Ecological Windows in Glacial Stream Ecosystems

Alpine streams and in particular glacial streams are subject to harsh environmental conditions during most of the year. However nutrient supply, light availability, discharge, and temperature favor ecological processes and biota during two short periods at the beginning and end of the annual flow pulse.

The Alps, a mountain range with rugged topography and steep slopes, are characterized by harsh environmental conditions. With increasing elevation, a growing portion of the annual precipitation falls as snow. Virtually 100% of the precipitation occurs as snow above 3500 m a.s.l. [1]. Snow and glacier ice form a transient water storage that is partly released as a distinct flow pulse during summer, particularly in glacier fed streams (see article p. 6). This radiation and temperature controlled flow pulse is an important factor in determining habitat conditions for algae and invertebrates in addition to climatic constraints such as snow cover or freezing during winter. However, until recently, knowledge on habitat conditions and benthic communities of glacial streams was based on studies typically restricted to the melting season [2]. In this article, we provide a general description of the physico-chemical habitat template of glacial streams using information from year-round studies in the Val Roseg and elsewhere [3] and we discuss the respective implications for benthic organisms.

Summer and Winter: The Unfavorable Seasons

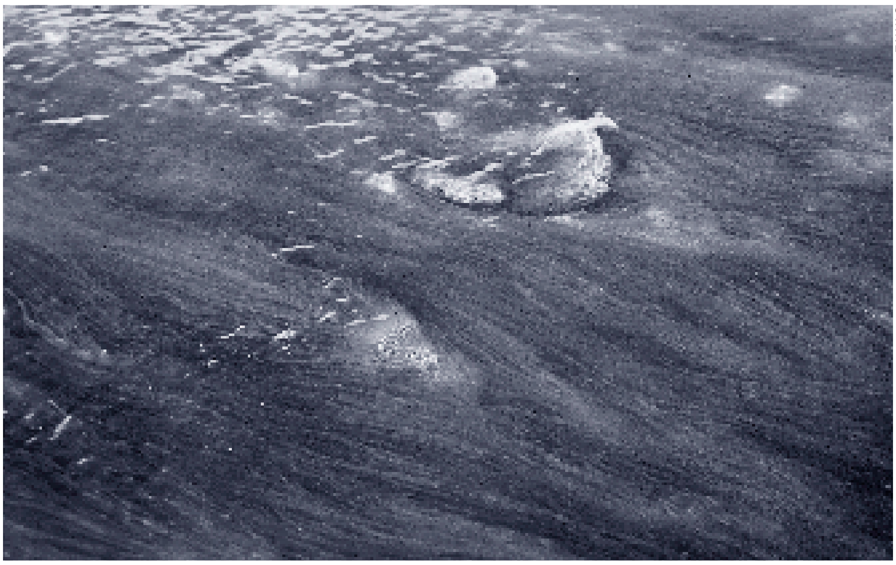
The glacial flow pulse during summer melt-off creates unfavorable habitat conditions in glacial streams (Fig. 1). They result from:

- high shear stress;
- bedload transport and thus low channel stability, especially when slopes are steep and sediment availability is high as in recently deglaciated glacier forefields;
- high turbidity caused by glacial flour, which attenuates light and scours the substratum;
- low concentrations of dissolved phosphorus and dissolved organic carbon [4];
- water temperatures <2 °C near the glacier snout.

High habitat heterogeneity, as for example in the Val Roseg flood plain (see article p. 14), mitigates the detrimental effect of the glacial flow pulse, at least in channels lacking surface connection to the main channel.

From late autumn to the onset of spring, habitat conditions are also harsh but considerably different from summer conditions. Temperatures close to 0 °C extend far downstream, discharge is low, and some streams may even fall dry or freeze to the bottom. No light reaches the stream bottom in snow-covered stream channels. However, exfiltration of relatively warm groundwater may prevent the formation of an ice and snow cover locally despite very low air temperatures, as for example in the Roseg flood plain and other glacial streams in the Swiss Alps [3, 5].

In alpine streams, periods of harsh environmental conditions are highly predictable compared with streams at lower elevation. For example, streams in the northern foothills of the Alps are frequently disturbed by almost randomly occurring spates that reflect the prevailing influence of the Atlantic climate [6].



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Dense algal mat formed by the Chrysophyte *Hydrurus foetidus* in the main channel of the Roseg River in January 1998.

Windows of Opportunity

The conceptual diagram (Fig. 1) summarises the relationships between regional climate, the environmental conditions in alpine streams and the response of the stream biota. The abrasive impact of moving bed sediments in summer constrains the abundance of invertebrates [2, 3] and impedes, together with the limited nutrient

