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## Scale, ecological fallacy, and the river continuum concept

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# Scale, Ecological Fallacy, and the River Continuum Concept

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A thesis submitted to  
The Eberly College of Arts and Sciences  
at West Virginia University  
in partial fulfillment of the requirements  
for the degree of

Master of Arts  
in  
Geography

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## **ABSTRACT**

### **Scale, Ecological Fallacy, and the River Continuum Concept**

Hope M. Childers

Concern over scale is not new, and it is not restricted to geographers. Spatial and temporal scaling is a conceptual and methodological problem for all sciences using geographic information. This paper teases out issues of scale and ecological fallacy from the literature and discusses how these issues influence the applicability of an influential theoretical framework in stream ecology, the River Continuum Concept (RCC). Investigators are faced with decisions regarding scale during sampling location selection, field data capture, and subsequent data interpretation. A thorough understanding of the heterogeneity of stream habitats and the life histories of the organisms being studied could enable investigators to make appropriate methodological choices with regard to sampling resolution and extent. It is crucial that investigators improve their ability to understand the consequences of aggregating and extrapolating data collected point samples in order to adequately evaluate ecological hypotheses operating over relatively broad spatial and temporal scales.

*This thesis is dedicated to  
Margaret Grace Childers.*

## **Acknowledgments**

I would like to thank my parents, Ron and Chris Sacco, as well as the faculty at Wheeling Jesuit College and the Department of Geology and Geography at West Virginia University, for giving me the tools to achieve my educational goals.

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## Chapter 1. Introduction

Ecology is the study of the structure and functions of nature. Structure includes the distribution and abundance of organisms as influenced by their biotic and abiotic environment. Function includes how populations grow and interact, including relationships between organisms and transfers of nutrients and energy. In ecological studies, primary information and measurements are generally collected at relatively large scales (ie. small plots) and that information is often aggregated or used to build models at radically different scales. In the social sciences, ecological analysis has come to mean any analysis based on aggregated data. A review of ecological fallacy, even if from the social sciences perspective, is important because in complex, nonlinear, discontinuous systems, such as those studied by stream ecologists, this is far from being a trivial problem and has significant ramifications for research design and analysis.

There has been considerable discussion, particularly in human geography, of the effects of moving from one scale to another (eg. Haggett, 1965; Harvey, 1968; and Hudson, 1992). One problem related to scale is coverage, or the difficulty of ensuring a regular monitoring of the world at relevant scales. In addition to coverage issues, standardization is a problem because it is often hard to obtain data having equivalent sampling frames. Data inequality is likely when comparing different parts of the earth's surface and when making comparisons over time. Standardization problems lead to inferential problems when information from various scales is linked. "Conclusions derived from studies made at one scale should not be expected to apply to problems whose data are expressed at other scales. Every change in scale will bring about the statement of a new problem, and there is no basis for assuming that associations existing at one scale will also exist at another" (McCarty, 1956 as qtd. in Haggett, 1965). Generalizations about patterns and processes at one level may be invalid for another level, which leads to ecological fallacy.

Concern over scale is not new, and it is not restricted to geographers. Spatial and temporal scaling is a conceptual and methodological problem for all sciences using geographic information. Mishandling scale can bias inference and reasoning, and can ultimately affect both



understanding and the decision-making processes. Temporal and spatial scale often plague data collection efforts. The system, or phenomenon, being studied may change more rapidly than one can measure it (e.g. insect populations), or it may change more slowly than the investigators life span (e.g. forest succession). In stream ecology and the study of macroinvertebrate communities, it has not been effectively shown whether variation at fine scales is significant relative to variation at coarse scales (Downes et al., 1993). Benthic community structure is a function of site-specific conditions and coarse scale influences such as geomorphological structure. “When we observe the environment, we necessarily do so only on a limited range of scales; therefore, our perception of events provides us with only a low-dimensional slice through a high-dimensional cake” (Levin, 1992).

The issue of scale becomes particularly relevant when considered in the context of ecological theory such as the River Continuum Concept (RCC). The RCC seeks to link patterns of aquatic community structure and function to fluvial geomorphic processes and the physical structure of streams. The RCC postulates that the physical structure, coupled with the hydrologic cycle, forms a template for biological responses, resulting in consistent patterns of community structure and function and organic matter loading, transport, utilization, and storage along the length of a river. Exploring ecological hypotheses, such as those suggested by the River Continuum Concept, often entails fine-scale measurements of samples or survey, which are then extrapolated for analysis of broad-scale phenomena (Vannote et al., 1980). In order to scale from the individual organism to the ecosystem and then to the landscape, there needs to be a better understanding of how information is transferred from fine to coarse scales (Jarvis and McNaughton, 1986). As Levin (1992) notes, “The key to understanding how information is transferred across scales is to determine what information is preserved and what information is lost as one moves from one scale to the other.”

The objective of this research is to explore the role that scale plays in the study of stream ecology, particularly in the study of macroinvertebrate communities. This research will tease out the issues of scale and ecological fallacy from the literature, and will then examine how these issues influence the formation and applicability of theoretical frameworks such as the River Continuum Concept. It will strive for a deeper understanding of stream ecology and the issues associated with scale by focusing on the following:

- *A review of scale issues in the context of stream ecology*
- *How does scale contribute to ecological fallacy and how does this influence the study of stream ecology and macroinvertebrate communities?*
- *How do scale and ecological fallacy issues influence the River Continuum Concept?*

The paper first introduces general issues of scale such as resolution and extent, pattern, variation, and autocorrelation. It then discusses these issues in the context of stream ecology and the study of macroinvertebrate communities by focusing on concepts such as ecological neighborhoods and taxonomic resolution. In particular, the study explores scale issues in stream ecology and the scale dependency of biological processes in streams. This is followed by an exploration of the different forms of ecological fallacy as they apply to the study of macroinvertebrate communities. Due to the nature of ecological data, conceptual models such as the River Continuum Concept (RCC) provide examples of ecological fallacy since data collected at a relatively large scale is often used to build small scale models. The final objective of this research is to examine the RCC in the light of the scale and ecological fallacy issues that have been teased out of the existing literature.

## **Chapter 2. Scale Issues in Geography and Stream Ecology**

### **The Challenge of Scale**

Geographic information technologies such as Remote Sensing and Geographic Information Systems have made spatial data easier to collect, aggregate, combine, and incorporate into ecological models. Although scale is well defined for some types of digital data, it is less well defined for other types of data. Scale is usually referred to as a small linear dimension; however, sometimes it is nearly impossible to characterize an observation with a linear measure. Sometimes spatial scale refers to a specific metric relationship between the size of a feature on a map or image to the corresponding dimensions in reality. In other instances, scale refers to the level of generalization at which phenomena exist, or are perceived, observed, or represented. To further complicate the matter, different disciplines have different ideas of what scale constitutes especially in terms of “large scale” and “small scale.” For example, what is considered to be small scale to an ecologist is large scale to a geographer or cartographer. In the geographic or cartographic discipline, a large-scale map shows features in detail, while a small-scale map only shows more generalized features. A map with a representative fraction of 1/10,000 is a large-scale map when compared to a small-scale 1/250,000 representation. The scale not only determines in what detail features are shown on the map, but also determines what features are shown. For example, a map of a local community may show individual houses, whereas a regional or national map may not. As scientific investigations become more data dependent and multidisciplinary, it is crucial that scientists are able to work at multiple scales with an understanding of how information is transferred from fine to broad scales and vice versa. The concepts of resolution, extent, autocorrelation, spatial heterogeneity, pattern, and variation are fundamental to geography, ecology and other sciences studying the relationships of processes occurring at different spatial and temporal scales.

The term scale is used in both spatial and temporal dimensions of research. Spatial or geographic scale refers to both the extent and the resolution of a study. In other words, it refers to the size or magnitude of a study and the degree of detail in the observations and measurements. Similarly, temporal scale refers to the frequency with which a measurement or observation is made. All

observations have a limiting spatial and temporal resolution. However, it is sometimes difficult to isolate a single measure to characterize observations. In both spatial and temporal studies, understanding scale is important because it describes the limits of our observations of the earth and the physical and social processes taking place upon it (Quattrochi and Goodchild, 1997). Resolution, also referred to as ‘grain’, defines the smallest object or feature that is included or discernible in the data. High spatial resolution enables small objects to be distinguished. Scale and resolution are related because there is a lower limit to the size of an object that can be distinguished, sampled, or represented. As scale becomes coarser, resolution diminishes. The extent and resolution of observations are important because they influence our ability to observe patterns of spatial heterogeneity and variation in the environment.

