From Stream Reach to Catchment

The Ecological Relevance of Spatial and Temporal Heterogeneity

The understanding of natural processes in rivers is based on the conceptual foundations that have been developed in the second half of the 20th century. Natural streams are ecosystems characterized by high spatio-temporal heterogeneity, which is of crucial importance for the diversity of species and processes. Stream systems are hierarchically organized and as important landscape elements tightly linked to the adjacent terrestrial ecosystems. A successful integrated stream assessment requires consideration of the multifaceted nature of stream ecosystems at different scales.

There are presumably few ecosystems that have been more affected by human activities than streams [1]. In Europe, North America, and in many other parts of the world, streams were dramatically altered before stream ecology was established as a science that provides understanding of natural processes in rivers [2]. It has been recognized that high spatio-temporal heterogeneity and tight linkage with the terrestrial environment are the essential characteristics of natural streams. Such knowledge must be considered to bring the substantially altered streams closer to their natural state and to implement integrated stream management practices in general.

The Four Dimensions of Streams [3]

The **longitudinal dimension** is an obvious stream characteristic. A natural stream can be understood as a continuum, where all stream sections are longitudinally linked and abiotic parameters such as temperature, light, slope, flow volume, stream power and size of stream bed sediments change from headwaters to the sea. This results in a longitudinal gradient of habitat conditions and resource availability and is finally reflected by changes in the structure of aquatic communities along the river continuum [4].

The downstream transport of solid and dissolved matter stands for the longitudinal, mainly unidirectional link. Organisms like fish may also move upstream but many stream dwellers such as insect larvae are passively transported downstream. There are, however, mechanisms compensating for this continuous "flushing loss"; some species migrate upstream against the current while other compensate for drifting by flying upstream before oviposition (compensation flight). Longitudinal and lateral influences are superimposed. Compared to lakes or forest ecosystems, streams receive far more particulate and dissolved material from adjacent terrestrial ecosystems. Streams are intimately linked to the adjacent land; in forested catchments, the energy balance is dominated by leaf litter input. This material is partly processed and transported downstream. Primary production by algae plays a only minor role since very little light penetrates through the tree canopy and reaches the surface of the stream bed. As the stream widens and more light becomes available, primary production becomes more important. In large rivers, the direct input of leaf litter becomes negligible in the overall energy balance.

The **lateral dimension** of streams becomes evident in areas where a stream is not laterally constrained by topography (Fig. 1). Lateral connectivity is pronounced in natural river-floodplain systems being continuously reshaped by floods and offering a rich diversity of habitats for terrestrial, amphibian and aquatic organisms. The transition zone between terrestrial and aquatic habitats is particularly important. Trees and shrubs along the stream bank provide energy for aquatic and terrestrial organisms. Large woody debris from the riparian zone may create high spatial heterogeneity, particularly in small streams.

The **vertical dimension** of streams and rivers is less obvious. The hyporheic zone is the transition zone between surface water and groundwater and provides habitats and refugia for animals and microorganisms. Microbial biofilms play an important role in the nutrient and energy balance of streams. Hyporheic organisms, for example, nitrify or decompose organic material [5]. As in floodplains, floods may reshape the hyporheic zone. In the absence of such events, fine sediments fill small cavities and void spaces and the hyporheic zone becomes isolated from the surface water.

The **temporal dimension** becomes manifest through the permanent change of the location of gravel bars, islands and channels within a river corridor. Flow is the dominant driver of temporal variation of rivers. Floods entrain, transport and deposit sediment, thereby destroying some habitats while creating new ones. Floods are the most common natural disturbances in streams. Frequently occurring floods reduce species diversity and favor species with short life cycles and a high adaptation potential. If floods are rare or lacking, poorly competing species become extinct. Species diversity is expected to be at a maximum if flood frequency is intermediate [6]. Water diversions for irrigation or hydropower production affect the natural flow and disturbance regime. In river sections with residual flow, floods can be very rare or largely absent. In channelized streams, water transmission is accelerated and the attenuation of flood peaks reduced. This increases disturbance frequency compared to the pre-channelized situation.

The Ecological Significance of Spatial and Temporal Heterogeneity

A natural river corridor is stable over long periods of time with respect to the general pattern of landscape elements (Fig. 1). The individual elements, however, are constantly changing: stream channels are shifting back and forth, gravel bars migrate, islands disappear and new islands are formed. This dynamic spatio-temporal heterogeneity is a prerequisite for high species diversity, and thus, has a high ecological value. Preservation of high species diversity in river corridors requires a natural flow regime and sufficient lateral space, which also includes an intact riparian zone (see article of H.P. Willi, p. 26). Stream or river assessment should therefore also include (eco-)morphological and hydrological aspects (see article of A. Peter, p. 7).

The Hierarchical Structure of Streams

Describing streams as hierarchically organized systems provides a useful framework for integrated stream assessment [7]. At the top level is the *stream system,* which includes all surface waters of a catchment, and which is composed of individual *stream segments.* Segments are portions of a stream characterized by relatively uniform geology and geomorphology. Stream segments, in turn, are made up of *stream reaches;* reaches are geomorphic units delimited by changes in slope, stream bank vegetation, or width of the valley floor. *Pool/riffle* systems are sub-units within stream reaches; a pool is an area within the stream, where flow velocity is low and water depth relatively large. High flow velocities and shallow water depths characterize riffles. The lowest hierarchical level includes the extremely diverse *microhabitats* as, for example, small deposits of sand or fine gravel, individual rocks, water plants, or dead wood.

The systems evolve within the boundaries set by the higher systems within the hierarchy. Slope, sediment load and flow regime determine the structure and the temporal variability of a stream section [8]. The flow regime, and to some extent the sediment load, are determined by conditions on the next higher level of the catchment. Processes that have significant effects at low hierarchical levels have a minor impact at superior levels. The typical average lifetime of the systems ranges from weeks to several hundred thousands of years or even millions of years. A microhabitat, such as a sand deposit in a pool, is reshaped several times per year. Pool/riffle sequences may survive for months or years, flood plains are renewed every 10 to 100 years, and the life span of the entire stream system is measured at geological time scales.


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Fig. 1: Stream bed of the Tagliamento (Italy).

The hierarchical level, at which river management tries to mitigate former anthropogenic impacts, determines how significant the effects will be and how fast the system will respond. The widening of the stream bed in a short reach of a stream may only have a local effect, while the removal of a sill at the end of a catchment may influence the fish population in the entire catchment [9].

Landscape Perspective

Streams are important elements of the landscape and intimately linked with adjacent ecosystems. The large-scale patterns of vegetation and land use within a catchment determine instream condition [10]. These parameters can override the local riparian influence. A study in Michigan demonstrated that the stream condition in different stream segments – as judged by the structure of fish populations – did not correlate with stream bank vegetation within the same stream segment. However, a significant correlation with stream bank vegetation and land use patterns in upstream sections could be shown [11]. These findings exemplify the fact that the hierarchically higher system level can override local effects and also demonstrate the limitations of ecomorphological methods.

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