Patterns and factors affecting brownification in a boreal river

A study on the brownification in River Storån, the biggest sub-catchment of Lake Bolmen in Southern Sweden

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Brownification – a process affecting the color of our lakes and streams

Lakes and streams in the northern hemisphere have during the last decades become increasingly more brownish in color, a process which has been given the name brownification. The color change has been attributed to an increase of the organic content in the water, which pose several challenges for the organisms inhabiting these aquatic environments as well as us humans for which the water constitutes a resource. For example, when surface water is treated to produce drinking water, the increased organic content requires higher efforts during treatment. Brownification also seems to be affecting Lake Bolmen, the tenth largest lake in Sweden, which serves as freshwater source for drinking water to about 750.000 people in Southern Sweden. It is in this context that a study was initiated in order to examine the potential drivers of brownification in the biggest sub-catchment of Lake Bolmen, the catchment of River Storån.

What are the drivers behind brownification?

The brownification of lakes and streams has been attributed to an increase of organic content in the water which are substances leached from the top soil layers, called humic substances. A number of theories have been proposed to explain the drivers behind the brownification process, among them the decrease of sulfur deposition from reduced industrial emissions, changes in land use through increased industrial forestry and changing patterns of hydrological and meteorological parameters such as precipitation, stream discharge and water temperature. More recently, the relationship between iron concentration and color has also been highlighted, as the presence of iron plays an important role in the water chemistry through ion exchange and formation of complexes with organic compounds.

What data can be used to examine the brownification process and its drivers?

The color export was retrieved from samples taken at four locations in the catchment between 1978 and 2018 by the river basin organization in the area, Lagans Vattenråd, and compared to data on precipitation, temperature and land use collected for the same time period from SMHI (Swedish Institute of Hydrology and Meteorology) as well as other sources.

About Lake Bolmen and the catchment of River Storån

Lake Bolmen is Sweden's tenth largest lake, covering an area of 183 km^2. It provides drinking water for circa 750.000 people in 12 municipalities in southern Sweden through a 82 km long tunnel which transports water from the water works near Skeen in the southern part of Lake Bolmen to Ringsjöverket treatment plant in Stehag, Scania where the raw water is treated and distributed for consumption.

The catchment of River Storån lies to the north of Lake Bolmen, and includes the main tributary to the lake, River Storån. The water basin organization have collected samples for analysis of color during varying intervals at six points in River Storån catchment from 1978 to present day (see points 530-568 in Figure 1).