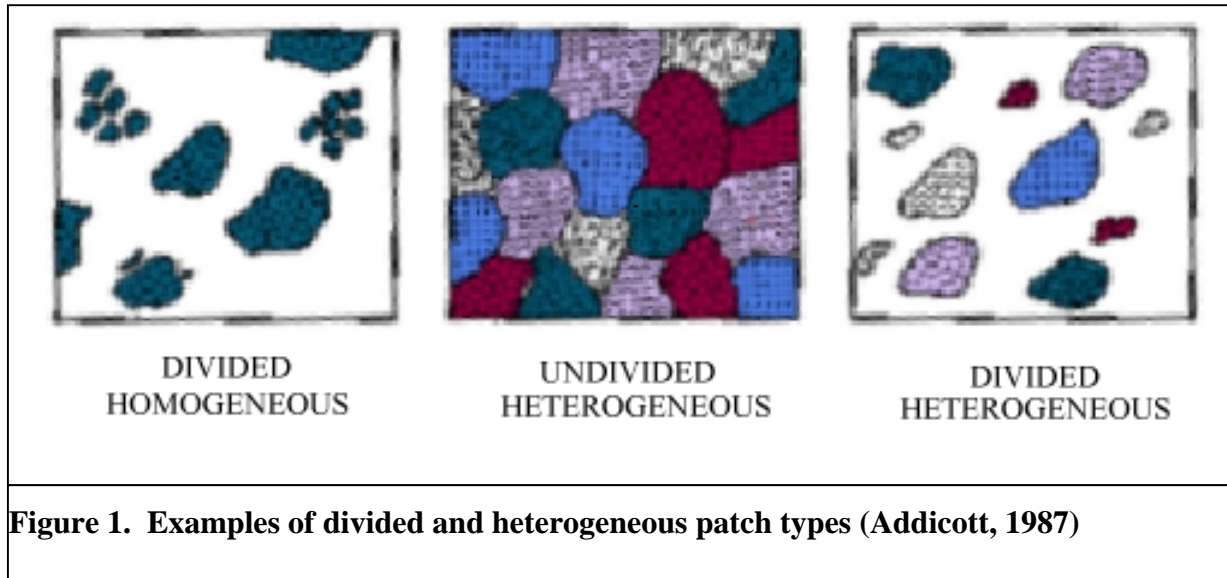
Autocorrelation is a general property of ecological variability observed along a time series or across geographic space. Most ecological phenomena exhibit spatial autocorrelation, the presence of pattern due to geographic proximity. Spatial autocorrelation occurs when variables for pairs of locations are more similar (positive autocorrelation) or less similar (negative autocorrelation) than expected for random pairs of observations. Spatial autocorrelation violates the basic assumption that observations are “independent” from one another. The most common forms of spatial autocorrelation are gradients and patches. Patterns observed as a result of variation due to gradients and patches represent some of the challenges posed by scale because detecting pattern depends on the extent of the study as well as the grain, or size of the individual units of observation. The overall extent and the individual units of observation limit the identification of pattern. One cannot detect patterns below the grain, and generalizing beyond the extent leads to ecological fallacies associated with aggregation and extrapolation.

### **Scale Dependency of Ecological and Stream Processes**

It has been argued that the problem of pattern and scale represents the central problem in ecology (Levin, 1992). Physical, biological and chemical processes are simultaneously occurring at various scales in space and time. Understanding pattern in terms of the underlying processes that create them is central to science. As Weins (1989) described, “Different patterns emerge at different scales of investigation of virtually any aspect of any ecological system”. Relationships

between physical and biological phenomena might be observed at one level of observation, but may be masked at another level of observation. For example, links between vegetation and climate might be observed at small, broad scales but be undetectable at large, finer scales where local biological interactions such as competition are prominent. Although hierarchy theory suggests that broad scale processes constrain finer scale processes, fine scale patterns can impose constraints on broad scale processes as well (Wiens, 1989). It is a challenge to examine processes simultaneously at multiple spatial and temporal scales, but it may be necessary in order to comprehend the intricate dynamics of a system.

Environmental patterning includes the spatial distributions of resources and other abiotic conditions. The distribution of stream habitats is often described as a patchy distribution, and a particular habitat in the stream is sometimes referred to as a patch. The patchiness of stream habitats is pervasive in nature and has been hypothesized to affect ecological processes and the distribution of benthic macroinvertebrates. The two types of patterning include division and heterogeneity. Division occurs when areas of unsuitable conditions separate patches. Heterogeneity occurs when patches are qualitatively different, but one patch is not necessarily more suitable for stream biota than the other. Spatial heterogeneity is important because it is functional in the context of stream ecology. A stream ecosystem without patterning could not function effectively. For example, a homogeneous stream would lack habitat diversity and macroinvertebrate consumers would not necessarily be near their food source. “Most natural ecological phenomena display geographical patchiness, and it is found at all spatial scales” (Legendre, 1993). Patchiness occurs when environmental variables are discontinuous among arbitrarily chosen sampling units. An environment can exhibit patchiness at different scales at the same time. Patches may or may not be divided by regions of relatively unsuitable environmental conditions, and patches may be homogeneous or heterogeneous.

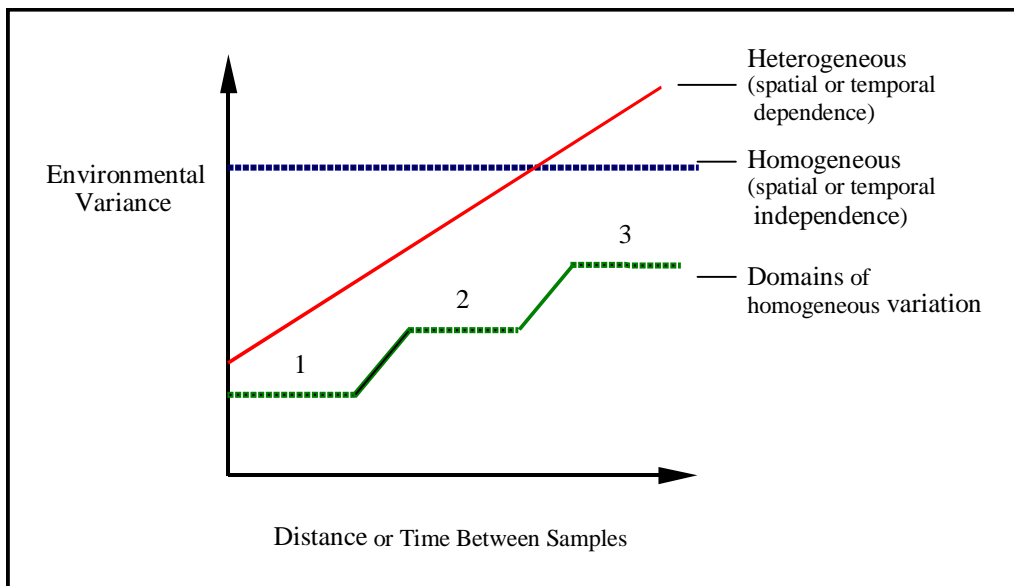


Spatial variation can also be continuous or discrete, and patches can vary in size, shape, spatial arrangement, and interconnectedness. Importantly, the complexity of heterogeneity cannot be captured with one measure of variation (Cooper et al., 1997). Scientists require a range of descriptive measures that take into consideration the scale dependency of the ecological patterns. Such measures should describe overall trends, overall variability, be related to location, and consider the influence of autocorrelation. Possible tools for describing spatial heterogeneity include regression analysis, semivariograms, numerical maps, fractal geometry, information theory, and nearest neighbor analysis (Cooper et al., 1997).

The occurrence of spatial and temporal variability, including heterogeneity and patchiness, in stream ecosystems is well documented. There have been several studies of the spatial and temporal patterns of benthic macroinvertebrates in streams (eg. Bunn, 1986; Corkum, 1992; Downes et al., 1993; Hutchens et al., 1998; Naiman et al., 1987). These studies have focused on changes in the arithmetic mean of the parameters over space or time. However, less work has been done on how variance in pattern or process changes with scale. Scientists are only just beginning to quantify variability in order to relate it to ecological processes and to help determine appropriate scales for examining those processes. Ecological variance is now accepted as being important rather than being a nuisance. The pattern of change in variation with change in sample grain or extent might suggest scales at which ecological processes can best be identified (Downes

et al., 1993; Cooper et al., 1997). Variance is most commonly used as a way to measure the precision of the sample mean, for example through the estimation of confidence intervals. However, the magnitude of variance depends on the spatial and temporal scale of the sampling regime (Horne and Schneider, 1995). Palmer et al. (1997) suggest looking at variance over space and time as a dependant or independent variable because changes in variance in one parameter might be related to changes in the mean of that parameter or another parameter.

