OrgC, N and P retention in a deep boreal lake (Pääjärvi, Finland)

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Background

- Lakes play a significant role in retention of the key elements, phosphorus (P), nitrogen (N) and organic carbon (orgC) along the hydrological pathway from terrestrial drainage basins to the seas (e.g. Jonsson & Jansson 1997; Seizinger et al. 2002; Kortelainen et al. 2004, Cole et al. 2007)

- In Finland, freshwater lakes cover 10 % of the land area and lakes are therefore potentially important nutrient modifiers (Lepistö et al. 2006, Einola et al. 2011)

- Sedimentation of P, in particular, may reduce the productivity of the food webs as P is often considered a limiting nutrient for algal growth in freshwater ecosystems (e.g. Vollenweider 1968, Dillon & Rigler 1974, Jonsson 1997, Arvola et al. 2010)

- Hydraulic residence time has proved to be a key factor in explaining differences among the lakes in terms of nutrient retention
• This is why we expect to see

  a) an increase in retention efficiency of major nutrients when hydraulic residence time extends, and the opposite with shorter residence time while

  b) an increase in retention per unit area along a shorter residence time due to the enhanced loading from the catchment

• To test the two hypotheses we used long-term intensive hydrological and loading information of Lake Pääjärvi, a medium-size boreal lake situating in southern Finland

• Regarding the focus of this presentation the data sets used for the analysis have a keystone role.
Material and methods

- Lake Pääjärvi; oligo-mesotrophic boreal lake with brown water in southern Finland (WGS84 - lat: 61.06469, lon: 25.13866)
- Lake’s surface area: 13.4 km²; Max and mean depths: 85 m and 15 m
- Catchment area: 199 km²
- Water level is controlled artificially with a maximum annual fluctuation of 60 cm
- Chemistry of 6 inflows monitored since 1995 on the weekly basis; the monitored sub-catchments comprise ~85% of the drainage basin
- Discharge measurements have been carried out in three inflows and the outflow since 1972; the measured inflows contribute 68% of the total discharge
- Standard methods were used for chemical analyses
Retention is the difference between the input and output of nutrients.

Eq. 1. \[ \text{Input} = Q \times C + D \]

where
- \( Q \) = discharge
- \( C \) = concentration of the element (P, N, orgC)
- \( D \) = deposition (P, N) to the lake

Eq. 2. \[ \text{Retention (\%)} = \frac{\text{Input} - \text{Output}}{\text{Input}} \times 100 \]
Pääjärvi catchment

- Haarajoki: 199 km²
- Löyttynoja: 81 km²
- Mustajoki: 81 km²
- Luhdanjoki: 25 km²
- Koiransuolenoja: 7 km²
- Letkunoja: 0.5 km²
- Löyttynoja: 9 km²
- Outflow: 58 km²

Map showing the catchment area with tributaries and outflow.
<table>
<thead>
<tr>
<th>Land-use</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>63</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>19</td>
</tr>
<tr>
<td>Peatlands</td>
<td>14</td>
</tr>
<tr>
<td>Lakes</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>
### R 1 – Annual retention (g m⁻²) of nutrients

<table>
<thead>
<tr>
<th>Year</th>
<th>OrgC</th>
<th>Tot-N</th>
<th>Tot-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>34.6</td>
<td>1.60</td>
<td>0.22</td>
</tr>
<tr>
<td>1996</td>
<td>28.2</td>
<td>2.52</td>
<td>0.09</td>
</tr>
<tr>
<td>1997</td>
<td>10.5</td>
<td>1.51</td>
<td>0.10</td>
</tr>
<tr>
<td>1998</td>
<td>57.4</td>
<td>3.72</td>
<td>0.22</td>
</tr>
<tr>
<td>1999</td>
<td>23.2</td>
<td>2.13</td>
<td>0.14</td>
</tr>
<tr>
<td>2000</td>
<td>27.0</td>
<td>2.95</td>
<td>0.17</td>
</tr>
<tr>
<td>2001</td>
<td>16.3</td>
<td>1.29</td>
<td>0.11</td>
</tr>
<tr>
<td>2002</td>
<td>9.5</td>
<td>1.04</td>
<td>0.08</td>
</tr>
<tr>
<td>2003</td>
<td>8.2</td>
<td>2.55</td>
<td>0.10</td>
</tr>
<tr>
<td>2004</td>
<td>33.8</td>
<td>1.19</td>
<td>0.22</td>
</tr>
<tr>
<td>2005</td>
<td>5.8</td>
<td>-0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>2006</td>
<td>29.9</td>
<td>5.01</td>
<td>0.13</td>
</tr>
<tr>
<td>2007</td>
<td>15.0</td>
<td>0.78</td>
<td>0.08</td>
</tr>
<tr>
<td>2008</td>
<td>27.4</td>
<td>1.92</td>
<td>0.13</td>
</tr>
<tr>
<td>2009</td>
<td>9.0</td>
<td>0.21</td>
<td>0.07</td>
</tr>
<tr>
<td>2010</td>
<td>12.8</td>
<td>1.22</td>
<td>0.11</td>
</tr>
<tr>
<td>Mean</td>
<td>21.8</td>
<td>1.85</td>
<td>0.13</td>
</tr>
<tr>
<td>SD</td>
<td>13.2</td>
<td>1.25</td>
<td>0.05</td>
</tr>
<tr>
<td>CV%</td>
<td>60.5</td>
<td>67.6</td>
<td>39.3</td>
</tr>
</tbody>
</table>

[Graph showing annual retention (OrgC, TN, TP) over years with data points for each year.

