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Key words: streams, water temperature, epilithic algae, macrophytes, mosses, geothermal influences.

Summary

Effects of temperature on periphyton in natural streams is poorly known. Rising air temperature in the future will affect aquatic habitats by many factors such as increasing growth rates and biomass of plants and macroinvertebrates. Most Icelandic streams are cold and pristine but there are also streams running from geothermal areas. Streams running from geothermal areas can be influenced by ground temperature or inflow of geothermal warm water. Hengill area SW Iceland has number of parallel streams with different temperature in a small area. We compared eight natural streams with different water temperature to estimate primary producers and to see how temperature might affect diatoms on stones by measuring chlorophyll a. Sampling was carried out for one year to get an estimator on seasonal changes of diatom biomass. There was significantly higher chlorophyll a concentration from epilithic diatoms in cold streams compared with warm streams. However there was much more abundance of macrophytes, mosses and macroalgae in warmer streams. Growth season in warm streams was short but it was long in cold streams. This could be due to heavy shading affect from bed vegetation in warmer streams on the epilithic diatoms. High chlorophyll a in cold streams can be explained by no stream bed vegetation and thus no shading affect. Community structure of diatoms between temperature regimes was very different; from warm streams we had many epiphyte diatoms but epilithic from cold streams. Diatom counts indicated low abundance of epilithic diatoms in warm streams and it supports the findings from chlorophyll a measurements. We concluded that temperature can have great affects on biomass of various primary producers and on the community structure within different temperature regimes.
Introduction

Few studies have been carried out for estimation of periphyton communities in unpolluted, pristine streams and very little is known about temporal variation of algal biomass. It is important to have reference data from pristine water conditions to be able to predict influences from nutrient enrichment and climate change on running waters (Lindstrøm et al., 2004, Vavilova, V. & Lewis, W. M. 1999). Rising air and water temperatures have significant influence on aquatic habitats by many factors (Cassie, 2006).

Water temperature has significant influence on water quality and biota in streams and rivers. Higher temperatures lead to increasing growth rates of organisms and control the presence or absence of species (Cassie, 2006).

Most Icelandic streams and rivers are pristine with low concentration of various nutrients (Brittain et. al 2008). Temperature, discharge and nutrient concentration is stable throughout most of the year in spring fed rivers and streams in Iceland. Limiting nutrients in streams can vary between seasons in streams and rivers due to precipitation, air temperature and production of algae and vegetation (Gíslason S.R. 1993, Chételat et.al 1999).

Biomass, species diversity and production of algae is usually low in arctic rivers due to long winters and low water temperature. However, some Icelandic streams originate in volcanic areas and are influenced by that, e.g. by unusually high water temperature and unusual water chemistry compared with streams at the same altitude in the same catchment.

The aim of this study is to estimate seasonal changes of epilithic diatoms from streams with different water temperature regimes by measuring chlorophyll $a$ from stones in the stream bed. We also compare the community structure of primary producers (macrophytes, mosses and macroalgae) between different temperature regimes.

In this study we investigate streams in the Hengill geothermal area, southwestern Iceland. Results from a pilot survey show that these streams have similar nutrient composition, pH, conductivity, slope and geology but different water temperature (Friberg et al., unpublished). The difference in water temperature is due to geothermal effects in the area. Thus, Hengill is a convenient study area to carry out comparative studies of natural streams with varying temperatures.
**Materials and methods**

*Research area*
The research was carried out in the Hengill geothermal area (360 - 380 m a.s.l.) in Southwest Iceland. Hengill is a volcano covering an area of c. 100 km². The area has many streams with different water temperature due to direct and indirect geothermal heating from the ground. The source of the heat can be from upwelling of cold groundwater or through the stream bed (Friberg, unpublished). The yearly average water temperature in the streams is from 4-40°C (Árnason et al., 1969).

*The streams*
Eight streams were selected based on background baseline researches from 2004 and 2005. The selection was based on water temperature, slope of the streams, conductivity, alkalinity and water chemistry. Four streams were classified as warm (15-25°C) and four as cold (4-10°C) but none of them had exactly the same temperature. Based on chemical analysis of water samples, the streams were not influenced directly from hot water but rather from ground heating. Colder streams have the water temperature as can be expected in natural mountain streams at similar altitudes. The streams are ideal for investigations of the effect of varying temperature regime because they are located in the same study area.

