Functional Process Zones and the River Continuum Concept

by Erin L. Hestir

ABSTRACT

Research conducted over the last three decades has demonstrated that the geomorphology and ecology of a river system are inextricably linked. Fundamentally, the physical variables used to describe a river network control the ecology of that network as well. One of the goals of river and stream ecology is to understand both structure and function of a river network. In order to do so, classification of both the physical and biotic variables that control ecological structure and function must be accomplished. If river networks are classified successfully, predictions about ecological patterns may be made. This chapter discusses the recent *riverine ecosystem synthesis* by Thorp et al. (2006), its proposed conceptual model for river ecosystem classification, and how this new tool can be used in terms of the classic predictive model, the River Continuum Concept.

INTRODUCTION & BACKGROUND

Over the past three decades, there have been many attempts to understand and describe the ecological complexity of rivers and streams, as well as identify patterns in riverine networks. Numerous conceptual models have been proposed, some complementary to previous and contemporary work. Other conceptual models contradicted previous work as the state of understanding for these complex networks evolved rapidly during that time. Thorp et al. (2006) have recently proposed a new conceptual framework in the *riverine ecosystem synthesis* that encapsulates work conducted since Vannote et al.'s (1980) seminal paper on river ecology. Their framework, intended to provide insight into both longitudinal and lateral patterns along river networks and ecological patterns across various temporal and spatial scales, draws heavily upon ecogeomorphology (Thoms and Parsons 2002), an emerging field of river research that emphasizes geomorphological impacts on fluvial ecology (Thorp et al. 2006).

The River Continuum Concept

First presented in 1980, the River Continuum Concept (RCC) proposed by Vannote et al. has dominated approaches to river and stream ecological research. This concept was predicated in large part on earlier work by Vannote recognizing that structural and functional characteristics of stream communities are controlled by the physical state of the stream. The River Continuum Concept posits that there is a continuous gradient of physical conditions from the headwaters to the mouth of any river. The conditions listed include width, depth, velocity, flow volume, and entropy gain. The RCC predicts that these physical gradients regulate biotic processes within the river, specifically nutrient dynamics. Although many exceptions to the RCC have been published since its original presentation (e.g. gradients are not generally viewed as continuous), the overarching concept of longitudinal change along a river continues to dominate alternative hypotheses to the RCC. Furthermore, this concept seems to adequately describe observations made in the field.

The ultimate goal of this project is to understand the Wallowa & Grande Ronde Rivers, Oregon, USA, in terms of the River Continuum Concept by testing whether any of the predictions made by Vannote et al. are realized through simple data collection procedures and analysis as we move from the headwaters to the mouth of the Wallowa and Grande Ronde Rivers.

Classification of Rivers and Streams

A fundamental goal of river and stream ecology is to understand both physical and ecological structure and function of a river network. However, this is challenging as these networks are open systems with high temporal and spatial variability in their physical structure (Thorp et al. 2006). To further this goal, Hawkes (1975) attempted to divide river ecosystems into discrete, longitudinally ordered zones. In 1980 Vannote et al. challenged Hawkes' zoning scheme when they presented the River Continuum Concept, which conceptualized river ecosystems as continua rather than separate, discrete zones. The conceptual model predicted that these ecological continua are strategically adapted to longitudinal (headwaters to mouth) energy efficiency.

The River Continuum Concept

Considered one of the most influential papers of the twentieth century, Vannote et al.'s model is still widely accepted for headwaters through medium rivers. The RCC makes two predictions: 1) a continuous gradient of physical conditions observable from the headwaters to a river's mouth; and 2) this longitudinal gradient of physical conditions will control biotic responses. Hence a continuum of organic matter loading, transport, utilization, and storage should also be observed along the river (Vannote et al. 1980, Thorp et al 2006). This model of longitudinally continuous ecosystems contrasted with earlier conceptualizations of isolated zones predictably distributed along the longitudinal dimension of a river (i.e. Hawkes 1975).

