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Paper presented at the 12th Northern Res.Basins Symposium/Workshop
(Reykjavik, Iceland – Aug. 23rd – 27th)

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The characteristics of stream and river ecosystems in arctic and alpine areas are determined mainly by the relative contribution of glacial meltwater, snowmelt, rainfall and groundwater. Each source generates a particular seasonal hydrological signature, affecting physical and chemical properties, and hence biological communities. The relative contribution of each source is sensitive to climate change. The study was concentrated on the glacial River W-Jökulsá and some non-glacial rivers in the central highlands of Iceland. The water in the glacial river was entirely glacial meltwater at the glacier margin, but the glacial contribution was about 20% 40 km downstream. However, its tributaries and non-glacial reference rivers were mainly springfed. The invertebrate fauna was confined to Chironomidae of the genus *Diamesa* close to the glacier, but other taxa (species and groups of species) occupied the river further downstream, where their diversity was close to that found in the reference rivers.

Introduction

Glacial rivers in Iceland are important for hydroelectrical development since 40% of all runoff water in Iceland is influenced by glaciers (Adalsteinsson *et al.* 2000). The downstream longitudinal change in species composition will be affected by increasing groundwater and tributary flow into the glacial rivers, which decreases the glacial influence on the river biota. The study was carried out on the glacial River W-Jökulsá in the central highlands of Iceland and non-glacial rivers in the same area, comparing the faunal composition of the two systems and the influence of glacial water on the biota.

Milner and Petts (1994) proposed a conceptual model, where species richness increased downstream from glacier, or in time from deglaciation, in accordance with increased maximum water temperature and channel stability. Close to the glacier snout, or where recent deglaciation has occurred, chironomid larvae of the genus *Diamesa* dominate the benthic invertebrate community, but further downstream other chironomid larvae (*e.g. Orthocladiinae, Chironominae*), caddisflies (Trichoptera) and stoneflies (Plecoptera) dominate the benthos. The conceptual model by Milner and Petts (1994) is being tested in a European project on Arctic and Alpine Stream Ecosystem Research (AASER). Our study is a part of the project and this paper is a contribution towards the understanding of such ecosystems by comparing communities of a glacial river with non-glacial reference rivers in the same area.

Site Description

The vegetation of the central highland of Iceland is very sparse with no trees, above 300-400 m a.s.l., except for small patches in the wetter areas. Allochthonous material does not enter the rivers until in the lowland areas, where grasses and low-lying vegetation cover the catchments.

The River W-Jökulsá originates in three main branches (eastern-, middle- and western branch) from the north-western outlet glacier Sátujökull of the Hofsjökull Ice Cap (Fig. 1). A hyaloclastite mountain ridge separates the eastern branch from the others. A fissure zone assumed to be connected with a central volcano, below the glacier (Björnsson 1988; Sigurdsson 1990) cuts through the area. The river flows in the slope of 5-10 ‰ for the most of the way from the glacier to the lowlands, except between the edge of the highland plateau and the lowland, where its slope is around 20 ‰ (Fig. 2). The glacier catchment is 90 km^2 out of 820 km^2 of the river catchment at the lowest gauging station in the lowland valley, 45 km away from the glacier. The annual average discharge at the lowest sampling site of the river is 21.4 m^3/s for 1971-1997 (Gauging station No. 145, National Energy Authority in Iceland, Hydrological Survey).

The research was carried out at five sampling sites, in the eastern branch within 7.5 km from the glacier snout at 860 m a.s.l. down to 790 m a.s.l. One site was located in the middle branch, 3 km from the glacier margin and two sites were located in the western branch, 3.5 and 22 km from the source. The three branches join 22.5 km from the glacier margin where one sampling site was located (630 m a.s.l.). Further two sampling sites were then located at the lowland areas 42 and 45 km from the source (220 and 160 m a.s.l.) (Figs.1 and 2). Seven sites in five non-glacial rivers in the same area as W-Jökulsá, were used as reference alpine sites (Fig. 1). They are mostly spring-fed and feed the glacial river, but two of the reference rivers, R.

