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Conceptualising Scale in Regional Studies and Catchment Science – Towards an Integrated Characterisation of Spatial Units

Danny MacKinnon* and D. Tetzlaff
University of Aberdeen

Abstract
This article examines conceptualisations of scale in catchment science and regional studies as the basis for the development of an integrated characterisation of spatial units. Our starting point is the apparent similarity in the scalar terminology utilised in the two fields, pointing to an area of potential conceptual overlap between physical and human geography. While our aim is not to produce an overarching theory of scale, we seek to advance understanding within both catchment science and regional studies by comparing their approaches to the analysis and understanding of spatial units. We also describe underlying principles of heterogeneity and complexity in the functioning and behaviour of catchments and regions. After clarifying scale definitions, this article examines notions of 'scaling' and 'rescaling' in each field and assesses catchments and regions as complex and open systems. In the penultimate section of this article, we develop an analytical framework based on the identification of certain dynamic attributes and concepts of integration, drawing upon the meta-theoretical language of complexity science.

Introduction

The growing emphasis on inter-disciplinarity in recent years has generated considerable concern about the entrenched divide between physical and human geography (Massey 1999; Harrison et al. 2004). In response, the 'conversation across the divide' initiative was launched, proceeding from a general discussion of language and approaches to assess some more substantive collaborative engagements (Harrison et al. 2004, 2006, 2008). In this article, we focus on scale as a key thematic link between physical and human geography (see Lane 2001; Massey 2001). The concept of scale is part of the spatial lexicon of sub-branches of physical geography such as geomorphology and hydrology that are integrated in the interdisciplinary field of catchment sciences (e.g. Blöschl 2001; Blöschl and Sivapalan 1995; Burt 2003; Soulsby et al. 2006a; Tetzlaff et al. 2008). The term is also widely utilised in human geography following the growth of an extensive literature on the social production of scale (see Brenner 1998; Smith 1993, 1995; Swyngedouw 1997), notwithstanding a recent call for the rejection of the concept (Marston et al. 2005).

Our starting point is the apparent similarity in the scalar terminology utilised by physical and human geographers, evident in the shared use of terms such as 'nesting', 'up-scaling' and 'emergence', bearing upon the larger philosophical issues of how scale is understood and operationalised in the physical and social sciences (Brenner 2001; Lane 2001). This article is concerned with the interdisciplinary research fields of catchment science and regional studies (encompassing sciences as climatology, geology, hydrology, ecology, soil science and geomorphology in the former case and strands of economic and political geography, planning, applied economics and political science in the latter).[1] Both fields have important roots in the regional geography of the first half of the twentieth century (Hartshorne 1939), suggesting that apparent similarities in scalar terminology may owe something to this common academic heritage. Both catchments and regions are spatially organised units of study that seem intuitively definable, but are in detail characterised by considerable complexity in both their internal structures and interaction with their external environments (see Figure 1), often limiting the effectiveness of management frameworks.

Well-reasoned calls for unifying theories for complex catchments started decades ago, encouraging research to develop macroscale equations from first principles in order to move towards a greater coherence in catchment science (Dooge 1986). The need for developing comparative principles and tools for implementing sustainable management of land and water resources has long been recognised (e.g. Newson 2002). Most sustainable management efforts require a broad spatio-temporal context based on a process-oriented understanding of how landscapes work in a spatially distributed context and a recognition of the spatial and temporal scales over which natural systems operate (Montgomery et al. 1995). The challenge of upscaling process understanding gained in smaller, experimental scales to larger scales, where management decisions are needed, requires an empirically based conceptualisation of small scale processes and how these integrate to produce new processes which emerge at larger scales (Tetzlaff et al. 2008). Thus, process conceptualisation needs to consider the form and function of catchment systems and is fundamentally important to understanding, extrapolation and prediction in catchment sciences (Reed et al. 2006). But even while the variables influencing catchment dynamics seem fairly well-established (e.g. Buttle 2006; Soulsby et al. 2006a), it has been difficult to generalise these and a universal approach to catchment characterisation and classification and consequent comparison remains elusive (Sivapalan 2005; Wagener et al. 2007).