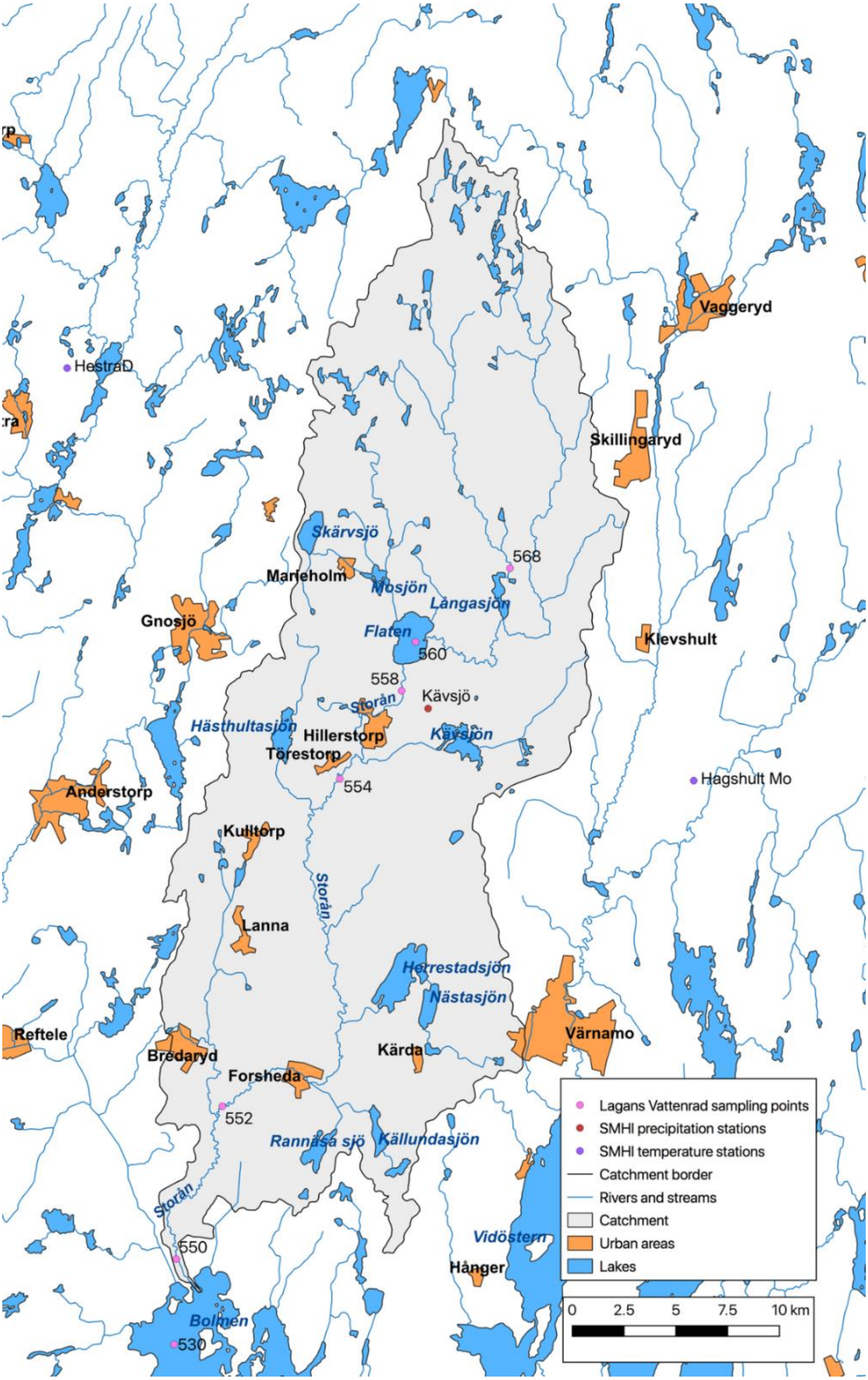

Figure 1. Overview of River Storån catchment showing Lagans Vattenråd's sampling points, SMHI's measuring stations, urban areas and water bodies. The catchment is in light grey with a black line marking its borders.

The catchment is dominated by forest, which comprises about 70% of the area. Agricultural lands comprise about 6-8%, while mires and wetlands make up for about 13 %. The national park of Store Mosse, consisting of a large bog, make up a significant part of the wetland coverage. Urban and industrial areas account for about 1%. The biggest urban settlements in direct connection to River Storån are Hillerstorp and Forsheda, with a population of circa 1500 inhabitants each.

Although River Storån is by far the biggest contributor of water volume it does not have the highest average color of the four main tributary inflows to Lake Bolmen (see Table 1). Even so, being the main inflow in terms of volume means that the river still contributes the biggest share of color when examined as a pollutant load, constituting a share of 64% of the pollutant load (see Table 2).

Tabell 1. Average color in tributaries to Bolmen

Stream	Average color (mg/Pt l)
Storån	192
Lillån	234
Unnen	105
Murån	291

Tabell 2. Contribution of color based on average color and discharge.

Stream	Contribution to total color/pollutant load (%)
Storån	64
Lillån	21
Unnen	12
Murån	3,5

Color, precipitation intensity seem to be increasing – but land use might be an even more important driver

Using the data from 1978 to 2018, the color in River Storån was found to be increasing, both when examining the average color and the extreme color values in the 95th percentile, which showed a positive linear trend. A Mann-Kendall test (statistical test used for data sets with seasonal variations) was also used to prove if there is a positive trend in the whole data set, containing all the color values from every sample from 1978 to 2018. The results show that a positive trend is taking place, supporting previous observations of increasing color in Lake Bolmen.

