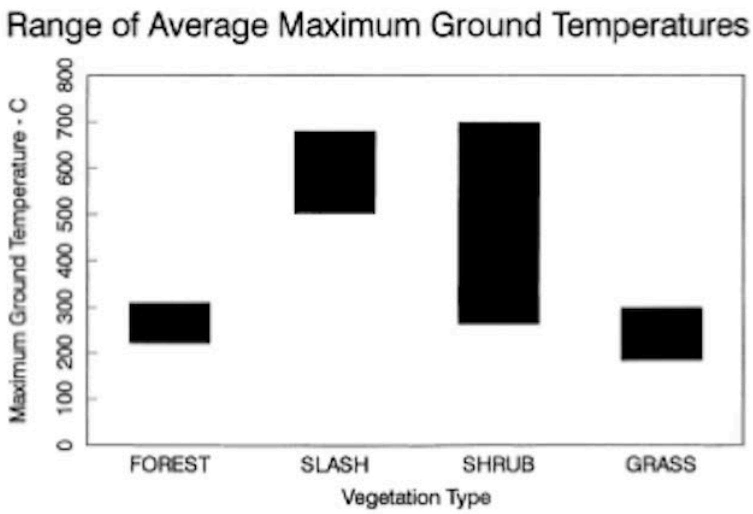
The fire effect in the soil is a complex process but a dependence of the severity of the fire can be seen. Mild degree of burning can have a positive effect on the ecosystem, increase of plant available nutrients; stimulation of herbaceous flora and reduce of an overcrowded forest. High-impact fires can have a negative effect; it can cause different changes in successional rates, changing above- and belowground species composition, produce changes in mineralization rates, change the C:N ratios, cause nutrient losses through accelerated erosion, generate volatilization of nutrients, cause entrainment in smoke columns and denitrification. The soil hydrological function can change and also its physical properties, decreases in micro- and macrofauna and its microbial population (Neary et al. 1999). The fire can also cause different fire resistance between different organic livings. An example is that fungi are less intolerant to heat then bacterial organism (Bollen, 1969).

A very little part of the heat generated in forest fires is absorbed and transmitted to the duff, litter or the soil on the forest floor. About 10 to 15 % of the heat has been estimated to be a part of the heating of the soil and the rest is released upwards (DeBano, 1976, Raison et al. 1985) The heat can be transferred by radiation, convection, conduction, mass transport, vaporization and condensation. *(DeBano et al., 1998).* The heat effect on the soil can varies with; duration of the fire, its magnitude, soil composition, moisture in the soil, the structure of the soil and previous land-use practice (Neary et al. 1999).

Experiments have showed different results when the temperature starts to vaporize in soils. (Cambell et al. 1994) showed that the temperature was 95 °C and the temperature stays there until the water content dropped below $0.02 m^3/m^3$. Another experiment showed that the water starts to vaporize as early as 80°C (Hungerford et al. 1990). The heat transfer in moistures soils can be more efficient then in dry soils due to the vapour movement and has a bigger heat effect then conduction <95°C (Albini, 1996) Studies have also shown that wet conditions can have a more severe damage to the microbial biomass then under a fire under dry conditions (Klopatek et al. 1990).

Nutrients can be leached from the soil after fire and as well removed as partial form by convection in smoke columns or by surface winds. The contribution of elements is dependent on the level the combustion has undergone. When the combustion is higher the result is a low-density fine gray-ash that can easily be transported by air. It have been showed that 11% of ash can be lost by convection columns (Raison et al. 1985)

The alteration of the soil depends on the heat that has been transported downwards and the amount of heat the soil composition tolerate before altering. The temperature in the soil can rise very slow due to that dry soil is good insulator (DeBano et al. 1998). In moist soils the temperature raises slowly because the water will not allow the temperature rise above the boiling point before the water have evaporated (Campbell et al. 1995).



Figur 2 Maximum ground temperatures during fires in forest, shrubland and grassland ecosystems (Adapted from Rundel, 1983)

Studies of severity on soils after wildfires in Australia showed that soils are good insulators and because of that the temperature never exceeded the ambient temperature 2-3 cm downwards. The time it takes for a forest to recover from a fire is dependent on witch type of fire that has spread. Slow-moving fires can do a lot more damage to the belowground then a fast moving fires e.g. grassland, even if the intensity is a lot less, 10 s at 1000°C couldn't be comparable to the damage after 30 min at 300°C (Humphreys and Craig, 1981).

The loss of organic carbon starts at temperatures between 100°C and 200°C (Kang and Sajjapongse, 1980; Giovannini and Lucchesi, 1997), when the temperature is above 200°C charring starts to occur. Lignins and hemicelluloses start to degrade at 130 – 190°C (Chandler et al., 1983). When the temperature rises to 300°C more structural changes starts to occur. This involves decarboxylation in the soil macromolecules HAs (Humic Acids) and FAs (Fulvic Acids) and the aromatic structures starts to increase (Almendros et al., 1990, 1992; Knicker et al., 1996).

Disturbance in the biological livings, protein degradation and plant tissue death starts at 40±70°C. In the temperature interval between 48±54°C dehydration of roots starts and between 70±90°C seed mortality starts (Neary et al. 1999).

Biological component threshold	Temperatures (°C)	Reference
Plant roots	48	Hare, 1961
Small mammals	49	Lyon et al., 1978
Protein coagulation	60	Precht et al., 1973
Fungi - wet soil	60	Dunn et al., 1985
Seeds - wet soil	70	Martin et al., 1975
Fungi - dry soil	80	Dunn et al., 1985
Nitrosomonas spp. -wet soil	80	Dunn and DeBano, 1977
Nitrosomonas spp. -dry soil	90	Dunn and DeBano,

		1977
Seeds - dry soil	90	Martin et al., 1975
VA mycorrhizae	94	Klopatek et al., 1988

Table 1 Threshold temperatures for biological disruptions in soils (adapted from DeBano et al., 1998)

In some specific cases when the fire intensity is high a water repellent layer is created. It happens when heating of partly decomposed organic material mixes with mineral soil, but also heating of fungal can create a water repellent layer. Studies have shown that the water-repellent layer is destroyed when the temperature is higher then 288°C. It also showed that the temperature 176 – 204°C is the optimal temperature to create a water repellent layer (DeBano, 1981). This layer is created horizontally and can increase water runoff and in steep terrain it increases erosion greatly (Neary et al. 1999). Thermal cracks in soil aggregates are also a causative agent that may increase leaching of the burnt area (Arocena & Opio, 2003).

pH

Organic matter and clay contains many acidity groups that can work as a pH buffer in the forest soils. Ion exchange can occur between base cat-ions (Ca, K, Mg and Na) and H^+. When the soil is rich in base cat-ions the ion exchange can make the organic matter more alkali when dispatching the H^+ ions from the negative charged organic collides (Ahlgren and Ahlgren, 1960; Wells et al., 1979). A rule of thumb is that a soil that is rich in organic matter is more acid then pure mineral soil (Magnusson, 2009; Certini, 2005).

Studies have shown that the pH usually goes up in the soil after fire but there are some examples when the pH had no significant changes. The burning rate and the quality of the soil is important in determining the amount the pH will change (Ahlgren and Ahlgren, 1960). The typical explanation as described above, is the high Ca, Mg and K content (base saturation) are displacing the H and Al ions that are absorbed on the negative charge colloids (Ahlgren and Ahlgren, 1960; Wells et al., 1979). The pH increase can have a short duration but in high pH soils where the pH is >8 the effect lasted up to three years due to release of K and Na oxides, hydroxides, and carbonates. The long lasted buffering effect is believed to be cause of the carbonates (Ulery et al., 1993). (Ahlgren and Ahlgren, 1960) also assumed that the pH raise is caused by the release of mineral salts, especially those who contains Ca.

According to Arocena and Opio (2003) the pH increase is related to the fire intensity. Only at high temperatures (>450– 500°C) when the organic matter is totally combusted, will lead to consequent release of bases.
The concentration of K, Ca, and Mg in the ash can be the depending factor to neutralize acidity in soil (Khanna et al. ,1994). Due to loss in in organic matter the cation exchange capacity in the soil can decrease (Oswald et al. 1999) and can have an effect on the electrical conductivity when the inorganic ions is released from the combusted organic materials (Certini, 2005).

N

Nitrogen is one of the most studied ion post-fire due to it's a macro-nutrition and a essential component for all living organism (Neary et al. 1999). The proportion of ecosystem N that can be found in the forest floor depends on the living plant and trees in the forest. It can rage between 7.8 – 72.4 % in the forest floor when looking at jack pine (P. banksiana) and black spruce (Piceamariana) forest (Morris and Miller, 1994). Variations of N after fire can be due to ammonium formation, effects on nitrification, volatilization, moisture changes in the soil, change of vegetation and addition of charcoal (Fritze et al. 1993, 1994; Schimmel & Granström 1996; Certini 2005; DeLuca et al. 2006).

Type	**Dry weight**	**N**	**P**	**K**
	Kg per hectare			
Trunk	52000	54	6	31
Bark	5100	18	3	10
Branches	22000	125	16	61
Softwood	6700	67	8	34
Tree above the ground	**79000**	**180**	**22**	**92**
Tree stump + root system	23500	45	8	24
Tree stump	6200	6	1	5
Tree	**102000**	**224**	**31**	**116**
Ground vegetation above ground	4000	40	4	20
Layer of mor inclusive roots	35000	525	24	52
Groundvegetation and mor	**39000**	**565**	**29**	**72**
Habitat (vegetation + mor)	**141000**	**789**	**60**	**188**

Table 2 Nutritional distribution for coniferous forest in costal area in North Sweden (Västerbotten). Tabel modified from Skogsstyrelsen compendium, skogsbruk Mark och vatten.