When the scale at which a variable is measured is changed to another scale, the variance of that variable also changes. If the extent remains the same in a heterogeneous environment, then increasing the sampling resolution, the size of the grain, can decrease spatial variance. As the sample size increases, more of the spatial heterogeneity is within a sample so there is less heterogeneity between the samples. If the individual units of observation stay the same, an increase in extent would include more area, which may also include greater spatial heterogeneity. Including greater spatial heterogeneity in the extent is likely to increase between-sample variance (Wiens, 1989). The following figure illustrates the possible relationships between the variance of a sampled parameter and the distance or time between samples.



**Figure 2. Possible relationships between variance and the distance or time between samples (modified from Palmer et al. 1997).**

If the environmental variance of a parameter forms a horizontal line when plotted against changes in the sampling interval then this would suggest that the study area is homogeneous with respect to that parameter. A steep slope suggests that variability increases with distance between samples and the variable exhibits spatial or temporal dependency. Another possibility is the presence of domains of homogeneous variation of a particular parameter (Palmer et al., 1997). In addition to the shape of the plotted variance, the slope of the trend line is also important because the rate at which environmental variance increases with increasing distance between samples could be considered a measure of environmental heterogeneity (O'Neill, 1991 as cited in Palmer et al., 1997).

Domains, or plateaus in environmental variance are important because they suggest the possibility that the same processes might be influencing or structuring the biota (Palmer et al., 1997). If *domains* of biological variation can be matched with domains of physical variation, then they may lead to a better understanding of what is generating the biological patterns. For example, if variation in macroinvertebrates parallels variation in substrate size then the observations might lead to a more thorough examination of the relationship between the substrate and the biological communities. The presence of *domains* might suggest that the same processes are structuring the biological community throughout the area of homogeneous environmental variance. The identification of domains might also determine an appropriate sampling scale if they indicate that the variability of a parameter is constant throughout identifiable reaches of a stream (Palmer et al., 1997).

Even when the distribution of organisms and the patterning of resources are identified, and the variance of parameters are explored there are still additional challenges to consider. For example, system openness can be scale dependent (Weins, 1989). A rock in a riffle might be open as far as immigration and emigration of macroinvertebrates but the riffle that the rock is on may not be open if the habitat surrounding the riffle is unfavorable for the macroinvertebrates. Furthermore, the distribution of the organisms and patterns of resources in the stream do not necessarily indicate how an organism utilizes the environment. The observed patchiness may not be important for a particular process. The scale at which one species perceives its environment



may or may not be the same scale at which another species perceives its surroundings. For example, relatively mobile organisms are affected by the environment differently than more sessile organisms. The patchiness of an environment may not be equally important to all organisms or processes, and the resolution and extent of a study should be related to the movement patterns of the organisms under investigation and the resources on which the organisms depend for survival. This idea of *an ecological neighborhood* (Addicott, 1987) addresses some of the issues raised regarding environmental heterogeneity and has the potential to provide a mechanism for scaling spatial and temporal patterns of organization while permitting closer attention to the organisms under study.

### **Scale Issues in the Study of Benthic Macroinvertebrate Communities**

Scale in the study and sampling of benthic macroinvertebrates is important because benthic macroinvertebrates are often the focus of investigations into stream ecological processes and are commonly utilized in water quality assessments. Macroinvertebrates are popular biomonitors because they are ubiquitous and are affected by environmental disturbances in a variety of aquatic habitats. A large number of taxa offer the possibility for a range of responses to environmental stresses and their somewhat sedentary nature allows for the spatial analysis of the effects of stream disturbance. In a sense benthic macroinvertebrates are used as continuous monitors within the stream. However, the abundance of macroinvertebrates is affected not only by water quality, but also by seasonal variations and changes in the stream's velocity or substrate. This necessitates ecological knowledge of the taxa involved and a carefully chosen experimental design (Rosenberg and Resh, 1993).

When sampling benthic macroinvertebrates, as with any other type of data collection, there are spatial and temporal issues of resolution and extent. Organisms, such as benthic macroinvertebrates are not distributed uniformly or randomly, nor are the physical variables that constitute their environments. Patterns in spatial autocorrelation also depend on grain and extent. If sample units are larger than the habitat and/or macroinvertebrate patches then the data collection process may miss the spatial structure. There are a variety of qualitative and semi-quantitative sampling methods as well as different sub-sampling methods used by stream

ecologists. Some methodologies limit sample collection to a single habitat (eg. riffle) while others collect samples from multiple habitats. Different methods may have somewhat different, indirect implications for spatial scale. It is beyond the scope of this paper to evaluate sampling protocols and sub-sampling methods. However, life history information for macroinvertebrates might help investigators make better decisions with regards to the selection of appropriate spatial and temporal scale.

Addicott (1987) suggested defining an *ecological neighborhood* by examining the ecological process of interest such as population growth and predator prey relationships, in a time scale appropriate to the process and the organism's activity or influence during that time period. In this definition, the ecological process of interest is still a major factor in determining the neighborhood because it determines the time scale over which to measure neighborhood size. Sometimes the neighborhood would be defined by the organism's mobility. In other instances, such as with filter-feeding macroinvertebrates, the region of influence might extend well beyond the macroinvertebrates' mobility. Even with careful development, the criteria required to determine *ecological neighborhoods* would still be somewhat arbitrary.

Addicott (1987) identified problems that complicate implementing the *ecological neighborhood* concept. The first obstacle is that investigators may be drawn to sampling at a scale, which corresponds to patch size even though the ecological neighborhoods will not always correspond to those patches. Secondly, ecological neighborhoods are not likely to always be at a scale at which an investigator can easily conduct a study. The data needed to determine neighborhood size, for example, might be hard to come by. Furthermore, the neighborhood size for a particular organism could change with each process that is explored (Addicott, 1987). A detailed analysis of neighborhood sizes relative to the sampling units and patches may be an unrealistic expectation. However, an explanation of the natural history of the study organisms would help justify the methodological choice of a particular sampling extent and resolution as well as provide a reminder to others of the importance of recognizing scale when comparing studies.

It is also imperative to consider temporal scale when sampling macroinvertebrates because variables that appear to control or constrain factors change with the time frame over which the stream is viewed and because macroinvertebrate populations fluctuate throughout the year. For example, in a geologic time frame, the slope of a channel is dependent on climate and geology. However, in a time frame of a few years, channel slope may be the independent variable controlling channel morphology and sediment transport (Frissell et al., 1986). Seasonal variation in the abundance and distribution of macroinvertebrates can also create sampling and temporal resolution problems. Life history knowledge of species involved can help, but there is often a lack of information on all life stages of some aquatic insects having complex life cycles. Sampling frequency is clearly dependent on the study objectives. For example, irregularly spaced samples, such as before or after a rain event, may be more valuable than regular monthly sampling.

Studies of macroinvertebrates are usually limited to samples that can be easily collected and this creates a temporal scale challenge for investigators. Studies often do not include samples during seasons when streams are frozen, flooded or dry. “As a result, we risk drawing improper conclusions about the factors shaping patterns of species distribution, abundance, and behavior based on a very narrow subset of potential selection pressures acting over limited times of an aquatic insect’s life cycle” (Peckarsky et al., 1997). Selection pressures such as predation, parasitism, and competition can have impacts on aquatic insects during different stages of their life cycles. The consequences of larval behavior, for example, may have a greater effect on fecundity in species with shorter adult life stages. Ephemeroptera have short adult stages and selection pressures on larval behavior can have a significant impact on adult reproductive success. Meanwhile, other taxa such as Odonata have a relatively long adult stage and are less dependent on factors affecting larvae. The long-term fitness of macroinvertebrates incorporates selection pressures and environmental stresses occurring over the insect’s entire life cycle. Biotic interactions and environmental stresses occurring at one life stage may be difficult to extrapolate to individual fitness and population dynamics at broader temporal and spatial scales (Peckarsky et al., 1997).

In addition to spatial and temporal issues of resolution and extent in sampling macroinvertebrates, there is a third and potentially more important type of resolution, that of taxonomic resolution. Ideally all macroinvertebrate organisms would be classified to the lowest practical taxonomic level. Species level identification requires a great deal of time and expertise; for practical reasons investigators often rely on coarser levels of taxonomic resolution. However, it is important to ensure that the taxonomic resolution is fine enough to meet the investigation's objectives. If the objective of an assessment is to generally assess the condition of a stream's aquatic community, then family level identification of the macroinvertebrates is likely to determine whether or not the stream community is impaired. However, if the objective is to observe organism response to a particular physical or chemical parameter then a finer taxonomic resolution might be necessary. Danehy and Ringler (1999) used a direct gradient analysis to identify the abiotic factors influencing the distribution of macroinvertebrates in headwater streams. They found that coarse taxonomic resolution and abundant taxa could actually mask the identification of environmental gradients. They also determined that the exclusion of rare taxa reduced the capacity of the direct gradient analysis to identify environmental gradients (Danehy and Ringler, 1999). When Reznicka and Butler (1999) studied the structure of benthic communities of lakes in different regions one species of Chironomus, *Chironomus cucini*, was found in deep mesotrophic lakes with oxygenated hypolimnia in Northern Forest and Rocky Mountain regions. Other Chironomus species were more widely distributed across mountain and plains regions. These findings support the possibility that the spatial distribution of some taxa may be dependent upon broad scale processes while the distribution of other taxa might depend on fine scale processes. Species level identification may be particularly important in systems having low taxonomic diversity.

