

Chapter 7

Scale

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Introduction: The Many Meanings of Scale

In his Robert H. MacArthur Award lecture in 1989, Princeton ecologist Simon Levin declared: ‘The problem of relating phenomena across scales is the central problem in biology and in all of science’ (Levin, 1992, p. 1961). Levin is not alone: inside and outside the academy, there is an effective consensus that scale is of the utmost importance to matters of humans and the environment. Consider these assertions: ‘The history of human cultural evolution has been the story of cross-scale subsidies’, from a paper on the resilience of social-ecological systems (Carpenter et al., 2001, p. 767); and ‘Scale is a nonreductionist unifying concept in ecology’, by two other prominent theorists (Peterson and Parker, 1998, p. 521). Scale is discussed with comparable gravity and still greater rhetorical flourish in more popular venues. Science journalist Elizabeth Kolbert, for example, opens her book on climate change, *Field Notes from a Catastrophe*, with the claim that: ‘For better or (mostly) for worse, global warming is all about scale’ (2006, p. 3). Pulitzer prize-winning columnist and neoliberal enthusiast Thomas Friedman puts it this way: ‘Hey, the more energy-saving bulbs Wal-Mart sells, the more innovation it triggers, the more prices go down. That’s how you get scale. And scale is everything if you want to change the world’ (*New York Times*, 22 December 2006, p. A31). For many people, scale is the fundamental conceptual challenge in the human and natural sciences, critical to progress in understanding and ameliorating human-environment interactions.

It remains remarkably unclear exactly what scale means and how to use it, however, and within geography the confusion is particularly acute. Biophysical geographers understand and employ scale much as ecologists do (where it is also much debated), but cartographers, Geographic Information Scientists, and especially human geographers have various other ideas of scale and its theoretical and methodological implications. The editors of a recent volume on the subject conclude that ‘conceptions of geographic scale range across a spectrum of almost intimidating diversity’ (Sheppard and McMaster, 2004, p. 256). Marston et al. (2005, p. 416),



after noting that ‘scholarly positions on scale are divergent in the extreme’, conclude that the concept is fundamentally flawed and should be banished from human geography altogether. A review paper in the journal *Ecological Economics* confirms the diagnosis but prescribes the opposite cure: ‘Now, scale issues are found at the center of methodological discussions in both physical and human geography’, the authors observe, but ‘common definitions do not exist for scale – even within disciplines – and especially in the social sciences’ (Gibson et al., 2000, pp. 226, 236). Nonetheless, they issue an unequivocal call: ‘The challenge of global environmental change requires that both the physical and social sciences be included in its study. If researchers are to generate accurate analyses of environmental change, the first step, we believe, is to push beyond the present cacophony and construct a common understanding of issues related to scale’ (p. 237).

The problem with scale derives in large part from a surfeit of meanings and uses. The word occupies nearly four pages of the original *Oxford English Dictionary*, and a search of the BIOSIS database finds the term in more than 85,000 abstracts since 1990. Richard Howitt (1998; 2003) discerns three ‘aspects’ or ‘facets’ of scale: as size, level, and relation. The first two are relatively well understood, he argues; they predominate in non-technical, quotidian contexts, and even in academic writings scale is usually a simple descriptor, not a concept. But it is only as relation that scale assumes the importance ascribed to it in recent decades, and the apparent clarity of the first two meanings has made understanding the third much more difficult. Conflating scale and level may be convenient and non-problematic when neither term is the focus of inquiry, but collapsing the two risks evacuating scale of conceptual importance altogether. In short, distinguishing scale as relation from its more casual or colloquial meanings is necessary if its significance for environmental geography is to be clarified, let alone realised.