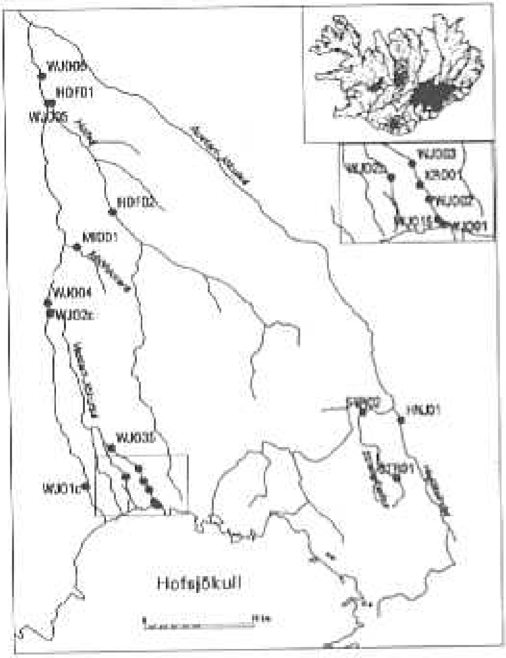

Fig. 1. The glacial River W-Jökulsá (abbreviaton WJO) and the reference rivers Krókafellslækur (KRO), Midhlutará (MID), Hofsá (HOF), Strangilækur (STR) and Hnjúkskvísl (HNJ) showing sampling sites.

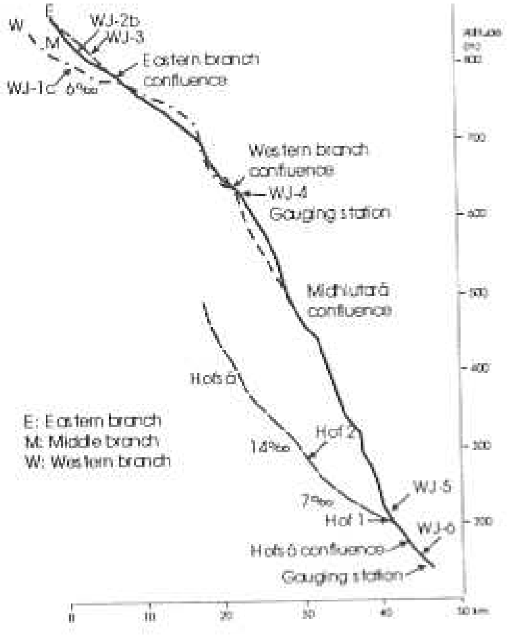

Fig. 2. Altitudinal profile of the River W-Jökulsá and its tributaries.

Strangilækur and R. Hnjúkskvísl flow into the glacial River East-Jökulsá that is confluent with W-Jökulsá below the lowest sampling site

R.W-Jökulsá and the non-glacial reference rivers run through barren areas most of their way. It is only at the lowland sites, where the catchments are covered with stout vegetation, mainly grasses and sedges. No woodlands were found in the catchments, though individual plants of *Salix arctica* and *S. herbacea* were found, especially along the riverbanks of the reference rivers.

Methods

In 1996 and 1997 the sites were sampled 2-3 times. The lowland sites (WJO05 and WJO06, and HOF01 and HOF02) were visited 3 times a year (May/June, July and September/October) but since most of the area is inaccessible until after spring thaw, the sites in the highlands were only visited twice during each year (July and September/October).

At each sampling site, conductivity, pH, discharge and temperature were measured and samples taken for analyses of suspended sediment, chlorophyll a, bryophyte biomass and macroinvertebrate density.

Conductivity and pH were measured with Cole Parmer conductivity meter 19820-00 and Orion pH meter model 230A.

Hydrological Survey of the National Energy Authority in Iceland has continuous measurements of discharge at gauging stations at WJO04, WJO06 and MID01. At the same stations and HOF01, water temperature was monitored. In addition to this, TinyTalk® temperature loggers were left àt 5 sampling sites during the sampling season in 1997.

Suspended sediment was taken from the water column of the rivers by repeatedly moving the sampler (US DH-48 sampler (Guy and Norman 1970)) slowly from the water surface to the bottom. Each sample was allowed to stand in a measuring cylinder until all sediment coarser than. 1.5 µm had settled according to Stokes law based on sediment balance weighing. Fine clay still in the suspension was filtered through a 0.2-0.45 µm mesh size membrane filter and weighed. The filtrate was dried by evaporation and weighed.