Notable was also the high correlation found between iron concentration and yearly precipitation, which seem to support the theory that the increase of iron is the result of wetter conditions in the upper soil layers due to increasing precipitation. The iron concentration in turn seems to be correlated to color, with a correlation coefficient of 0.81 at the outlet of River Storån, as can be seen in Figure 3.

A moderate to high correlation was established between yearly average precipitation and color, the highest being 0.74 near the precipitation measuring station in the catchment. At the outlet of River Storån a correlation coefficient of 0.67 was found, of moderate significance (see Figure 4).

A moderate negative correlation between sulfate concentration and color was found in several of the sampling points (Figure 5 shows the correlation at the outlet of River Storån). This indicates that there might be a relationship between the two though it is relatively weak compared to other parameters.

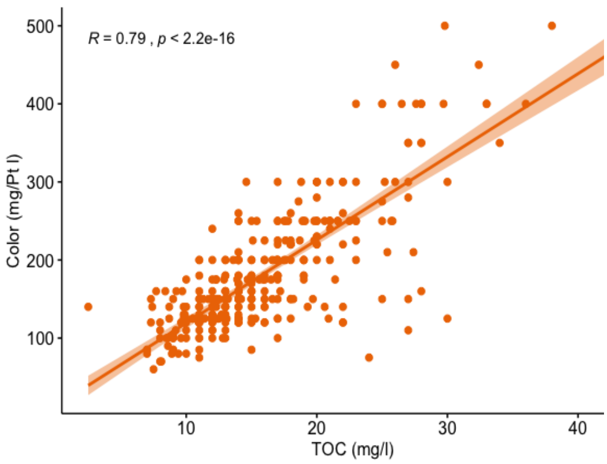

Figure 2. Correlation between TOC and color at the outlet of River Storån (1978-2018).

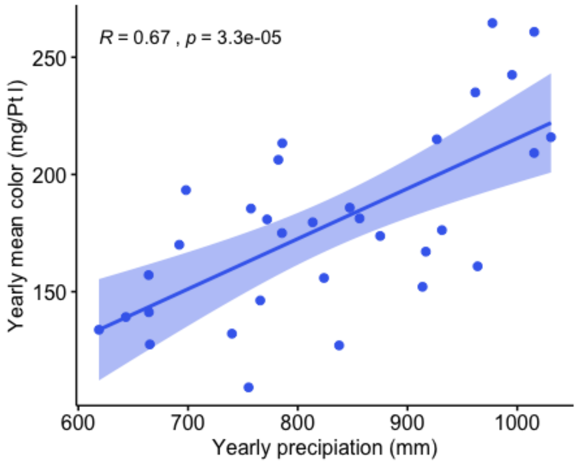

Figure 4. Correlation between yearly average precipiation and color at the outlet of River Storån from 1978-2018.

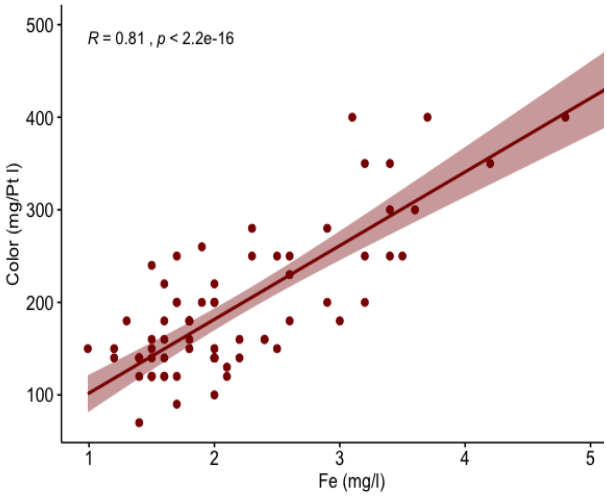

Figure 3. Correlation between iron and color at the outlet of River Storån (2011-2017).