In some studies an increase of N pools has been reported (Kutiel and Naveh, 1987; Prieto-Fernández et al., 1993) the increase is believed to be due to, increased pH and temperature that promote increased mineralization rates after fire (Raison, 1979). An increase of N-fixing bacteria has also been observed after fire (Johnson, 1992). According to (Carreira et al., 1994; Pappa et al., 2008; Rodríguez et al. 2009) a fire can cause an increase of the N availability in the ecosystem in the short term. But in the long term the fire can be the cause loss in N. But there are also studies that have not shown any significant changes in the total available N in the Ae and the Bm horizons (Arocena et al. 2002).

(Almendros et al., 1984a,b; Viro, 1974; Vega, 1986) showed that the C/N ratio is usually lower after fire, which promote availability of N for growing plants.

Nitrogen is the first of the macro-nutrition that starts to volatilize at 200°C. Most of the nitrogen is volatilized as N^2, NO_x and sometimes as ammonia (Magnusson, 2009). When the temperature have reach over 500°C over half of the N in organic matter can be volatilized. Burning of woody debris and organic matter on the forest floor is where the most volatilization of nutrients happens. The fire intensity can vary much between forest fires and so does the volatilization of the nutrients (Neary et al. 1999). The loss of N through volatilization can be as high as 39 % in a coniferous forest (Grier, 1975). (Durán et al., 2009) implies that new studies should not only consider the inorganic N, which have been seen traditionally as the main N source for plant and trees. Even labile organic N should be in considering giving an overall understanding of the impact after fire, when labile organic N can be especially important in N-poor soils for plant uptake. In semi-arid regions with slow decompositions rates and with limited N can the recovery of soil-nutrients be slow. (Neary et al. 1999) suggests that mineralization and nitrification can be enhanced by fire disturbance at these conditions.

P

Phosphorus is likely to be less affected by fire then N, when P resistance to volatilisation and leaching are greater (Certini, 2005). Also most of the P-pool can be found the soil and not the forest floor. Around (94±98%) of P is in the soil and therefore the impact of the fire will not be as severe as for N (Neary, 1999). P starts to vaporize in higher temperatures (774 °C) so its more stable nutrient compared to N (Weast, 1988).
The fire can anyway have a big impact on the P bioavailability if there is a pH raise after fire. This has a positive effect on the bioavailability when the peak lies at pH 6.5 (Sharpley 2000). Organic pools of soil P can be converted to orthophosphate after fire. Orthophosphate are the most available form of P for plant and trees (Cade-Menun et al. 2000), binds in later stages through chemisorption to Al, Fe and Mn in acidic soil. In alkaline soil orthophosphate binds to Ca-phosphate. Studies have shown that this effect can be very variable, but with a common increase of available P in the first months after fire. (Certini, 2005)

K

Potassium can have a tendency to remain unchanged compared with N and P post fire. But there is a general increase of K after combustion of the soil organic matter and it can be depended on the burnt tree species, soil properties and pathway of leaching process (Certini, 2005). K starts to vaporize at 760 °C (Weast, 1988).
Studies have shown that the availability of the nutrients K, Mg and Ca in a *Q. rubra–Populus grandidentata* forest found elevated levels that went back after 3 months (Adams et al., 1980). Elevated levels have also been showed for some years in a mesic black spruce boreal forest in Quebec in two of three test sites. But in one test site the levels were lower for K in the burnt site compared to a cut and controlled area. (Simard et al., 2001).

Effects on the organic matter and carbon

The most important effect a fire has on the belowground system is the combustion of the organic matter (Certini, 2005). The effect the fire has on organic carbon is dependent on the severity and the type of the fire. There are three types of fires canopy, aboveground and underground fires. The slope can also have a difference in the combustions of the organic matter. Studies have shown that SOIL organic carbon can be totally destructed or in some cases even increase in abundance due to external input. (González-Pérez et al. 2004) In laboratory tests the combustion can be 100 % of C in soils (Almendros et al. 1984; Fernández et al. 1997) while in wildfires in pine forest it have shown that losses can be up to 50 % 10 cm down in the upper humic cambisol (Fernández et al., 1997). In moderate fires observations usually shows that the C increases (Rashid, 1987).
After fire soil physic-chemical properties can change due to creation of a water repellent layer (Savage, 1974; DeBano, 2000) this and the removal of herbaceous layer with its roots can increase the soil erodibility can be due to loss of the topsoil layer (Díaz-Fierros et al. 1987; McNabb and Swanson, 1990; Andreu et al., 1996, González-Pérez et al. 2004).
(González-Pérez et al. 2004) infers that litter that are usually removed when doing soil sampling is turned to fine grained ash that are mixed with the soil after a fire and that can be a explanation of the increase of C content in the samples.

Part II

Site description

The wildfire-affected area is located in north Sweden 90 km northwest from the town Luleå, close to a village called Bodträskfors (see figure 2 and 3).

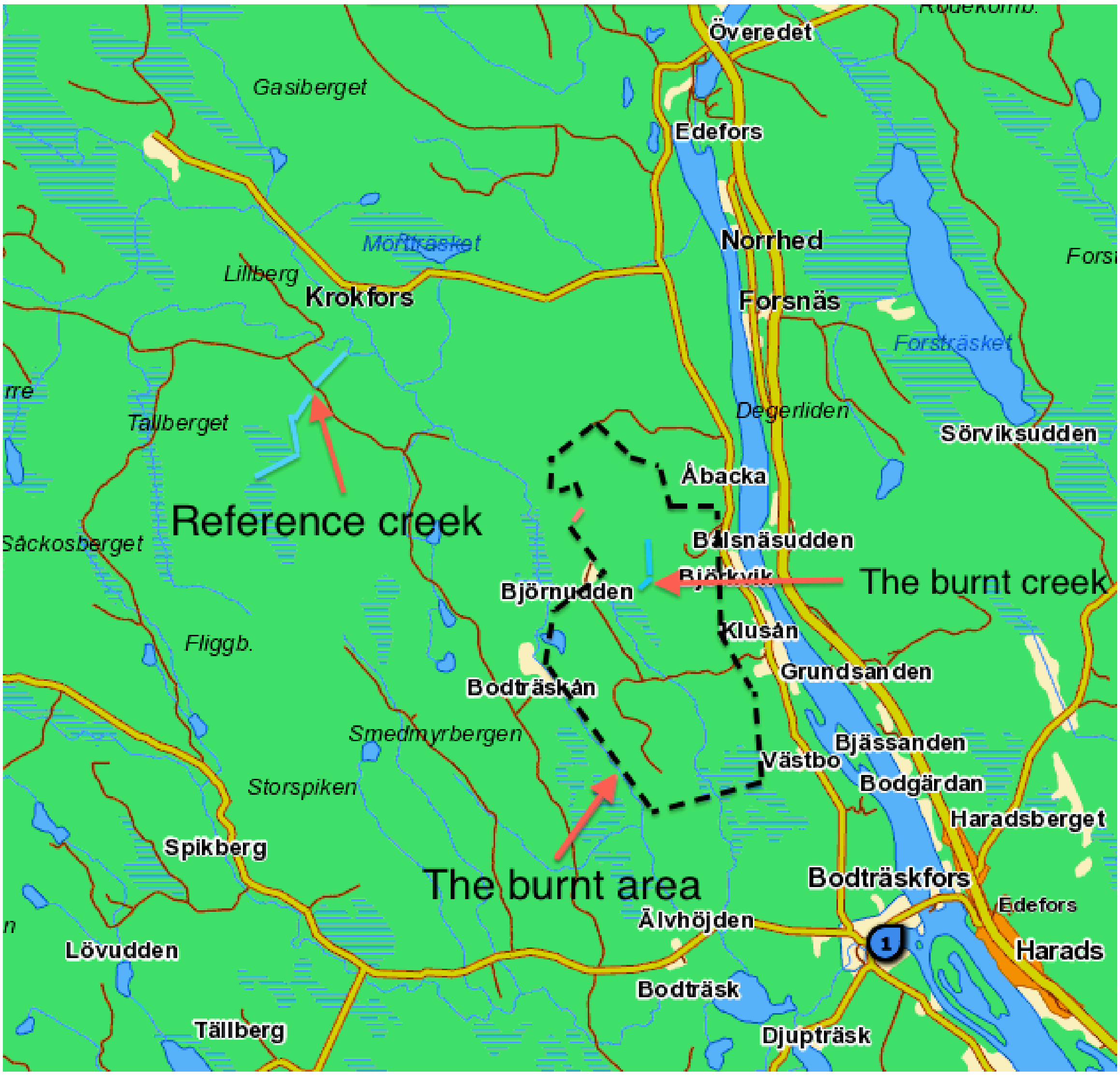


Figure 2 Location of the burnt area and the reference site.

