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Short-term effects of a boreal wildfire on water quality

immediate

Abstract

In 2014 Sweden experienced the largest and most severe wildfire in modern time. The burnt area is intensively managed for forestry which includes extensive drainage of peatlands in some catchments. The immediate effect of fire on the downstream water quality is rarely quantified and possible interactions with land-use and land cover charect eristics is not well known. We studied water quality (No3, NH4.....etc) in 9 catchments from 3 weeks to one year after the fire occurred. A simple burn severity map was produced with remote sensing techniques. Maps on land cover and drainage (ditches) were extracted from data bases. Our results show that an extremely high sulfate pulse (1-2 months after fire) were buffered by the release of base cations, and likely presence of organic matter, which largely suppressed surface water acidification in the area. In line with earlier results, the increased nutrient export returns quickly to normal values and is not detectable one year. Differences in the water chemical response were linked to differences in land cover and drainage. Ditched and forested wetlands burn deeper and may contribute ......Lakes and and natural wetlands are more fire resistant... Nutrient leaching is generally higher in areas with high wetland cover where organic matter is oxidized by the fire. In conclusion,......

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Introduction

Wildfires are a natural phenomenon but human activities are altering both the driving factors (climate) and the vulnerability (land-use factors) of ecosystems, increasing both frequency and severity of fire impacts. The boreal zone has experienced an intensified fire regime over the last decades and this trend is predicted to continue Flannigan, Stocks, Turetsky, and Wotton (2009). This is an issue of concern given that wildfires play a major role in altering nutrient status of soils and waters. Yet, few studies have investigated the impact boreal wildfires have on water quality and how this is altered by land-use and landscape characteristics. Here we address this topic by capitalizing on a wildfire in Sweden that occurred in a managed area with multiple catchments and an ongoing water quality monitoring program.

Postfire water quality is determined by what is hydrologically exported to streams and lakes. After fire there is an increase of available nutrients in the soil that can leech out, mainly caused by an increase in soil pH which is associated with an increase in exchangeable cations (e.g.Ca2+,Mg2+, and K+, and the anion SO42) in soil González-Pérez, González-Vila, Almendros, and Knicker (2004). These ions are easily exported to streams and lakes and studies have shown post-fire peaks in sulphate (SO42-), chloride (Cl-) and base cation concentrations (Carignan, D'Arcy, and Lamontagne (2000) Mast and Clow (2008) Bladon et al. (2008) Bladon, Emelko, Silins, and Stone (2014)). If acid anions (NO3-, SO42- and Cl-) dominates over base cations a acidity effect is observed in downstream waters (Lydersen, Høgberget, Moreno, Garmo, and Hagen (2014)). This acidification effect is enhanced in areas which have higher concentrations of stored S from acid rain or have a high proportion of peatlands Bayley, Schindler, Parker, Stainton, and Beaty (1992). Post-fire acidification can also result in high aluminum concentrations Lydersen et al. (2014) and possibly other metals (e.g. Fe, Mn, and Cu) Certini (2005). However, a high base cation concentration may counterbalance the acididyt effect (Carignan et al. (2000)). There is also a an increased availability of dissolved P in the soil post-fire Certini (2005) and in boreal Canada burned watersheds exported more phosphorus per unit area than reference watersheds even after 4 years post-fire Burke, Prepas, and Pinder (2005).

Nitrogen levels can increase dramatically post-fire (eg Bladon et al. (2008) and Carignan et al. (2000)).

Following fire soil organic nitrogen is either volatilised or largely converted into inorganic forms (i.e. NH+4 and NO-3) Certini (2005). Nitrite is mainly formed from NH+4 through nitrification up until months after the fire Certini (2005). Both NH4+–N and NO3–N are available to plants, but with non-existing vegetation cover after a severe fire, these compounds are leached out Smith, Sheridan, Lane, Nyman, and Haydon (2011). Nitrite concentrations may peak shortly after the fire and return to reference values within 2-3 years (eg Bladon et al. (2008) and Carignan et al. (2000)). However, other studies in have reported high concentrations of nitrite up to 5-9 years post-fire (Hauer and Spencer (1998) Mast and Clow (2008)). In contrast to nitrite, ammonium is expected to be held by the soil to a higher degree because it adsorbed onto negatively charged surfaces of soil particles Mroz, Jurgensen, Harvey, and Larsen (1980). However, a study observed a NH+4 pulses that lasted over 2 growing seasons Grogan, Burns, and Iii (2000). ONLY N. Am.!! Add TURNER ref?