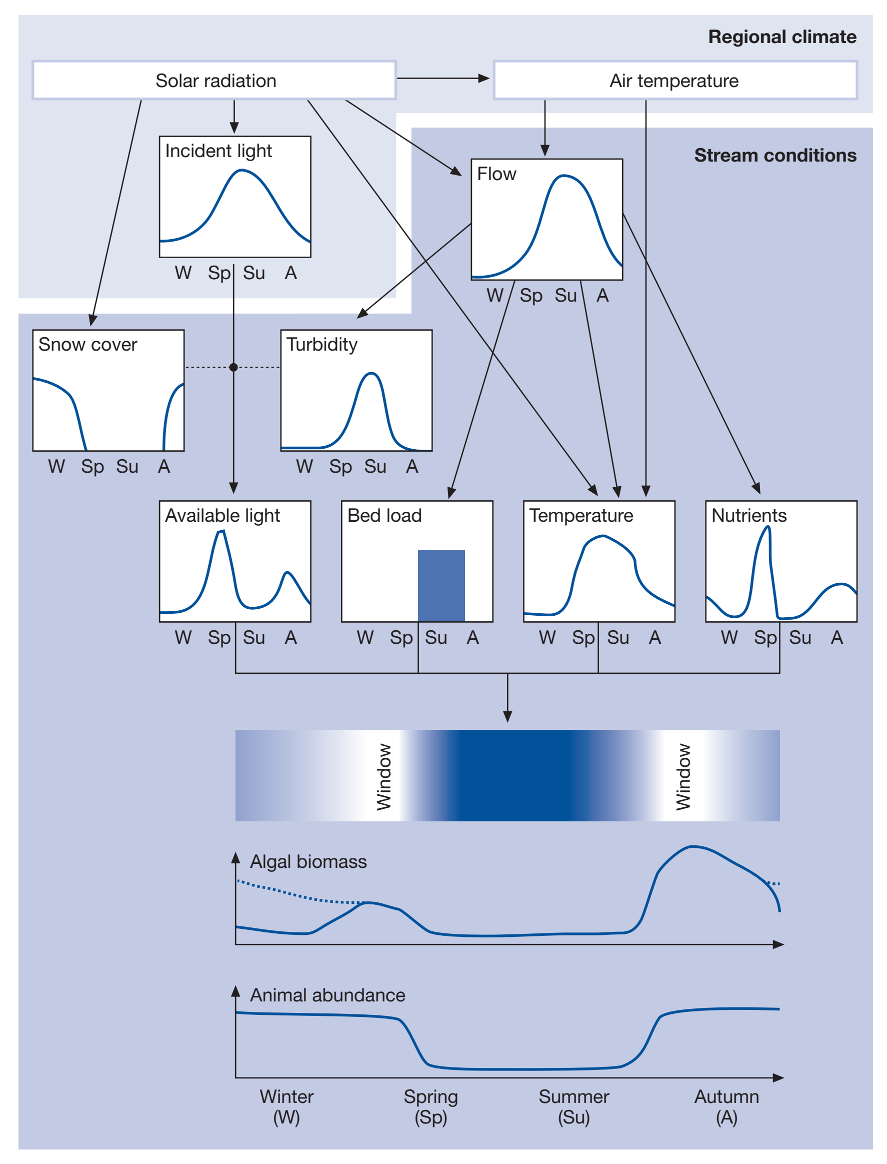

Fig. 1: Windows of opportunity in the physico-chemical habitat template of glacial streams (conceptual diagram). The regional climate characterized by solar radiation and air temperature controls discharge and incident light, and influences water temperature. Rising air temperature and solar radiation increase the release of cold melt water, which halts the vernal increase of water temperature. With the onset of glacial melt, turbidity reaches high levels and bed load transport occurs during periods of high flow. In spring, melting snow releases large amounts of dissolved nitrogen compounds originating from aerial depositions, but during summer large amounts of melt water dilute nutrients. The primary energy source of benthic algae is light. The amount of available light depends on both incident light, which changes seasonally, and light attenuation, which is affected by glacial flour in summer or snow cover in winter (dotted line = algal biomass in streams without snow cover in winter). High flow, bed load transport and suspended solids in summer impose major constraints on the growth of benthic organism in contrast to periods in spring and autumn.

and light availability, the accrual of benthic algae. During the vernal flow increase, however, moderate discharge coincides with relatively high temperatures and nutrient concentrations and low turbidity. In autumn, discharge is again moderate, turbidity low, and temperature slightly lower than in spring. Algae can respond rapidly to these relatively favorable conditions, particularly in autumn but also during spring. Algal biomass in channels covered by snow is low but in open reaches, algae may even proliferate in winter (see photograph). The period from autumn to spring is characterized by maximum invertebrate density and species richness [3, see also article p. 22]. Environmental conditions during winter impose less constrains on benthic invertebrates than on algae; some species even complete their life cycles in snow and ice covered channels.

Global Warming Affects Alpine Streams

In conclusion, sampling during all seasons is necessary to attain a holistic perception of the structure and function of alpine stream ecosystems. This became evident in the Val Roseg Project as well as in other studies [3, 7]. In glacial streams, periods of harsh environmental conditions are separated by relatively short but benign time intervals. This temporal pattern is highly predictable and reflected by corresponding changes in abundance and species richness of benthic organisms. Future climate change scenarios predict a decline of ice-/snowmelt dominated systems. Concomitantly, there will be an increase of streams with snowmelt- and rain-dominated flow regimes. In such streams, the annual flow pulse will already end in early summer and rain-induced floods will become more frequent. The less predictable flow regime and the extension of the autumnal window of opportunity into late summer will affect the structure and dynamics of benthic communities.

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