Rather than attempting to offer a general socioeconomic characterisation of regions, our assessment is informed by a more specific concern with economic development. From this perspective, contemporary regional studies can be seen as comprised of several strands of research, including geographical political economy (see Hudson 2006; MacKinnon et al. forthcoming; Swyngedouw 2000) and institutional economic geography (Amin 1999; Gertler 2008; Morgan 1997), while the growth of the 'new economic geography' (Krugman 2000) has reinvigorated the regional science tradition. Geographical political economy has been particularly influential in underpinning several recent conceptualisations of scale in human geography and regional studies (Brenner 2001; Smith 1995; Swyngedouw 1997), reflecting its broader theoretical agenda of uncovering the social production of space under capitalism (Harvey 1982; Smith 1984). At the same time, and drawing upon institutionalist concepts, 'new regionalist' thinking has focused attention on the role of less tangible social and institutional factors within regions, often bracketed as 'untraded interdependencies', in fostering economic development (Amin 1999; Lovering 1999; Morgan 1997; Storper 1995). Much of this research has relied on single region case studies, avoiding direct classification and comparison. Partly as a result, according to some critics, conceptualisation within regional studies is 'fuzzy' (Markusen 1999). In response, there is now growing recognition of the need for more comparative empirical research (Coe et al. 2008; Gertler 2008; MacKinnon et al. forthcoming), requiring more sophisticated regional typologies informed by analyses of key attributes, an approach that has already been adopted in catchment sciences.

This article compares conceptualisations of scale in catchment science and regional studies, asking whether or not apparent similarities reflect meaningful conceptual parallels. Key dimensions of scale are outlined in Table 1 which aims to contextualise the understanding and application of scalar terminology in each of the two research fields. While this article does not seek to produce an overarching theory of scale to span the disciplines, we seek to advance understanding within both catchment science and regional studies by comparing the approaches that they adopt. Certain basic parallels in the definition and meaning of scale are apparent, alongside important differences in the conceptualisation of scalar processes. In catchment science, the current paradigm is based on small scale understanding and subsequent upscaling to the catchment scale where decisions are made. In contrast, in regional studies, the system is directly studied at the scale of interest, and there are no corresponding small scale theories. We also describe underlying principles of heterogeneity and complexity in the functioning and behaviour of catchments and regions, providing the basis for the development of an analytical framework that identifies dynamic attributes of catchment and regions and concepts of integration. This framework is viewed as representing a step towards an integrated characterisation of spatial units through the identification of a common meta-theoretical language derived from complexity science, although this will obviously need to be accompanied by more substantive theories that are specific to catchment sciences and regional studies.

Table 1. Comparison of scalar terminology utilised in regional studies and catchment science

	Regional studies	**Catchment sciences**
Spatial units	Regions	Catchments
Scale	Size, level and relations	Cartographic, geographic, process and modelling scales
Flows and networks	Flows of knowledge/ information, goods/services, capital and people through labour market. Supported by 'untraded interdependencies'	Surface flows (water, particle, sediments) and networks (flow paths, channel networks) Subsurface flows (lateral, vertical) and network (macropores)
Connectivity	Movement of key actors and knowledge underpins learning and innovation. Links to global pipelines	Connectivity of flow paths, between channel networks, between habitats, within soil profiles – importance for transport and transfers
Scaling	Rescaling processes, politics of scale and 'jumping' scale.	Aggregating / disaggregating data Tools: for example, tracers, GIS, models
Scaling problems	Openness of regions Tracking of cross-scale processes Different processes differently scaled	Heterogeneity, threshold behaviour and non-linear responses, cross-scale correlations, emergence
Conceptualisation	Reconceptualisation of region as adaptive, path dependent system and identification of dynamic attributes	Rationalisation of a conceptual view of a process or a system and quantifying major influencing factors
Complexity	External openness and internal heterogeneity of regions	Complexity of attributes and processes due to spatial distribution, interlinkages, temporal changes
Self-organisation	Aggregate order emerges from micro-behaviours, but also 'embeddedness' of latter in broader structures	Evolution of catchments as self-organising systems for regulating water and sediment fluxes

The remainder of the article is structured thematically. First, we clarify scale definitions in both fields, relating these to catchment and regions as the basic spatial units. Second, we examine notions of 'scaling' and 'rescaling' in each of the two fields. Third, we then assess catchments and regions as open systems which can be understood through the principles of self-organisation, complexity and emergence (Sivapalan 2005; Harrison et al. 2006; McDonnell et al. 2007). Fourth, we synthesise our study by outlining the basis of the analytical framework highlighted above. This is followed by a brief conclusion.

Scales: Catchments and Regions

The concept of scale is often used in different ways depending on the context and disciplinary perspective (Goodchild and Quattrochi 1997). In catchment investigations, the following definitions are commonly used (Zhang et al. 2004): a *cartographic map scale* referring to the proportion of a distance on a map to the corresponding distance on the ground; a *geographic scale* being defined as the size or spatial extent of a study; a *process scale* referring to the scale at which processes operate in the environment; an *observational scale* as being the spatial resolution which is used to measure an object and the *modelling scale* relating to the processes and application of a model (Table 1).