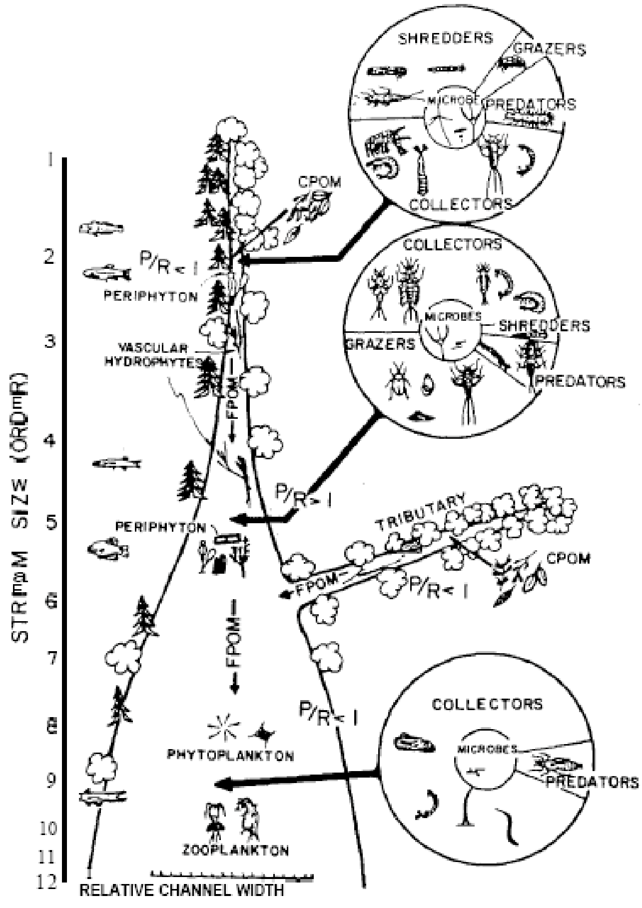

Figure 1. Vannote et al.'s longitudinal relationship between stream size and ecological structure and function (reproduced from Vannote et al. 1980)

Many predictions stemming from the RCC have been criticized. The concept of ecological continua is not realized when applied to real rivers. In terms of stream hydraulics, instead of observable gradients, there are often abrupt discontinuities in water flow that result in abrupt changes in substrate size. This in turn results in abrupt changes in species assemblages (Statzner and Higler 1986). Perry and Schaeffer (1987) did not observe the predicted continuum in species assemblages; they were able to demonstrate only a minor downstream gradient in bottom-dwelling river species. They characterized species distributions in a river as punctuated gradients, rather than ecological continua. Benda et al. (2004) identified tributary junctions at biological hotspots in the network dynamics hypothesis (NDH), further refuting the concept of an ecological continuum, and highlighting the fact that rivers are better viewed as networks. Junk et al. 1989, stated that Vannote et al.'s concept that downstream foodwebs were highly dependent on organic matter leakage from upstream (see Fig. 1) was contradicted by the flood pulse concept in lateral floodplains. Thorp and Delong 1994, 2002, criticized the RCC because it did not take into account autochthonous production (within system productivity).

In an attempt to reconcile the RCC with subsequent river research, Thorp et al. acknowledged these criticisms of the RCC, and highlighted work done by Townsend (1989), Poole (2002), and Montgomery (1999), that proposed alternate explanations of patterns in river networks. Rather than being continuous gradients of energy resources, *sensu* Vannote et al., rivers are composed of patchy discontinuities in which communities are more likely to respond to local landscape features rather than any sort of longitudinal gradient. That is, an ecological community within a stream segment may be as equally differentiated from neighboring communities as from up or downstream communities, based on local processes (Poole, 2002). This presented the concept of ecological patchiness within a river as an alternate to ecological continua in river ecology.

