Temperature regime in a braided river system: an indicator for morphological heterogeneity and ecological potential

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Abstract: *Water temperature is one of the most important abiotic variables in streams and strongly influences the distribution and abundance of freshwater organisms. It might be assumed that in natural streams home to heterogenous habitats also a wide range of thermal habitats exist, whereas in altered and channelized streams variability in water temperatures will be less pronounced. In order to test this hypothesis a case study at river Sense in Switzerland was carried out. At five river reaches characterized by different morphological patterns variability of water temperature was analysed. Temporal variability could be investigated by means of temperature loggers, whereas detailed temperature measurements in each water body along predefined transects served to elaborate spatial variability. As a key result if could be shown that there is an evident correlation between morphological characteristics and spatial variability of water temperatures.*

Keywords: *water temperature, river morphology, abiotic variables, biodiversity, ecological potential*

1. INTRODUCTION

1.1. Role of water temperature in freshwaters

The distribution and abundance of organisms in freshwaters are conditioned by their abiotic environment. The most important variables in fluvial environments are most often current, substrate and temperature (Allan & Castillo, 2007). Temperature has been repeatedly recognized as a key environmental variable (Arscott *et al*, 2001) structuring both aquatic invertebrates (Vannote & Sweeney, 1980, Ward & Stanford, 1982, Hawkins *et al*, 1997) and fish (Illies, 1961, Welcomme, 1979, Torgersen *et al*, 1999).

Stream temperature usually varies on seasonal and daily timescales, but it also shows spatial patterns depending upon morphological characteristics and exchange with the groundwater. In addition tributaries have a substantial impact on the temperature of the main river. Therefore temperature depends strongly by groundwater inflows, nevertheless in the majority of cases it increases from the spring to the mouth, allowing the distinction of cold and warm water regions along a stream. As every species is restricted to some temperature range also its geographic distribution is related to a certain range of latitude and elevation (Allan & Castillo, 2007).

The hypothesis that alteration and homogenization of physical habitat is the most significant threat to biodiversity and ecosystem functioning leading to biodiversity decline (Allan and Castillo, 2007) is widely accepted. Consequently, the assumption that restoring physical habitat heterogeneity will increase biodiversity underlies many river restoration projects (Miller *et al*, 2009). By delivering heterogeneous physical habitats it might be assumed that also a wide range of thermal habitats are created favoring greater biodiversity as well as provide unique thermal niches for endemic taxa (Milner *et al*, 2001).

Spatial and temporal temperature heterogeneity are important characteristics of natural and near-natural rivers. Thus, the hypothesis can be established that at river reaches with a natural morphology spatial variability of temperature will be higher than at reaches with a highly altered morphology, with stream temperature being variable between habitats only a few meters apart (Hauer & Hill, 2006). In order to verify this hypothesis at river Sense in Switzerland an extensive temperature measurement campaign was carried out. In this paper the objects, methods and analysis of the campaign are presented.

1.2. The river Sense

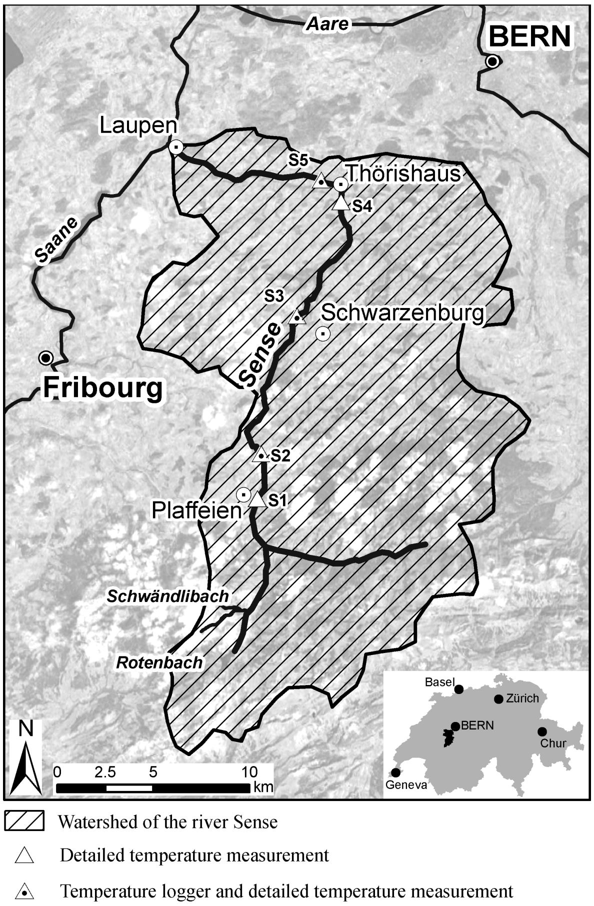


Figure 1 River Sense site location map.