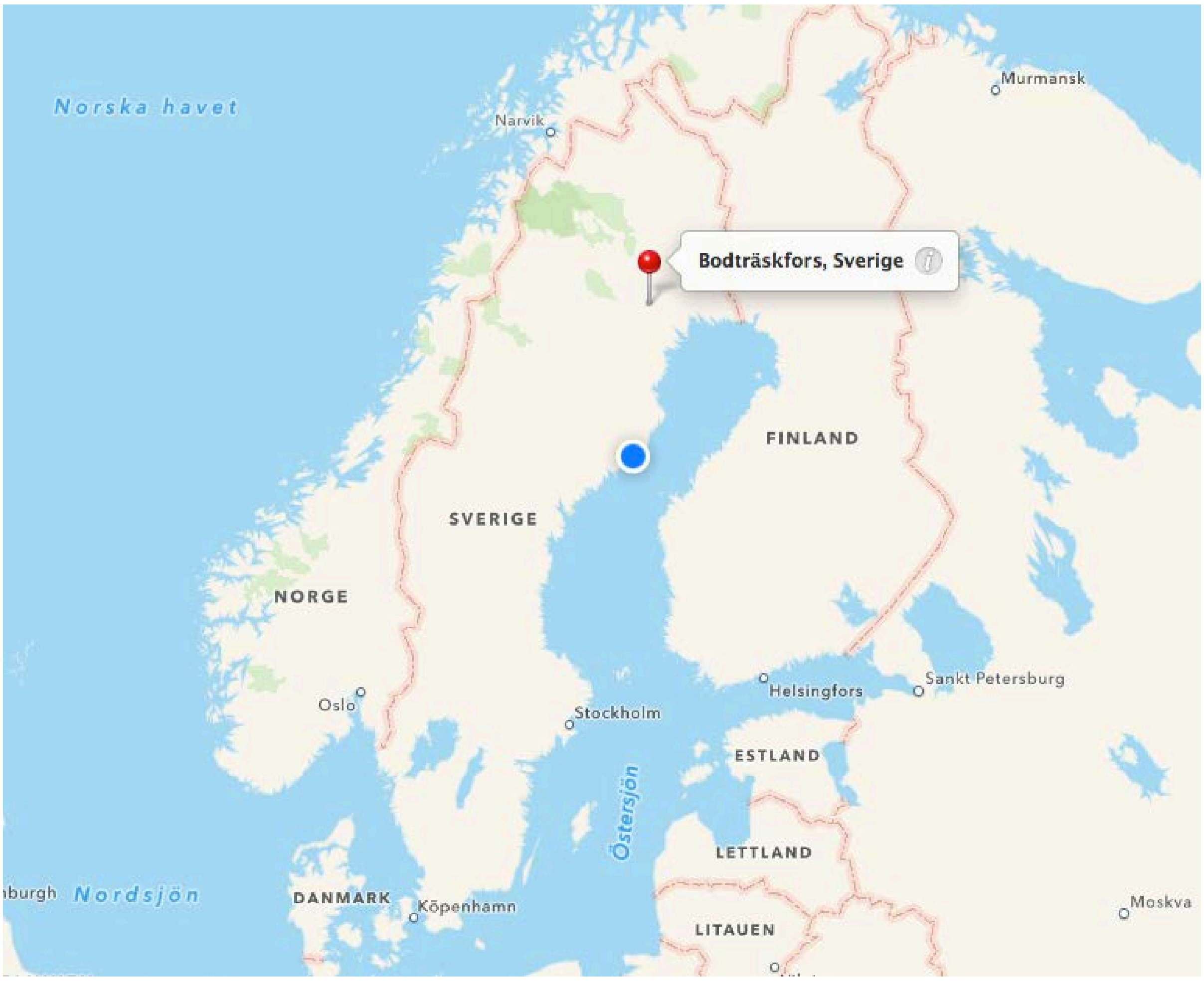


Figure 3 The location of Bodträskfors.

The forest lies in the middle boreal zone (see figure 1), a biome that stretches through Eurasia and North America.

More then 94 % of the site was covered by coniferous forest and mesic dwarf-shrub type dominated with 50 % but also the lichen type and wet dwarf shrub type were common, 22 % each. After the fire around 6% were untouched and due to mires covering the area. The small creek (Tiljetonbäcken), where the samples were taken, starts in the top of the small hill Klusåberget (273m a.s.l.) in a small pond (see fig. 2). Klusåberget were not subject to harvesting before and after the fire. Therefore the sampling where divided in two sites within the burnt area. On site when referring to 'burnt creek' is between the small pound on Klusåberget and 400 meter downstream.

The reference site is similar to the burnt area. It is located around 6 km northwest from the burnt area and have reminiscent vegetation. The domination of coniferous forest is 75%, a little less compering to the burnt area. The mesic dwarf-shrub is similar with 50 % and wet dwarf-shrub 26 %. The creek that where sampled is named Förstmyrbäcken and starts in a mire (26 % of the reference site is covered with mires). It runs towards northeast 3.5 km before it converging in the stream Bodträskån. The samples taken in Förstmyrbäcken are referred as 'reference creek' and the sampling site is located 1 km from were it converging into Bodträskån.

Geological description

The burnt area and the reference area is within the fennoscandian shield and consists mainly of the Edefors suite (1.81–1.78 Ga) that ranges from syenites to granites and are alkali-rich and distinctly metaluminous rock (Öhlander & Skiöld, 1994). The Edefors suite is similar to the Lina suite and intruded in the end of the Svecokarelian orogeny. The burnt area consists of medium to coarse-grained granite. The medium grained granite spread out on an area on top of the hill where outcrops have been observed. The coarser grained granite is around the hill and a quartz diorite to gabbro intrusion can be found close to Stortjärnen.

Soil Type

Both the reference area and the burnt area are covered of quaternary till with medium boulders.

Sampling, measurement and analyses

Tot N and Tot P

Were analysed 2007 and 2009 respectively to the standards SS EN ISO 11905 and SS EN ISO 6878:2005 mod. Tot N and Tot P analyses were performed at ALcontrol in Umeå, 2007 and at the Geochemical Laboratory, Swedish University of Agricultural Sciences in Uppsala, 2009.

Conductivity and pH

Measurements were done between the years 2007 - 2009 by a Hydrolab MS-5 Minisonde. Calibrations were done every sampling week by using three pH standards 4, 7 and 10. The conductivity was calibrated to 147 µS/cm using a 0.001 M KCl solution.

K

A peristaltic pump with plastic tubing was used when sampling for major element K. The water was taken directly from the creek and passed through a 0.22 µm nitrocellulose filter that were cleaned by 5% CH_3COOH solution for 7 days and rinsed repeatedly with MilliQ© deionized water. The filters where attached to Geotech© Acrylic In-Line filter holders. Both the filter holders and the tubing was acid cleaned in 5% HNO_3 and rinsed thoroughly with MilliQ© deionized water. The filtered water where collected in polyethylene (LDPE) containers that where cleaned in 5 % HNO_3 (SP grade, sub boiling distilled in house) and cleaned with MilliQ© deionized water before use. Before sampling in field the containers where cleaned twice in creek water. K where analysed by ALS Scandinavian laboratory in Luleå and by the standard EPA 200.7. K had to be re-analysed because the detection limit was to low. For that inductively coupled plasma sector field mass spectrometry (ICP-SFMS) was used. The measurements were conducted in 2007 and 2009.

Result

ph

Measurements between 2007-2009 (see fig.4) shows that groundwater from the fire area has a lower pH then the reference site. During the spring flood in 2007 the pH got lower and both had their lowest levels at pH 4,8. Immediately after the spring flood the both sites started to rise and got their pH peak in beginning of July when the reference site had a pH of 6,2 and the burnt site had a pH of 5,3. After July the pH started to fall and the reference site showed a pH of 5,9 in November. The burnt site got a lower reading in the end of August with a pH of 5,0 and in November the pH went up to 5,2.

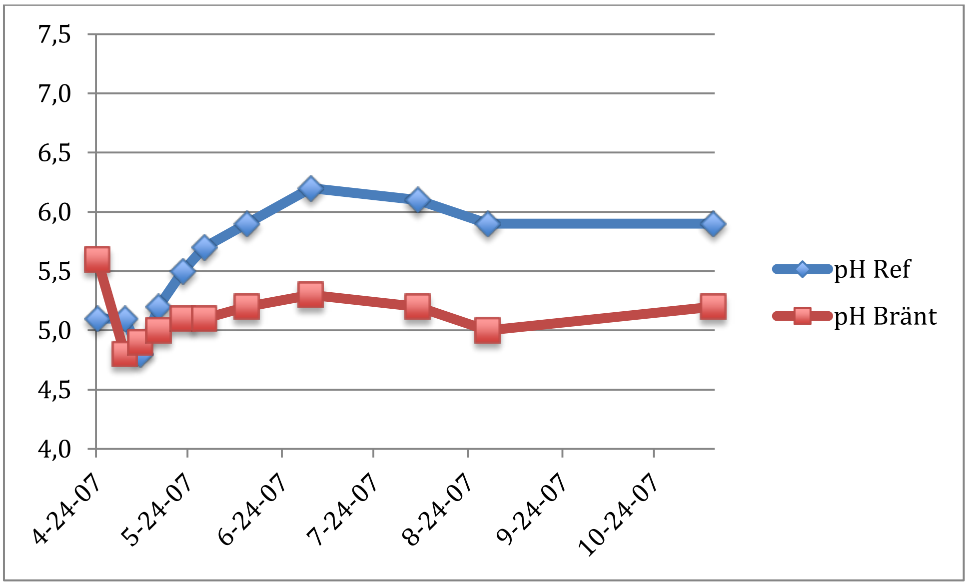


Figure 4 pH 2007 with a lower pH in the burnt area.

In 2008 analyses showed that the pH also went down during the spring flood. This can only seen for the reference site when the burnt site misses analyses before the spring flood. In the Middle of the spring flood the reference site had even lower pH then the burnt site. This lasted only for a short period and after the spring flood the pH in the reference site went over the burnt site. Both sites had a peak in the middle of June and in the end of June the pH went down again. The last analyse were made in middle of September and it showed a heavy raise in both sites. The reference site had a pH of 6,9 and the burnt site had a pH of 6,3. That was the highest recorded in all three years.