Catchments as geomorphologically, hydrologically and ecologically relevant management units are usually spatially delineated on the basis of watersheds or drainage divides and mainly determined from surface topography, and thus appear to be clearly bounded. Recent work has characterised catchments as bio-physical, adaptive systems with a history which is constantly evolving and changing (e.g. Belyea and Baird 2006; Kumar 2007). Catchments are heterogeneous at all scales due to variability in input (precipitation, snowmelt), geology (material, bedrock topography), soils (pores, macropores, fractures, soil moisture, layering), vegetation etc. (McDonnell et al. 2007). Such variations mean that scales applied in particular investigations are usually selected pragmatically to be relevant to the issue of interest. In particular, the variability of sub-surface conditions and processes makes it difficult to characterise and understand catchments and their boundaries. Tools such as geophysics, which take sub-surface processes into account considering vertical links within bounded catchments and thus provide insights into the 'fourth dimension', are still under development. However, virtual experiments have helped to characterise the nature of lateral and vertical processes in the cryptic sub-surface such as flow path ways, transport and storage of particles and water (Lehmann et al. 2007; Weiler and McDonnell 2006). Such consideration of sub-surface processes is highly important to be able to gain a holistic understanding of the heterogeneity and boundaries of catchments and their dominant processes within these boundaries. A process-based conceptualisation of catchments can form the basis for a landscape specific assessment of the status of, and the linkages between, physical and biological resources and processes which is, in turn, a prerequisite for sustainable management (Montgomery et al. 1995). Thus, catchment science attempts to answer questions such as how catchments work, what has happened in the past and what are the current conditions, and the sensitivity of the catchment to environmental changes such as climate change or future landscape management.

In human geography and regional studies, scale is used in three main senses: the *size* of a particular unit, the existence of different *levels* of organisation and the *relations* between these different levels (Howitt 2003) (Table 1). The crucial insight of recent debates is that scale is socially constructed through the strategies of various social actors and organisations, challenging the traditional view of scales as natural or pre-given entities (Marston 2000; Smith 1993). From this perspective, any particular spatial scale such as 'the national' or 'the regional' is a product of wider processes and social relations (Swyngedouw 1997). Since around 2000, however, the scale literature has been criticised by post-structuralist advocates of relational thinking for casting social relations in overly hierarchical and structuralist terms, invariably stressing the 'vertical' links between different levels of organisation (see Marston et al. 2005). While this relationalist approach makes some valid points about the need for a more open conception of space, scales can themselves be viewed in relational terms. As such, the call to abandon scale as an analytical category (Marston et al. 2005; Moore 2008) seems premature and misconceived. An alternative approach is the development of a plural and fluid conceptualisation of scale which is sensitive to its interaction with other dimensions of space (for example, place, territory, networks and mobility) (Jessop et al. 2008 forthcoming; Leitner et al. 2008).

In a similar fashion to catchments, regions are generally defined as bounded portions of the earth's surface which are distinguishable on the basis of their particular internal characteristics. The issue of scale has often complicated the study of regions which have been identified at a range of scales, from large 'world regions' to small local areas or neighbourhoods within cities. Since the early 1990s, the so-called 'new regionalism' has flourished in economic geography and regional studies (Lovering 1999), based on the argument that regions have become more prominent as units of economic organisation and political action under late capitalism (Amin 1999; Morgan 1997; Storper 1995), although different strands of this research emphasise different facets of regional development (e.g., transaction costs between firms, knowledge flows, state restructuring) (MacLeod 2001; Painter 2008). While traditional explanations of industry agglomeration highlight flows of goods and services, capital and individuals between firms, supported by investments in shared infrastructures (Malmberg and Maskell 2002), recent approaches emphasise the importance of knowledge spillovers (Bathelt et al. 2004; Henry and Pinch 2000; Morgan 2004), supported by local ‘untraded interdependencies’ composed of intangible sets of skills, attitudes and habits that tie firms together in particular locations (Storper 1995). Successful growth regions are typically characterised by high levels of connectivity through the movement of key individuals and knowledge, relying upon mechanisms such as labour turnover between firms, the establishment of new firms as spin-offs from existing organisations and informal exchanges involving ‘gossip’ and ‘rumour’ (Henry and Pinch 2000; Saxenian 1994).

This section has revealed a number of differences and similarities in the conceptualisation of scale between catchment sciences and regional studies. In particular, the two fields share a basic dimension of scale in terms of the size of spatial units and have moved towards the development of process-based conceptualisations of scale. In regional studies and human geography, this is often couched in terms of the relationships between units and levels of organisation. Both catchments and regions are physically or socially constructed out of a set of heterogeneous processes, interlinkages and flows, although there are obvious differences between the underlying physical and social processes. Bringing together notions of scale from the two fields would serve to greatly increase this heterogeneity and complexity. From a catchment science perspective, for instance, the introduction of additional scales of human organisation would highlight both local variations in the attitudes and views of residents and ‘stakeholders’ and the importance of management frameworks agreed at the national and European scales. At the same time, the measurement and modelling of scalar processes is a more prominent theme in catchment sciences, while regional studies is concerned with linking the development of regions to broader processes of political and economic globalisation (Amin 1999; MacLeod 2001; Storper 1995).