Channel stability of the river reaches was evaluated according to Pfankuch (1975), where increasing number indicates increasing instability of the channel.

The slope of the rivers was estimated from maps of the scale 1:20,000 with 5 m contours.

Satellite images (resolution 30x30 m) were used to estimate vegetation cover of the catchment areas. Plant species occurring along the riverbanks were recorded and their cover percentage estimated on each visit.

Estimates of the origin of water are based on mass balance calculations of discharge at different stations, *i.e.* increase in discharge in a lower sampling station compared with an upper station and changes occurring in conductivity (increase downstream compared with glacial water).

For macroinvertebrate sampling, a grid was laid out, where a reach of 15 m was along the riverbank and the other axis straight across the river to the far bank. The sampling took place at 10 randomly selected coordinates, where a stone was removed while holding a net of mesh size 250 µm below. The stones were rinsed in water to remove the invertebrates and the water was then sieved (mesh size 250 µm) and the sample preserved in 70% alcohol. Each stone was placed on a grid paper as it had been in the river and its outlines drawn to estimate its area. This was then used to estimate marcroinvertebrate density (Gíslason *et al.* 1998). Bryophyte biomass was estimated by using the same stone samples as for the invertebrates, all bryophytes were rinsed off, dried and weighed. Samples for chlorophyll a were taken by scraping biofilm from three replicate stones within an area of 9 cm^2. The samples were kept in dark until frozen and analysed in high performance liquid chromatography (HPLC).

Results

Physical and Chemical Parameters

The dissolved solids, as deduced by the conductivity of the water, indicated that the middle branch (WJO2b) is fed by melt water originating directly or interacting with the assumed volcanic area, as its mineral content was already high (> 50 µS/cm) in July, while the other branches (WJO03 and WJO1c) had conductivity as low 10 µS/cm (Figs.3 and 4). In July 1997 WJO1c was dominated by clear melt water, but later in the season (September) all branches were silted. Then the conductivity in the eastern branch was still low, while the other branches had high conductivity (> 40 µS/cm), indicating that the glacial melt water was mixed with geothermal water. Because of the assumed mixing, the glacial melt water in the middle and western branches had high concentration of dissolved solids and consequently was not easily distinguished from groundwater. Thus the estimated glacial influence is to a great extent based on direct discharge measurements and mass balance calculations. In the middle reaches, all glacial tributaries are gathered at the gauging station close to WJO04. Mass balance calculations indicate that the groundwater inflow is rather high in conductivity. In September 1997, the conductivity was estimated at ca. 100 µS/cm, but considerably lower in July, presumably due to melt water influence. In the lower reaches where glacial influence was rather low, especially in late September and early October, the conductivity was 90-100 µS/cm.

In mid winter R.W-Jökulsá is mainly spring fed. At the upper gauging station (WJO04) the discharge decreases to less than 1 m^3/s while the discharge at the lower gauging station (WJ006) is usually around 15 m^3/s. At that discharge, total dissolved solids (TDS) commonly vary between 65 and 80 mg/l, which corresponds to