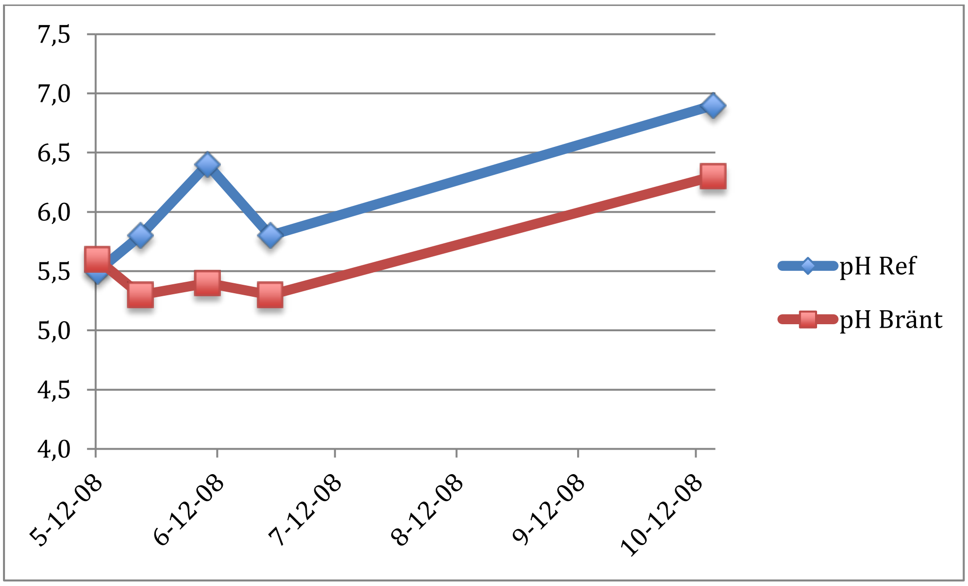
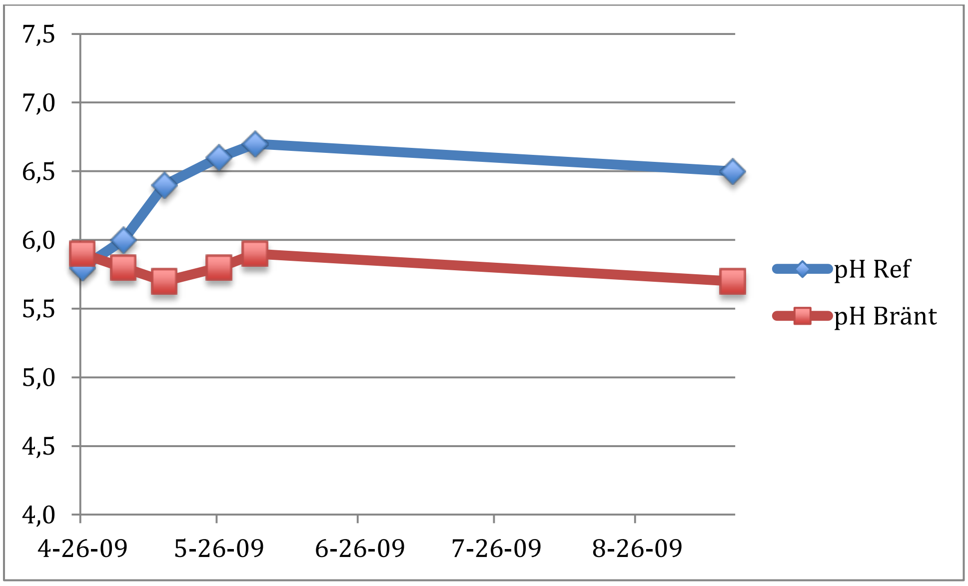


Figure 5 pH 2008 the pH is still low in the burnt area.

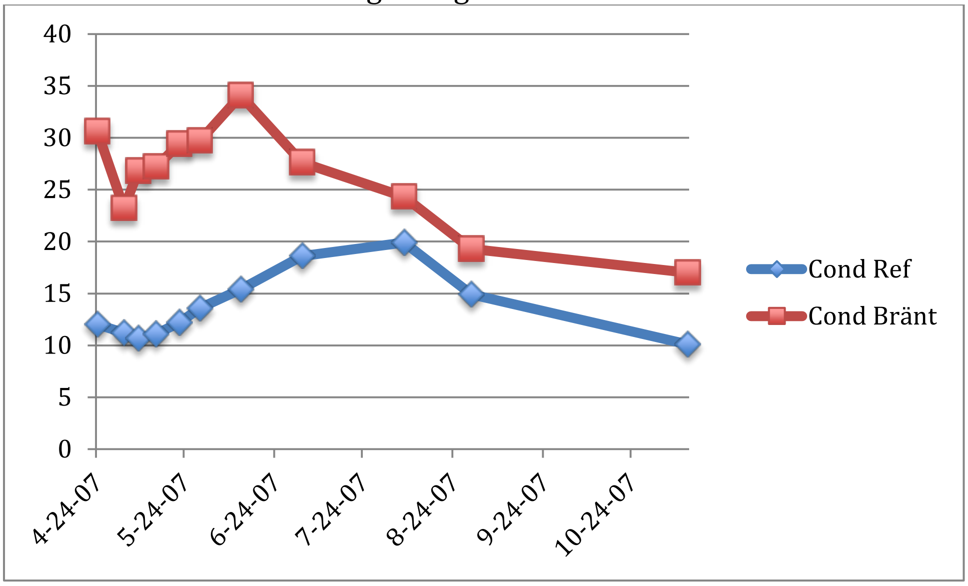
In the end of April in 2009 the burnt site had a higher pH before the spring flood. During the spring flood the burnt site got a lower pH while the reference site had an increased pH during the whole spring flood, the burnt site got a increase only after the spring flood was over. In 2009 the pH peak was in the beginning of June for both sites with a pH of 5,9 in the burnt site and 6,7 in the reference site. After June the last sample was taken in the middle of September and showed a decline at both sites.



Figur 6 pH 2009 the pH is higher in the burnt site but still lower then the reference site.

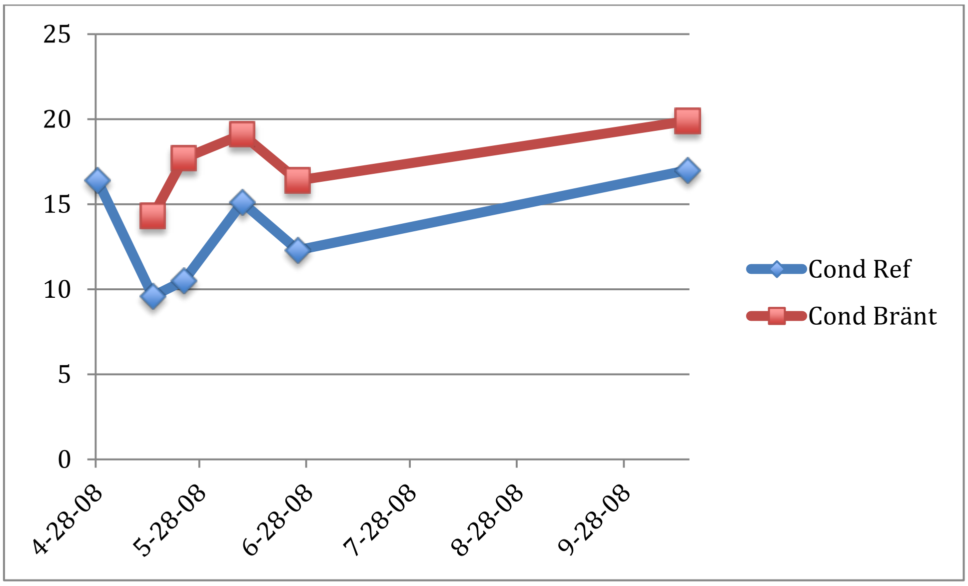
Conductivity

There is a clear difference between the two sites. The water in the burnt area has much higher conductivity then the reference site in 2007. During the spring flood there is a small drop in conductivity in both sites. After the spring flood there is an increase in both sites during the beginning of the summer. The burnt site has still a higher conductivity but it the end of the summer there is a clear drop in the Burnt site. The reference site has still a lower conductivity bit the difference is not as much in the end on 2007 as it was in the beginning.



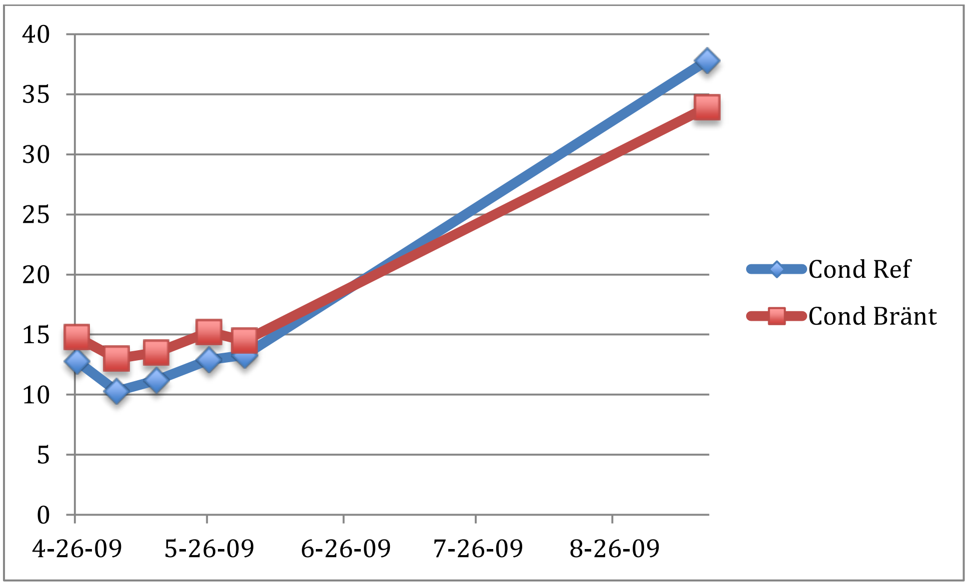
Figur 7 Conductivity (µS/cm) 2007 A clear difference between both sites.

In 2008 there has been a clear equalization between the two sites compared to the previous year. The sampling stared just in the end of the spring flood in the burnt site and there is a clear raise in conductivity in both sites just after the spring flood. During the summer there is still a higher conductivity in the burnt site but not as much as compared the previous year.



Figur 8 Conductivity (µS/cm) 2008 The difference in not as clear.

In 2009 equalisation is clearly and there is almost no difference now between the two sites. There is also another big difference between this year and the previous two years. The conductivity goes up to levels that not has been seen before.



Figur 9 Conductivity (µS/cm) 2009 The conductivity is almost the same in both sites.

N-tot

After the fire the first test results showed a big variation during the spring flood in 2007. The burnt area showed a higher N-tot content when the highest water melting occurred, but went down with the decreasing water runoff. The reference site showed occurrence of a similar pattern, but had grades that were around 4 µM lower then the burnt site during flooding. When the spring flood was over the both sites had a suddenly fall of N-tot in the creeks and the burnt area had even lower values (9,3 µM) then the reference site (10,7 µM). This drop lasted only for a short period and under the summer. Both creeks had an increase in the same rate. But the burnt area increased more, and in the end of June the burnt creek had higher values that lasted the whole year trough. The highest values that the reference creek got (20,7 µM) were measured in the beginning of July. In the burnt creek the highest value (24,9 µM) were measured beginning of August. The burnt creek had higher values throughout the whole autumn.