Montgomery (1999) concluded that the RCC was valid only for low-relief watersheds with relatively constant climate and simple geology, descriptors that are decidedly not applicable to the Wallowa and Grande Ronde Rivers. An alternate concept known as "process domains" was proposed. This concept is centered on the importance of local geomorphic conditions and landscape-scale disturbances. Furthermore, it can be applied to regions of high relief, variable climates, and complex geology, such as the Grande Ronde River basin. Montgomery's process domains focus on the spatial variability in geomorphic process that governs temporal patterns of disturbances that, in turn, influence ecosystems (Montgomery 1999).

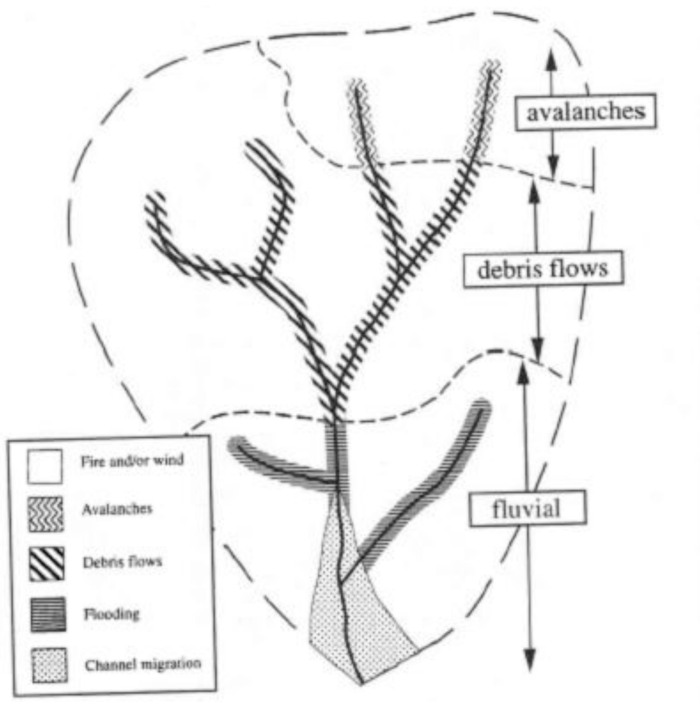

Figure 2: An example of coarse-scale (landscape-scale) riverine process domains for Pacific Northwest drainage basins (reproduced from Montgomery 1999).

HYDROGEOMORPHIC PATCHES & FUNCTIONAL PROCESS ZONES

In spite of the criticisms of the River Continuum Concept, it did, and to a large extent still does, inform many empirical observations of ecological patterns in river networks. This is because it is one of the few conceptual models that provide predictive power. River ecologists continue to ask the question, "How predictable are rivers' ecological communities along longitudinal dimensions of river networks?" Thorp et al. caution that this answer is complex due to dependency on scale. Nevertheless, it should be answerable. In support of this declaration, they cited Thoms and Parsons (2003), who used 230 hydrological and geomorphic variables to describe rivers. Their study supported the concept of spatial zonation along longitudinal gradients, at least in terms of hydrological characteristics. This implies that patterns along the longitudinal dimension of a river network, although not continuous, do exist. They should be observable, and perhaps the RCC should not be disregarded in its entirety.

Hydrogeomorphic Patches

Thorp et al. propose an alternative to the concept of continuous, longitudinal gradients of physical conditions. Rivers can instead be viewed as downstream "arrays" or networks (Benda et al. 2004) of large "hydrogeomorphic patches" formed by catchment-scale geomorphology and flow (Thorp et al. 2006). These patches are defined by shifts in hydrological and geomorphic conditions. These physical boundaries (shifts) may be distinct, or indistinguishable by field observation, but can be delineated using standard geomorphological techniques and terminology (Thorp et al. 2006). For example, an area of river with a constricted flow channel would be considered a hydrogeomorphic patch, as would a braided channel, an area with extensive slackwater, and an area with a broad floodplain. These various patches are expected to differ in physical and chemical conditions. Therefore, their ecological communities should vary significantly as well. Hence, patterns of ecological structure and function in a river network are controlled by hydrogeomorphic patches. Easily identifiable patches can be used as a template for the identification of "functional process zones," ecological communities controlled by the hydrogeomorphic patches (Thorp et al. 2006).