The River Sense is a fourth order watercourse in a 432 km^2 watershed situated in the cantons of Fribourg and Bern, Switzerland (Figure 1). Downstream from the confluence of several headwater streams (near Plaffeien – Figure 1), the main stem of the river flows for 35 km before confluencing with the River Saane. The watershed is one of the last unregulated rivers in Switzerland where hydrographic events are driven by snowmelt and precipitation events without any power schemes or major flow diversion works.

Moreover, between Plaffeien and Thörishaus for an overall length of around 20 km the river Sense results to be morphologically almost unaltered. Near Plaffeien the morphology of the river is characterized by a braided river pattern where sediment transport capacity is high. As the river progresses downstream, the channel enters into a single-thread incised limestone bedrock gorge and then progresses again into a braided river system. More downstream it enters into a semi-trained, single-thread riffle-pool dominated channel morphology. Prior to confluencing with the River Saane, the River Sense, having undergone river training over the past several decades, results to be in a channelized state with a trapezoidal sections where both river banks are shaped by a rip-rap protection.

In the braided parafluvial zones of the river, the morphology is dominated by frequent channel avulsions, mid channel and side channel bars resulting in a highly diverse habitat environment (Lorang & Hauer, 2006) with frequent bank retreats, tree losses, woody debris, emergent vegetation and successional terrestrial species. In the main and secondary channels fast flowing (riffles) and low velocity reaches (pools) are following one each other creating locally backwater areas, too, whereas in more remote areas stagnant water zones are to be found. Mid and side channel bars, floodplains and terraces are inundated with varying frequencies. Therefore, river dynamics in these areas are very high.

Conversely in the single-thread orthofluvial zones (in particular where river training works have been employed), usually the whole river bed is filled with water reaching the base of both river banks. Therefore, the variability of water depths and flow velocities is strongly limited, resulting in a quite uniform distribution of hydraulic habitats.

1.3. Objects of the study

The object of the present study is to verify the hypothesis that a more natural morphology delivers also a greater variability to the temperature regime of a stream. To pursue this object at river Sense several temperature loggers were installed where temperature was measured continuously for at last one year. Additionally, in order to get a picture of spatial temperature variations at a meso-scale level at five distinct river sites detailed temperature measurements were carried out along predefined cross sections. The measurements were carried out in summer and late fall when the temperature of surface water and groundwater are distinctly different.

The following questions to be answered were defined:

- (i) What are the characteristics of temporal temperature variability? Can temperature be related to season and local meteorological conditions?
- (ii) What are the characteristics of spatial temperature variability? Does water temperature change along the water course?
- (iii) Can temperature variability at the meso-habitat scale be related to the morphological patterns?

2. FIELD DATA COLLECTION

2.1. Location of temperature loggers and detailed temperature measurements

Figure 2 Sampling sites at river Sense: (1) naturally braided (S1), (2) naturally meandering in a gorge (S2), (3) naturally braided, right bank slightly protected (S4), (4) with partial protection of the right bank (S4), and (5) channelized (S5).

To test the hypothesis that greater morphological variability delivers more diverse temperature patterns 5 sites with different morphological characteristics have been defined They are numbered from upstream to downstream (S1 – S5). In Figure 1 the location of the sites is represented, Figure 2 shows photos of the study reaches. The reaches have a length between 620 and 1’850 meters and have been divided by minimum number of 14 and a maximum number of 19 regularly spaced transects. The transects were defined in a way to cover all the available meso-habitats that are to be found in a site.

2.2. Measurement of temporal variability

At all sites temperature loggers with hourly registration were installed in May 2009. At some sites they are still functioning, whereas due to the high dynamics at river Sense some temperature loggers after some have got lost or they are not more concerned by the water due to a shift of the channel system. Comparable data are only available for S2, S3, and S5.

2.3. Measurement of spatial variability

Moreover, along the predefined transects in 2010 two series of detailed temperature measurements have been performed. The first time series was carried out by end of August (henceforward called series 08/10) and the second time series at the beginning of November (henceforward called series 11/10).