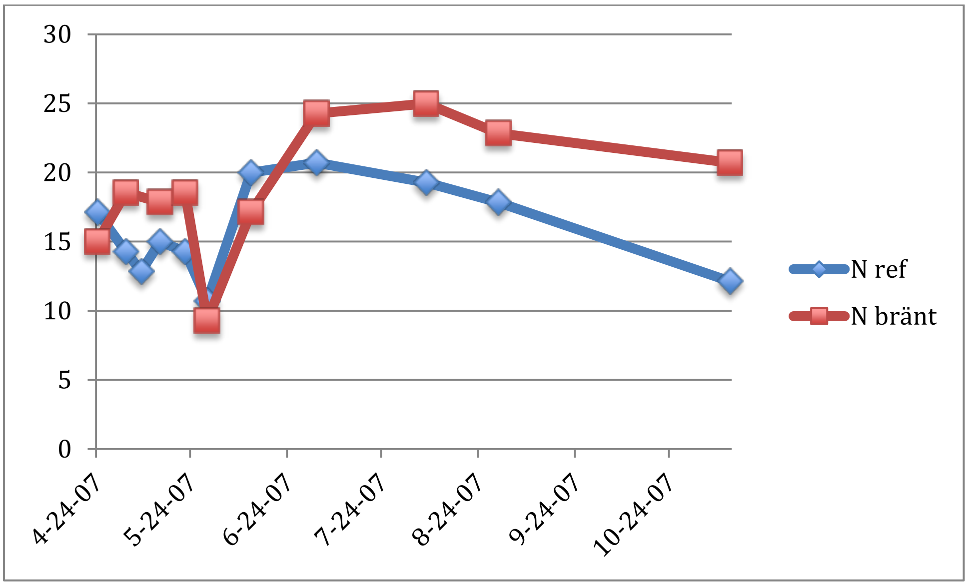


Figure 7 Result of N-tot in 2007 shows a higher N concentration in the burnt area.

Two years after the fire measurements showed a different outcome of N-tot in the creeks. Sampling started a bit later so the first measurements were just after the peak of the spring flood. In the burnt area the first measurement showed a value of 15,5 μM that went up and peaked in the beginning of June (24,05 μM). Measurements were sparse under the summer and in the autumn but the last measurement in middle of October showed a heavy decline compared to the year before. The reference site had a higher peak (25,05 μM) than the year before and even a higher peak then the burn creek. The last measurement gave a similar concentration of N (7,1 μM) as the burnt creek (6,9 μM) that where lower then the year before.

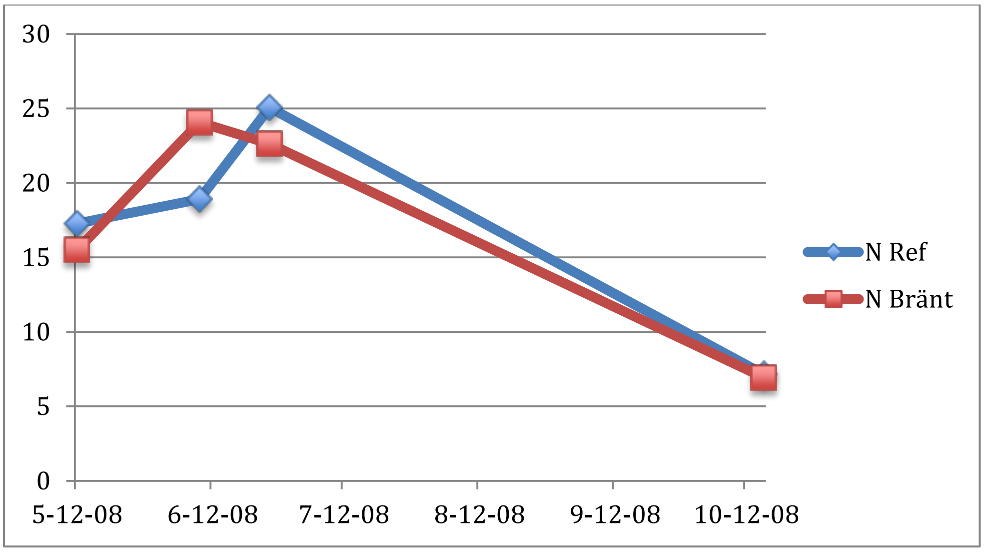


Figure 8 N-tot 2008 measurements shows no big difference between both areas.

In 2009 sampling of N-tot were only conducted to June. The data showed a similar trend of the both sites. Both had relativity high concentrations in April compared to the earlier years and showed a negative trend after the spring flood. The data was incomplete for the late summer and autumn.

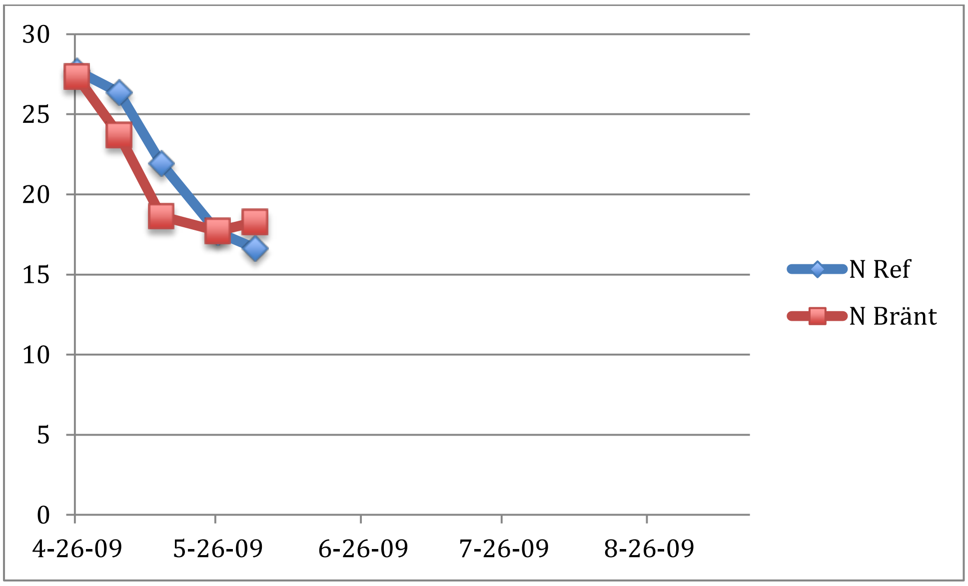


Figure 9 N-tot 2009 measurements show a lower N concentration in the burnt area during the spring.

Tot-P

When the sampling started in 2007 tests showed that the burnt site had higher concentration of P then the reference site. In end of April the burnt site had a concentration of 1,83 μM compered to the reference site with a concentration of 0,11 μM. In the beginning of May, when the spring flood peaked, the concentrations went down to 0,71 μM in the burnt site but went up to 1,01 μM following a decline short after. The reference site had low concentrations the whole spring and troughout the whole year with a mean value of 0,09 μM. In the summer P is relative stable in the burnt site and peaked in the beginning of June with a concentration of 0,66 μM. In September the last test results showed that the concentrations in the burnt site (0,45 μM) was still much higher than the reference site (0,08 μM).

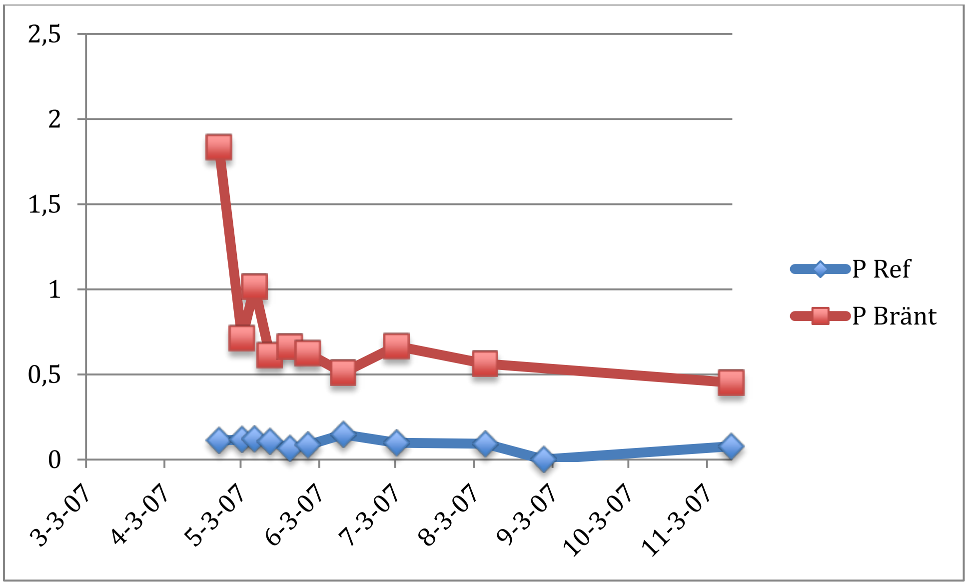


Figure 10 2007 P was higher in the burnt area.

2008 test result showed still a higher P concentration in the burnt creek compared to the reference creek. In the spring flood the concentration of K was 0,45 µM in the burnt site compared to the reference creek, were the concentration was 0,12 µM. Short after the spring flood concentrations of P went up in the burnt site to 0,95 µM for a short period following a drop to 0,43 µM. In end of June there is a raise of P concentrations in both the burnt site and the reference site, following a small discharge under the summer period. The last sampling taken in middle of October showed drop of P, meanwhile the burnt site went down to the lowest concentration in 2008 (0,25 µM) and the reference site with a concentration of 0,09 µM.