Variation in surface water quality at the catchment scale in the boreal landscape is mainly controlled by landscape heterogeneity Humborg et al. (2004). A major influence on surface water pH is proportion of peatlands in the catchment through the release of organic acids Buffam, Laudon, Temnerud, Mörth, and Bishop (2007) . Peatland cover also reduces the nitrite concentration in surface waters Sponseller, Temnerud, Bishop, and Laudon (2014). Despite the clear effect of landscape characteristics on water chemistry this aspect has received little attention when examining the effect of wildfire on water chemistry. For example, wildfire can cause severe disturbance to peatlands and potentially increase oxidation of S with subsequent leaching as a result. Similary, nitrite may not be retained in peatlands after fire.

A wildfire in Sweden in 2014 created the oppertunity to study the effect of wildfire on water chemistry in a managed landscape with a high cover of peatlands. To quantify the effects of wildfire on water quality, and to understand the drivers behind variation in water quality responses to fire, before-after data is needed and catchment needs to be replicated. The burnt area consists of multiple catchments allowing us to investigate local variation in post-fire responses. One of the catchments is included in a national water monitoring network enabling comparison with long-term trends in water chemistry. This before-after approach is complimented by comparing data with nearby long-term monitored catchments. Hence, compared to most studies, our study does not rely on only post-fire data and a few reference sites (see Mast 2013 and Betts and Jones, 2009 for other before-after studies).

The overarching goal of this study is to investigate the short-term (2 years) effects of a boreal wildfire on stream and lake water chemistry. Downstream data from five burned watersheds are presented together with data from ten lakes. Post-fire data are contrasted with: 1) pre-fire data for one stream and lake within the burned area, and 2), reference lakes and streams in the surrounding with similar land-use characteristics. Together this is a unique opportunity to quantify the impact of the wildfire on water chemistry and to test how current trends in water chemistry are altered by a fire. Furthermore, we want to explore if catchment characteristics is associated with the post-fire water chemistry. In particular we tested if the changes in water chemistry were associated with the proportion of peatlands and catchment size. Finally, we use stream flow data to estimate fluvial exports of S and base cations for two catchment during the first year after the fire.

Methods

The wildfire started on the 31 of July 2014 in the county of Västmanland, located in the central parts of Sweden. The forest fire lasted for 12 days and a total of 14 000 ha were consumed by the fire. During the initial days (31/7 – 3/8) the spreading of the fire were of moderate intensity but the 4th of august the wind and fire intensity increased which drastically enlarged the fire affected area. Five streams and ten lakes, larger than 1 ha, located inside the affected area and three lakes adjacent to the area were sampled. One of the measured streams (Garsjobacken), and one of the lakes (Marrsjon) are part of the Swedish regional monitoring program (RMO) since 1995. Sampling points and catchment characteristics are presented in Figure 1 and table .

Sampling and chemical analysis

The first post-fire measurements of the streams were made on the 21 of August (2014). During the first months the streams were frequently sampled but logistic constraints made it hard to sample all streams the same day. The streams were in general measured every second to fourth week, except parts of the winter. Synoptic measurements (what is this?) were made at XX occasions during measurement period. The lakes were sampled at three occasion: 2014 October 28th, 2015 October 28th, and 2016 December 1st. A few lakes were sampled more frequently. The water sampling procedure and water chemistry analysis were made according to the Swedish monitoring program Fölster, Johnson, Futter, and Wilander (2014) using SWEDAC accredited methods at the geochemical laboratory at the Department of Aquatic Sciences and Assessment at the Swedish University of Agricultural Sciences (Sonesten, 2015).

Stream flow data were modelled for two catchments that are included in the Swedish Swedish Meteorological and Hydrological Institute's (SMHI) catchment database for which their S-HYPPE model produces daily flow data. Model outputs were compared to pressure data (transducers XX model etc).

Catchment delineation and peatland cover

The catchments of the sampled streams were produced in ArcGIS 10.3, software from ESRI, using a national elevation model from Lantmateriet (2015a) that had a resolution of 2x2 m and accuracy of 0.5 m. When rain hits the surface it will run in the steepest slope direction which is determined in the elevation model. By grouping the surfaces of the steepest slopes with the same direction watersheds were delineated. Catchment delineation was visually quality checked to ensure high accuracy of the delineation process. Peatland cover for each catchment was estimated from the Swedish soil layer raster (The Geological Survey of Sweden, SGU).