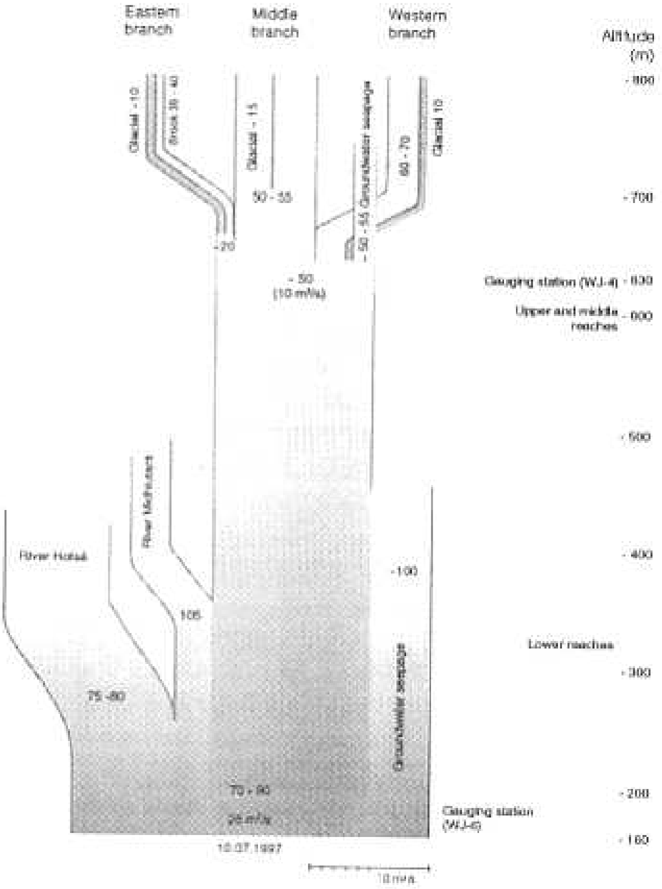

Fig. 3. Estimates of the origin of water in R. W-Jökulsá in the upper, middle and lower reaches in July 1997. The width of the channels reflects the discharge. The numbers refer to the conductivity (µS/cm at 25°C). The lightest shading indicates quantity of glacial water and the darkest shading indicates the groundwater composition.

90-120 µS/cm(Adalsteinsson *et al.* 2000), or similar to that estimated as the groundwater component late in the summer season.

Physical and chemical parameters changed downstream in the glacial river (Fig. 5). Maximum temperature recorded over the summer increased downstream, from the permanent 0°C at the glacier snout to 11.8-13.5°C 4.5 km downstream. The maximum temperature was similar in R.W-Jökulsá and the reference rivers, except at the glacier snout. Higher values were recorded in some of the reference rivers (17.3°C). Temperature expressed as degree-days was between 168 (WJO04) and 231 (WJO06) in W-Jökulsá and 203 (MID01) and 279 (HOF01) in the reference rivers from 25 May to 7 July 1997 (Fig. 5), but these sites are at a comparable altitudes. From 8 July to 23 September 1997 greater differences were found in number of de-

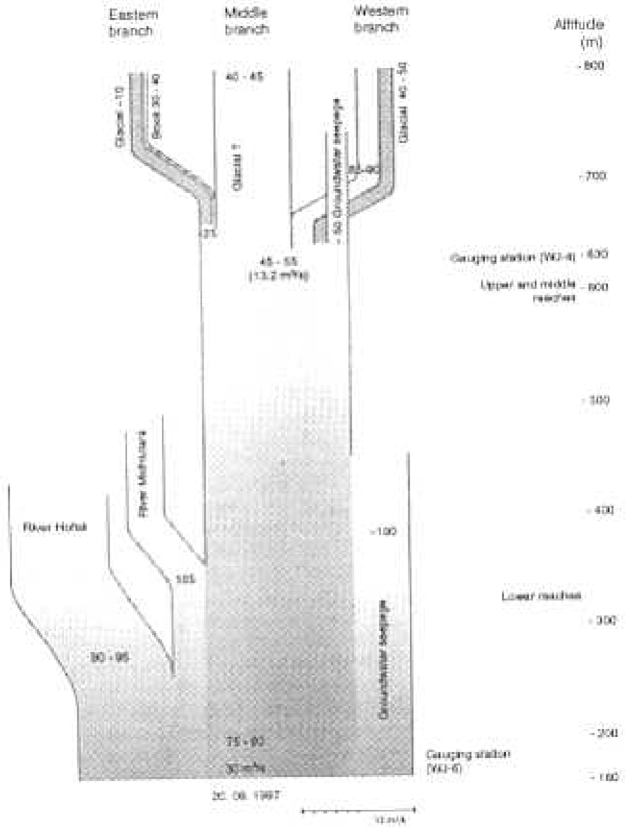

Fig. 4. Estimates of the origin of water in R. W-Jökulsá in the upper, middle and lower reaches in September 1997. The width of the channels reflects the discharge. The numbers refer to the conductivity (µS/cm at 25°C). The lightest shading indicates quantity of glacial water and the darkest shading indicates the groundwater composition.

gree-days between the glacial river and the reference rivers (Fig. 5). The number of degree-days were 180 units higher at the lowest sampling site of the reference rivers than at the lowest sampling site of R.W-Jökulsá, but these sites are at similar altitude.