In what follows, I first review the various uses and meanings of scale in geography, including ‘the scale question’ in human geography. Scale as size, level, and relation are not mutually exclusive – indeed, they build on and presuppose one another – but they are analytically distinct; many, if not all, of the debates about scale in recent human geography can be traced to conflation among these meanings. I then examine the emergence of scale in ecology, in order to clarify why it is considered of such overriding importance to our understanding of ecosystems and environmental problems. For ecologists, scale is intrinsically spatio-temporal, playing a key role in the critique of equilibrium models and assumptions that has gathered momentum over the past three decades. The conclusion develops a framework for theorising scale to advance research in environmental geography.

The edited volume *Scale and Geographic Inquiry* provides a valuable overview of geographical scale. In their introductory essay, the editors note that ‘different concepts of scale are employed in geography’s various subdisciplines’, but that ‘there has been little attempt to integrate across these subdisciplinary perspectives’ (Sheppard and McMaster, 2004, p. 2f.). A brief summary of scale’s various meanings in geography is therefore warranted. It is useful to organise them into the three facets of size, level and relation.

Scale as Size

In this first and simplest sense, scale refers to measurements expressed in terms of standardised units. ‘Space and time are not scales until they are divided into seg-

ments that can be used for measurement' (Rykiel, 1998, p. 488). A scale is used to ascertain some attribute of an object or phenomenon – such as length, mass, volume, velocity, and so forth; in geographical contexts, scale in this sense generally refers to *size*. *Cartographic scale* is the oldest kind of geographical scale, having emerged with the science of cartography during the eighteenth century. It refers to the mathematical relationship between a map and what it represents: the 'representative fraction' or ratio of a unit space on a map to space in the world, such as 1:62,500 for maps in which one inch represents one mile. Expressed in this way, smaller scale maps depict larger areas than do maps of larger scales, resulting in the peculiarity that cartographers employ 'large scale' and 'small scale' in the opposite way from scholars in other fields. Choice of scale has obvious implications for cartographic generalisation: Smaller scale maps (depicting larger areas) necessarily sacrifice details that can readily be included on maps of larger scales (depicting smaller areas). (Hereinafter, I will use 'small' and 'large' scale the way non-cartographers do, to avoid confusion.) Scale is a central conceptual and representational issue in cartography because it strongly determines selection, simplification, classification, and symbolisation. Different tasks – depicting a neighborhood, a city, a region or a continent, for instance – call for the use of different cartographic scales.

Developments in Geographical Information Science (GISc) raise the possibility of overcoming constraints of cartographic scale, at least in theory. Digitised data can be assembled and analysed across multiple scales, such that details visible at small scales are not lost (to the computer, at least) when one 'zooms out' to much larger scales. As Sheppard and McMaster (2004, p. 4) note, however, this does not mean that 'there is no scale' in GISc, because the underlying data are themselves typically derived from scaled sources. (Think of what happens when one zooms in on Google Earth, for example: the image becomes blurry at certain scales, then regains focus when the programme shifts to an image taken at another scale.) The technical details and particularities of GISc cannot be adequately reviewed here, but the issues of scale discussed below are nonetheless relevant to that field.

Cartographic scale is principally a representational issue, but in the second half of the twentieth century other fields in geography identified empirical corollaries: situations in which spatial analysis resulted in different (or even opposite) conclusions depending on the scale employed. The distribution and intensity of poverty, for example, might look very different if the smallest unit of analysis were city blocks rather than census tracts, cities, or entire states. Openshaw (1977; 1984) famously demonstrated that the boundaries and size of units for spatial aggregation could determine whether two variables correlated positively, negatively, or not at all: a form of ecological fallacy known as the modifiable areal unit problem. *Observational scale* refers to this methodological issue, which at face value resembles cartographic scale: At what spatial dimensions can one best perceive and analyse particular phenomena? Even when the question is not posed as such, scientists cannot avoid this issue: 'Because science is about the search for and explanation of patterns, all scientific inquiry explicitly or implicitly incorporates scale into the process of identifying research objects: the very act of identifying a particular pattern means that scale, extent, and resolution have been employed' (Gibson et al., 2000, p. 221).