Analyses

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Results

Effects on N and P concentrations

Nitrate and ammonium increased rapidly post-fire and ammonium quickly returned to pre-fire values within a 12 months in both streams and lakes (streams:Fig. 2ace, lakes: SM fig 1). Nitrate, however, continued to show spring pulses. Soluble phosphorous also increased in streams and lakes but the magnitude varied and there are indications of spring pulses. Interestingly, the lake with long-term data did not show a clear response to the fire, although the whole catchment burnt severely. This is a rather large lake with a small catchment and the lake covers 21 percent of its catchment.

Proportion peatland cover of the catchments did not consistently correlate with post-fire nutrient concentrations. Nitrogen in lakes and streams correlated with total catchment area (Fig. 2bd, sample date for streams 3 months post-fire and for lakes 2.5 months), but not for phosphate (Fig. 2e). However, this relationship was not supported for early samples in streams (1 months post-fire). Accounting for catchment or lake size in the analyses did not improve result in a correlation with proportion peatland.

Effects on S, Si and Ca concentrations

Sulphate and calcium concentration followed the same pattern as N and were after a year similar to normal values (Fig. 3ae). In contrasts, the response of Si concentration was less obvious and the fire likely had a minor impact on the concentration of this element (Fig. 3c). Differences in response among lakes and

Table 1: **Characteristics of the 20 catchments.**

Streams	Site name	Latitude	Longitude	Watershed area (ha)	Upland forest (%)	Clear-cut forest (%)	[illegible]
1	Märrsjöbäcken	59.93975	16.04151	374	60	14	[illegible]
2	Sågbäcken	59.94575	16.16739	447	71	9	[illegible]
3	Vallsjöbäcken	59.87722	16.08246	1832	71	8	[illegible]
4	Gärsjöbäcken	59.92148	16.22886	2174	57	9	[illegible]
5	Gottricksbäcken	59.85722	16.11434	492	57	12	[illegible]
6	Myckelmosbäcken	59.89688	16.27152	935	67	5	[illegible]
7	Ladängsbäcken	59.81867	16.17334	1439	61	11	[illegible]
Lakes							
8	Snyten	59.97343	16.01339	2354			
9	Märrsjön	59.94867	16.05693	233			
10	Hörendesjön	59.95714	16.18718	3584			
11	Lilla Grillsjön	59.94019	16.07991	209			
12	Stora Grillsjön	59.92877	16.09018	391			
13	Stora Vallsjön	59.91165	16.1156	1322			
14	Gärsjön	59.92114	16.22385	2168			
15	Björktjänern	59.89458	16.12473	113			
16	Hannsjön	59.89845	16.21749	88			
17	Stora Gottricken	59.87124	16.14243	119			
18	Sörlången	59.86371	16.14665	87			
19	Öjesjön	59.85376	16.24121	502			
20	Fläcksjön	59.87032	16.31943	3388			

streams were also here correlated with catchment size (Fig. 3bdf), rather than peatland cover. For early samples in streams (1 months post-fire), no correlation with catchment size or peatland cover were found.

Impact on pH, ion charges and DOC

Fire had a marginal effect on pH in streams and lakes. In streams, there were a short acidification pulse the first few months but then pH have slowly increased over time (Fig. 4ab). Analyses of ions showed that the pH did not change much due to drop in organic acids (RCOO-) post-fire while sulphate increased (Fig. 4c-f). Thus, the acids canceled out each other and pH remained fairly constant. DOC showed a marked decrease immediately after the fire???? (Fig. 5??).

Discussion

Our results..

Acknowledgments

We thank...