The choice of spatial, temporal, and taxonomic scale must be driven by the questions being asked. The extent and resolutions of an investigation to identify water quality problems might be different than one to compile a biological inventory or focus on predator-prey interactions. Many ecological studies focus on a single species, while others consider assemblages of species or ecosystems. If macroinvertebrates are studied with an inappropriate extent or grain then the

patterns, which are identified, may be more artifacts of scale rather than patterns caused by ecological processes.

In geography and ecology, appropriate scales of measurement and analysis depend on the questions asked, the individuals studied, and the time periods considered. As Levin (1992) concluded, how the scale of observation affects the description of pattern and how species experience their environment are central issues to spatial and temporal pattern and the effects that pattern has for populations and ecosystems. To examine the problem of pattern and scale there must be measures to describe pattern before the pattern can be related to either its causes or consequences. Heterogeneity is functional and necessary. There is no single scale at which to study and model ecosystems, but that does not mean that observations at all scales will produce meaningful results. If methods to quantify patterns of variability over space and time are coupled with multi-scale studies then this combination may provide insight as to how information is transferred across scales and how to simplify and aggregate models. The patterns and processes observed in streams are dependent upon scale. Spatial, temporal, and taxonomic units need to be appropriate for the processes under study. Inappropriately transferring conclusions from one scale to another is the basis of ecological fallacy.

## Chapter 3. Ecological Fallacy and Stream Ecology

### Ecological Fallacy

Robinson (1950), was the first to bring attention to the problem of ecological fallacy, and especially the differences between an individual correlation and an ecological correlation. An individual correlation is one in which the object being described is indivisible and the variables describing the object are properties of individuals rather than statistical constants such as rates or means. An ecological correlation, exists when the statistical object is a group rather than an individual. In the latter case, variables are descriptive properties of groups such as percentages. Robinson clarified the ecological correlation problem, by demonstrating mathematically the exact relationship between ecological and individual correlations and by showing the manner of that relation upon the practice of using ecological correlations as substitutes for individual correlations. He termed this ecological fallacy. Individual and ecological correlations are functionally related by the basic equations of the analysis of covariance. It is theoretically possible for the correlations to be equal, but it is not probable, and Robinson (1950) suggested that ecological correlations cannot validly be substituted for individual correlations.

Alker (1969) generalized on Robinson's idea exploring the probability of other inferential fallacies. Alker suggested that in addition to fallacies of disaggregation, there are also fallacies of aggregation and extrapolation. As a result, he outlined five forms of ecological fallacy: *individualistic fallacy*, *cross-level fallacy*, *universal and selective fallacy*, *contextual fallacy*, and *cross sectional fallacy*. *Individualistic fallacy* is the reverse of Robinson's primary worry because it is the fallacy arising from the generalization from individuals to collective relationships. In other words, it is the assumption that the whole is no more than the sum of its parts. *Universal fallacy* assumes that patterns observed in a sample holds for its entire population. *Selective fallacy* suggests that data from chosen cases can be used to prove a point. *Contextual fallacies* are possible because, even at the same level of analysis, context or circumstances could alter the strength of the causal or statistical relationships. *Cross sectional fallacy* assumes that what is observed at one point in time applies to other times. *Cross-level fallacy* is the fallacy of aggregation, also known as the modifiable areal unit problem, which assumes that a relationship

observed in one aggregation of a population is a universal feature of that population. Cross-level fallacy raises a problem for general systems theory because even if “regions of data” obey the same set of relationships, aggregated systems may demonstrate different associations (Alker, 1969).

### **Individualistic Fallacy**

Individualistic fallacy is the assumption that the whole is no more than the sum of the individuals. In the study of stream ecosystems, individuals are aggregated into populations, and populations are aggregated into communities. However, communities should not then be summed and labeled ecosystems because an ecosystem also includes the physical environment. Stream ecosystems are sometimes characterized by a description of the physical or biological components that can be easily or more accurately measured. However, stream ecosystems are not only the measurable components, but also the functional relationships between the components.

### **Universal and Selective Fallacies**

Universal fallacy assumes that patterns observed in a sample, hold for the entire population. Selective fallacy applies when chosen cases are used to prove a point. In light of the heterogeneity, or patchiness of streams described in the previous chapter, it would be a universal fallacy to assume that a benthic macroinvertebrate sample collected from a riffle would be representative of an entire stream reach. A riffle is likely to be more taxa rich and have different taxa than a slow moving pool. Aside from the concerns due to spatial autocorrelation, choosing cases to prove a point is dangerous if there is insufficient evidence to demonstrate that the chosen case is not an aberration or an “outlier”. Universal and selective fallacies are similar in that they both draw attention to situations in which a sub-sample of a population is isolated to represent a “universally” true relationship. If sampling is random, the inference can be statistically evaluated and possibly supported. However, random sampling methods aren’t always practical for studies in stream ecology.

### **Contextual and Cross-Sectional Fallacies**

Contextual fallacies occur when circumstances change the strength of a causal or statistical relationship. For example, in the case of a toxic discharge from a point source, the volume of water flowing in the channel influences the water chemistry and necessarily the effect of the toxic discharge on the organisms in the stream. If the toxic discharge remains constant, low stream flows, such as during a drought, would exaggerate the effect of the toxic discharge while high stream flows during a flood might minimize the effects of such a discharge. Different circumstances may apply at different times. Therefore, some contextual fallacies might also be considered to be cross-sectional fallacies where one assumes that what is observed at one point in time also applies to other times. Cross-sectional fallacies reinforce the importance of temporal scale as introduced in Chapter 2. In the context of macroinvertebrate sampling, seasonal differences can lead to considerable variation in macroinvertebrate abundance and species assemblage (Rosenberg and Resh, 1993; Johnson et al., 1993). Some of the taxa that are abundant in an eastern North American stream during April will have emerged as adults and be absent from the stream in June. An understanding of the frequency and seasonal timing of life-cycle processes is necessary for a complete and accurate evaluation of a benthic macroinvertebrate population.

### **Cross-Level Fallacy**

Areal units are the spatially aggregated properties of smaller units. The difference between areal units and other collectives is that they are “modifiable”. To solve problems associated with the use of aggregated data, it is important to examine the basis of areal units and the kinds of effects their properties may have on the ability to observe the behavior of individuals. The interaction areas of different individuals are not the same, and may or may not overlap. Areal units are often larger than the areas of interaction of the individual. Furthermore, the contacts of individuals are not distributed randomly among the individuals populating the areal unit nor are they limited to those within the unit. Therefore, aggregated data could be insufficient for describing complex phenomena.



The modifiable areal unit problem is probably the most widely recognized form of ecological fallacy in geography. Most geographic data refer to points in space, but usually data are aggregated into spatial units which are the 'individuals' used in geographic analysis. Openshaw (1979, 1983, 1984) suggested that when data are aggregated spatially, the fallacy should be broken down into two effects: the *scale effect* and the *aggregation effect*. In the case of the scale effect, the larger the aggregation unit, the larger the correlation between two variables. The aggregation effect implies that if one provides enough possible aggregations for a situation, one could obtain the full range of possible values for the correlation between two variables. It may be possible for researchers to produce a particular result by selecting the aggregation that provides the desired result. Likewise, Taylor and Johnston (1979) caution against inferring relationships from a single aggregation. Holt et al. (1996) emphasize the importance of including area effects and the ways in which relationships between variables may vary across areas and their incorporation into the statistical models used for analysis. Models of area effects need to account for positive spatial autocorrelation, and the fact that individuals within the same area tend to be more alike than individuals in different areas. Models of area effects may be useful in understanding the causes of aggregation effects, but they are unlikely to easily resolve the problem of how to adjust the results of an area-level analysis to provide reliable estimates of individual-level relationships.

Statistics calculated using the mean of data in geographic areas are usually different from those calculated directly from data for individuals. Aggregation effects depend on the sample sizes upon which the arithmetic means are based, the number of areas used in the analysis, and the degree to which the data is homogeneous within the area. Auxiliary variables may explain much of the intra-area homogeneity and explain the causes of the ecological fallacy (Holt et al., 1996). Steel and Holt (1996) propose a model for grouped populations, which tries to break down group level bias into two components: one due to the variables and the other due to intra-group correlations between variables. Their model provides a framework for the analysis of group effects and could be used to predict the effect of aggregation on statistical procedures and calculate adjusted group level estimates.