Scaling: Upscaling and Regionalisation

Scaling describes what happens to the characteristics of an object or process when its scale, that is, dimensions and size, are changed proportionately (Zhang et al. 2004). In physical geography, many environmental processes affecting catchments and humans are found at larger – regional (e.g. geology) and global (e.g. climate systems) – scales. However, due to financial and technical constraints, detailed investigations are often not possible at larger scales (> 10^2 km^2). To understand the hierarchical connections between such larger scales, nested approaches which integrate small scale process variability are required to elucidate the spatial distribution and their interlinkages of processes in relation to catchment characteristics (Tetzlaff et al. 2008).

Obviously, the process of scaling is problematic due to scaling issues in catchment sciences such as spatial and temporal heterogeneity, relevant process non-linearities, specific dominance of processes at different scales, cross-scale correlations and emergence (e.g. Peterson 2000, Sivapalan et al. 2003). Due to heterogeneity, upscaling, that is, the transfer of knowledge obtained at a smaller scale to a larger scale, often requires the identification of the dominant processes evident at the catchment scale rather than attempting to capture all small scale variability and complexity (Blöschl 2001). New developments to facilitate identification of dominant processes, conceptualisation at different spatial scales and consequent upscaling are often driven by gaining new data through the application of innovative technologies (Soulsby et al. 2008). For example, in hydrology, important tools in upscaling for identifying dominant processes include hydrochemical and isotopic tracers, geophysics, remote sensing, nested monitoring and synthesis into GIS frameworks and models aiding integrated conceptualisation at catchment scales. The chemical properties of water are particularly useful as 'fingerprints' to identify – in an integrated way – the pathways it has taken through the landscape and the length of time taken to reach stream networks. For example, conservative isotopic tracers, such as ^{18}O and ^{2}H, form part of water molecules and comparing the isotopic signature of stream flow to that of precipitation (and other waters in soils and groundwater) can elucidate the time taken for rainfall to be transformed into runoff and allows an evaluation of the nature of flowpaths involved as well as insight into how such descriptors change with increasing catchment scale (Soulsby et al. 2006b). This means that tracers are particularly useful in upscaling studies as their dynamics reflect the integration of process interactions at fine spatial and temporal scales (Tetzlaff et al. 2007a). In this way, tracers aid extrapolation of observations across multiple scales and understanding of the 'averaging' which characterizes the emergent functioning of catchment systems at larger spatial and temporal scales. Experimental work involving tracer investigations can also be incorporated into GIS frameworks and model applications, which both provide further important tools for upscaling, informing processes understanding and management guidance (e.g. Dunn et al. 2008; Tetzlaff et al. 2007a). In principle, being physically based and spatially distributed, such models can predict processes across scales or rather identify connections between small scale variability and large scale emergence. However, errors and uncertainties can arise due to the fact that their theoretical foundation is based on small-scale physical laws (Kirchner 2006).

The concept of rescaling underpins recent research in regional studies, particularly in terms of the central 'new regionalist' claim that regions have become more important as units of economic organisation and political action (Lovering 1999; MacLeod 2001). Here, 'rescaling' refers less to the need to 'upscale' from detailed local process studies for management purposes and more to changes in the operation of the political and economic processes being studied. This represents a key difference in conceptualisations of scale between the two disciplines, whereby 'rescaling' in regional studies relates to changes in the operation of the broader economic and political system (capitalism) in contrast to changes in the scale of study in catchment sciences. Catchment dynamics are, of course, influenced by global environmental systems such as climate, but current interest in 'upscaling' is not directly related to changes in these broader systems. Central to economic and political forms of rescaling is the much-vaunted process of globalisation which means that actors such as multi-national corporations and financial institutions operate at an increasingly global scale of activity (Coe et al. 2004; Dicken 2004; Swyngedouw 1997). This has been accompanied by the rise of the supranational scale of governance through bodies such as the European Union. Such 'upscaling' from the national to the global and supra-national levels has been matched by a parallel 'downscaling' from the national to the regional and local. As a result, regions are more directly exposed to international competition, fostering a pre-occupation with enhancing 'competitiveness' through the development of knowledge-based industries and innovation (Jones 2008; Martin 2006).

The related concept of the 'politics of scale' refers to how different groups seek to influence and control the different territorial levels of organisation and the relationships between them (Smith 1993; Swyngedouw 2000). In this context, the different scalar bases and spatial mobility of different groups are important sources of power as indicated by the familiar contrast between global capital and place-bound labour (Peck 1996), an unequal relationship that is mediated by state institutions at various scales (Castree et al. 2004). Such scalar relationships are not set in stone, however, as indicated by organised labours' efforts to upscale its organisation through global frame agreements and the like (Castree 2000; Cumbers 2004; Wills and Waterman 2001). In this respect, Smith (1995) develops the idea of 'jumping scale', referring to the ability of social groups and organisations to move from lower to higher levels of activity in pursuit of their interests. Similarly, Cox (1998) argues that local actors construct 'spaces of engagement' with regional, national and/or supra-national institutions in pursuit of objectives such as securing European financial support or opposing a particular development proposal (MacLeod 2001).