The River W-Jökulsá was loaded with suspended material, more than 370 mg/l at all sites in July 1997, but little or negligible in the reference rivers (Fig. 5). Ion concentration increased, as shown with the conductivity, pH increased, from appr. 6.8 to 7.7, suspended solids increased from 120 to 360 mg/l at 22.5 km downstream from the glacier, where all the branches have joined, and then decreased to 85 mg/l. Chlorophyll a increased from 0.1 mg/m^2 to 1.6 mg /m^2 from the glacier snout to 1.4 km from the glacier, declined again to 0.1 mg/m^2 at 7.5 km from the glacier and increased again downstream to 0.16 mg/m^2. These changes are in association with de-

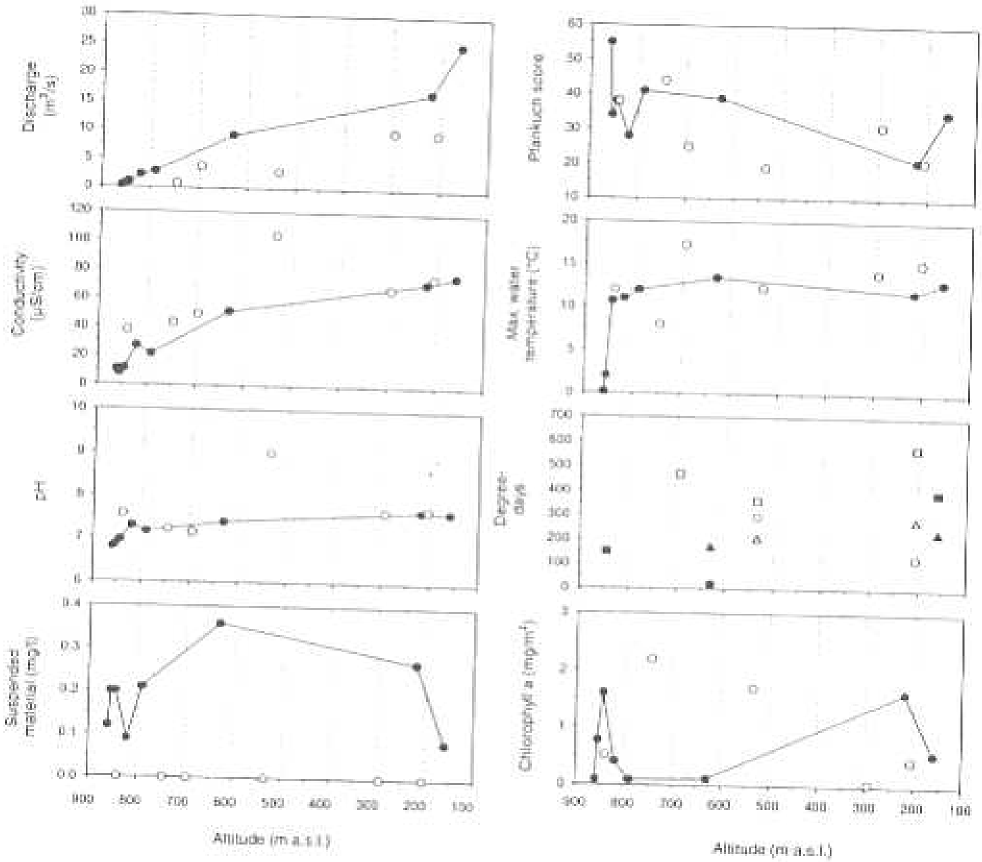

Fig. 5. Physical and chemical data from the glacial River W-Jökulsá and form the reference rivers in July 1997. Filled symbols (circles, triangles and squares) represent R. W-Jökulsá and empty symbols represent data from the reference sites. The data on degree-days is for three periods: 19 October 1996 – 24 May 1997 (circles), 25 May – 7 July 1997 (triangles) and 8 July – 23 September (squares).

creasing proportion of glacial melt water, that was ca. 50% in the uppermost reaches of the river and 20% 42 km downstream, when tributaries and groundwater had entered the river (Adalsteinsson *et al.* 2000). Pfankuch index of channel stability declined downstream from 55 to 21-35 indicating increasing channel stability (Fig. 5).