Observational scale has two components. *Resolution*, or *grain*, is the smallest unit of measurement: it determines the precision or detail captured by a certain method. *Extent* is the overall dimensions of a study: the area (and time period) over

which measurements are made. 'Small scale', in this context, typically denotes a finer resolution, while 'large scale' indicates a large extent; practical constraints generally dictate a small extent for fine-grained studies and a coarse grain for studies that have a large extent. Combining a fine grain with a large extent is difficult because a fine grain captures greater variability, which in turn necessitates larger sample sizes, even at a small or medium extent. Often, grain and extent are constrained by the technical capacities of available instruments for measurement (and of computers for analysing the resulting data): If one has only a meter stick, for example, the grain can be no smaller than a millimeter, and extents of greater than, say, fifty meters are likely to be impractical. Likewise with temporal scale: annual rainfall, for example, is too coarse a resolution to understand vegetation patterns where seasonal variability is high. Choosing one's grain and extent carefully is important precisely because 'patterns that appear at one level of resolution or extent may be lost at lower or higher levels' (Gibson et al., 2000, p. 221). Conversely, the advent of new observational tools and technologies can strongly affect the kinds of questions that scholars pose and the theories they construct. As Church (1996, p. 153) puts it: 'The space and time scales of observation constrain the structure and physical content of functionalist theories [in geomorphology] through their control of the resolution of information in the theory. Our theoretical construction of order in nature is bound by the tyranny of the scales'.

Observational scale is principally an epistemological issue, but subsequent work in ecology and biophysical geography indicates that scale may have ontological implications as well. *Operational scale* refers to the idea that phenomena occur at determinate spatial (and temporal) scales in the real world: that scale is an actual, material property of processes, not simply a matter of how they are observed. The Coriolis force, for example, determines patterns of winds and weather systems at very large scales: It is why low-pressure systems rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. However, contrary to popular belief, it does not affect which way water spins down the drain, a process at much smaller spatial and temporal scales. Similarly, tectonic drift occurs over very long time periods and very large areas, but at smaller scales it is, practically speaking, not only invisible but generally irrelevant. For both ecologists and biophysical geographers, operational scale is ontologically real.

A key point of agreement among geographers and ecologists is that no single 'correct' scale exists for either field: different processes operate at different scales and must be studied accordingly. Identifying the operational scales of processes and reconciling them with observational scales are therefore central challenges of research. The former may be termed the *ontological moment* of scale, the latter its *epistemological moment* (Sayre, 2005). One must work back and forth between the two moments (dialectically or, at the least, hermeneutically), incrementally reducing epistemological obstacles and thereby strengthening ontological insights. Over time, the observational scales utilised by scientists should more closely reflect the operational scales of material processes.

Scale as Level

That different processes have different operational scales raises difficult questions about their interactions. If the Coriolis force can give direction to something as big and powerful as a hurricane, shouldn't it also affect water going down the

drain? Can one 'scale down' from a large or slow process to a smaller or faster scale in a simple, linear fashion, or not? How can a relationship identified at a small scale be extrapolated 'up' to larger scales? Multiscale analyses, and the study of cross-scale linkages, aim to address questions such as these. In order to do this, scientists classify phenomena into various levels based on the scales at which they can be observed or measured: the organism level and the community level in ecology, for example. The spatial and temporal units of measurement appropriate for each level tend to coalesce in a pattern: larger areas with longer time-periods, smaller areas with shorter time-periods (figure 7.1). Whether such levels are ontologically real or merely artifacts of observation can only be determined by empirical research.

It is easy to see how level and scale might become confused, since they are interchangeable *in this sense of scale*. In common usage, for example, one can generally refer to 'the urban level' as 'the urban scale' without loss of meaning (even though the extent of this level may vary depending on historical and geographical context). Epistemologically, scale as level involves choices of what will and will not be observed and analysed: A study conducted at 'the community scale' focuses on phenomena of certain (more or less determinate) spatial and temporal dimensions, and it may choose to ignore (or hold constant) processes at other levels for the purposes at hand.