Experience gained in working with similar data, or indeed the objectives of a study, is likely to influence the choices of scale and areal units. However, by continuously looking at contrasting scales, it may be possible to minimize the disadvantages of the chosen scale approach and take advantage of another scale's strengths (Ambrose and Williams, 1981). Bird (1993) suggests that one way of doing this is to modulate to another scale of approach during the course of a study in order to provide a critique of the results achieved. Criticisms of the initial approach generated by modulating to the new scale of approach may force investigators to start again with a new strategy.

Combining macroinvertebrates collected at different locations across a riffle into one sample or combining site specific data from different streams within a watershed to describe the watershed are examples of aggregating data in stream ecology. If an ecologist is trying to convey the condition of streams in a large region, he or she might be tempted to aggregate site specific data to hydrologic cataloging units (HUC) which could mask the condition of some streams. In a more localized study where the objective is to study species interactions, one might not even be able to appropriately aggregate rocks within a riffle. The meaning of areal units and the kinds of effects their properties may have on one's ability to observe patterns and/or the behavior of individuals are particularly important in the context of macroinvertebrate data. The discussion on ecological neighborhoods in Chapter 2 highlighted the idea that the interaction areas of different macroinvertebrates are not the same and may or may not be overlapping. Furthermore, aggregation units can be larger or smaller than the individuals' ecological neighborhoods. Aggregation units that are not meaningful in terms of macroinvertebrates and the spatial heterogeneity of streams are both reasons why aggregate data could be insufficient to describe stream communities.

### **Extrapolating Across Scales and the Importance of Multi-scale Investigations**

In general, stream ecologists recognize the importance of spatial heterogeneity and the scale dependency of the data they collect. However, the limits as to how far data can be aggregated and extrapolated remain undefined. Turner et al. (1989) outline a procedure for predicting across scales. They suggest that investigators must first identify the spatial and temporal scales of the

process being studied and understand the scale dependence of the controlling factors of that process. Then methods for translating predictions from one scale to another need to be developed and empirically tested across multiple spatial scales. Fourier transformations, multi-scale ordination, fractals, as well as empirical methods could be employed to identify the scales of processes. Scale, aggregation, and extrapolation may not be as big a problem if the systems of interest are spatially and temporally homogeneous. In some homogeneous cases it may be possible to even sum process measurements. In heterogeneous systems, such as aquatic systems, it is not possible to sum directly when predicting across scales. Often, weighted averages are not even appropriate since heterogeneity can influence processes in nonlinear ways (King et al., 1988 as cited in Turner et al., 1989). As spatial heterogeneity increases, there is an increase in the difficulty of predicting across scales (Turner et al., 1989).

Stream ecologists have, therefore, recently acknowledged the need for simultaneous measurements at multiple scales. Studies need to be conducted across multiple scales, thereby identifying the mechanisms and the consequences of processes occurring at various scales for each set of patterns observed (Cooper et al., 1997b as cited in Peckarsky et al., 1997). Peckarsky et al. illustrate that the patterns of biotic interactions such as predator-prey or competitive interactions observed at local scales do not translate to patterns observed at broader spatial and scales. They conclude that, “our ability to extrapolate from individual behaviors to populations and communities in streams will improve when we consider the repercussions of individual behaviors and environmental factors over broader spatial and temporal scales” (Peckarsky et al., 1997).

Carter et al. (1996) examined relationships between physical variables and the benthic community structure at three spatial scales. The biological samples included traveling kicknet samples of the riffle habitat, which sought to include as much of the riffle variability as possible. Physical parameters were taken in the field and from topographic maps at three scales; the sampled riffle, a reach length of ten-twenty stream widths, and stream segments having no change in stream order. The physical variables were highly correlated between the three scales. The physical variables at the stream reach scale and the stream segment scale were better able to

predict macroinvertebrate groups than did the physical variables collected at the sampled riffle scale. However, the sampled riffle scale may seem inadequate because the physical variables may need to be measured at a finer resolution. Unfortunately, high correlations between variables within and among scales make it difficult to determine which physical variables most influence the benthic community structure (Carter et al. 1996).

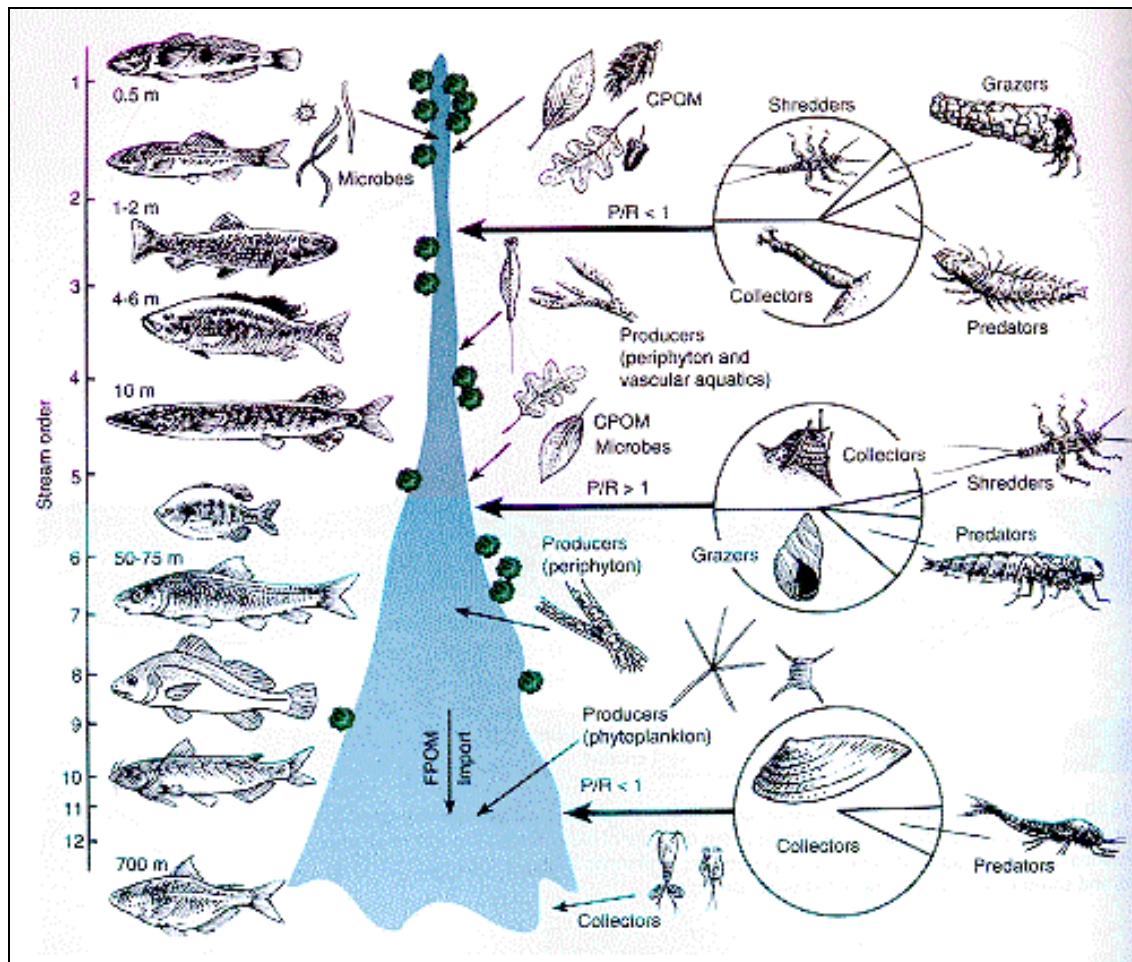
Downes et al. (1993) examined macroinvertebrate abundance between sites having the same stream order; the riffles within the same site; and groups of stones within the same riffle. They found that significant variation in faunal densities can occur at scales represented by groups of stones. They also found that riffles at the same site can vary considerably. Individual taxa demonstrated different spatial patterns, but these patterns were sometimes obscured when the taxa were lumped into functional feeding groups. Downes et al. (1993) suggest that, “If streams elsewhere are as variable as ours, then field experiments in stream ecology are done at spatial scales that are irrelevant for some species, which are affected by processes operating at much larger or smaller spatial scales”. They emphasize that the potential consequences of spatial variation and the effects of aggregation should influence experimental designs to test hypotheses in stream ecology.