Hydrogemorphic Patches vs. Process Domains

Initially Thorp et al.'s hydrogeomorphic patch concept appears to be synonymous with Montgomery's process domains. However, in proposing the concept of the hydrogeomorphic patch, Thorp et al. were attempting to distinguish their patches as similar to, but ultimately more sophisticated than Montgomery's process domains. Montgomery's designation of process domains takes a "top-down" approach, working from the landscape scale disturbance pattern down to the stream. Thorp et al. take a more holistic approach to their patch designation which is more in step with Vannote et al.'s original physical variables (width, depth, velocity, and flow volume). Thorp et al. acknowledge that while landscape scale patterns of disturbance are a significant source of control on patterns of river ecology, hydrologic discontinuities and the floodplain/riparian zone are also significant physical controls. They intuit and acknowledge that scale matters; these systems are open, and fundamentally, patches rely on upstream inputs as framed by the River Continuum Concept. Process domains come out of a rejection of the RCC, whereas hydrogeomorphic patches are an attempt to the resolve process domains with the RCC.

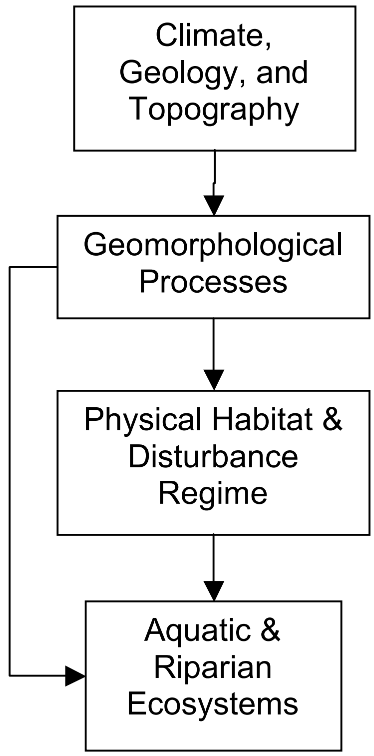

Figure 3: Process domains: a top-down approach. A schematic representation of the relationship among landscape processes, habitat structure, and riverine ecosystems (redrawn from Montgomery 1999).

Functional Process Zones

Although termed a zone, functional process zones do not describe Hawke's concept of a fixed river zone. They grow from Montgomery's process domains, but ultimately differ from them as they describe the ecological processes within hydrogeomorphic patches, rather than within purely geomorphic regions affected by terrestrial landscape disturbances (process domains). Hydrogeomorphic patches are the template upon which a functional process zone may be visualized, but a functional process zone itself describes and classifies the ecological functions that are controlled by the physical parameters of that zone.