This concern with cross-scale issues highlights the differential scaling of regional development processes. Tracing and assessing cross-scale processes represents a key methodological challenge for regional studies – paralleled, as we have seen, in catchment science. There is an increasing range of publicly available data covering various aspects of regional performance, but it is inherently difficult to relate specific indicators to particular scalar processes and flows. Formal modelling remains the basis of the regional science tradition, boosted by the development of new analytical techniques such as those associated with the 'new economic geography' (Krugman 2000; McCann 2007). In the absence of human tracers, the alternative approach favoured by many researchers in the regional studies tradition is to reconstruct the operation of cross-scale processes from actors' own accounts (see Allen and Cochrane 2007), based on data gathered by surveys and/or interviews (see Tickell et al. 2007). While cross-scale processes such as learning and the circulation of skilled personnel may not be directly visible to researchers, they can be indirectly gauged by following the main actors involved (Henry and Pinch 2000). Such research tends, however, to be confronted with the problem of 'observational equivalence' in terms of the difficulty of inferring causality from empirical observations, reflecting the possibility of alternative explanations and providing no basis for subsequent prediction (McCann 2007; Overman 2004). Accordingly, process measurement and conceptualisation is a major problem for regional studies.

This review of concepts of 'upscaling' and 'rescaling' demonstrates that the tracing and assessment of dominant, cross-scale processes is a key concern in both catchment sciences and regional studies. Greater divergence between the two fields is apparent, however, when the focus moves from basic definitions and understandings of scale to understandings of scalar processes such as 'upscaling' and 'rescaling'. The concern with 'upscaling' in catchment sciences requires approaches that integrate small scale heterogeneity at larger scales, identify dominant processes and conceptualise the integration of such processes. In contrast, 'rescaling' in regional studies refers to changes in relations between different spatial levels of organisation (the local, regional, national, supranational) that are driven by the restructuring of the broader political and economic system in question (capitalism); a process commonly summarised as globalisation (Coe et al. 2004; Dicken 2004; Swyngedouw 1997). Such rescaling requires an empirical focus on cross-scale processes, suggesting a role for both modelling-based approaches, depending on the availability of suitable cross-scale data, and efforts to trace linkages by following the main actors as they move between scales. Notwithstanding the important differences between notions of upscaling and rescaling, the basic parallels uncovered in the previous section indicate a need for an overarching conceptual terminology and framework, leading us towards complexity theory (see Harrison et al. 2006).

Openness, Complexity and Emergence

As previously mentioned, catchment sciences have identified and described enormous heterogeneity and process complexity through the application of new technologies in field experimental and modelling studies (McDonnell et al. 2007; Sivapalan 2005; Soulsby et al. 2008). However, although catchments are complex and impossible to understand completely due to their heterogeneity, it is possible to observe enough pattern to the linkages within and between physical, ecological and human systems to begin to reasonably model how they interact and change (Montgomery et al. 1995), which is crucial in order to understand and predict responses of catchments to environmental or climatic change. McDonnell et al. (2007) propose a new vision to view heterogeneity as a 'concisely defined feature rather than an infinitely complex set of data' and process complexity as a 'coherent experience of catchment functioning rather than a detailed description of process dynamics.' Recent work advocates viewing catchments as complex adaptive systems, which involves a clear need to understand their self-organising structure from an evolutionary perspective combining the ecological response to fluxes of water and sediments (e.g. Couwenberg and Joosten 2005; Belyea and Baird 2006). For example, network structures and flows occur and may self-organise at all scales. These are always exhibiting some kind of compromise between forces that result in movement and forces that resist motion (McDonnell et al. 2007). Of course, these fluxes and forces vary in response to changes in forcing factors which can include both short-term and long-term instability as a result of environmental change.

New theories have emerged emphasising the importance of spatial context, connectivity and geometry in catchment science, moving away from traditional local unit quality towards recognition of spatial processes including neighbourhood effects, size and connectivity (e.g. Lane et al. 2004; Tetzlaff et al. 2007b). Within hydrology, concepts such as representative elementary watersheds have been applied to describe the critical size of a spatial unit which is needed to examine the emergence of different processes at aggregated scales (Beven 2007; Woods et al. 1988). Highly variable small scale processes are smoothed at larger scales; however, environmental changes may alter this small-scale response and can result in major changes in intra-catchment response which need to be predicted correctly (Sidle 2006; Tetzlaff and Soulsby 2008). The emergence of new processes at new scales is still not fully understood and often not predictable on the basis of current process understanding (McDonnell et al. 2007). Moreover, it is context dependent. However, filtering out 'unimportant' features and details at the smaller scale might aid the identification and prediction of emergent processes (Sivapalan 2003). Furthermore, identification of threshold behaviour and process non-linerarity is vital to improve understanding of catchment response and behaviour at different scales and to aid conceptualisation (Zehe et al. 2007). In addition, the identification of 'hot spots' – which are usually local and very small in their scale but highly important for the overall catchment response – and their incorporation into conceptual models of catchments is crucial (McClain et al. 2003).