Allardt (1969) contended that ecological analysis has been more severely restricted than other forms of analysis. Although he agrees with Robinson that ecological correlations are usually not equal to corresponding individual correlation, he acknowledges that ecological correlations are not solely used as substitutes for individual correlations, nor are they inherently less important or less valuable than individual ones. “Ecological correlations may retain their validity even after it has been shown that the ecological and individual correlations clearly differ” (Menzel as cited in Allardt, 1969). There may be deliberate uses of ecological fallacy because individual correlations may not be the primary objective. Ecological correlations are often used when causal explanations or interpretations are the specified objective. The persistence of ecological correlations, in spite of their weaknesses, may be indicative of results having high informative value through such interpretations (Allardt, 1969). In other words, just because an investigation is guilty of ecological fallacy, that does not mean that the study’s findings are invalid. After

adjustments are made to account for the aggregation effects or other ecological fallacies the resulting trends may still be the same. Nevertheless, multi-scale studies are needed to complement traditional studies that have been conducted at single spatial, temporal, and process or organizational scales. The difficulty lies in choosing scales that are not arbitrary, and yet are meaningful with regard to the physical and biological processes involved. The results of Carter et al. (1996) support the idea that broad scale physical processes may influence local scale processes. However, Downes et al. (1993) demonstrated the need for ecologists to be aware of local scale variation. Aggregating local variation and extrapolating fine scale measurements to broad scale phenomena are forms of ecological fallacy. It is crucial that investigators improve their ability to understand the consequences of aggregation and extrapolation in order to properly test hypothesis such as the river continuum concept (RCC).

## Chapter 4. The River Continuum Concept

It has been suggested that issues of scale and ecological fallacy are particularly significant in the context of broad theoretical models designed to model universal ecological processes. The River Continuum Concept is such a model, and it is used here to illustrate aspects of scale and ecological fallacy. The River Continuum Concept (RCC) seeks to link patterns of aquatic community structure and function to fluvial geomorphic processes and the physical structure of streams. The hypothesis postulates that the physical structure, coupled with the hydrologic cycle, forms a template for biological responses, resulting in consistent patterns of community structure and function and organic matter loading, transport, utilization, and storage along the length of a river. Thus the biological organization in rivers conforms structurally and functionally to kinetic energy dissipation patterns of the physical system. According to the RCC, the lotic system is a continuum from headwaters to river's mouth. Headwater streams (1st-3rd order) are heterotrophic, dependent on terrestrial input of detritus, and the dominant consumers are shredders and collectors. As stream size increases (4<sup>th</sup>-6<sup>th</sup> order), the input of organic matter shifts from particulate organic matter to primary production from algae and rooted vascular plants. In this portion of the continuum, the major consumer groups are now collectors and grazers. The zone at which the shift to autotrophy occurs is primarily influenced by the degree of forest shading, but can also vary due to factors such as climate and elevation. Mid-sized streams are expected to exhibit the widest range of temperature and hydraulic conditions. They are therefore predicted to have the highest biological diversity. As stream size continues to increase (>6th order) the system shifts back to a heterotrophic system as the amount of fine particulate organic matter and dissolved organic matter increases. A phytoplankton population may develop and the bottom consumers are predicted to be mostly collectors. The proportion of predators remains relatively constant throughout the continuum (Vannote et al., 1980). Figure 3 illustrates the changes expected in the functional groups of macroinvertebrates along the continuum as suggested by the River Continuum Concept. According to the hypothesis, the structure and function of biotic communities along the continuum are in dynamic equilibrium with the physical environment, and it should be possible to predict biota based on the variability of the environment and the source of energy for biological production (Vannote et al., 1980).



**Figure 3. The River Continuum Concept (Smith, 1990)**

In addition to issues of stream size, structure and function, the RCC also involves ecosystem stability, species replacement, the storage and processing of organic material, and time invariance and the absence of succession. For example, where there is considerable physical variation in the stream there may be high species diversity or greater complexity in species function, which helps to maintain stability. An 'equilibrium' of energy flow is attributed to seasonal or longitudinal species replacement as well as to the production and physical retention of organic material. Time invariance and the absence of succession are attributed to the dynamically balanced physical setting and the concept of heritage. The latter concept implies that in river systems, the total absence of a population is rare and biological subsystems are shifting spatially rather than changing in the temporal sense typical of plant succession. On an

evolutionary time scale, the spatial shift is in two directions. The downstream shift involves aquatic insects while the upstream shift involves mollusks and crustaceans (Vannote et al., 1980).

The RCC has been proposed as a framework for integrating predictable and observable biological features of river systems with the physical environment. Although the model was developed with natural, unperturbed ecosystems in mind, the concept is believed to accommodate many unnatural disturbances as well. In many cases, alterations can be thought of as a reset mechanisms that cause the continuum response to be shifted upstream or downstream depending on the type and location of the disturbance (Vannote et al., 1980). Many studies have examined longitudinal changes in community organization, and have tested the predictive capability of the concept. Shortly after the hypothesis was introduced, its generality was criticized (Winterbourn et al., 1981). However, the concept has been supported by several investigations (Minshall, 1982; Minshall, 1983; Cushing, 1983; and Bruns, 1982), but several modifications and refinements to the RCC have been proposed (Bruns et al., 1984; Brussock et al., 1991; Minshall et al., 1985; Statzner and Higler, 1985). The RCC defines the general condition and was not intended to be used in an individualistic context. Including additional factors such as climate, geology, tributaries, location specific lithology, geomorphology, and long-term human disturbance factors has been suggested in order to clarify and refine the concept (Minshall et al. 1985).

The RCC proposes that “biological communities in most habitats can be characterized as forming a temporal sequence of synchronized species replacement” and that “studies of biological systems established in a dynamically balanced physical setting can be viewed in a time independent fashion” (Vannote et al., 1980). The lack of temporal variation proposed by the RCC suggests a diminished importance of temporal scale. However, Statzner and Higler (1985) contest that species replacement for energy utilization is restricted by geography, and current “knowledge” rejects the lack of succession and variation over time. Although there is evidence of seasonal species replacement in some regions, the temporal sequence of species replacement may only be applicable to streams subject to distinct seasonal differences in abiotic factors. For example, streams in New Zealand do not demonstrate the same type of seasonal replacement as



do streams in North America (Winterbourn et al., 1981). Based on long-term studies for insects and fish, Statzner and Higler (1985) do not believe that time invariance occurs. Statzner and Higler expect that the biological community in the stream is reestablished after a low frequency cataclysmic event (eg. flood, landslide, wildfire) similar to the way communities become reestablished in the terrestrial environment, through succession. If there is temporal variation, then temporal scale remains important, even in a “dynamic equilibrium.”

Testing the RCC necessarily involves exploring patterns in physical, biological, and chemical data collected within and along a river system. In heterogeneous environments such as streams, patterns may vary with change in the spatial scale of observations. When the scale at which a variable is measured changes, the variance, and therefore the pattern of the variable, changes as well. Physical variations at the microscale, such as the local effects of lakes and tributaries, have been suggested to complicate the continuous gradient expected by the RCC (Statzner and Higler, 1985). Bruns et al. (1984) also brought attention to the importance of tributaries in the river continuum. Tributaries modified the relationships hypothesized by the RCC in regard to gathering collectors, predators, periphyton, and the composition of transported organic matter. The transport of organic matter appears to be most susceptible to these tributary effects. Small tributaries appear to accelerate longitudinal changes in community composition while large tributaries seemed to reverse them. In other words, downstream of larger tributaries, the composition of functional groups more clearly approximated what would have been expected in upstream reaches (Bruns et al. 1984).

Similarly, Brussock et al. found macroinvertebrate communities to be more affected by riffle-pool geomorphology than by longitudinal trends, suggesting that a “reach level” perspective based on channel form is needed to complement the RCC. “Refinement of the RCC could be accomplished by establishing downstream longitudinal biological patterns for streams in regions where the physical template among streams is relatively homogeneous . . .” (Brussock et al., 1991). Brussock and Brown support the RCC in that the geomorphic processes and physical structure of the stream channel appear to play a role in the biotic community structure. However,

they suggest that the RCC model could be made more applicable by establishing longitudinal patterns with streams or regions where the physical template is approximately the same (1991).

Despite the proposed refinements and extensions, the river continuum hypothesis has had a profound influence on stream ecology and continues to be a primary hypothesis of how lotic systems function. If biological patterns in streams are dictated by the physical template, then it is necessary to understand the physical patterns across time and space, in which the importance of appropriate scales of data collection and analysis of the physical parameters involved are emphasized. The RCC is one case where it is critical that scale and ecological fallacy concerns must be addressed.

## **Chapter 5. Scale, Ecological Fallacy, and the River Continuum Concept**

Addressing scale issues in the context of the RCC is challenging due to the complexity of concept itself. The RCC addresses physical, biological, and chemical changes that are taking place on many continuous scales simultaneously. Scale and ecological fallacy issues need to be explored and conceptualized in complex circumstances such as this because the natural environment is complex and interdependent. The RCC operates over broad spatial scales and represents the tradition of stream ecologists studying phenomena operating over broad scales. Not least, scientists have been forced to make decisions regarding scale during sampling location selection, field data capture, and subsequent data interpretation.