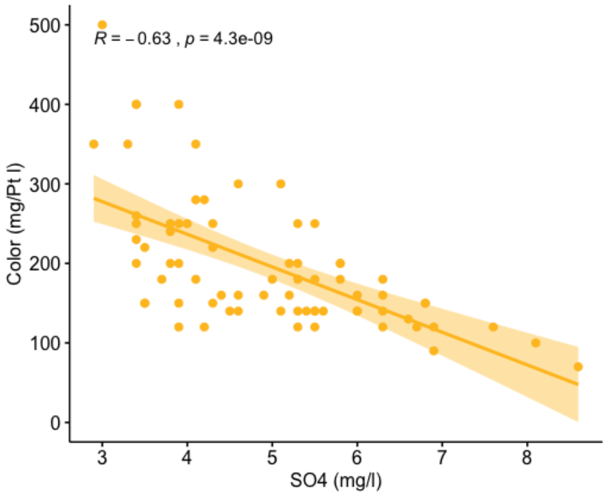

Figure 5. Correlation between sulfate concentration and color at the outlet of Storån (2011-2017).

The differences in land use between the sub catchments around Lake Bolmen seem to be related to freshwater color, as the catchments having the highest forest and wetland coverage also have the highest color values. An interesting observation of a significant increase in color downstream from areas with large wetlands in River Storån suggest that they contribute significantly to the color, however further investigations are needed to confirm this theory

No clear relationship between air or water temperature and color could be established, however the air temperature in the area shows an increasing trend.

Challenges in data reliability and consistency

Some of the relationships investigated in this report between color and different parameters rely on data that is either modelled or contain inconsistencies, making it difficult to assess and compare these relationships.

The data from Lagans Vattenråd is inconsistent in frequency, with the number of measurements of color varying from year to year. Measurements of sulfate and iron were only conducted between 2011 and 2017 and contains a gap of one year during 2013 when no samples were taken. The absence of a continuous data series for these parameters during the whole investigated period means it is hard to examine their relationship with color or brownification. To be able to draw more conclusions on their relationship with color a longer time period of study would be more adequate, as the change in color is a slow process happening over decades.

Measured flows in River Storån are rare to come by

No observed flow data was available for the catchment of River Storån. Instead the discharge data for River Storån were generated from the SMHIs HYPE model, which is calibrated with observed flow data measured at the outlet of Bolmen. The HYPE model is used for large scale modeling of for example phosphorus load to the Baltic Sea, and while it might be optimal for such large scale conditions it might not be suited to accurately model flow of minor rivers or streams in sub-catchments such as that of River Storån. To better understand the relationship of discharge and color, ideally one would measure observed flows on multiple points along River Storån, for varying depths or stream channel types, in combination with measurements of color.

Many of the data series used in the study are incomplete and where not taken between consistent intervals. This proves a difficulty when trying to establish relationships with other parameters when parts of the data have different sample frequency or when there is data missing for certain periods of time. To compare the precipitation with color, a challenge was presented as the available measurements on precipitation from SMHI were made with small and consistent frequencies while the color data from Lagans Vattenråd consisted of monthly samples with varying intervals in between.

A cross correlation analysis that takes into account a lag effect for the parameters representing the drivers might also have been be able to give useful insights, as the impact on color from some of the potential drivers likely has a delayed effect.

What the future holds in store with regards to brownification

As with many other processes concerning water quality in the natural environment, brownification seem to be the product of several different factors. This is very important to remember when researching the topic and applying and discussing theories of the driving factors behind the process. As the color Lake Bolmen and River Storån is increasing, and much likely will continue to increase, it is important to continue to monitor the water quality and the parameters related to brownification. With the right steps taken to better understand the relationships governing the process, improved predictions can be made regarding the water quality, which can help preserve the valuable resource that are our fresh water lakes.

Picture of one of the main tributaries to Bolmen, Lake Unnen.