Both the economic landscape in general and individual regions can be viewed as complex, adaptive systems characterised by openness, emergence and non-determinacy (Boschma and Martin 2007; Essletzbichler and Rigby 2007). They are both profoundly shaped by forces and influences inherited from the past, as classically expressed in Massey's spatial divisions of labour model (Massey 1995). More recently, this has fostered interest in the construction of an evolutionary economic geography (Boschma and Frenken 2006; Boschma and Martin 2007; MacKinnon et al. forthcoming). From an evolutionary perspective, regions are composed of heterogeneous bundles of firms, routines and institutions which themselves evolve at different rates (Essletzbichler and Rigby 2007). The tension between forces favouring movement or mobility and those resulting in stability and fixity is also a major issue in regional studies, particularly in terms of how relatively stable regional 'permanences' established at a particular point in time may be undermined in the future by changing political and economic conditions (Harvey 1996; Swyngedouw 1997). A key feature of regional systems is path dependency, referring to the ways in which certain outcomes emerge and evolve as a consequence of a region's own history (David 2001, p. 19; Martin and Sunley 2006, p. 399). In addition to the influence of complexity theory, relational approaches also highlight the internal heterogeneity of regions and their external openness in terms of the various flows that connect them to other regions (Allen and Cochrane 2007; Amin 2004). In this context, there is a need to understand the diverse responses of regions to an increasingly turbulent economic and political environment (Grabher and Stark 1997), echoing the concern with the variable responses of catchments to climatic and environmental change. From an evolutionary perspective, pre-existing regional variety provides the essential 'friction' that 'grinds' against market-based selection processes to preserve diversity (Grabher and Stark 1997, p. 542; cf. Massey 1995).

In summary, complexity theory provides an overarching conceptual language and framework for assessing notions of scale in catchment science and regional studies (see Harrison et al. 2006). From this perspective, catchments and regions are both open systems subject to constant interaction with their environments and characterised by a high degree of connectivity between key components, non-deterministic dynamics and adaptive behaviour (Martin and Sunley 2007). The properties of self-organisation and emergence can be applied to both types of spatial units, meaning that large-scale structures tend to emerge spontaneously from the interactions between micro-level behaviour, although this micro-behaviour may also be affected by larger social and physical systems (Peck 2005; Sheppard 2002). In catchment sciences, new theories emphasise the importance of spatial context, connectivity and geometry and recognise spatial processes such as neighbourhood effects, size and connectivity. Scale-independent issues such as threshold behaviour and non-linear response have been identified, but a fuller understanding of emergence is needed in order to aid scale-independent conceptualisation. While regions can be defined in evolutionary terms as open and adaptive systems characterised by properties of path dependency, emergence and non-determinacy, there is still a lack of understanding of the forces governing their responses to an increasingly turbulent economic and political environmental and the role of various inherited attributes in shaping such responses.

Indicators of Similarities and Concepts of Generalisation – Towards the Characterisation of Spatial Units

In catchment sciences, it has been argued that a paradigm shift is needed towards the development of unifying ideas and organising principles that might facilitate extrapolation and prediction of processes in different provinces and across scales (e.g. McDonnell et al. 2007). In regional studies too, there is growing recognition of the need to move beyond single region case studies in order to examine the operation of similar processes across different places. The similarity concept, that is, identification of similarly responding units, is one way forward when the nature and operation of processes are not fully understood (Blöschl 2001). However, simply describing the heterogeneity of processes and consequent complexity will not improve the ability to extrapolate and predict, particularly when we recognise that forms of heterogeneity and complexity may themselves be subject to change over time (Tetzlaff et al. forthcoming). Moreover, 'organising' or 'optimality principles' are required in order to develop diagnostic generalisation tools as analytical frameworks to provide a basis for cross-scale characterisation and prediction (Figure 1). Such principles require the definition of indicators of similarities and attributes of spatial units characterising the physical and socio-economic behaviour of catchments and regions, respectively. Indicators of similarities may allow a systematic investigation of interactions of functioning in both catchment sciences and regional studies and the development of integrated classification tools (Wagener et al. 2007) for understanding both catchment behaviour and functioning of regions.

