The Val Roseg project: habitat heterogeneity and connectivity gradients in a glacial flood-plain system

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Abstract The Val Roseg Project is a holistic ecological study of an alluvial flood plain in the Swiss Alps. Major geomorphic features consist of a proglacial reach below the terminus of Tschierva Glacier, the outlet stream of a glacial lake at the terminus of Roseg Glacier, and the glacial flood plain. Here we describe the habitat heterogeneity of the glacial flood plain, which is 2.6 km long and up to 510 m wide. Transects were established every 150–200 m to investigate gradients of turbidity, temperature, nutrients, organic matter, and surface water–groundwater interactions. Six distinct channel types have been identified, based on the correspondence between connectivity and physico-chemical characteristics. Seasonal and diel variations in discharge are marked and play a prominent role in structuring the habitat template. The entire flood plain shifts from dominance by glacial meltwater in summer to a groundwater-controlled system in winter.

INTRODUCTION

Alpine stream ecosystems have been proposed as sensitive indicators of climate change and anthropogenic impacts (McGregor et al., 1995), yet relatively little is known of their ecology (Ward, 1994). Despite interest in high mountain streams by European limnologists early in this century (Steinmann, 1907; Thienemann, 1912; Steinböck, 1934; Léger, 1937), we are not aware of a single holistic ecological study that has been conducted on a glacial flood plain. Therefore, we initiated a comprehensive ecological investigation of a pristine glacial flood-plain system in the Swiss Alps (Fig. 1) to determine how spatio-temporal heterogeneity (a) contributes to biodiversity patterns of lotic zoobenthos, groundwater fauna and periphyton in a harsh environment and (b) influences ecosystem processes such as productivity and decomposition dynamics. In this paper we focus on habitat heterogeneity and connectivity for the surface waters of the flood-plain complex.

DESCRIPTION OF STUDY AREA

Val Roseg is situated in the Bernina Massif of the Swiss Alps (Fig. 2). In the upper Roseg catchment (49.5 km², 42% covered by glaciers) elevations range from 1990 m a.s.l. at the downstream end of the glacial flood plain to 4049 m at the top of Piz
Bernina. The Roseg River is a second-order tributary of the River Inn, a major tributary of the Danube. The primary water source is meltwater from two valley glaciers: the Tschiera Glacier (6.2 km²) and the Roseg Glacier (8.5 km²). Five major stream reaches are apparent (Fig. 2). This paper focuses on the lotic channel types of the flood plain, which is 2.6 km long and up to 510 m wide and has a mean slope of 3.3%. The width of the main channel in the flood-plain reach ranged between 10 and 26 m during early summer flow conditions (c. 5 m³ s⁻¹).

**MAPPING, SAMPLING AND ANALYSIS**

In summer 1996 the positions of individual channels, springs, and marshes were determined along 17 transects spaced 150-200 m apart along the length of the flood plain. The width, depth, and wetted perimeter of each channel were recorded along each transect. Aerial photographs (infrared and colour images, spatial resolution 0.1 m) were taken on 3 September 1996 from a helicopter at 500 m above ground level.

Water temperatures were recorded continuously at selected locations with temperature loggers. Other physico-chemical samples were collected using standard procedures and measurements were conducted employing analytical methods described in Tockner et al. (1997).

**RESULTS AND DISCUSSION**

Only selected parameters, from a suite of physico-chemical variables are referred to in this paper. To portray the habitat heterogeneity of the glacial flood plain, we present a typology of channel (habitat) types and examine aspects of flow dynamics, the temperature regime, and spatio-temporal patterns of turbidity and specific conductance.
Fig. 2 Location of the upper Val Roseg catchment, showing the five major stream reaches (modified after Tockner et al., 1997).
Fig. 3 Habitat diversity of the glacial flood plain, showing the distribution of channel types (modified after Tockner et al., 1997).
The Val Roseg project: habitat heterogeneity and connectivity gradients

Channel typology

The glacial flood plain exhibited a much greater degree of habitat heterogeneity than expected, which was reflected by a diversity of channel types (Fig. 3). Based on the correspondence between connectivity and physico-chemical attributes, six major channel types were identified, as follows:

(a) **Main channel** (M)—the primary channel (thalweg) draining the flood plain. Fed primarily by glacial meltwater.

(b) **Side channels** (S)—eurhythmic side channels connected to the main channel at their upstream and downstream ends; may not contain surface water under low flow conditions.

(c) **Intermittently-connected channels** (I)—pararhythmic side channels that are permanently connected to the main channel downstream and intermittently connected to the main channel upstream.