In the reference streams similar trends in chemical parameters were observed with regard to altitude as in R.W-Jökulsá. However, pH and conductivity were higher in all the reference rivers, pH 7.2-9.0 and conductivity 40-110µS/cm at 25°C. Chlorophyll a was higher (0.4-2.2 mg/m^2) in the reference rivers than in the R. W-Jökulsá, except for one station in R. Hofsá (HOF02), where the value was only 0.05 mg/m^2.

Pfankuch index declined faster at lower altitudes in the reference rivers than in the glacial river, indicating more stable river channels in the reference rivers.

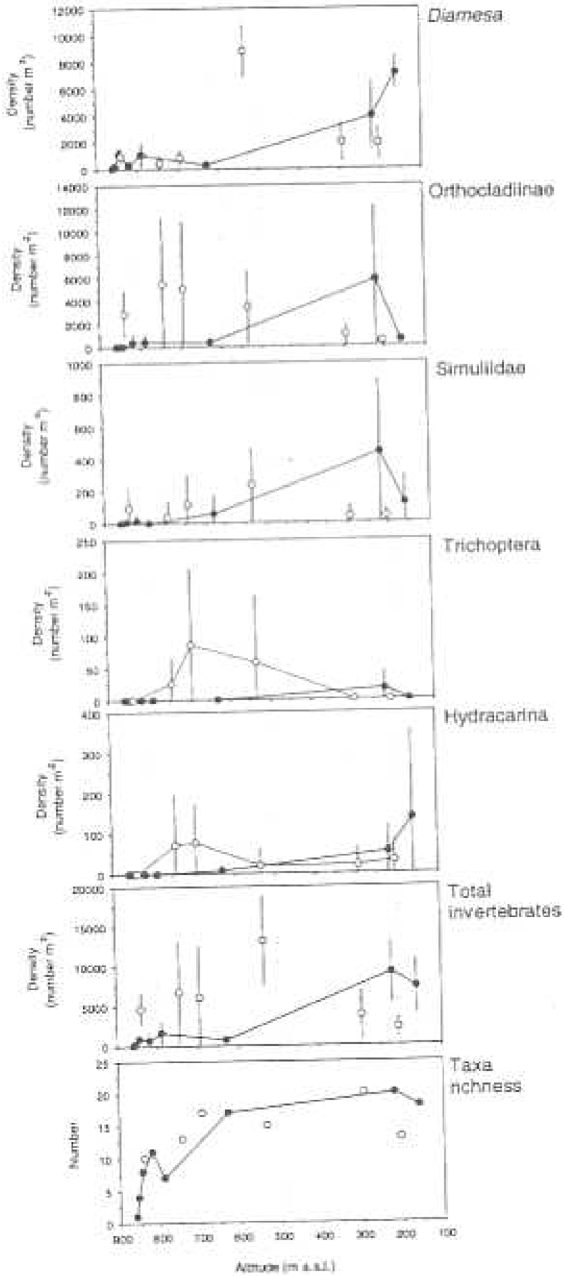

Fig. 6. Mean densities and taxa richness of macroinvertebrates in the glacial River W-Jökulsá and the reference rivers in July 1997. Standard deviations of the means are shown for the densities. Filled circles represent the glacial River W-Jökulsá; open circles represent reference rivers.

Biota

Chironomid larvae of the genus *Diamesa* dominated the benthic invertebrate communities in R.W-Jökulsá and in the non-glacial reference rivers (Fig. 6). Only a single specimen of Chironomidae (*Diamesa bohemani / zernyi*) was found at the glacial snout, but their densities increased downstream, reaching densities of 7,200-9,100 /m^2 at the station 42-45 km from the glacier. Number of taxa (species and species groups) increased downstream, with Orthocladiinae (Diptera: Chironomidae), caddis larvae (Trichoptera), blackflies (Diptera: Simuliidae) and water mites (Acarina) increasing downstream from the glacier, reaching maximum densities at 42 km from the glacier (Fig. 6). These taxa were only found in low densities in the upper reaches of the glacial R. W-Jökulsá and not found close to the glacier margin. They were on the other hand found at all sites of the reference rivers, except the caddis larvae, which were not found at KRO01.