Advancing along the transects temperature measurements have been carried out at each location where water came across. In the braided river system for each channel with flowing water temperature was recorded at the left and right boarder and in the center of the channel where the maximum water depth was reached. In stagnant water zones and backwaters a singular temperature measurement in the center of the zone was executed. Moreover, each single temperature measurement was correlated to qualitative classification of water depth and flow velocity at the measured point as well as to a air temperature record.

By comparing mean temperature during the measurement campaigns to overall mean temperatures calculated by means of the temperature logger data at investigation, it can be concluded that series 08/10 reflects the situation when water temperature is slightly above the mean, whereas series 11/10 represents a situation with water temperatures are at a level between the overall mean and the overall minimum.

3. ANALYSIS AND RESULTS

3.1. Temporal variability

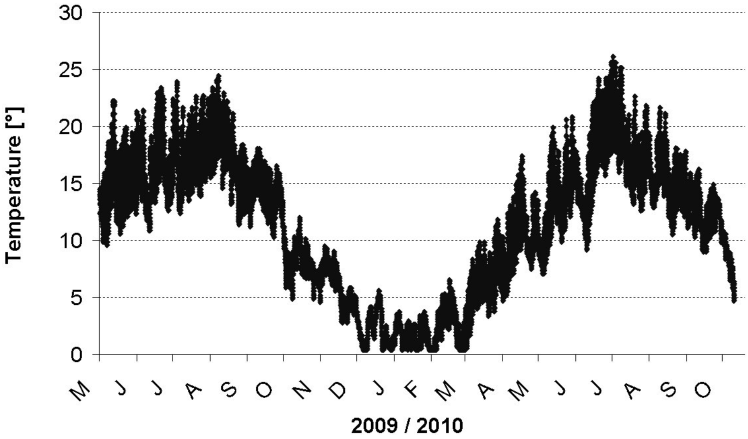


Figure 3 Temperature graph at site S5 from May 2009 to October 2010

The records at the temperature loggers are able to deliver a good picture of temporal variability. For fishes average July temperature and maximum July temperature are relevant. In July 2009 at S2 an average temperature of 15.0° C (maximum temperature 21.6° C), at S3 an average temperature of 16.7° C (maximum temperature 26.4° C), and at S5 an average temperature of 17.0° C (maximum temperature of 23.4° C) was measured. The average temperature is increasing in the downstream direction. However, the maximum temperature of 26.4 C was measured at S3. Temperatures > 19° C cause thermal stress for the brown trout (Elliott 1994) and the tolerance zone or death is a question of exposure time. The observed 26.4° C in S3 are very critical and trout will move to thermal refugia (cold water patches) if they are available. The observed summer temperatures are also in a critical range for bullhead (*Cottus gobio*). Bullhead prefer summer temperatures that are distinctly less than 20° C. The survival of both species in summer time highly depends on the observed thermal refugia in S3. In S5 summer maximum temperature was lower probably because of the effect of tributaries with colder water.

Comparable January temperatures are available for January 2010 at sites S3 and S5. At S3 the average January temperature was 1.1° C (minimum temperature of 0° C) and at S5 average January temperature was 1.6° C (minimum temperature 0.4° C).

Figure 3 shows the temperature graph resulting from the hourly measurements at the temperature logger of site S5. The maximum of the period was reached in August 2010 with 26.1° C, the minimum several times between January and March with 04° C. It can be observed that daily fluctuations in sunny days in summer can be around 10° C, whereas in winter the difference between daily maximum and minimum temperatures is not more than 3 – 4° C.

3.2. Spatial variability

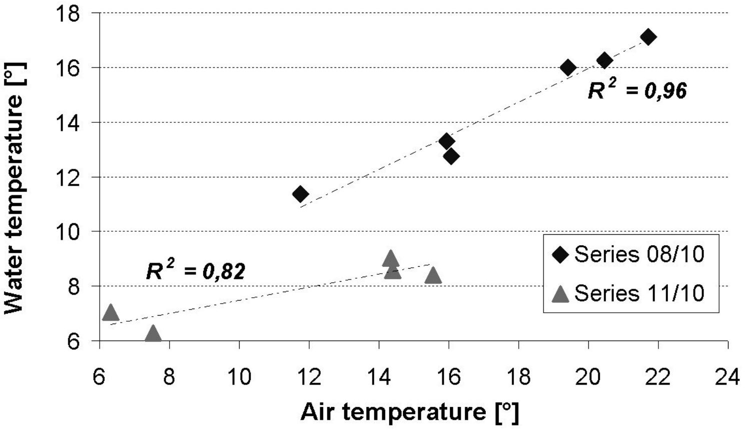


Figure 4 Correlation between mean air temperature and mean water temperature during the measurement campaigns of 2010