(d) **Groundwater channels** (G)—fed by water upwelling from contiguous aquifers at their upstream end and connected to the main channel downstream.

(e) **Tributaries** (T)—enter the flood plain as a surface water channel originating in the uplands; water sources are from hanging glaciers or hillslope aquifers.

(f) **Mixed channels** (X)—contain a mixture of water derived from two or more of the other channel types.

Even these major channel types do not fully express the habitat heterogeneity of the glacial flood plain. Based on the specific water source (e.g. deep vs shallow groundwater; alluvial vs hillslope aquifer; subglacial groundwater), groundwater channels alone encompass several distinct subtypes (Ward *et al.*, 1998).

Flow dynamics

Seasonal and diel variations in discharge are marked (Fig. 4), as expected in a system fed by glacial meltwater, and play a prominent role in structuring the habitat template of the flood plain. Surface waters underwent dramatic cycles of habitat expansion, contraction, fragmentation, and reconnection on a seasonal basis (Fig. 5), an attribute of stream ecosystems that has received little attention (Stanley *et al.*, 1997). The
number of channels per transect varied from 1 to 11 during high discharge in summer (6.2–10.7 m$^3$ s$^{-1}$), from 1 to 7 during low discharge in autumn (0.9 m$^3$ s$^{-1}$), and from 1 to 6 during the low discharge in winter (0.2 m$^3$ s$^{-1}$). Total channel length declined from 17.6 km during summer, to 14.2 km in autumn, to only 5.4 km in winter. The entire flood plain shifts from dominance by glacial meltwater in summer to a groundwater-controlled system in winter.

**Temperature regime**

A much greater degree of thermal heterogeneity was recorded than anticipated for a glacial flood plain (Table 1). The main channel, influenced most directly by glacial meltwater, had the lowest mean temperature (3.5°C) and the lowest diel amplitude

<table>
<thead>
<tr>
<th>Channel type</th>
<th>Daily mean (range)</th>
<th>Diel amplitude (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>3.5 (2.8-4.1)</td>
<td>2.6 (0.5-5.7)</td>
</tr>
<tr>
<td>Intermittently-connected</td>
<td>5.4 (3.9-7.9)</td>
<td>4.6 (1.4-9.0)</td>
</tr>
<tr>
<td>Mixed</td>
<td>5.9 (5.0-7.2)</td>
<td>4.2 (0.9-7.2)</td>
</tr>
<tr>
<td>Groundwater</td>
<td>4.9 (4.1-5.8)</td>
<td>3.1 (0.9-5.3)</td>
</tr>
</tbody>
</table>
(2.6°C). The groundwater channel combined a relatively high mean temperature (4.9°C) with a low diel amplitude (3.1°C).

**Turbidity and specific conductance**

Turbidity and specific conductance were used as indicators of hydrological connectivity and water source (Fig. 6). These two parameters were inversely related along both

![Diagram](image-url)

**Fig. 6** (a) Longitudinal changes in turbidity and specific conductance in the main channel under high (August), medium (September) and low (November) flow conditions (modified after Ward *et al.*, 1998). (b) Turbidity and specific conductance as a function of channel type. Means (± s.d.) of the average values for individual channels within each channel type. M = main channel; I = intermittently-connected channels; X = mixed channels; G = groundwater channels (modified after Tockner *et al.*, 1997).
temporal and spatial dimensions. For example, as discharge declined from summer to winter, turbidity decreased but specific conductance increased. The spatial patterns of these parameters also were inversely related, with turbidity decreasing and specific conductance increasing from the main channel type toward the groundwater channel type. Because groundwater channels do not have upstream surface connections with the main channel, they do not receive turbid glacial meltwater. In addition, groundwater-fed channels receive “older” water that has had more time to increase in ionic strength, whereas glacial meltwater typically has specific conductance values lower than 15 μS cm\(^{-1}\).

**CONCLUSIONS**

The surface waters of the Val Roseg flood plain exhibit a high degree of habitat heterogeneity, much of it attributable to the diversity of channel types. Preliminary analyses reveal an aquatic fauna that is also much more diverse and abundant than one would expect in a glacial environment that undergoes cyclic expansion and contraction. Groundwater channels, individually stable, yet collectively encompassing greater spatial heterogeneity than other channel types (Ward et al., 1998), may play a major role in sustaining the ecological integrity of the flood-plain complex. Future research will investigate the ecological strategies that enable biotic assemblages to sustain populations under the harsh conditions experienced in glacial flood-plain habitats.

**REFERENCES**