*Field work*
Sampling was carried out in March, April, May, June, July, August, September and December 2006. Conductivity, pH, temperature and nitrogen in the form of ammonia (NH₄) were measured in all streams on each sampling occasion. At each sampling occasion 10 stones were collected randomly from each stream. The stones were covered with aluminium foil to avoid light. Chlorophyll *a* was measured in the laboratory using a spectrophotometer. Estimation of macrophyte and moss cover was carried out in May 2007. Five samples were collected randomly from each stream using surber sampler of 20 x 20 cm. The total cover was estimated in percentages within each frame. Average vegetation cover was calculated for each stream (Table 1).
**Physical and chemical parameters**

Temperature was measured at every sampling occasion and with temperature loggers (Onset 32 K StowAway TidBits) to get measurements for a fine scale. Conductivity, pH and ammonia ($\text{NH}_4$) were also measured in every sampling occasion.

**Laboratory work**

Stones were kept in 96% ethanol in a refrigerator for 24 hours. After 24 hours, the ethanol was filtered and its volume was measured. Each stone was placed on a labelled paper towel to dry and later the stone surface area was measured with aluminium foil. The aluminium foil was wrapped over the area where the algae had accumulated. An unfolded square of known aluminium foil area was weighted for calibration and calculation of area.

The following equation from Hauer and Lamberti (2007) was used to calculate the unknown area of each rock:

$$A_r = \left(\frac{A_k}{W_k}\right) \times \frac{W_{ref}^2}{W_{rf}}$$

$A_r$ = known area, $W_k$ = known weight and $W_{rf}$ = weight of aluminium foil.

From each sample 4 ml of ethanol were put in a cuvette for chlorophyll measurements. Wavelengths of A665 and A750 were measured. The wavelength A665 was used to get an estimator of chlorophyll $a$ but A750 was used for correction of particles that might be in the cuvette. To estimate degraded chlorophyll $a$ 1 N HCl was added in each cuvette and the sample was measured again.

The formula from Talling and Driver (1961) was used to determine chlorophyll $a$ $\mu$L/cm² for each sample.

$$\text{Chlorophyll } a \, \mu\text{L/cm}^2 = \frac{(13.9 \times (A665-A750) \times \text{mL ethanol in the sample})}{(L \times \text{cm}^2)}$$

The number 13.9 is a constant for measuring chlorophyll $a$ in 96% ethanol (Talling and Driver, 1961).
**Statistical analysis**

The statistical software R was used for data analysis. The difference among warm and cold streams and the impact of the covariates nitrogen, conductivity, pH and temperature was studied by a linear mixed effect model over time (months) grouped by streams. The effects were tested with the restricted maximum likelihood estimation (REML), following a stepwise procedure (see Crawley, 2002). To test the difference of chlorophyll between the two temperature regimes we used t test for logarithmic changed data.

**Results**

![Ammonia (NH₄) concentration (mg/L) from each stream. Sampling period was from March to December 2006.](image)

Figure 1. Ammonia (NH₄) concentration (mg/L) from each stream. Sampling period was from March to December 2006.
Nitrogen concentration in form of ammonia (NH$_4$) was low throughout the period except for September when it was high in all streams (1 Figure).

Maximum precipitation occurred in September and the air temperature was above the freezing point (see appendix).

Cold streams had on average higher ammonia concentration than warm streams (ratio 3:1). The difference was however not significant according to t test (p-value 0.3695).

Figure 2. Average water temperature and 95% CI for warm and cold streams from March to December 2006. Open circles represent warm streams and filled represent cold strea
Figure 3. Average conductivity and 95% CI for warm and cold streams from March to December 2006. Open circles represent warm streams and filled represent cold streams.

Cold streams had a significantly lower conductivity than warm streams (p<0.000**).
Figure 4. Average pH and 95% CI for warm and cold streams from March to December 2006. Open circles represent warm streams and filled represent cold streams.
In March, chlorophyll \textit{a} concentration was low in both temperature regimes. It increased in April in the cold streams but decreased in the warm streams. In May, the warm stream had a peak but the peak was in September for cold streams. The summer growth in warm streams began in May and ended in August when chlorophyll values decreased rapidly. However, it began in April and ended in September in colder streams (figure 5).
Chlorophyll $a$ values were higher in colder streams compared with warm stream in most cases (except for May). There was highly significant ($p < 0.001$) difference between the two temperature regimes according to t test for log transformed data.