Of course, such defined classes or 'generalisation units' may still contain massive internal complexity, but such classification might still allow some kind of grouping of features and the comparison of spatial units. However, the uniqueness of places (Beven 2000), that is, of regions and catchments, which have evolved as a consequence of individual features such as initial conditions and historical evolution, means that generalisation approaches such as classification systems or similarities indices will never be capable to predict precisely the behaviour of spatial units. Still, understanding the general behaviour and functional traits of spatial units might help to recognise the outlier and contextualise existing process-understanding in individual research catchments (Tetzlaff et al. forthcoming). In regional studies, researchers need to move beyond the ritual claim that geography 'matters' to actually identify its key effects, drawing out the influence of local specificity and contingency in the context of broader processes of change (Massey 1995).

Informed by these considerations, Figure 1 presents an analytical framework for the characterisation of catchments and regions as spatial units, based on the development of certain integrating concepts. We believe that this framework makes a necessary contribution towards the development of a

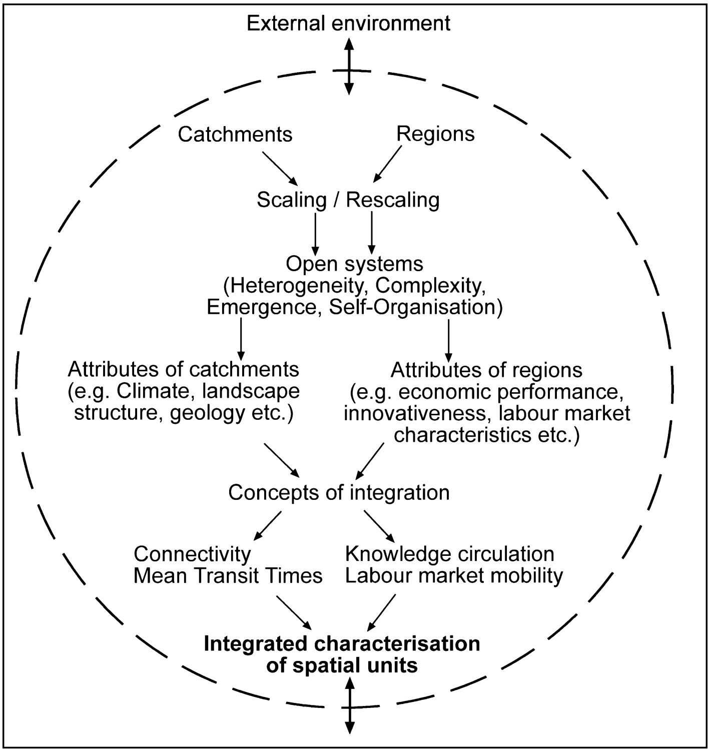

Fig. 1. An analytical framework for the integrated characterisation of spatial units.

more integrated understanding of spatial units, but acknowledge that it is far from sufficient, requiring to be supplemented by ancillary domain-specific theories that pertain to the explanation and prediction of the specific physical and social process under investigation (see Hodgson and Knudsen 2006). As described above, catchments and regions are subject to complex processes of scaling and rescaling in relation to both their internal organisation and their interactions with the broader external environment which surround them (Figure 1). Drawing upon the meta-theoretical language of complexity theory, both types of units are defined as open systems characterised by the properties of heterogeneity, complexity, emergence and self-organisation.

The influence of complexity theory directs us towards dynamic rather than static attributes of spatial units. These are largely descriptive, providing a characterisation of key aspects of the functioning and operation of catchments and regions as open systems. In the case of catchments, such attributes include, for example, climate, landscape structure and geology. Key dynamic attributes of regions are economic performance, innovation and labour force skills, measured by change over a specified period of time in selected indicators.

The selection and investigation of such attributes feeds into 'concepts of integration' which are designed to integrate heterogeneity and process complexity of spatial units, leading to parsimonious descriptions of their responses to changes (Figure 1) (McDonnell et al. 2007). For example, in catchment hydrology, the concept of connectivity – as a measure of the degree of connections – and the concept of transit times provide tools for an integration of process heterogeneity and interactions across scales. The concept of connectivity, that is, for example, connectivity between the channel network and the surrounding hillslopes (hydrology) and connectivity between spatially continuous, heterogeneous habitat patches (ecology) – has obvious potential as a unifying theme where exchange of concepts and cross-fertilization of ideas between research directions can occur (Tetzlaff et al. 2007b). Transit times (TT) reflect the average time taken for a water molecule to travel through a catchment from rainfall to runoff and are usually estimated by modelling tracer input-output relationships according to various Transit Time Distributions in order to gain an integrated understanding of the emergent behaviour of complex catchment mixing processes by assessing the timing of water movement through the catchment. Thus, TT can be used as simple hydrological descriptors that can be very insightful in terms of conceptualizing flow paths and mixing processes at the catchment scale (McGuire and McDonnell 2006; Soulsby and Tetzlaff forthcoming).

