Increasing TOC and Fe concentrations in surface waters from forested headwater catchments in eastern Finland

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Introduction

• Water colour has been observed to be increasing in lakes and rivers across Europe and North America, particularly during the last 15-25 years
• Increased concentrations of DOC (TOC) in surface waters
• Several explanations to this phenomenon:
  - climatic warming
  - decrease in acidic deposition
  - land-use changes
• The dominant explanatory factor seems to be different in different geographical regions
• Also Fe has significant role in water brownification.
• Fe bound to high molecular weight organic colloids in boreal waters
  colour increases in pace with increasing Fe concentrations
  the cycles of TOC and Fe strongly interlinked

• The effect of Fe on water colour varies depending on its oxidation state, hydration, and chemical complexation
• Increasing Fe concentrations in rivers observed e.g. in Sweden (Kritzberg & Ekström 2012)
• Only little attention has been paid on the temporal changes in Fe, particularly in forested boreal catchments.
Study objectives

1) how the annual and seasonal Fe concentrations have changed in forested headwater catchments in eastern Finland.

2) which catchment characteristics and hydrometeorological parameters correlate with stream water Fe concentrations.

3) whether any trends in Fe conc. correlate with TOC conc., which would suggest a similar driver behind both trends.

4) whether Fe conc. are increasing more from peat dominated catchments compared to mineral soil dominated
Trends in TOC and Fe

Fe-concentrations

TOC-concentrations

1995-2006
Peatlands as source of TOC and Fe

- The Fe concentrations from peatland dominated catchments (> 50% cover) during 1995–2006 averaged 1915.0 μg L⁻¹ and from the mineral soil catchments (peatland proportion < 20%) 288.0 μg l⁻¹

- The average TOC concentrations respectively 27 mg L⁻¹ and 12.2 mg L⁻¹

- Toc concentrations increased 14-44% and those of Fe 21-74%

- Peatlands, where redox processes are predominant, are the main source of terrestrial Fe in surface waters.
The annual and seasonal trends in Fe-concentrations (1995-2006); the direction and statistical significance (+/-) of the trends.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Annual</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>October-December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kivipuro</td>
<td>+</td>
<td>+</td>
<td>(+)</td>
<td>+</td>
<td>(+)</td>
</tr>
<tr>
<td>Liuhapuro</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Murtopuro</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Suopuro</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Välipuro</td>
<td>+</td>
<td></td>
<td>(+)</td>
<td>+</td>
<td></td>
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<tr>
<td>Korsukorpi</td>
<td>+</td>
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<td>(+)</td>
<td>(+)</td>
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<tr>
<td>Porkkasalo</td>
<td></td>
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<tr>
<td>Kangaslampi</td>
<td>+</td>
<td></td>
<td></td>
<td>(+)</td>
<td></td>
</tr>
</tbody>
</table>

- No significant change in the annual Fe-exports!
• According to mixed model regression analysis the Fe concentrations were explained by:

<table>
<thead>
<tr>
<th>Season</th>
<th>Effect of Peatland%</th>
<th>Effect of Water temperature</th>
<th>Effect of Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>+Peatland%</td>
<td>+Water temperature</td>
<td>-Runoff</td>
</tr>
<tr>
<td>Spring</td>
<td>+Peatland%</td>
<td>+Tree stand volume</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>+Peatland%</td>
<td>+Water temperature</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>+Peatland%</td>
<td>+Air temperature</td>
<td>-Runoff</td>
</tr>
</tbody>
</table>
- Trends in the Fe- and TOC-concentrations correlated with peatland coverage
Annual TOC concentrations vs. Fe-concentrations in stream water by catchments
• The Fe concentrations did not increase noticeably more than TOC concentrations.
• The estimated trend slopes for TOC and Fe showed a strong positive correlation with each other.
Relationship between the slope estimates of the trends (in 1995–2006) in the mean annual concentrations of TOC and Fe in the studied 8 catchments.
• As our catchments are situated in a region of low deposition and temperature was a dominant driving force explaining the TOC increase the implication is that Fe must also be responding to changes in hydrometeorological conditions.

• Fe concentrations are proposed increasing mostly because of changed redox conditions, particularly in organic soils.
Air and water temperature 1978-2006 in the region of monitored catchments in eastern Finland

Air temp. increased in summer and autumn  
Water temperature increased

- Air temp. increased in summer and autumn
- Water temperature increased

Graphs showing the mean air temperature and mean water temperature over the years from 1978 to 2006, with a noticeable increase in both during summer and autumn, and an increase in water temperature as well.
Precipitation and runoff (Sarkkola et al. 2009)

No change in annual precipitation

Runoff was decreasing

Vuosivalunta, mm

Annual runoff, mm
• Increased late autumn–early winter temperature and increased winter precipitation in the form of rainfall

increasingly anoxic conditions in previously aerobic soil profiles.

Increasing Fe solubility and leaching to receiving water bodies (reduced Fe (II) -> oxidized Fe(III))
• Since coloured water absorbs more solar radiation than clear water, it may be that the increase in Fe and TOC is resulting in increased stream water temperatures.

• The warmer late autumn–early winter periods with more rainfall are reflected also in the Fe concentrations of the next year.

• Higher soil moisture conditions not only during the current autumn–winter period but also during the next spring and early summer.
Conclusions

- Increased water colour or water browning in the lakes and rivers of North Europe may not only be due to the increased TOC concentrations but also to the increased Fe concentrations.

- The driving force would be the change in redox conditions, particularly during the late autumn and early winter periods.
• Fe and TOC were in the correlation with each other; mostly in peat dominated catchments; risk of Fe leaching may be considerable in peatlands if the increase in the organic matter exports continues.

• Future catchment studies should integrate water quality monitoring programmes with concurrent soil and soil water observations.
References


Thank you!
The study sites

• 8 forested headwater catchments (area: 29-494 ha) in Eastern Finland

Time series:
• Nurmes-catchments: 28 years (1978-2006)
• Valu-catchments 15 years (1992-2006)

• Testing period in this study 1995-2006

• Both pristine and managed catchments

• No significant effects of management during the monitoring period
Main stream and weir on pristine Liuhapuro catchment. Runoff was monitored continuously and element concentrations were analysed from water samples taken about 1-2 times/month (Photos Sakari Sarkkola)
• Annual and seasonal (Spring, Summer and Autumn) runoff and mean Fe- and TOC-concentrations and exports calculated from daily and weekly measurements

• Trends in the concentrations and exports were tested by Seasonal-Kendall –test.

• Regression approach (OLS and Mixed modeling) were used to describe the relationships between trends as well as to identify the factors affecting the concentrations and exports.

• Main results of TOC published earlier (Sarkkola et al. 2009)