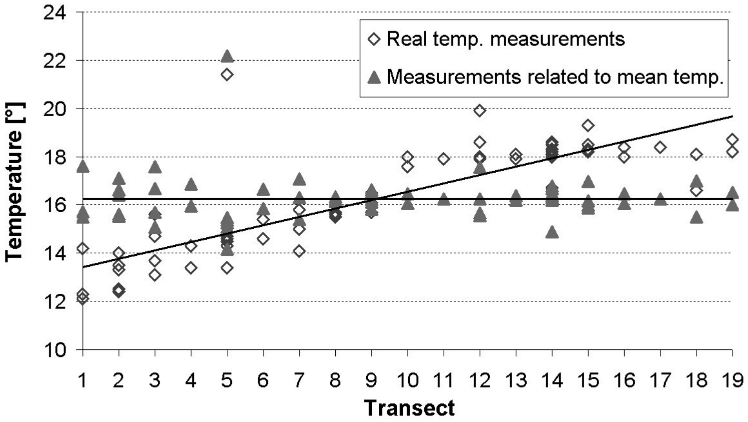
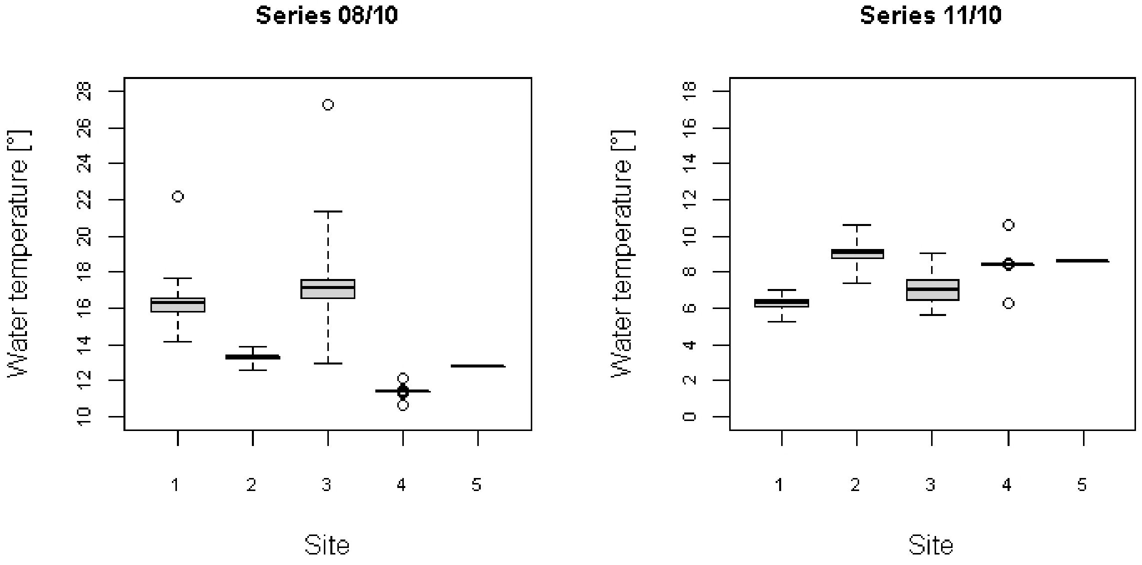


Figure 5 Real temperature measurements and adjustment to overall mean water temperature during data collection (Site S1 and series 08/10)

As weather conditions were not stable during the measurement campaigns, mean air temperature and therefore also mean water temperature amongst investigation sites varied. Figure 4 states that there is a strong correlation between these variables. However, the clear distinction between series 08/10 and series 11/10 confirms that water temperature experiences both annual fluctuation. In fact, the water temperature regime in November (series 11/10) is much lower than in august (series 08/10), therefore at days with relatively high mean air temperatures for November (the three points on the right on the lower line in Figure 4) mean water temperature nevertheless was remarkably lower than on days with similar air temperatures in August (series 08/10). From Figure 4 it can be confirmed, too, that stream temperature varies much more narrowly than air temperatures (Hauer & Hill, 2006).