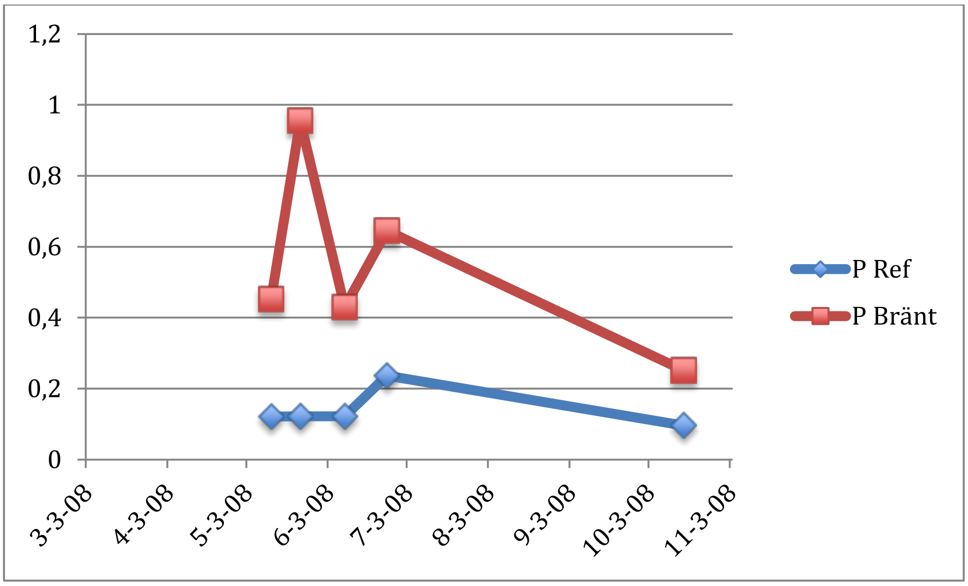


Figure 11 2008 still higher in the burnt area.

Year 2009 showed a still high P concentration under the spring flood in the burnt area with a concentration of 2,20 µM. In the reference area the concentration had the highest measured concentration at the same time through the three years of testing with concentration of 0,56 µM P. The high concentration declined in both sites after the spring flood and the burnt site had the lowest values of P through the summer with a mean value of 0,24 µM. In the reference creek the mean value was 0,10 µM throughout the summer to the fall.

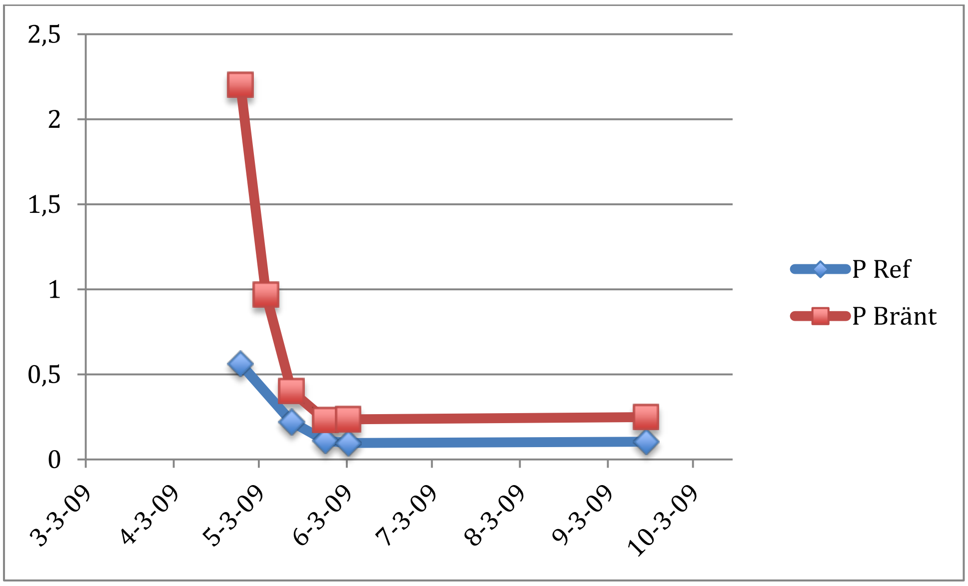
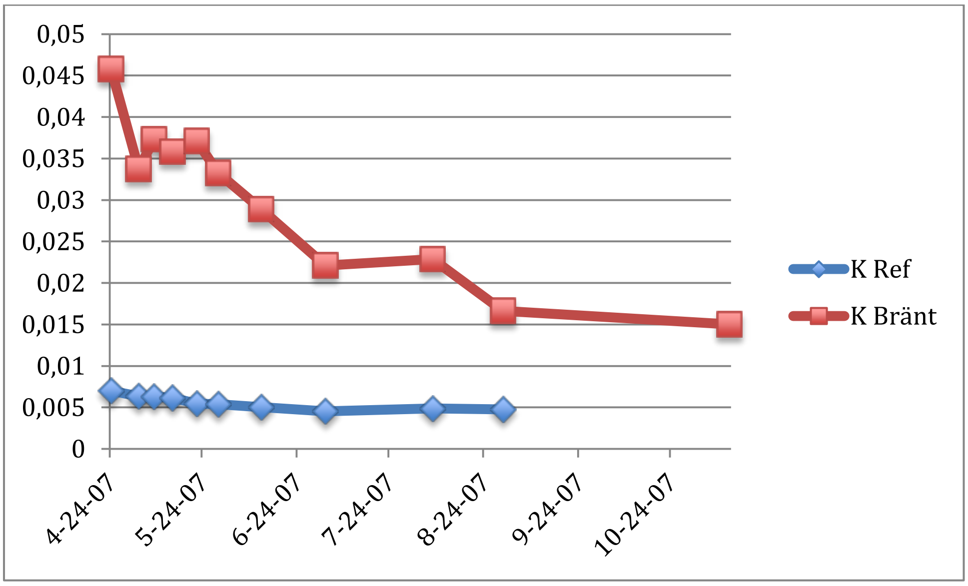


Figure 12 2009 P levels is almost the same in both areas.

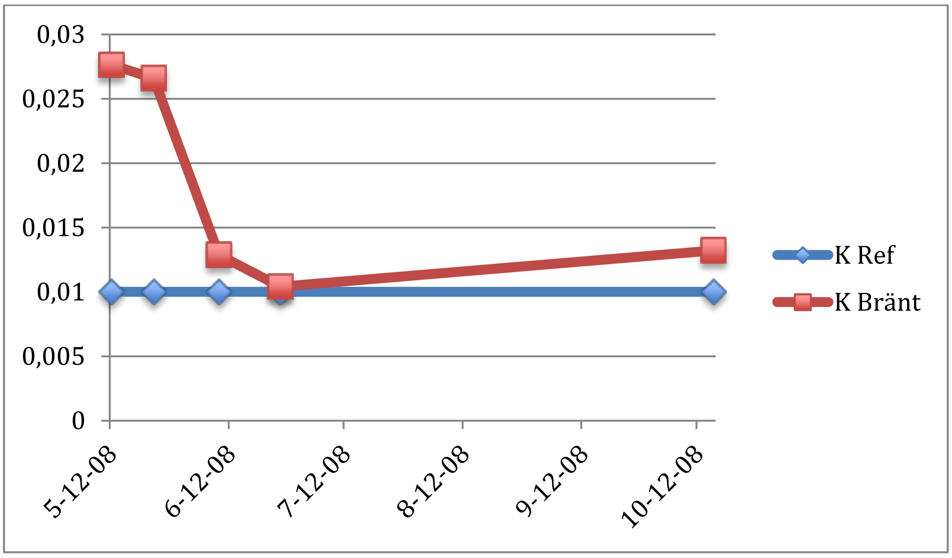
K

In the beginning of 2007 analyses showed a higher K content in the burnt creek. In the end of April the K concentration was 0,46 µM in the burnt area compared to 0,007 µM in the reference creek. Sampling showed a bigger flux of K in the burnt site varying between 0,046 – 0,015 µM. The reference site showed a minor variation between 0,007-0,005 µM. In 2007 the water discharge was the highest between the 14th and the 22nd May and then the concentration went down to around 0,036 µM in the burnt creek. In the reference site there was no big difference in the variation through the whole year. When the discharge went lower the concentration in the burnt creek got lower. In August the burnt creek had a concentration 0,023 µM and the concentration got lower in the fall. The last sample showed a concentration of 0,015 µM in the burnt area.



Figur 13 2007 with much higher K levels in the burnt site.

2008 data shows that K concentration in the burnt creek is lower than the year before. K concentration varies between 0,028-0,010 μM in the burnt site. The data from the reference site in not complete when the assay couldn't detect the low K concentration in the creek. The summer sampling of in the burnt site detected that the burnt site had a reduction of K. Assay showed a concentration of 0,01 μM in the end of June and 0,013 μM concentration in middle of September.



Figur 14 2008 Higher K levels during the spring flood.

2009 data shows a similar trend as 2008. The K concentration in the burnt creek is highest in the end of April simultaneous with the maximum discharge from the spring flood (0,045 μM). The reference site had meanwhile the highest value of all three years of sampling (0,015 μM). After the spring flood the concentrations in the burnt site went down to nearly the same concentration as the reference creek. The last sampling showed a K concentration of 0,012 μM in the burnt creek and 0,007 μM in the reference creek. The last sample in the middle of September couldn't be detected in the assay for the burnt creek. The reference site had a concentration of 0,005 μM in the same time.