Testing the RCC has traditionally entailed the collection of point samples that are then used to characterize the benthic communities of a stream reach. These reach characteristics are subsequently extrapolated to larger stream segments where generalizations are made about stream segments having the same stream order. Sampling site selection is obviously dependent on the scale of the maps and other information products used in locating potential sampling stations. Stream ecology investigations entail field measurements of biological, chemical, and physical parameters. However the following discussion focuses on scale in terms of the collection, aggregation, and extrapolation of benthic macroinvertebrate samples. The discussion teases out a few examples of scale and ecological fallacy in the context of one of the most influential hypotheses in stream ecology.

### **Scale of Field Data Capture**

Several factors come to play in the selection of data capture which ultimately influence the 'scale' of data collection. Firstly, the scale of data capture is partially defined by the equipment used to collect the samples and by the stream reach in which the samples are collected. Surber and Hess samplers have frames designed to standardize samples by the area of the riffle sampled. In the case of kick nets and dip nets, investigators usually strive towards an equal level of sampling effort rather than standardizing the area sampled.

Second, choices of scale and sampling equipment during field data capture are determined not only by the stream habitat but are also influenced by previous educational and work experiences. In other words, how and what we observe is value laden. Methodologies can become standards because of tradition, rather than because they are ‘appropriate’ for testing specific hypotheses. Significantly, the tradition of large-scale work in ecology has produced an opinion that small-scale variation is insignificant and should be ignored or averaged (e.g. Stutzner & Higler, 1986; Minshall et. al. 1985b as cited in Downes et al., 1993). The lack of concern for local variability is reflected in terms of field data capture when a single sample from a single habitat is collected and then used to characterize the stream reach.

Third, depending on the methodology of the study, the length of a stream reach can either be a predetermined length or could be relative to the stream size (eg. 20 times stream width). Stream reaches are often viewed as the principle sampling unit to collect stream data. This is the case when there is only a single or composite sample per reach. In studies with multiple samples per reach, one could argue that sampling within a stream reach is similar to an individual investigation where the stream reach is the extent of the sampling area and the sampling dimensions or level of sampling effort define the resolution of the samples.

Fourth, in addition to concerns regarding the scale of data capture, scientists must also make decisions regarding taxonomic scale when processing and identifying benthic samples. The subsampling of benthic samples is not likely to impact the relative abundance of functional feeding groups. However, the sample size or number of organisms counted and classified from the sample can affect taxa richness metrics. The RCC predicts that more taxa are likely to be found in the mid-reaches of streams, or where the stream habitat is most diverse. If the objective of a study were to test the taxa richness central to the RCC, then adjusting for differences in sample size might be necessary. This could be accomplished by either using a fixed count method or a rarefaction procedure (Sovell and Vondracek, 1999).

As for taxonomic scale, Macroinvertebrates identified at the family level would be less useful in testing the RCC than those identified to the genus level because some families of organisms

would present problems regarding trophic classifications. Some familial classifications can easily be transferred to functional feeding group classifications such as shredders, predators, collectors, and grazers. Other families, would present problems at this taxonomic resolution because individuals within a family may belong to different functional feeding groups. For example, Chironomidae includes both collectors and predators (Merritt and Cummins, 1996).

### **From Sampled Riffle to the Stream Reach**

In addition to the actual sampling mechanism applied, additional scale issues arrive when moving from the sampled site to a representation of the stream itself. Abbreviated field sampling, such as a single or composite sample, could undermine the accuracy of analysis if the sample is not representative of the stream reach, or if the stream reach is not representative of the stream segment. Single habitat protocols, focusing on riffle and run habitat are sufficient when the objective is to detect stream impairment. However, in the case of the RCC the objective is to paint a more complete picture of the benthic community, often in streams with variable habitats. Streams in many regions vary from cobble dominated riffles to low gradient streams with sandy or silty sediments. When field investigations are restricted to one habitat type, as in the case of riffles, then low numbers of a functional feeding group could be due to the sampling protocol. For example, shredders might be in the debris dams rather than on the sampled riffle.

Combining organisms collected from different microhabitats within a reach into a composite sample denies any information about spatial variability within the reach. As discussed in Chapter 2, benthic macroinvertebrates have been found to vary spatially and temporally. It would be an ecological fallacy to automatically assume that a single sample would be representative of an entire reach. However, in a study utilizing a multi-habitat sample within a reach of 20 bank widths, additional sampling within the reach only minimally changed biological metrics (Rabeni et al., 1999). Including organisms in the sample from a variety of habitats within the reach is likely to reduce within-site variability of samples and provide a better representation of the stream reach.

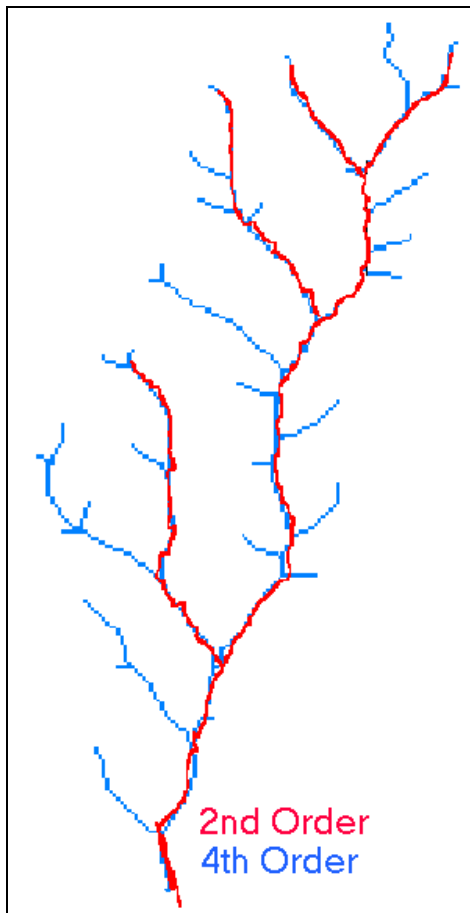
### **From Stream Reach to Stream Segment**

In order to test the RCC, samples collected at the riffle scale are traditionally extrapolated to represent a stream reach which is then in turn extrapolated to a stream segment. The stream segment is a length of stream having no change in stream order. Investigations are often limited both by the number of samples used to characterize stream reaches and by the number of stream reaches used to characterize stream segments. In some cases only one site is sampled for each change in stream order within a stream network (Corkum, 1992). In one study only a total of five sites were sampled in streams ranging from 1<sup>st</sup> to 9<sup>th</sup> order, and the sites were not even physically connected in the same watershed network (Naiman, 1986). As previously mentioned, Rabeni et al. (1999) found a single multiple habitat sample to be fairly representative of the stream reach in which the sample was collected. However, macroinvertebrate samples collected from one stream reach were less representative of other reaches within the same stream segment. Samples were more representative of reaches within their own stream segment than they were of reaches in other reference stream segments even when the reaches were in the same ecoregion.

Before extrapolating from a stream reach to a stream segment investigators should determine whether the reach being sampled is appropriately sampled and whether the reach is representative of the stream segment. For example, the instream habitat (eg. riffles, runs, pools, etc.) should be consistent throughout the stream reach and stream segment. Investigators should also note abrupt changes in the amount of sunlight reaching the stream and the potential influence of tributaries that can influence the proposed continuum. Sampling from a single reach of a stream and extrapolating that information to describe a stream segment may be adequate if the morphological features of the reach are typical of the entire stream segment and if the results are reproducible (Rabeni et al., 1999). Additional sampling naturally improves the ability to describe the benthic assemblage, but importantly there is the common tradeoff between resources available for a sampling program. Rabeni et al. (1999) found a 10% improvement in the ability to detect impairment by sampling an additional reach on a stream. The value of sampling an additional reach depends on the study objectives and the resources available. For example, the goals of the study might be better met by using resources to sample reaches on twice as many stream segments rather than sampling two reaches on the same stream segment.

### Aggregating Stream Segments

The RCC hypothesis implies gradients of faunal abundance. However, studies interpreting or testing the RCC sometimes compare data using discrete classes of stream order. The aggregation of stream segments by stream order seems to be an attempt to summarize information in an organized manner in order to make statements at a broader scale. Using stream order to aggregate stream segments assumes that stream order is highly correlated with drainage area, stream width, and stream discharge. Studies that compare classes of stream orders or sizes should include replication within each class so that the variation between sites in streams of the same size can be examined. According to Downes et al. (1993) studies that have replication within the classes often use the arithmetic mean of the replicate data rather than examining the variation between them. Other studies have used regression analysis to seek trends, but without proper replication.