Of course, phenomena that scientists classify at different levels do interact with one another in the real world, and studies of such interactions require some kind of ordering principle among levels. Various metaphors have been used: a pyramid, ladder, scaffold, or the famous 'Russian doll' of nested, recursive systems (Herod

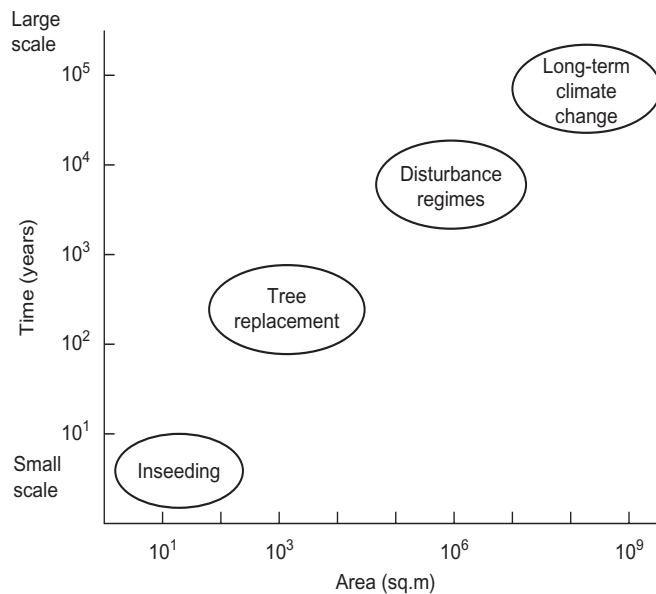


Figure 7.1 The hierarchy of space-time scales. The space/area and time/rate of processes tend to co-vary, lending support to the notion of hierarchically ordered levels in space-time. *Source:* Sheppard and McMaster (2004, p. 12), reproduced with permission.

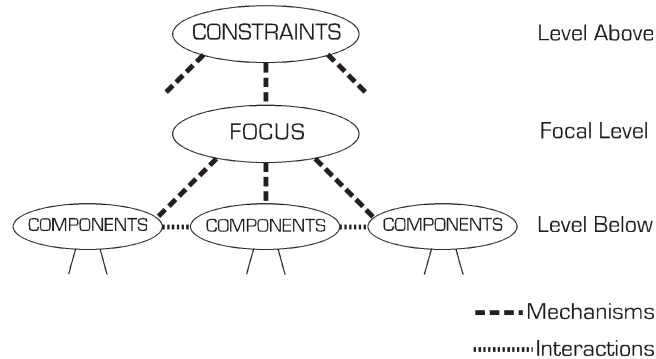


Figure 7.2 Relationships between levels in a system, as conceived in hierarchy theory. Processes at the focal level are constrained by the level above. They are driven by interactions among components at the level below. Figure by Darin Jensen.

and Wright, 2002). The prevailing approach in biophysical geography, as in ecology, is hierarchy theory (Allen and Starr, 1982), in which phenomena are classified based on functional relations or operational scales. Wu and Loucks (1995, p. 451) argue that ecological studies should examine (at least) three levels: the level of the process at issue, plus the levels above and below it (figure 7.2). 'The higher level provides a context and imposes top-down constraints on the focal level, and the lower level provides mechanisms and imposes bottom-up constraints'. Note that causality here is not unidirectional (*contra* Leitner and Miller, 2007): The outcome at a given level is determined both at that level and by the interaction of processes that link it 'upwards' and 'downwards' to adjacent levels.