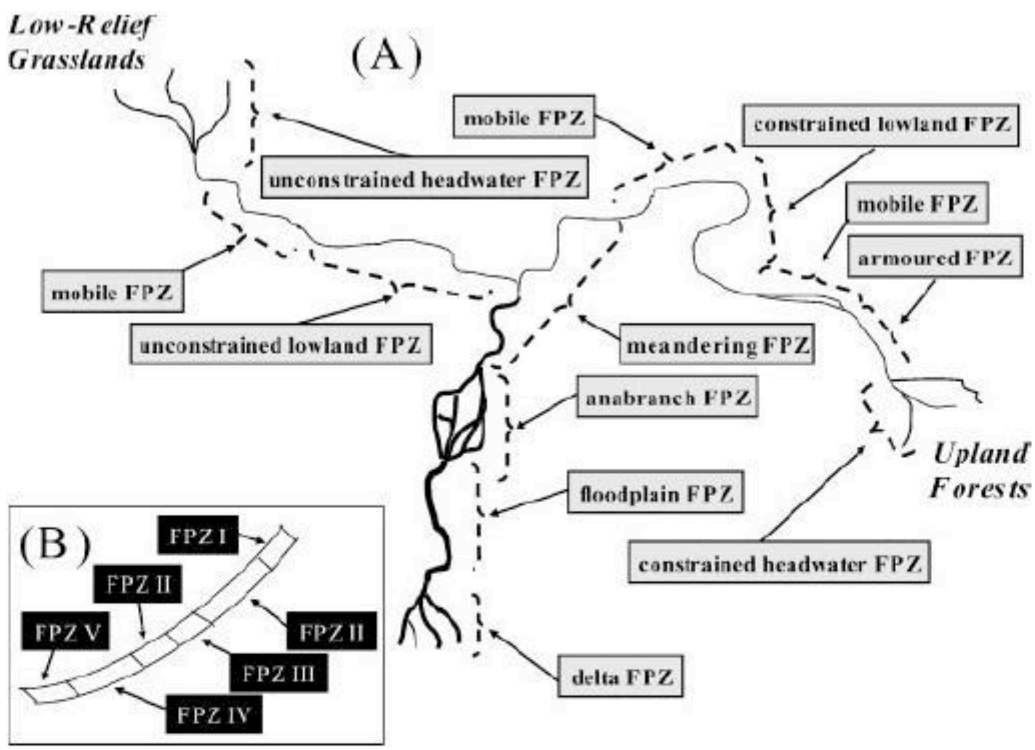

Figure 4: A. a schematic view of a river network with various functional process zones that are formed by large hydrogeomorphic patches. B. The same or similar type of functional process zone may be present in more than one part of a single tributary, and may be arranged in an order that is not always predictable (Reproduced from Thorp et al. 2006).

Classification of Ecological Patches

Thorp et al. present the functional process zone, and support its hydrogeomorphic foundation. In order to better apply the functional process zone as a stream/river classification tool, it is useful to think about it in terms of ecological patches. Frissell et al. (1986) also recognized that larger landscape processes are fundamental to the classification of stream habitats. They also propose a geographically integrating hierarchical framework that accounts for spatial and temporal scale variation (a stated goal of Thorp et al.'s *riverine ecosystem synthesis*). Such a hierarchical approach allows for a winnowing of the set of variables needed at lower levels. It also provides for integration of data from different sources, and allows for the selection of different resolutions at which to work (Frissell et al. 1986). According to Frissell et al. (1986), this hierarchy should be spatially nested, and classified according to geomorphic boundary delineation and a description of key characteristics that would allow the differentiation of that class from others.

Frissell et al.'s approach to a nested hierarchy of habitat classification may facilitate an understanding of the variability within a defined functional process zone, characterized in terms of habitat patches. Ideally, a functional process zone should contain variability that could be attributed to this spatially nested hierarchy of habitat classifications. But ultimately, following the assumptions in Thorp et al.'s definition of a functional process zone, the variability between functional process zones should be greater than the variability within the functional process zone.

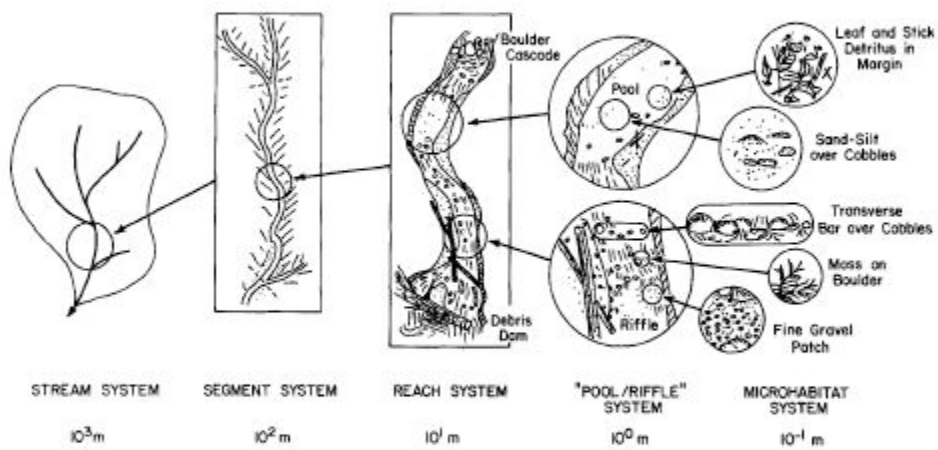

Figure 5: A spatially nested hierarchical organization of a stream system and its habitat subsystems. (Reproduced from Frissell et al. 1986).