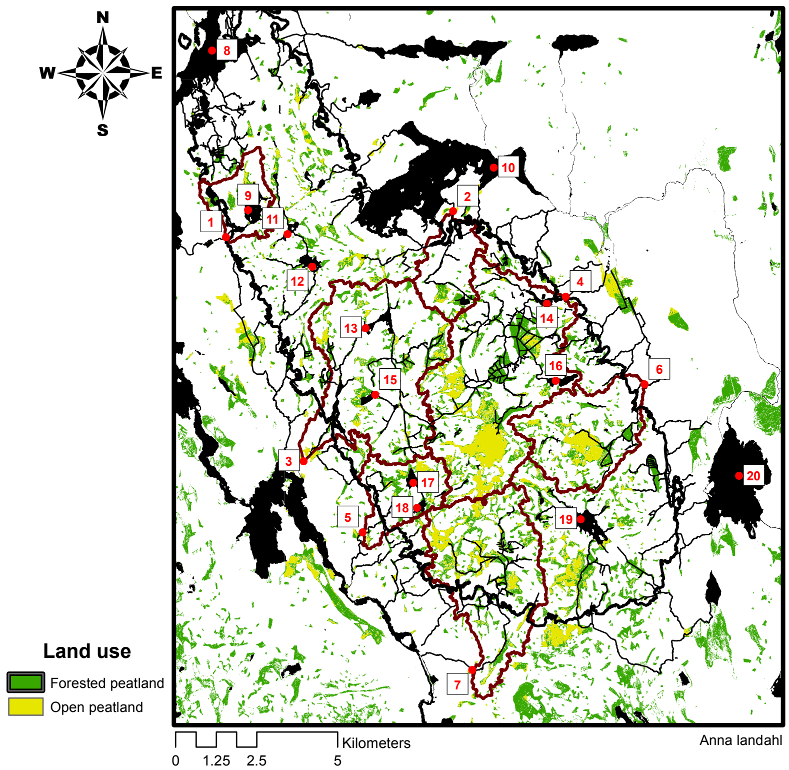

Figure 1: Map indicating the location of the 20 sampling stations. Catchment characteristics of the sampling stations are given in table 1. Red lines mark the catchments for the sampled streams. Narrow black lines are ditches and strems while the thick black line illustrates the outer limit of the fire.