According to linear mixed effect model temperature and ammonia ($\text{NH}_4$) were significantly influencing chlorophyll $a$ concentration ($p<0.01$). Conductivity had significant influence on chlorophyll $a$ as well ($p<0.05$). In general, conductivity was lower in colder streams (figure 3). Ammonium and conductivity were covariates with temperature ($p<0.01$). Alkalinity (pH) had no influence on chlorophyll $a$ concentration.

Table 1. Average vegetation cover (%) in stream bed and standard deviation for warm and cold streams. Sampling date was 16. May 2007.

<table>
<thead>
<tr>
<th>Warm stream</th>
<th>Average and standard deviation</th>
<th>Cold stream</th>
<th>Average and standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS1</td>
<td>99±2.2</td>
<td>IS7</td>
<td>9±10.2</td>
</tr>
<tr>
<td>IS5</td>
<td>92±8.4</td>
<td>IS9</td>
<td>0</td>
</tr>
<tr>
<td>IS6</td>
<td>2.5±20</td>
<td>IS11</td>
<td>0.5±1.1</td>
</tr>
<tr>
<td>IS8</td>
<td>60±43.0</td>
<td>IS13</td>
<td>0</td>
</tr>
</tbody>
</table>

The warm streams had more bed vegetation cover than the cold streams. Warmer streams had bed vegetation cover from 2.5 – 99%. Stream 6 had low vegetation cover compared with other warm streams. The colder streams had from 0% - 9% vegetation cover. The standard deviation was high in IS8 and IS7 which indicates patchy vegetation cover in the stream bed (Table 1). Warm streams were dominated by mosses, filamentous green algae ($\text{Mougeotia}$ and $\text{Cladophora}$ spp) and $\text{Nostoc}$ but the cold streams were dominated by epilithic diatoms. Only the warm stream IS6 had similarities to cold streams with high diatom biomass.
Discussion and conclusions

Nitrogen (in the form of NH$_4$) had significant effect on biomass increase in the streams according to the mixed effect model. Colder streams had on average higher NH$_4$ than warmer streams (3:1) but the difference was not significant. Ammonium was found to be a cofactor with temperature by increasing biomass of epilithic diatoms. More ammonium in cold streams could be because submerged plants and mosses remove nitrogen compounds from the stream water for growth (Moss 2005).

Conductivity seemed to influence chlorophyll $a$ concentration with temperature and the mixed effect model indicated that low conductivity favoured chlorophyll $a$ increase. We cannot say that low conductivity has positive effects on epilithic diatom growth because of other factors like shading effects that may play more important role in warmer streams. High conductivity could be affecting biomass increase of other primary producers such as macrophytes and mosses.

Alkalinity (pH) did not have significant influence on chlorophyll $a$ and it was very similar between temperature regimes.

Chlorophyll $a$ from epilithic diatoms was generally higher in colder streams, and the difference between temperature regimes was significant. The growth season was longer in the cold regime compared with the warm. The growth season is long in cold streams is because there are no shading effects from bed vegetation. Short growth season for diatoms in warm streams is most likely because of heavy shading effect and growth of other primary producers during spring and summer. Other primary producers take space, light and nutrients from the epilithic diatoms. The warm streams had much higher biomass of mosses, macrophytes and macroalgae than the colder. In some cold streams there were no macrophytes or mosses at all.

However, macrophytes, macroalgae and mosses are important habitat for epiphytic diatoms and other epiphytic algae groups (Allan, J.D. 2006).

Identification and counts of diatom frustules from the streams have indicated much more abundance of epilithic diatoms in colder streams than in those that are warmer. However, there were more epiphytic diatoms identified in warm streams though the total abundance was much lower than for the colder streams.
Dominant algae groups for warmer streams are *Nostoc* and various groups of filamentous green algae (*Mougeotia, Cladophora*). Most of the identified diatom species found in warmer streams were epiphytic diatoms (i.e. *Rhoicosphenia curvata*). Colder streams are more like arctic and subarctic streams with dominance of diatoms (i.e. *Achnanthes, Diatoma, Nitzschia, Fragilaria*) and little or no macrophytes and mosses (Brittain 2008). This indicates great role of water temperature as a factor that controls succession of plants, mosses and algae in streams and the importance of habitat structure of those groups influenced mainly by water temperature. Other factors such as pH, conductivity, and geology were similar for all streams and therefore it was possible to acknowledge the water temperature as main factor on the variation in our streams.