Reconciling the functional process zone with the River Continuum Concept

Controlled by the underlying hydrologic and geomorphologic characteristics of a hydrogeomorphic patch, defined by the shift in these characteristics, and classified in terms of habitat variability, functional process zones present a conceptual model that can easily be applied to field observations along the Wallowa and Grande Ronde Rivers. However, upon classification of stream and river ecological structure and function, the more basic question must be asked. "How do these hydrogeomorphic patches distribute along the longitudinal dimension of the river network. Can functional process zones be predicted by the River Continuum Concept?"

In order to determine whether functional process zones can be predicted by the RCC, it is important to understand that both functional process zones, and their underlying hydrogeomorphic patches are scale dependent. Temporally, flow disturbance varies along the downstream direction. Short term flood pulses are important in headwaters, whereas longer term flow history is more significant to lowland rivers (Thorp et al. 2006). In terms of temporal flow variability, a continuum or gradient concept can be applied to this facet of the hydrogeomorphic patch.

Organic matter and trophic dynamics on the other hand, may not be longitudinally-predictable facets of the functional process zones. In general, headwaters tend to have shorter retention times for organic matter than do downstream river-floodplain areas. But the retention time is highly variable, and dependent on the hydrogeomorphic patch (Thorp et al. 2006). A longitudinal continuum may be interpolated, but cannot be proposed as a general rule. Other variables also control functional process zones such as geomorphology and hydrology, as well as climatic conditions may demonstrate a continuum governed by elevation change, but cannot necessarily be expected to follow a longitudinal continuum. It appears that the River Continuum Concept can reliably predict some features of the functional process zone, but not others; and may be highly site specific.

CONCLUSION

Although the River Continuum Concept has its flaws, which have been covered extensively in the proceeding literature, it also is a very useful tool for river and stream classification; it may help us understand ecological patterns within a river network. Vannote et al. (1980) conclude, "A concept of dynamic equilibrium for biological communities, despite some differences in absolute definition, is useful because it suggests that community structure and function adjust to changes in certain geomorphic, physical, and biotic variables such as stream flow, channel morphology, detritus size loading, size of particulate organic material, characteristics of autotrophic production, and thermal responses."

The predictive power of the RCC makes it one of the most useful tools for studying the ecological patterns along the longitudinal dimension of a river network. Thorp et al. (2006) predict substrate size and temperature regime to follow a longitudinal continuum, with localized caveats. Although there are limitations, the concept of functional process zones is reconcilable to the RCC. For example, if hydraulic forcing is considered, and hydrogeomorphic patches are identifiable in terms of shifts or changes in this physical variable, then predictions can readily be made that support a longitudinal continuum of functional process zones. In other words, if we define a continuum of discontinuities where transitions are the critical determinants of species assemblages, then the functional process zone concept works in the context of the RCC.

During our trip down the Wallowa and Grande Ronde Rivers, many physical and biotic parameters will be measured in order to test the predictions made by the RCC. Thorp et al.'s riverine ecosystem synthesis has appeal for river and stream ecologists. Through traditional approaches and techniques, hydrogeomorphic patches should be easily recognizable and defined. It follows that functional process zones should be easily mappable onto these patches by simple field measurements and an understanding of habitat variability. If functional process zones can be mapped, then we will be able to test whether Thorp et al. have indeed succeeded in reconciling their conceptual model to the RCC.

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