Most biophysical systems are theorised as constitutive hierarchies. This means that relations are not simply bureaucratic, in which 'higher' levels dictate what happens at 'lower' ones (known to political scientists as an exclusive hierarchy). Nor are they inclusive, as in taxonomy, in which each level simply encompasses those below it. In a constitutive hierarchy, units at one level, when combined at the next level up, may display patterns of self-organisation and 'emergent properties' that cannot be discerned in, or deduced from, their behaviour at the focal level (Gibson et al., 2000). The idea is often expressed as 'the whole is greater than the sum of its parts'. Landscape ecology descends in part from this insight, sometimes glossed as 'holism' or the study of 'holons' (Naveh and Lieberman, 1984). Similarly, 'complex adaptive systems' are defined by heterogeneity and unpredictability as 'pattern emerges from the interplay between processes that generate novelty and those that winnow that novelty' (Chave and Levin, 2004, p. 31). Chaos theory and panarchy (Gunderson and Holling, 2002) are other recent attempts to make sense of such phenomena, which Church (1996, p. 167) locates 'in the zone between mechanistic and contingent explanation'.

Scale as Relation

It is here that scale as relation emerges. Not only is there no single 'correct' scale for understanding social or ecological systems, but neither can one assume linearity

across scales. As Chave and Levin (2004, p. 32) note, scaling relationships – between metabolic rate and body size, for example, or between area and species richness – ‘are among the most robust empirical generalisations found’ in ecological systems – but they are not linear. They cite financial crashes and traffic jams as ‘typical of the dynamics found in complex adaptive systems’: as the component parts interact and adapt, positive feedback loops can trigger abrupt, extreme, unpredictable change. Economies of scale are another example: how the division of labour and the expansion of production result in non-linear increases in output and qualitatively new social phenomena can only be understood relationally.

Scale as relation requires a strong conceptual distinction from level. It is, so to speak, an order removed from scale as level, defined by the spatial and temporal relations among (processes at different) levels. To address scale as relation, then, one must eschew the conventional synonymy of scale and level.

Among ecologists, scale as relation is part of a larger critique of equilibrium models and assumptions. In a famous 1977 article, Robert May presented mathematical models of systems with ‘a multiplicity of stable states’, inspired by empirical cases of grazing ecosystems, fisheries, insect outbreaks in forests, and host-parasite systems. He likened ecosystem dynamics to a marble in a cup. If the cup formed ‘a single valley’, then the system would always return to a single stable state following disturbance, and historical effects would be unimportant. But if the cup were a ‘dynamical landscape pockmarked with many different valleys, separated by hills and watersheds’, then ‘the state into which the system settles depends on the initial conditions: the system may return to this state following small perturbations, but large disturbances are likely to carry it into some new region of the dynamical landscape’. Scale is thus not only a spatial issue but also a temporal one. Any equilibrium presupposes some period of time over which stability persists; it might turn out to be unstable if evaluated at a different temporal scale. Moreover, ‘if there are many alternative locally stable states, historical accidents can be of overriding significance’ (May, 1977, p. 471).

Understood in this way, scale is central to current notions of sustainability and resilience in complex adaptive systems involving humans and the environment. Once one admits the possibility of multiple stable states, one cannot avoid the issue of thresholds or ‘breakpoints’ between them. May (1977, p. 477) emphasised that ‘continuous variation in a control variable can produce discontinuous effects’ and that ‘increasingly severe nonlinearities can make the dynamical behaviour range from a stable point, through a bifurcating hierarchy of stable cycles, into a regime which is in many ways indistinguishable from random noise’. In the three decades since, ecologists have struggled to model complex systems and quantify thresholds of non-linear change. Predictive knowledge of thresholds has remained elusive, but theory and conceptual models have advanced considerably and empirical observations are accumulating (Crumley, 1994; Westoby et al., 1989). There is also growing interest in the hypothesis that unsustainable resource use results from ‘mismatches of scale’ between human and natural processes (Lee, 1993; Cumming et al., 2006). Determining the relevant processes involved, and their operational scales, thus becomes a necessary prerequisite for advancing both research and management (for an example involving fisheries, see Perry and Ommer, 2003).