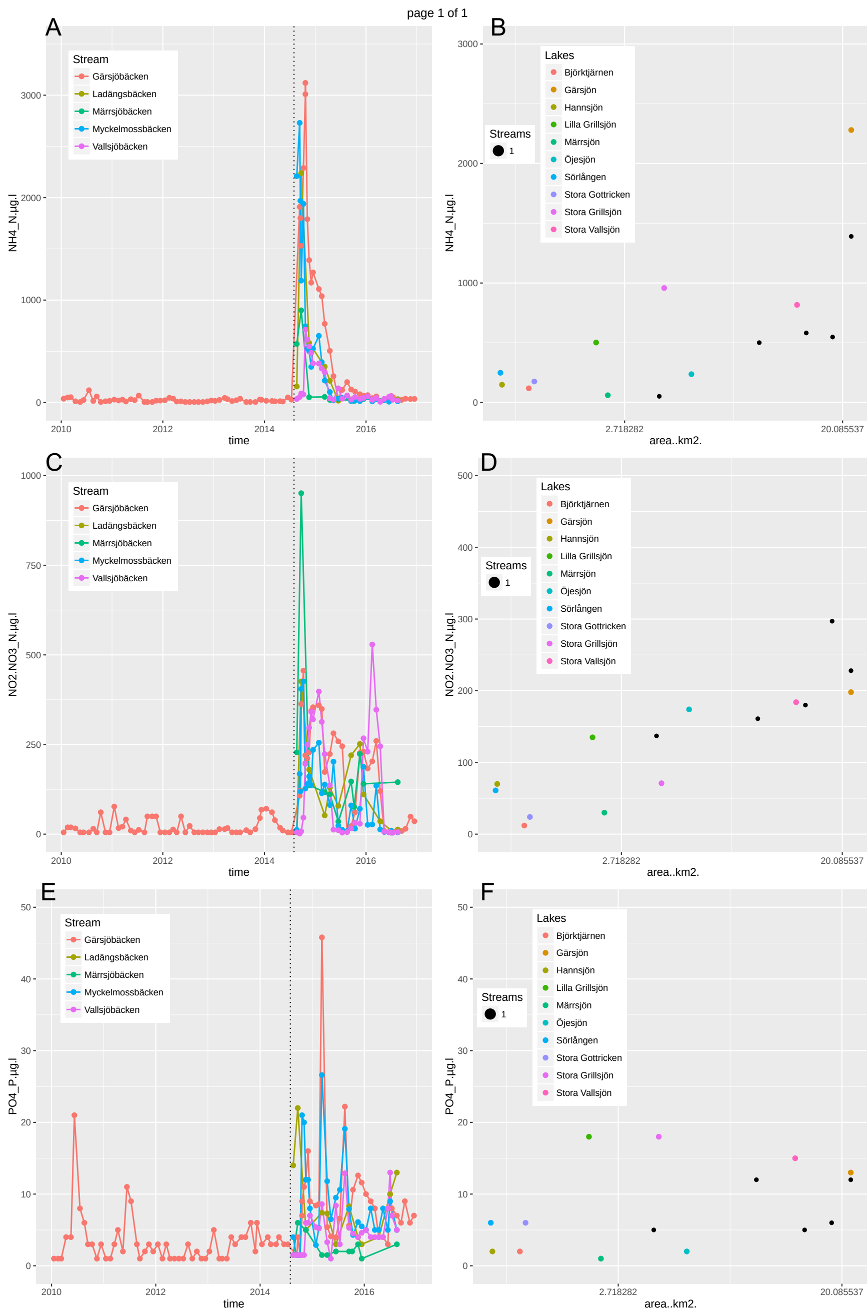

Figure 2: Ammonium, nitrate and phosphate concentration in streams and lakes. A,C,E) data from five streams of which one was sampled prior to the fire (Gärsjöbäcken). B,D,F) response variables plotted against (log) catchment size for lakes (colors) and streams (black points).