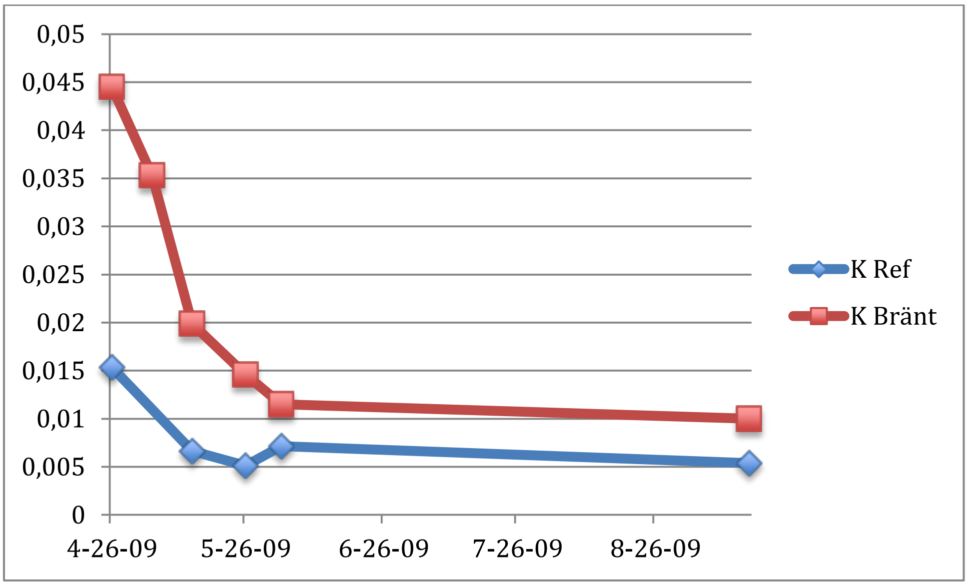


Figure 3 K 2009 still high K levels.

Discussion

pH

In 2007 results from the burnt creek shows a higher pH then the reference site in the beginning of the spring flood. The pH drop was detected only in 2007 and this variation can't be compared and analysed to the next two years when the sampling started later in 2008-2009. Only when the highest dispatch from the spring flood occurred, a clear drop was showed in both test sites. This can be an effect from the release of and the degradation of the organic matter to the stream during the high water dispatch causing release of H^+ (Ingri, 2012) The big difference in pH variation in both sites is clear after the spring flood. The pH increases in the reference site from a pH below 5 to a pH over 6, and this is probably due to the decrease of organic matter in the reference stream. The burnt stream doesn't have the same pattern. During the summer the pH stays low and doesn't have the same gain in pH as the reference stream. This can have different explanations one can be due to the buffering effect between the ash and the organic matter from the organic-rich topsoil layers (Ahlgren and Ahlgren, 1960; Wells et al., 1979). The buffering between the cat-ions in the ash and the organic matter can give a constant release of H^+ to the runoff water and lowers the pH for long time. More erosion can also be an other explanation (Neary et al. 1999). Erosion can give a higher transport of loose material including organic matter from the burnt site organic matter through the whole summer. The bedrock is the same in both areas so this cant be the cause of the almost one pH higher water in the reference site.
2008 has a similar trend with a decline of pH during the spring flood and a raise just after. The big difference is that the pH in the both streams is much higher in the autumn compared to the year before. Why we have this big difference is hard to explain but can be as simple as there has been an error when sampling were conducted. The sampling frequency is also lower this year and the year before and that makes the data more unreliable 2008 and 2009.

In 2009 there is a clear raise of pH in the burnt site during the spring flood. This can imply that the cat-anions have started to deplete and the buffering effect with the organic matter has started to fade. But still there is a clear different between these to sites and it's probably due to the big cat-anion exchange happening and consistent releases of H^+ that is in progress.

Conductivity

In 2007 the burnt site have a higher conductivity than the reference. This is also probably due to the transport of cat-anions that are accumulated in the ash, to the stream. But even here the effect of a higher degree of erosion (Neary et al. 1999) that can be a significant agent, witch leads to a higher transport of organic material and leached ash particles to the stream. These things alone or together may give a higher transportation of ash and organic material and followed by a higher conductivity in the burnt creek. The ash has a high content of cat-ions that can give a higher conductivity when it's leeched. In 2008 there is a clear decrease in the burnt creek compared to the previous year. The burnt area and the spring flood don't give a clear increase in conductivity and have almost the same levels. This may be due to most of the loose material have been leached out from previously year. In 2009 the two sites show almost the same trend and now there is probably no more extra ash and loose organic material that can be transported to the creek.

N

Data show a gain of nitrogen in the burnt creek during the spring flood, summer and fall in 2007. The gain is not as much as for potassium and phosphorus the same year and it's likely that the lower concentrations of N, compered to K and P has to do with the vaporization temperature (Magnusson, 2009). Volatilization starts at 200°C for N and for P and K its over 700°C. This could mean that the duration of the fire was too short or the temperature wasn't high enough for P and K to volatilize, but for N a big part of the N pool could volatilize and that has been showed in old studies (Minroe, 1986; Friend, 1989; Harvey et al., 1979; Ballard and Hawkes, 1989). Data from 2008 shows its almost no difference between the burnt site and the reference site. The lower concentration here might have to do with higher consumption of N in the burnt area but also a loss of N by denitrification (Neary et al. 1999). In 2009 there is less N in the burnt creek compared to the reference creek. This may depend on even higher N uptake of plants in the burnt area causing the N pool to be more depleted in the burnt area.

P

In 2007 there is a clear gain in of phosphorus in the burnt creek. Especially in end of April and in the beginning of the spring flood when the measurements showed more than 16 times higher P in the burnt area. The high vaporization temperature (Weast, 1988) that is demand for phosphorus is probable due to the big gain when the ash stills contains high P concentrations, which later on can be leeched out the stream. The next year has a similar trend in the spring and it goes down during the lower water runoff in the summer. This can be a consequence of the smaller discharge during the summer that will give a lower content of P in the runoff water. One other explanation of the decline in P during the summer is that the plants can absorb P when growing. The bioavailability is around pH 6,5 (Sharpley 2000) for P so if the pH goes up in the burnt area the uptake may increases if the pH is lower in the soil. Analyses from 2009 shows that the increase during 2007 and 2008 is almost gone to the same levels as for the reference site and it might be a result of the depletion of ash that have been drained out and a recovery of the vegetation that can take up the nutrients in a higher grade than before. Especially if P has been converted to Orthophosphate that has a higher bioavailability (Cade-Menun et al. 2000).

K

Analyses from 2007 shows that the burnt site has a big increase in potassium and it´s consistent for the whole year. In the beginning of the year the burnt site has K levels more then 6 times the reference creek. The explanation is probably the same for K as well as for P; the ash, that has is highly abundant in these ions, are being leeched or eroded with the runoff water and gives the burnt creek high concentrations of both elements and organic material. Analyses have shown that K is a crucial element and shows very high grades after the fire in Bodträskfors. There is a clear difference between N and K and its probably due to K is more stable in high temperatures (Weast, 1988) and do not vaporize as easy as N. This may give a richer K concentration in the burnt area even if N is more abundant in organic matter. In 2008 there is still an increase of K during the spring flood and during the summer there is no big increase and it's probably a sign of leaching is very small and that the growing vegetation in the area absorbs K when growing. In 2009 the levels of K is still high in large water dispatches, sometimes 3 times more, and it still shows that there is a effect in the burnt area from the fire. In the summer and fall, when the dispatch is small, there are still almost 2 times higher K grades in the burnt area.

Future studies

In future studies there will be a good idea to have an even more similar reference area when the reference in this study have more mires then the burnt area and could give a different water-chemistry. The sampling occasions the first year could be better to have more constituent throughout the study. This could give a better and more reliable data that are easier show sampling errors that could have occur. I would also be good to have at least two more year of analyse to see if the water chemistry goes back to the normal values.
Also a good future study could be to look at N bacteria's survival after a forest fire. Since N is an important nutrient for the living forest.

Reference:

Adams PW, Boyle JR. (1980) Effects of fire on soil nutrients in clearcut and whole-tree harvest sites in Central Michigan. Soil Sci Soc Am J 44:847–850

Ahlgren, I.F., Ahlgren, C.E., (1960). Ecological effects of forest fires. Bot. Rev. 26, 483–533.

Albini, F. A. (1996). Iterative solution of the radiation transport equations governing spread of fire in wildland fuels. Fiziha Goreniya i Vzryva 32, 71-82

Almendros G, Polo A, Lobo MC, Ibánez JJ. (1984) Contribucio´n al estudio de la influencia de los incendios forestales en las caracterısticas de la materia orga´nicadelsuelo:II.Transformacionesdelhumusporignicio´nen condiciones controladas de laboratorio. Rev Écol Biol Sol 21: 154 – 60.

Almendros G, Gonza´lez-Vila FJ, Martın F. (1990) Fire-induced transformation of soil organic matter from an oak forest: an experimental approach to the effects of fire on humic substances. Soil Sci 149:158–68.

Almendros G, González-Vila FJ, Martın F, Fründ R, Lüdemann H-D. (1992) Solid state NMR studies of fire-induced changes in the structure of humic substances. Sci Total Environ 117/118:63–74.

Andreu V, Rubio JL, Forteza J, Cerni R. (1996) Postfire effects on soil properties and nutrient losses. Int J Wildland Fire 6:53–6.

Arocena, J.M., Opio, C., (2003) Prescribed fire-induced changes in properties of sub-boreal forest soils, Geoderma 113 1–16.

Ballard, T.M., Hawkes, B.C., (1989) Effects of Burning and Site Preparation on Growth and Nutrition of Planted White Spruce. Forestry Canada, Pacific and Yukon Region, Victoria, BC BC-X-309.

Bayley, S. E., Schindler, D. W., Mooney, H. A., Medina, E., Sculze, E. D., and Walker, B. H. (1991) The role of fire in determining stream water chemistry in northern coniferous forests. John Wiley & Sons Ltd., Chichester, UK.

Bollen GJ. (1969) The selective effect of heat treatment on the microflora of a greenhouse soil. Neth J Plant Pathol 1969;75:157–63.

Brandt, J.P, (2009) The extent of the North American boreal zone. Environmental Reviews 17(1): 101-161.

Cade-Menun BJ, Berch SM, Preston CM, Lavkulich LM (2000) Phosphorus forms and related soil chemistry of Podzolic soils on northern Vancouver Island. II. The effects of clear-cutting and burning. Can J For Res 30:1726–1741

Campbell GS, Jungbauer JD Jr, Bidlake WR, Hungerford RD (1994) Predicting the effect of temperature on soil thermal conductivity. Soil Sci 158:307–313

Campbell GS, Jungbauer JD Jr, Bristow KL, Hungerford RD (1995) Soil temperature and water content beneath a surface fire. Soil Sci 159:363–374

Carreira J.A., Niell F.X., and Lajtha K. (1994) Soil nitrogen availability and nitrification in Mediterranean shrublands of varying fire history and successional stage. Biogeochemistry 26: 189–209.