While ecologists turn to ever more sophisticated mathematics and models to understand scale as relation, human geographers explore the matter through metaphors and theory. Howitt (1998) examines musical scales, pointing out that the

value of each note is determined not simply by its individual qualities but also by the other notes and its position among them. Any change in one note affects the scale as a whole, and vice-versa; the scale is more than the sum of its parts, and this 'gestalt' can be perceived in the way certain scales provoke spontaneous cultural associations. Howitt's metaphor is suggestive, even if exactly how musical scales might elucidate human and environmental processes remains unclear. He argues that 'scale is better understood dialectically than hierarchically' (Howitt, 1998, p. 52). Ecologists rarely employ such terminology, but the underlying point strongly resembles the idea of emergent properties or panarchy: shifting scales results in qualitative, rather than merely quantitative, change.

Scale in the Discipline of Human Geography

Scale has a rather different genealogy in human geography, although the underlying methodological and theoretical issues converge with those elsewhere in the discipline and in ecology. As in the physical sciences, social science disciplines have divided and defined themselves – intentionally or unwittingly – by scale (as size, both operational and observational): psychology studies individuals; anthropology villages, clans or tribes; sociology neighborhoods or cities; political science governments and states, etc. Each discipline could thus take its own scale more or less for granted. (The separation of micro- from macroeconomics is the exception that proves the rule.) As Gibson et al. (2000, p. 221) observe: 'Overt choices of particular scales to identify specific patterns are generally taken more consciously in the natural sciences than in the social sciences'. Human geography, with its diversity of subdisciplines and methods, could not so easily avoid the issue, but many topics had operational and thus observational scales that seemed obvious and could therefore remain implicit. In recent decades, however, the economic, political and cultural dynamics of globalisation have called into question the scales of previous human geographic research.

A typical classification of human geographical scales includes the body; the household; the neighborhood; the city; the metropolitan area; the province or state; the nation-state; the continent; and the earth as a whole (Sheppard and McMaster, 2004, p. 4). (The region is another oft-employed geographical scale, albeit one whose position in this classification is variable. . . .) By the preceding analysis, this is simply a list of levels; the implied nested hierarchy resembles the way ecologists conventionally imagined organisms, populations, communities, ecosystems and biomes. If one questions the stability of these categories, however – how they are produced, reproduced or transformed – or if one asks how multiple levels interact, then the issue of scale as relation is raised. This is how 'the scale question' in human geography has emerged.

For political ecology in particular, and environmental geography more generally, one might trace recent debates about scale to Piers Blaikie and Harold Brookfield's landmark book, *Land Degradation and Society*, which addressed problems of aligning observational and operational scales and working across scales (1987, pp. 64–74). '[I]t is very evident that we must take care to define the scale at which we are working if the social causes and consequences of degradation are to be described adequately'.

But the scale question in critical human geography also has its roots in political economy: an article by Peter Taylor (1982) that defined the local, national and



global as the scales of experience, ideology and capital accumulation, respectively. Taylor characterised the global scale as the most 'real', reflecting the Marxian-materialist priority given to production and simultaneously reinforcing a top-down, hierarchical notion of scale.

Building on the work of Henri Lefebvre and David Harvey, Neil Smith (1993, p. 96f.) criticised geography for taking its scales – 'localities, regions, nations and so forth' – for granted, and for trivialising geographical scale 'as merely a question of methodological preference'. Focusing on the ontological rather than the epistemological moment, he stressed the importance of scale in spatial differentiation. '[S]cale is produced in and through societal activity which, in turn, produces and is produced by geographical structures of social interaction . . . [T]he production of geographical scale is the site of potentially intense political struggle'. Smith proceeded to offer a typology of geographical scales similar to the list given above, but he treated them as operational rather observational. He specified the processes that produced each scale materially: for example, daily commuting for the urban scale, and capital circulation and uneven development for the global. Insofar as Smith considered how each scale is determined by interactions with the others, he pointed beyond scale as level towards scale as relation.