Examples of such concepts of integration in the case of regions include knowledge circulation and the mobility of individuals in labour markets (Figure 1), the importance of which is apparent from a number of studies of dynamic growth regions (Bathelt et al. 2004; Henry and Pinch 2000; Saxenian 1994). Interestingly, recent work indicates that the circulation of knowledge and skilled personnel is becoming increasingly international and cross-scale in nature (Amin and Cohandet 2004; Saxenian 2006), reinforcing our emphasis on the openness and complexity of regions. This treatment of catchments and regions as open systems that can be investigated through a focus on certain dynamic attributes and concepts of integration might provide the basis for moving towards a more integrated and overall characterisation of the functioning of spatial units.

Conclusions

Our starting point for this article was the marked similarity in the scalar terminology used in catchment sciences and regional studies, pointing to a further area of conceptual overlap between physical and human geography alongside discussions of space and time (Harrison et al. 2004, 2006; Massey 1999; Raper and Livingstone 1995). Despite the differences between the natural and social processes with which the respective disciplines are concerned, certain parallels are apparent in the treatment and conceptualisation of scale (Lane 2001). In particular, both disciplines have moved towards the development of a process-based understanding of scale and associated patterns of connectivity. At the same time, important differences in scalar terminology and conceptualisations are also apparent. Catchment science is confronted with the problem of 'upscaling' from detailed process studies to provide a scientific underpinning for management strategies at the catchment scale while increased recent interest in regions as units of economic organisation and political action reflects broader 'rescaling' processes over the past two decades (Storper 1995). While upscaling in catchment sciences refers to changes in the internal organisation of catchment and in the focus of study, rescaling refers to changes in the nature and operation of the broader system of capitalism. In methodological terms, divergence is also evident, leading to the development of ever more sophisticated methods to capture, extrapolate and predict dominant processes in catchment science while regional studies – in contrast to regional science – have tended to largely eschew modelling, replying largely on surveys and interviews with key firms and actors.

Acknowledging such differences, our aim has been the development of a new analytical framework (Figure 1) for the integrated understanding of scalar processes in catchment sciences and regional studies. Our approach incorporates the principles of complexity theory, underpinned by the belief that it is necessary to move beyond a simple description of the principles of heterogeneity, emergence and self-organisation. Our framework is focused on processes of scaling and rescaling as crucial aspects of catchments and regions that are viewed as open systems. This leads into the identification of dynamic attributes which can be assessed and measured through various direct and indirect indicators, focusing on changes in conditions over time. Concepts of integration represent key dimensions of the underlying processes of interest such as connectivity or knowledge circulation which connect different spatial units and scales. In this way, we hope to stimulate new thinking about the operation and functioning of catchments and regions as open systems characterised by heterogeneity and complexity.

Short Biographies

Danny MacKinnon is Senior Research Fellow in the Department of Geographical and Earth Sciences, University of Glasgow. He is an economic and political geographer with interests in regional economic development, devolution and state restructuring and labour geography. He has authored or co-authored papers on these issues for a number of journals, including *Environment and Planning A*, *Progress in Human Geography* and *Regional Studies*. He is the author of *An Introduction to Economic Geography: Globalisation, Uneven Development and Place* (Pearson, 2007) (with Andy Cumbers) and

Diverging Mobilities? Devolution, Transport and Policy Innovation (Elsevier, 2008) (with Jon Shaw and Iain Docherty). He holds an MA from the University of Dundee and a PhD from the University of Edinburgh.

Dr. Doerthe Tetzlaff holds a Readership in Hydrology at the School of Geosciences, University of Aberdeen, Scotland, which is funded as part of the pan-Scottish SAGES (Scottish Alliance for Geosciences, Environment and Society) initiative in which she plays a key role. Her main expertise is in catchment hydrology, tracer applications, spatial modelling and hydroecology developing new conceptual models of how water moves through the landscape, how GIS and other modeling tools can be used for prediction and how interdisciplinary study of water quantity and quality can be used to advance our predictive capabilities. Her work has led to > 50 innovative, senior-authored and co-authored peer reviewed publications, including several Invited Commentaries. Consolidating her published research, Dr Tetzlaff has strong research links with numerous internationally leading groups in Europe and North America. She is playing a leading role in the Prediction in Ungauged Basins initiative of the International Association of Hydrological Sciences. She holds a BSc from the University of Potsdam, an MSc from the University of Hannover and a PhD from the University of Freiburg, all Germany.

Notes

* Corresponding author: Danny MacKinnon, Department of Geographical and Earth Sciences, University of Glasgow, University Avenue, Glasgow G12 8QQ. E-mail: danny.mackinnon@ges.gla.ac.uk.

[1] Regional studies can be distinguished from the parallel field of regional science by its interdisciplinary nature, openness to a range of theoretical approaches and methodologies and strong policy orientation (Pike et al. 2007). Regional science, in contrast, is based on formal economic modelling (McCann 2007).

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