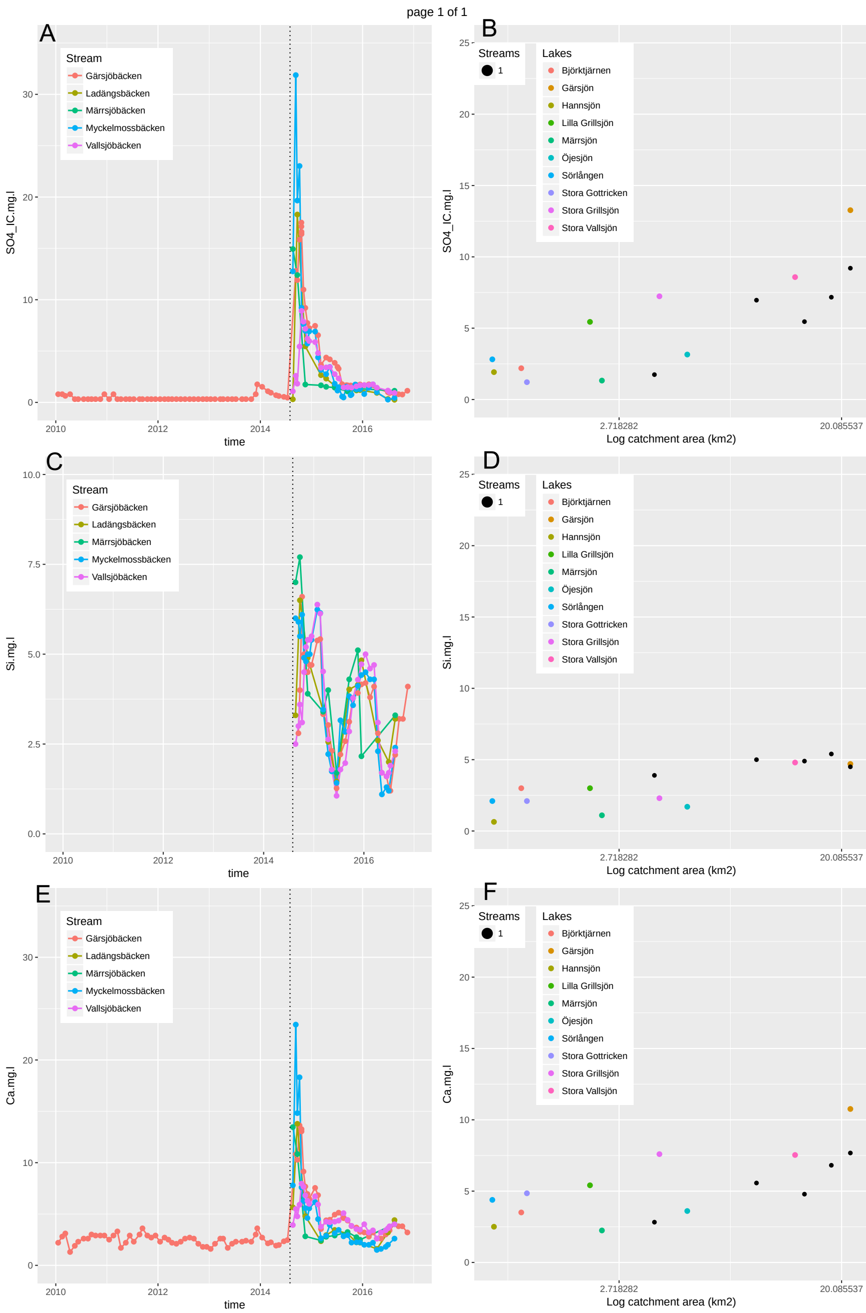

Figure 3: Sulphate, silicon and calcium concentration in streams and lakes. A,C,E) data from five streams of which one was sampled prior to the fire (Gärsjöbäcken). B,D,F) response variables plotted against (log) catchment size for lakes (colors) and streams (black points).

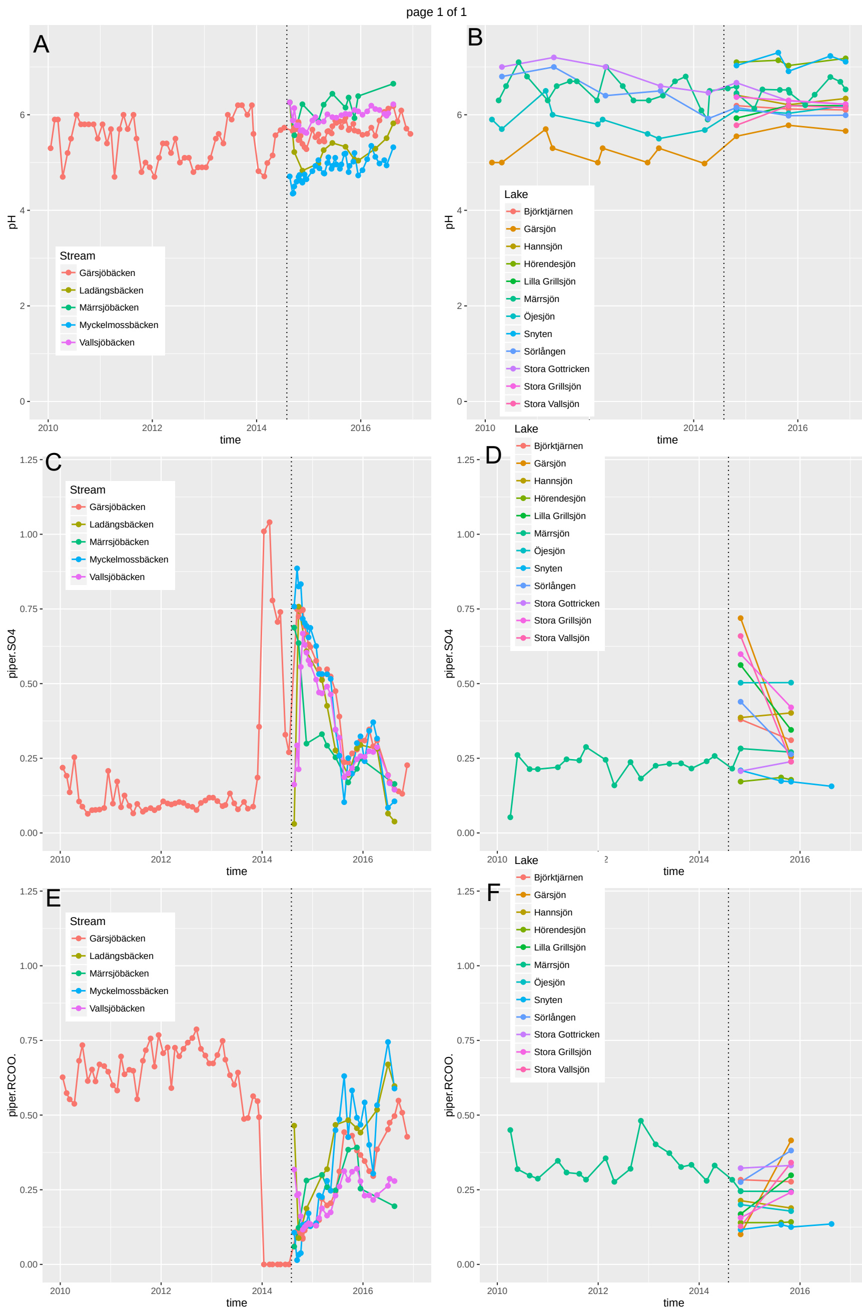

Figure 4: Repla............