Human geographers have proceeded to explore the production and politics of scale further, particularly in regard to the city, the nation-state, and the global economy. Scale as level provides the framework for these studies, insofar as the nation-state is construed as 'above' the city and 'below' the global in a socio-spatial, hierarchical order. But the point usually is to understand the historical-geographical constitution and reconfiguration of levels in relation to one another – such that scale is construed, at least implicitly, as relational. Erik Swyngedouw (1997) introduced the term 'glocalisation', for example, to capture the combination of upward and downward shifts in the scale of accumulation and regulation with the advent of globalisation. Neil Brenner (1998, p. 464) argued that 'scales are not merely the platforms within which spatial fixes are secured, but one of their most fundamental geographical dimensions, actively and directly implicated in the historical constitution, reconfiguration, and transformation of each successive configuration of capitalist territorial organization'. Viewed as a process of *rescaling*, globalisation 'entails less an obliteration of the national spatial scale than its rearticulation with the subnational and supranational spatial configurations on which it is superimposed' (Brenner, 1997, p. 299).

In different ways, both Swyngedouw and Brenner shift attention away from scale *per se* and towards the processes that produce (patterns that have) scales. Like Smith, they are concerned with operational scale. Swyngedouw (1997, p. 141) is explicit: 'The theoretical and political priority . . . never resides in a particular geographical scale, but rather in the process through which particular scales become (re)constituted In short, scale . . . is not and can never be the starting point for sociospatial theory . . . the kernel of the problem is theorising and understanding "process"'. Swyngedouw's (2004; 2007) empirical research reflects this approach and is widely credited for bringing ecological processes (such as hydrologic cycling) into cogent relation with political-economic processes such as capital accumulation and governance. Brenner (1998, p. 466) emphasises 'the relational, mutually interdependent character of geographical scales under capitalism', and he develops a thesis that clearly transcends scale as size or level:



the forms of territorialization for capital are always *scaled* within historically specific, multitiered territorial-organizational arrangements. The resultant scale-configurations, or ‘scalar fixes,’ simultaneously *circumscribe* the social relations of capitalism within determinate, if intensely contested, geographical boundaries and *hierarchize* them within relatively structured, if highly uneven and asymmetrical, patterns of sociospatial interdependence (Brenner, 1998, p 464, emphases in original).

Terms such as ‘scaling’, ‘rescaling’, ‘scale effects’ and ‘jumping scales’ all draw attention not only to the ongoing production of scale (and therefore its historical contingency and malleability) but also to the non-linear, complex outcomes that are hallmarks of scale-as-relation.

Research along these lines has more recently opened into vociferous debates about the conceptual status of scale throughout human geography. In an oft-cited article, Marston (2000) reviewed the literature and argued persuasively that geographical scale is socially constructed. Bodies, neighborhoods, cities and so forth are not given *a priori* but produced through social processes; geographers have gone astray, she argued, by taking their scales for granted and by privileging certain scales – such as the nation-state or the global economy – over others such as the household. Marston’s article provoked a response by Brenner (2001), followed by several further contributions (Marston and Smith, 2001; Purcell, 2003; Sayre, 2005). Subsequently, Marston et al. (2005) changed course and expanded the controversy by making a case ‘to expurgate scale from the geographic vocabulary’ altogether; a flurry of responses ensued, almost all of them critical of this position (e.g., Collinge, 2006; Jonas, 2006; Leitner and Miller, 2007). There is neither need nor space to review these exchanges in detail here. Two points suffice to defuse much of the controversy.

First, the debate has suffered from a confounding of scale’s epistemological and ontological moments. The critique of conventional geographical scales stemmed initially from epistemological considerations: Taking the local, the national and the global as *a priori* givens may obscure the interactions among various scales; a crude hierarchy theory risks overlooking actors and processes at ‘smaller’ or ‘lower’ scales by privileging ‘larger’ or ‘bigger’ ones. These are important points, but in choosing a scale for observation one is not necessarily making any ontological commitments or claims. Most of the substantive issues raised in the debate, however, concern the ways that the operational scales of governance, reproduction, regulation and accumulation have shifted in recent decades and how people contest and transform the scales of actual processes in the world. This is not to say that the two moments are separate or unrelated – on the contrary, their dialectical relation is of the utmost importance. But confounding the two moments collapses the dialectic (Sayre, 2005).