In order to eliminate noise due to temporal temperature flux during measurements and to determine spatial variability in a statistically correct way, adjustment of data was necessary. In fact, the time frame needed for data collection varied between one hour at the channelized site (S5) and 4 hours at the natural sites S1 and S3. As a consequence, due to the daily temperature flux air and water temperature varied during the measurement. Thus, progressing from one transect to the next, mean water temperature per transect changed not due to spatial variability, but to temporal variability. To calculate spatial variability of water temperature for each transect the difference between the overall mean water temperature of the investigation site and the mean water temperature of the transect was calculated and then at each transect this difference was added to the single temperature measurements at the transect. Figure 5 shows a graphical example of this approach.


Series 08/10

Series 11/10

Figure 6 Boxplots with median, interquartiles, whiskers (to data points corresponding four times the interquartile range) and extreme outliers

Figure 6 shows boxplots of the temperature data (adjusted to the overall mean as explained above). Different observations can be made:

(i) As there aren’t any secondary channels, backwater or stagnant water zones, at site S5 spatial variability was non-existent neither in August nor in November. Therefore it can be assumed that throughout the whole year spatial variability at channelized sites is non-existent.

(ii) At the semi-channelized site S4 there are some stagnant water zones (represented by the outliers in the figure), that are cut off from the main channel after events with major discharges and where water temperature can reach relatively high values. However, due to evaporation this zones tend to disappear after a while and their ecological value is questionably. In the area concerned by flowing water also at site S4 spatial variability of water temperature is almost non-existent.

(iii) Also at sites S1 and S3 cut-off zones with high temperatures were observed during the measurement campaign 08/10. In the series 11/10 this measurements doen’t appear anymore, a sign that these zones are to be interpreted rather as puddles and might have disappeared shortly after the measurement campaign.

(iv) Omitting the outliers, statistical parameters of spatial temperature variability have been calculated (Table 1). At the braided sites S1 and S3 and, with some restrictions, at the naturally meandering site S2 spatial variability, represented by the standard deviation, is much higher than in the semi-channelized site S4 or in the channelized site S5. When referring to the coefficient of variation c_v which is the quotient of mean and standard deviation and is a better comparative measure (Schneider, 1994), it becomes evident that at natural sites variability remains in a similar range throughout the season with generally smaller temperature ranges when temperature is lower. Site S3, due do its several backwater zones at laterally flowing secondary channels shows a particularly interesting water temperature pattern.

Table 1 Mean, standard deviation and coefficient of variation for water temperature measurements at the investigations sites for two measurement series

	Series 08/10			**Series 11/10**		
Site	**mean**	**sd**	**c_v**	**mean**	**sd**	**c_v**
S1	16.2	0.62	0.039	6.3	0.36	0.058
S2	13.3	0.26	0.019	9.0	0.57	0.063
S3	16.9	1.36	0.081	7.1	0.86	0.122
S4	11.4	0.04	0.004	8.4	0.02	0.002
S5	12.7	0.00	0.000	8.6	0.00	0.000

4. CONCLUSIONS

Water temperature strongly influences life conditions for freshwater taxa. In streams water temperature strongly depends on the geographical position, but also on groundwater and tributary inflows. Water temperature generally increases with the distance of a stream from its source influencing the distribution and abundance of aquatic organisms.

At river Sense in Switzerland measurements have been carried out in order to analyse temporal and spatial variability of water temperature.

By means of temperature loggers installed at different sites of the river it could be shown that there are seasonal and daily fluctuations. In summer maximum temperatures of around 26° C were measured, whereas minimum temperatures in winter are at the freezing point. Daily fluctuations in summer are in average around 10° C in summer and 5° C in winter.

In order to analyze spatial variability detailed temperature analysis have been carried out at five morphologically different investigation sites. At the semi-trained and channelized sites spatial variability was almost non-existent, whereas at the natural sites that are characterized by a braided river pattern thermal variability is quite high. Therefore, it can be concluded that in reaches with heterogeneous physical habitats also temperature variability is higher favoring greater biodiversity as well as provide unique thermal niches for endemic taxa.

This is particularly important for the most abundant fish species in the Sense River that are brown trout and bullhead. Both are negatively affected by high temperatures (> 20° C) and depend on cold water refugia. The chance that in morphologically pristine river reaches, where riparian vegetation is present providing shading and preventing streams for heating up, such refugia are available is higher than in channelized reaches where temperature variability is non-existent. Thus, spatial temperature variability can be seen as an indicator for a good ecological potential as it is correlated intrinsically to a heterogeneous physical environment. Especially if the general water temperature level in streams is raising due to climate change the presence of cold water refugia can become essential for aquatic species to survive.

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