Invertebrate densities were one order of magnitude higher in the non-glacial reference rivers than in the glacial river at high altitudes, except for *Diamesa* spp. At the lowland sites (205-295 m a.s.l. and 30 and 42 km from the glacier) the total densities were lower at the reference river sites (HOF02, HOF01), than at comparable sites in the glacial River W-Jökulsá.

Discussion and Conclusion

In the conceptual model by Milner and Petts (1994), maximum temperature and channel stability are considered the determining factors of taxa richness and density. The marginal difference recorded in the maximum water temperature between the glacial river sites and nearby non-glacial sites may be due to that the silted glacial water absorbs more heat on a sunny day than the clear non-glacial rivers (Fig. 5). Spring thaw occurs in April and May in the lowlands but in June in the highlands. Also, the rivers in the highlands are covered with ice from November to April, but only covered occasionally during the winter in the lowlands. Temperature expressed as degree-days differed considerably between the glacial River W-Jökulsá and the reference rivers for the summer months (8 July-23 September 1997), especially in the higlands, but less in the lowlands (Fig. 5). We found that *Diamesa* species are widely distributed in temperatures above 2°C, up to 17°C and so are other groups, like Orthocladiinae, blackflies and caddis larvae. This indicates that maximum temperature may not be the determining factor, but average temperatures or degree-days could play an important role (Fig. 5), but degree-days were considerably higher during the late summer season (8 July-23 September 1997) in the reference rivers than in R.W-Jökulsá. The distribution of chironomid species in the River W-Jökulsá and the reference rivers is discussed by Ólafsson *et al.* (2000) in relation to maximum temperatures and temperatures expressed in degree-days.

All the reference rivers are dominated by spring water, except during the spring thaw. The Pfankuch index was 39 (range 21-55) for the sites in the glacial river and 29 (19-44) for the sites in the reference rivers. This indicated that channel stability is lower in the glacial river. The glacial river had a discharge variation of 10 to 100 m^3/s 42 km away from the glacier and 22.5 km from the glacier margin its discharge was similar in summers, but reduced to a few hundred litres per second in winters. Except for the area immediately downstream from the glacier, the river bed consists of boulders embedded in silt and sand. At the lowest station in the reference River Hofsá the bottom consists of boulders and sand, possibly due to influence of glacial water during the spring spades, which could explain the similarity of the benthic density in the lowest sampling sites in the glacial and non-glacial rivers.

In a study on the benthic communities in rivers in Iceland, Gíslason *et al.* (1998) concluded that catchment characteristics, mainly geology, vegetation cover, topography and lakes in the river basins were the main determining factors of species richness and invertebrate density. These factors influenced the retention of water and the quantity of organic matter drifting in the water, and hence, the invertebrate communities feeding on organic matter or benthic algae. Suspended material in glacial rivers, which in this case was above 370 mg/l (transparency less than 10 cm), and above 1,000 mg/l during July 1996 (Adalsteinsson *et al.* 2000), may possibly halt algal growth on the bottom and make filtering inefficient for invertebrates.

The occurrence of species followed the sequence of the conceptual model by Milner and Petts (1994) (Fig. 6), where species richness increased downstream and groups, like caddisflies (Trichoptera) and stoneflies (Plecoptera) became more common in the downstream sampling sites, especially at the lowland sites of the glacial river.

Lowland sites of the River W-Jökulsá harboured higher diversities and higher densities of invertebrate groups than highland sites. At the lowland sites temperatures expressed as degree-days were higher, ice-free periods were longer and riverbeds were coarser (boulders) with higher quantity of chlorophyll a, which are possibly related to more stable substrate. Higher temperatures and higher stability lead presumably to higher densities and higher diversities of invertebrates.

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