Inflow data for each year is also provided.]
Result 2 – Retention vs load

Phosphorus retention vs. load

Nitrogen retention vs. load

Organic carbon retention vs. load

R 3 – Retention vs retention

P retention vs. N retention

P retention vs. organic carbon retention

N retention vs. organic carbon retention

y = 0.7708x

$R^2 = 0.9476$

y = 0.2832x

$R^2 = 0.3232$

y = 0.3706x

$R^2 = 0.6325$

y = 0.0163x + 97.772

$R^2 = 0.1644$

y = 0.0032x + 58.475

$R^2 = 0.6975$

y = 0.0586x + 572.92

$R^2 = 0.3815$

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$R^2 = 0.9476$

y = 0.2832x

$R^2 = 0.3232$

y = 0.3706x

$R^2 = 0.6325$

y = 0.0163x + 97.772

$R^2 = 0.1644$

y = 0.0032x + 58.475

$R^2 = 0.6975$

y = 0.0586x + 572.92

$R^2 = 0.3815$
R 4 – Retention vs residence time

- **Phosphorus retention vs. residence time**
  - $R^2 = 0.0436$
  - $y = 689.9x \cdot 1.3$
  - $R^2 = 0.689$

- **Nitrogen retention vs. residence time**
  - $R^2 = 0.0113$
  - $y = -2025\ln(x) + 4587.3$
  - $R^2 = 0.1508$

- **Organic carbon retention vs. residence time**
  - $R^2 = 0.3536$
  - $y = 35827x \cdot 2.20$
  - $R^2 = 0.717$
R 5 – Weighted mean concentrations (mg m\(^{-3}\)) of N and P fractions, and orgC in the input and in Lake Pääjärvi during 1995-2010

<table>
<thead>
<tr>
<th></th>
<th>NO(_3) + NH(_4)-N</th>
<th>OrgN</th>
<th>TN</th>
<th>PO(_4)-P</th>
<th>TP</th>
<th>OrgC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>912</td>
<td>546</td>
<td>1458</td>
<td>7.9</td>
<td>40</td>
<td>11300</td>
</tr>
<tr>
<td>Lake</td>
<td>932</td>
<td>440</td>
<td>1372</td>
<td>1.8</td>
<td>10</td>
<td>11151</td>
</tr>
<tr>
<td>Change</td>
<td>-20</td>
<td>106</td>
<td>86</td>
<td>6</td>
<td>30</td>
<td>149</td>
</tr>
<tr>
<td>Change%</td>
<td>2.2</td>
<td>19</td>
<td>5.9</td>
<td>78</td>
<td>75</td>
<td>1.3</td>
</tr>
</tbody>
</table>
R 6 - Stoichiometric ratios of orgC:N:P in the input, lake and retention

<table>
<thead>
<tr>
<th></th>
<th>OrgC</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>730</td>
<td>81</td>
<td>1</td>
</tr>
<tr>
<td>Lake</td>
<td>2881</td>
<td>304</td>
<td>1</td>
</tr>
<tr>
<td>Retention</td>
<td>440</td>
<td>32</td>
<td>1</td>
</tr>
</tbody>
</table>
R 6 – Iron & P retention

Fe retention >96%

y = -296.59x + 113.5

R² = 0.832
Conclusions

• In Lake Pääjärvi the retention efficiency of P (74%) clearly exceeded that of orgC (34%) and N (27%)

• In Pääjärvi there is a tight relationship between the retention of nutrients per unit area and the amount of nutrients entering the lake while there was no clear relationship between the efficiency of nutrient retention and water residence time, except with orgC – a relationship which was negative

• The long-term P retention was lower than if the values would be calculated using the models of Kirchner & Dillon (1975) and Larsen & Mercier (1976) both of which overestimated the retention capacity by 10-15%. In contrast, the model of Frisk (1978) fit well with our mass-balance calculations

• Retention per unit area clearly increased along with shorter residence time, and this in particularly in case of orgC and P
Although the processes influencing nutrient retention in Lake Pääjärvi are not well known, iron seems to contribute significantly to the sedimentation of P.

Earlier Simola & Simola & Uimonen (1983) have found that in the deep area of the lake the accumulation of iron (55 g m\(^{-2}\) a\(^{-1}\)) has been stable over several decades, an estimate which exceeds 4 times the iron retention of this study.

Organic nitrogen composed almost 50% of total N in the inflows and 60% in the lake.

The variability in loading was lowest with N while in retention it was highest; P retention was clearly most stable on the annual scale.

Dissolved inorganic P contributed \(<20\%\) of total P both in the lake as well as in the inflows.

As a whole the annual orgC input (allochthonous + autochthonous) to the lake will be appr. 100 g C m\(^{-2}\), and \(~20\%\) of that will be lost by the in-lake processes.
Aknowledgements:

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THANK YOU!