Certini, Giacomo. (2005) Effects of fire on properties of forest soils: a review, Oecologia 143: 1–10

Chandler, C., Cheney, P., Thomas, P., Trabaud, L., Williams, D., (1983). Fire in Forestry, Volume 1: Forest Fire Behaviour and Effects. Wiley, New York.

Cofer III WR, Koutzenogii KP, Kokorin A, Ezcurra A. (1997) Biomass burning emissions and the atmosphere. In: Clark JS, Cachier H, Goldammer JG, Stocks B, editors. Sediment records of biomass burning and global change. NATO ASI Series, vol. I. Berlin, Germany: Springer;
p. 51.

DeBano LF, Savage SM, Hamilton DA. (1976). The transfer of heat and hydrophobic substances during burning. Soil Sci Soc Am J 1976;40:779 – 82.

DeBano, LF. (1981) Water repellent soils: a state-of-the- art. Gen. Tech. Rep. PSW-46. Berkeley, CA: U.S. De- partment of Agriculture, Forest Service, Pacific South- west Forest and Range Experiment Station. 21 p.

DeBano, LF. Neary, Danel G. Ffolliott, Peter F. (1998). Fire's effects on ecosystems. John Wiley & Sons, Inc.

DeBano LF. (2000) The role of fire and soil heating on water repellency in wildland environments: a review. J Hydrol 231/232:195–206.

Díaz-Fierros F, Rueda BE, Pérez Moreira R. (1987) Evaluation of the U.S.L.E. for the prediction of erosion in burnt forest areas in Galicia (N.W. Spain). Catena 14:189–99.

Durán Jorge, Rodríguez Alexandra, Fernández-Palacios José María and Gallardo Antonio. (2009) Long-term decrease of organic and inorganic nitrogen concentrations due to pine forest wildfire. Ann. For. Sci. 67 (2010) 207.

Espen Lydersen, Rolf Høgberget, Clara E. Moreno, Øyvind A. Garmo & Per Christian Hagen. (2014), The effects of wildfire on the water chemistry of dilute, acidic lakes in southern Norway, An International Journal ISSN 0168-2563 Volume 119 Combined 1-3 Biogeochemistry

Eriksson, H., Edberg, F., and Borg, H., (2003). Effects of forest fire and fire fighting operations on waterchemistry in Tyresta National Park, Stockholm, Sweden. Journal De Physique.IV:JP107,427430.

Fernández I, Cabaneiro A, Carballas T. (1997) Organic matter changes immediately

after a wildfire in an Atlantic forest soil and comparison with laboratory
soil heating. Soil Biol Biochem 29:1–11.

Friend, A.L., (1989) Differences in Nutrient Distribution Between Adjacent Cut and Uncut East-Slope Cascade Forest Stands Suggest Nutrient Losses. Forestry Sciences Laboratory, PNW Research Station, Wenatchee, WA.

Giovannini G, Lucchesi S (1997) Modifications induced in soil physico-chemical parameters by experimental fires at different intensities. Soil Sci 162:479–486

González-Pérez, Jose´ A., González-Vila, Francisco J. Gonzalo Almendros. Knicker, Heike. (2004). The effect of fire on soil organic matter—a review. Environment International 30 855–870.

Grier, C.C. (1975) Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Can. J. For. Res. 5, 599± 607.

Harvey, A.E., Jurgensen, M.F., Larsen, M.J., (1979) Role of forest fuels in the biology and management of soil. USDA Forest Service, General Technical Report INT-65, Intermountain Forest and Range Experimental Station, Ogden, UT.

Humphreys, F.R., Craig, F.G., (1981) Effects of fire on soil chemical, structural and hydrological properties. In: Gill, A.M., Groves, R.H., Noble, I.R. (Eds.), Fire and the Australian Biota. Australian Academy of Science, Canberra, pp. 177–200.

Ingri, johan (2012), Från berg till hav – en introduction i miljögeokemi, Studentlitteratur, Lund.

Larsen, J.A., (1980). The Boreal Ecosystem. Physiological Ecology. Academic Press, New York, p. 500.

Lucas E. Nave, Eric D. Vance, Christopher W. Swanston, and Peter S. Curtis. (2011). Fire effects on temperate forest soil C and N storage. Ecological Applications, Vol. 21, No. 4 (June 2011), pp. 1189-1201

Kang BT, Sajjapongse A. 1980. Effects of heating on properties of some soils from Southern Nigeria and growth of rice. Plant Soil;55:85–95.

Khanna PK, Raison RJ, Falkiner RA (1994) Chemical properties of ash derived from Eucalyptus litter and its effects on forest soils. For Ecol Manage 66:107–125

Klopatek JM, Klopatek CC, DeBano LF (1990) Potential variation of nitrogen transformations in pinyon-juniper ecosystems resulting from burning. Biol Fert Soils 10:35–44

Knicker H, Almendros G, Gonza´ lez-Vila FJ, Martın F, Lu¨ demann HD. (1996) 13C- and 15N-NMR spectroscopic examination of the transformation of organic nitrogen in plant biomass during thermal treatment. Soil
Biol Biochem 1996;28:1053–60.

Kutiel P. and Naveh Z. (1987) The effect of fire on nutrients in a pine forest soil. Plant Soil 104: 269–274.

Kutiel P, Shaviv A (1992) Effects of soil type, plant composition and leaching on soil nutrients following a simulated forest fire. For Ecol Manage 53:329–343

Magnusson T. (2009) Skogsbruk – mark och vatten, Skogsstyrelsen, Skogsskötselserien nr 13 s.31,47

McNabb DH, Swanson FJ. (1990) Effects of fire on soil erosion. In: Walstad JD, Radosevich SR, Sandberg DV, editors. Natural and prescribed fire in Pacific Northwest forests. Corvallis (OR): Oregon State Univ. Press; p. 159–76.

Minroe, D., (1986) Effects of site preparation on seedling growth: a preliminary comparison of broadcast burning and pile burning. USDA For. Ser. Res. Note PNW-RN-452.

Morris, L.A., Miller, R.E. (1994) Evidence of long-term productiv- ity change as provided by field trials. In: Dyck, W.J., Cole, D.W., Comerford, N.B. (Eds.), Impacts of Forest Harvesting on Long-Term Site Productivity, Chap. 3. Chapman and Hall, London. pp. 41±80.

Neary, Daniel G., Klopatek, Carole C., DeBano, Leonard F., Ffolliott Peter F. (1999). Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122 51-71.

Nordblad, F. (2011). Wildfire Influences on Stream Water Geochemistry in a Boreal Catchment. Luleå University of Technology.

Natural Resources Canada, 2014, Webadress: http://www.nrcan.gc.ca/forests/boreal/13077

Oswald BP, Davenport D, Neuenschwander LF (1999) Effects of slash pile burning on the physical and chemical soil properties of Vassar soils. J Sustainable For 8:75–86

Pappa A.A., Tzamtzis N.E., and Koufopoulou S.E. (2008) Nitrogen leaching from a forest soil exposed to fire retardant with and without fire: a laboratory study. Ann. For. Sci. 65: 210.

Prieto-Fernández A., Villar M.C., Carballas M., and Carballas T. (1993) Short-term effects of a wildfire on the nitrogen status and its miner- alization kinetics in an atlantic forest soil. Soil Biol. Biochem. 25: 1657–1664.

Raison R.J. (1979) Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: a review. Plant Soil 51: 73–108.

Raison, R.J., Khanna, P.K., Woods, P.V. (1985). Mechanisms of element transfer to the atmosphere during vegetation fires. Can. J. For. Res. 15, 132-140.

Rashid GH. (1987) Effects of fire on soil carbon and nitrogen in a Mediterranean oak forest of Algeria. Plant Soil 103:89–93

Rodríguez A., Durán J., Fernández-Palacios J.M., and Gallardo A. (2009) Wildfire changes the spatial pattern of soil nutrient availability in Pinus canariensis forests. Ann. For. Sci. 66: 210.

Roger D. Hungerford, Michael G. Harrington, William H. Frandsen, Kevin C. Ryan, and Gerald J. Neihoff. 1990. Influence of fire on factors that affect site productivity. Sounders College Publishing, Philadelphia.

Savage SM. (1974) Mechanism of fire-induced water repellency in soil. Soil Sci Soc Am Proc 38:652–7.

Sharpley A. (2000) Phosphorous availability. Sumner ME (ed) Handbook of soil science. CRC, Boca Raton, Fla., pp D18– D38

Simard DG, Fyles JW, Pare´ D, Nguyen T. (2001) Impacts of clearcut harvesting and wildfire on soil nutrient status in the Quebec boreal forest. Can J Soil Sci 81:229–237

Sjörs, H. (1999) The background: Geology, climate and zonation. Acta Phytogeographica Suecica 84, 5-14.

Smith Hugh G., Sheridan Gary J., Lane Patrick N.J., Nyman Petter, Haydon Shane. (2011) Wildfire effects on water quality in forest catchments: A review with implications for water supply. Journal of Hydrology 396 (2011) 170–192.

Ulery AL, Graham RC (1993) Forest fire effects on soil color and texture. Soil Sci Soc Am J 57:135–140

Weast, R.C. (1988) Handbook of Chemistry and Physics. CRC
Press, Boca Raton, FL.

Wells, C.G., Campbell, R.E., DeBano, L.F., Lewis, C.E., Fedriksen, R.L., Franklin, E.C., Froelich, R.C., Dunn, P.H., (1979) Effects of fire on soil: a state-of-knowledge review. USDA Forest Service General Technical Report WO-7. Washington, DC.

Öhlander B, Skiöld T. (1994) Diversity of 1.8 Ga potassic granitoids along the edge of the Archaean craton in northern Scandinavia: a result of melt formation at various depths and from various sources. Lithos Volume 33, Issue 4, Pages 265–283