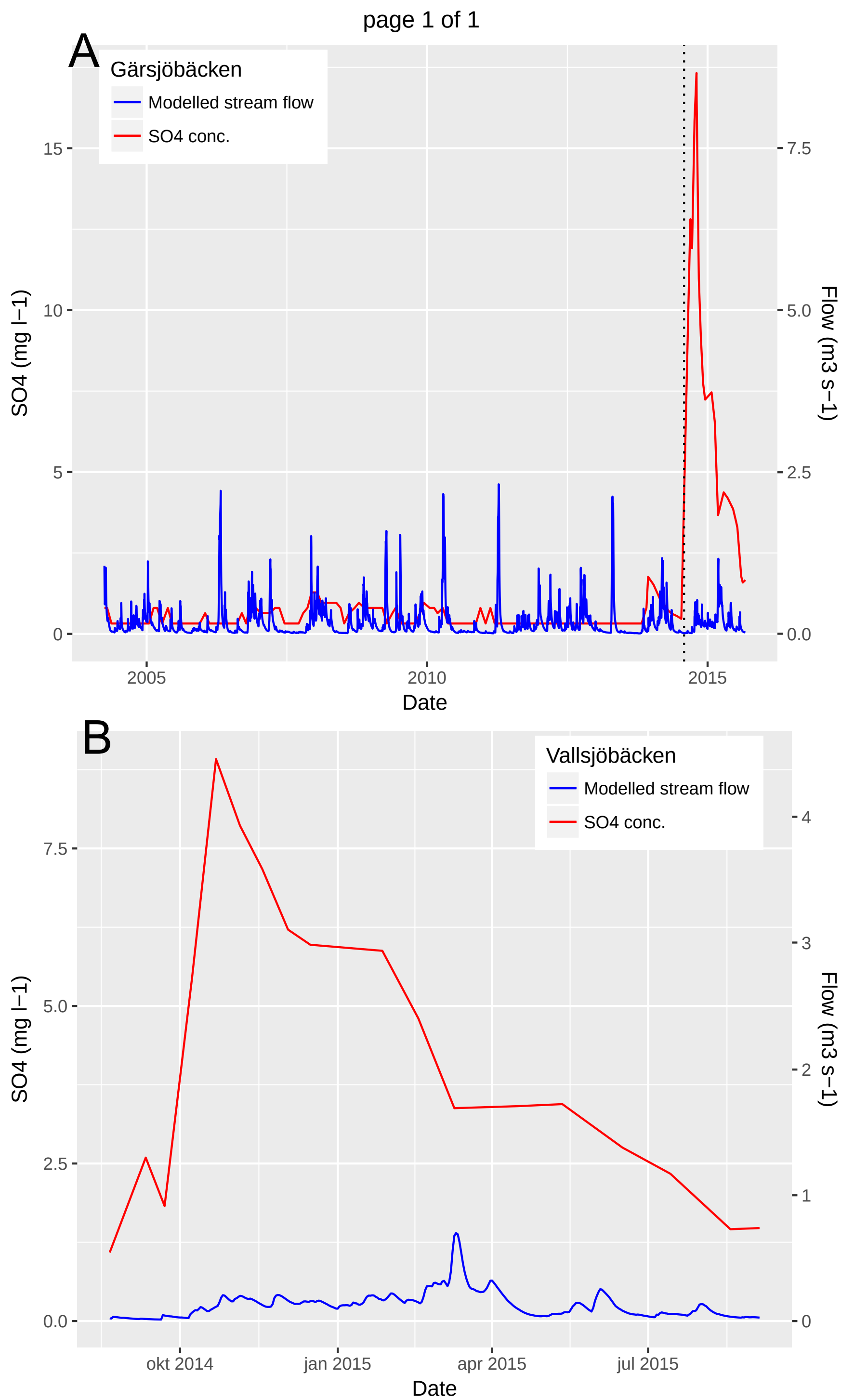

Figure 5: Modelled daily stream flow data and interpolated sulphate concentrations for the two largest catchments in the burnt area. (A) Gärsbjöbäcken have been sampled over longer time period (here we show data over 10 years prior to the fire), while sampling at (B) Vallsjöbäcken started after the fire.

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