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**References**


Appendix

Figure 6. Boxplots for log transformed chlorophyll a µg/cm² values from epilithic algae in warm and cold streams. Original data were highly skewed to right.
The highest average temperature was in July. The average temperature went from minus to plus in April and back again to minus in November (figure). The variation of temperature within month was not high (table).

Table 2. Mean temperature (°C) and 95% confidence intervals for Ölkelduháls data.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean</th>
<th>Upper 95% CI</th>
<th>Lower 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-1.59</td>
<td>-0.55</td>
<td>-2.62</td>
</tr>
<tr>
<td>February</td>
<td>-0.94</td>
<td>0.05</td>
<td>-1.93</td>
</tr>
<tr>
<td>March</td>
<td>-1.66</td>
<td>-0.83</td>
<td>-2.48</td>
</tr>
<tr>
<td>Month</td>
<td>Precipitation (mm)</td>
<td>Accumulated Precipitation (mm)</td>
<td>Rate of Change (mm)</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------</td>
<td>--------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>April</td>
<td>0.29</td>
<td>1.15</td>
<td>-0.57</td>
</tr>
<tr>
<td>May</td>
<td>3.39</td>
<td>4.15</td>
<td>2.62</td>
</tr>
<tr>
<td>June</td>
<td>7.45</td>
<td>7.85</td>
<td>7.06</td>
</tr>
<tr>
<td>July</td>
<td>9.64</td>
<td>10.13</td>
<td>9.14</td>
</tr>
<tr>
<td>August</td>
<td>8.67</td>
<td>9.02</td>
<td>8.32</td>
</tr>
<tr>
<td>September</td>
<td>6.43</td>
<td>7.13</td>
<td>5.73</td>
</tr>
<tr>
<td>October</td>
<td>2.54</td>
<td>3.4</td>
<td>1.67</td>
</tr>
<tr>
<td>November</td>
<td>-0.91</td>
<td>0.05</td>
<td>-1.87</td>
</tr>
<tr>
<td>December</td>
<td>-0.95</td>
<td>-0.04</td>
<td>-1.87</td>
</tr>
</tbody>
</table>

Figure 8. Average precipitation (mm) in Ölkelduháls 2006.
The average precipitation was low in May and August but high during winter months. It was at its maximum level in September and also very high October (figure). Wide confident intervals were in January and September (table).

Table 3. Average precipitation and 95% confidence intervals for sampling months 2006.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average precipitation</th>
<th>Upper 95% CI</th>
<th>Lower 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>10.52</td>
<td>14.32</td>
<td>6.71</td>
</tr>
<tr>
<td>February</td>
<td>10.71</td>
<td>17.33</td>
<td>4.08</td>
</tr>
<tr>
<td>March</td>
<td>6.48</td>
<td>9.03</td>
<td>3.93</td>
</tr>
<tr>
<td>April</td>
<td>7.38</td>
<td>10.41</td>
<td>4.34</td>
</tr>
<tr>
<td>May</td>
<td>3.69</td>
<td>5.74</td>
<td>1.64</td>
</tr>
<tr>
<td>June</td>
<td>8.31</td>
<td>11.79</td>
<td>4.83</td>
</tr>
<tr>
<td>July</td>
<td>6.57</td>
<td>11.46</td>
<td>1.69</td>
</tr>
<tr>
<td>August</td>
<td>5.27</td>
<td>7.42</td>
<td>3.13</td>
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<tr>
<td>September</td>
<td>16.40</td>
<td>24.46</td>
<td>8.34</td>
</tr>
<tr>
<td>October</td>
<td>15.94</td>
<td>21.47</td>
<td>10.41</td>
</tr>
<tr>
<td>November</td>
<td>10.58</td>
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<tr>
<td>December</td>
<td>15.38</td>
<td>21.35</td>
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