One reason that stream ordering is used is that it provides a quick and convenient means of classification. The main purpose of stream ordering is to describe portions of the stream network according to their position in the overall network. The relationships between stream order, watershed size, stream width, and stream discharge may be a meaningful way to aggregate stream ecology data. However, stream order is dependent on the stream ordering method and the scale of the map or GIS coverage being used to represent the stream network. Furthermore, there are at least 11 methods of stream ordering, though the Strahler method is the one most commonly used. Figure 4 demonstrates how stream order is dependent upon the scale of the information used for the classification. Both networks are ordered using the Strahler method. The red stream network is generated from a stream coverage at

**Figure 4. Scale Dependency of Stream Order**

the 1:100,000 scale while the blue stream network was created using a flow accumulation model and a 1:24,000 Digital Elevation Model (DEM). Since stream order is only meant to indicate the relative position of a stream within the stream system, these scale issues may not be particularly important in the context of one study. However, the scale at which the stream order was determined is important as far as standardization is concerned, and when results from one investigation are compared with results from another investigation.

Aside from scale standardization issues, the heterogeneous nature of stream segments brings into question the use of stream order as an aggregation unit for stream macroinvertebrate communities and positions the concept firmly at the center of issues concerning scale and ecological fallacy. Some interpretations of the RCC, (e.g., Minshall et al., 1983) assume homogeneity within stream sections having the same stream order. Others have found stream habitat and their communities to be variable and spatially diverse when collecting and observing the stream at a finer resolution (Resh, 1983; Phillips and Harlin, 1984; Frissell, 1986). Differences in faunal abundance between sites within the same stream order, and even within the same riffle, have been reported (Bunn, 1986; Barnuta, 1990; and Downes et al., 1993). Downes et al. (1993) not only demonstrated that faunal abundances can vary considerably over scales from individual stones to sites within the same stream order, but also that taxonomically or functionally related taxa may not vary in the same manner.

The dependence of the concept on discrete groupings such as stream order results in scale and aggregation issues because the aggregation can mask both the variation and pattern in the data. In order to interpret results in a broader context and extrapolate information gathered at specific sites, one would need to have an indication of the variability within the stream system. A more scale conscious interpretation of the RCC would combine the RCC with patch theory, discussed in Chapter 2, in order to provide a more complete hypothesis for what is likely to be found in nature. In reality streams are more likely to exhibit a patchy distribution of  $P/R \leq 1$ ,  $P/R \geq 1$ , and  $P/R \leq 1$  rather than just a longitudinal zonation. For example, moss patches with epiphytic growth do occur in headwater streams (Bretschko 1995). Frissell et al. (1986) describe one hierarchical framework for stream habitat classification that incorporates geomorphic and



riparian variables at different spatiotemporal scales. A similar classification system could lead to more meaningful aggregation of stream ecology data.

### **Extrapolating from Region to Region**

It is clear from the literature that the River Continuum Concept is occasionally treated as fact rather than as a hypothesis (Minshall et al., 1992 as cited in Downes et al., 1993). Some streams do exhibit at least some of the patterns predicted by the RCC, but the RCC is not a universal concept. The RCC is an example of universal fallacy because the concept, in its original form, doesn't apply to streams in all geographic regions. This was the basis of some of the criticisms made of the concept shortly after it was introduced (eg. Winterbourn et. al., 1981). Streams studied by benthic biologists in the northeastern United States may indeed behave as predicted. However, the RCC is not as applicable in biomes or ecoregions where distinct seasonal variations in abiotic factors do not occur, where there is no tree canopy, or where the canopies are primarily coniferous rather than deciduous.

Corkum (1992) suggested that macroinvertebrate community composition might be a function of both longitudinal gradients and lateral dimensions (vegetation away from channel). Bretschko (1995) similarly concludes that river/land ecotones greatly influence the stream ecosystem irrespective of stream order. Many aspects of the lotic ecosystem correlate with the spatial distribution of macroinvertebrates. Local hydrological features, riparian vegetation, characteristic climax vegetation of biomes, as well as land use practices within drainage basins all interact to account for distribution patterns. Corkum (1992) expects that the relative influence of longitudinal gradients and lateral dimensions varies with river size and among biomes, suggesting that impacts are hierarchical and that the biome level of organization is the most structuring force. Their results and those of others (Winterbourn et al., 1981) suggest that it is inappropriate to strictly apply the RCC to all ecoregions and/or physiographic areas.

### **Alternative Scales of Observation and Analysis**

Finally, studies to test the RCC and other hypothesis in stream ecology almost always start with a map. Maps and the concept of scale are human constructions that represent the cartographer's

perception of the earth. Maps are not direct representations of reality. The blue lines representing streams on a map may be somewhat arbitrary when viewed in terms of the functional relationships of stream communities. Headwater streams are underrepresented on most maps as a result of both the scale of the map and the interpretation of the data used to create the map. In the context of the RCC, where the focus is on changes in the structural and functional attributes of stream communities, it may be more appropriate to determine sampling locations and aggregation units such as stream order based on a stream network where streams are defined by ecological function. For example in WV, a stream could be assumed to be perennial if it supports aquatic macroinvertebrates species requiring greater than six months residency in flowing waters during the life cycle (Smithson, 1997). Such an approach to defining and ordering stream networks would define streams based on the life histories of the aquatic macroinvertebrates present. If investigators exclude the uppermost headwater streams either because of geographic scale or the observation of a dry channel, investigators may not be adequately studying the uppermost portions of the continuum.

## Chapter 6. Conclusion

The River Continuum Concept (RCC) addresses physical, biological and chemical processes simultaneously occurring at spatial and temporal scales. Like most investigations of stream ecological processes, benthic macroinvertebrates are the focus of most studies designed to test this hypothesis. The scale of benthic macroinvertebrate data capture is defined not only by the equipment used to collect benthic samples, but also by the variability within the sampled stream reach, the sampling protocol used, and taxonomic resolution used to identify the organisms. The heterogeneity or patchiness of stream habitats is pervasive in nature and has been hypothesized to affect ecological processes and the distribution of benthic macroinvertebrates. Single habitat protocols and the use of composite samples deny information about the spatial variability of the sampled stream reach. A thorough understanding of the distributions and life histories of benthic organisms could enable investigators to make appropriate methodological choices with regard to sampling resolution and extent.

Testing the RCC has traditionally entailed the collection of benthic samples at fine scales, which have then been used to make generalizations at relatively broad scales. Ecological fallacy issues surface when moving from the sampled site to a representation of the stream itself and when data is compared using discrete classes of stream order. Before extrapolating from a sampled site, to a stream reach, and then to a longer stream segment, one should consider whether the sampled sites adequately represent the reach and whether the stream reach is representative of the stream segment. Studies that compare classes of stream orders or sizes should include enough replication within each class so that the variation within each class can be examined. A combination of the RCC and patch theory might provide for a more complete hypothesis of what is likely to be found in nature. Furthermore, extrapolation of the RCC to all ecoregions and/or physiographic areas is not supported in the literature.

Scale and ecological fallacy issues are central to the RCC because relationships between biological, chemical, and physical phenomena might be observed at one level of observation and analysis, but masked at another level. The choices of spatial, temporal, and taxonomic scale

must be driven by the question being asked, and the individuals or processes being studied. Investigators must be cognizant of scale and ecological fallacy issues so that they can incorporate these issues into methodological decisions throughout the experimental design and analysis of studies testing the RCC and other broad scale hypotheses.

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#### **Master of Arts in Geography, 2000**

West Virginia University, QPA 3.88, GIS and Remote Sensing concentration

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### Work Experience

#### **GIS Analyst**, Signal Corporation, January 1999-Present

Provide GIS, database management, data analysis, data visualization, and mapping support to **U.S. Environmental Protection Agency Region III**.

#### **Instructor**, Ohio County Schools Adult Education, Spring 2000

Responsible for planning and teaching a 10-week course in *Basic Computers*.

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Provided GIS and Remote Sensing support for the development of educational modules designed to engage high school students in collaborative scientific inquiry and analysis.

#### **Teaching Assistant**, West Virginia University, August 1997-May 1998

Responsible for planning, facilitating, and evaluating Introduction to GIS Labs, prepared materials for Introduction to GIS, Advanced GIS, and Exploratory Data Analysis classes.

#### **NNEMS Fellowship**, Environmental Protection Agency, Summer 1997

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#### **Research Assistant**, West Virginia University, August 1996-May 1997

Database and GIS coverage management for Wheeling Creek Watershed Project.

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Collected and analyzed watershed samples and data including: GPS, macroinvertebrate, vegetative, hydrologic, and chemical parameters.

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