Second, the acrimony and confusion reflects a persistent failure to distinguish between scale as size, level and relation. Almost all contributors employ scale both in its second sense (where scale and level are interchangeable) and in its third sense (where they are not) without recognising the problems this entails. Marston et al. (2005, p. 420) argue that scale may ‘be simply and effectively collapsed into’ level; they proceed to use the terms interchangeably or together, as in the phrase ‘levels of scale’ (p. 422). But they do not even acknowledge the existence of scale as relation (despite citing Howitt’s papers on the subject), and collapsing scale into level compels them to make hierarchy into an inherent attribute of scale. Since their real animus is hierarchy, they indict scale *tout court*. It is true that Brenner, among

others, understands scale as inherently hierarchical, but this reflects his own failure to distinguish scale as level from scale as relation. The former does entail hierarchy (or some such principle of ordering); the latter does not. Furthermore, there is nothing inherently hierarchical (or 'vertical') about emergent properties, complex interactions, or thresholds of nonlinear change. Other frameworks that have been proposed in recent years, such as networks (Leitner, 2004; Taylor, 2004) and heterarchy (Crumley, 2005), confirm that one can critique hierarchy theory yet retain a strong emphasis on scale. Leitner (2004, p. 246) notes that 'networks are themselves scaled', and that '[n]etwork scales are emergent properties of sociospatial processes operating inside and beyond networks'. It is precisely by rescaling processes that networks have the potential to bypass or subvert conventional hierarchies of power.

Conclusion: Towards an Integrated Conceptual Framework

A remarkable and apparently unwitting convergence has occurred in ecological and geographical conceptions of scale in the past two or three decades. From very different starting points, drawing on ideas and insights from across the social and natural sciences, scholars in both fields have moved from scale as size and level to scale as relation. The common interests and ideas include emergent properties, hierarchies and networks, non-equilibrium, thresholds of change, spatio-temporality, path dependence and self-organisation. The challenges and opportunities for integrative work and collaboration are growing in number and importance.

How to integrate ecological and geographical scale for purposes of environmental geography? The following six principles can be derived from the preceding analysis of geographical and ecological scale:

1. Scale is *relational*. Its scientific value lies not in absolute or discrete measurements of a phenomenon in terms of size, duration, or magnitude, but rather in exploring relations among phenomena so measured.
2. The focus of theorising about scale must therefore fall on *processes* rather than on scale *per se*, because it is through processes that relations among phenomena are manifest.
3. Processes are simultaneously spatial and temporal; while many uses of scale are implicitly spatial, the concept as developed here is intrinsically spatio-temporal.
4. There is no single 'correct' scale for studying or understanding societies, ecosystems, or their interactions; any given process may, however, have an appropriate or best scale for research.
5. Scales are *produced*, whether by human-social, geophysical or biological processes. They have an ontological moment, insofar as they are integral to the constitution of material processes; they have an epistemological moment, insofar as one's scale of observation determines the patterns (or lack thereof) that one observes. The two moments are dialectically related.
6. A major topic for further research and theorising on scale concerns *thresholds* of non-linear or qualitative change across scales (for any given process) and between processes of different scales. It is at these points that *scaling effects*, *mismatches of scale* or *rescaling* are manifest, and where critical issues of social-ecological change and sustainability may be engaged most fruitfully.

It remains to be seen whether and how collaboration and integration can be achieved, both practically and theoretically. There are growing numbers of interdisciplinary research projects and funding opportunities aimed at the social-ecological interface, such as the National Science Foundation's Coupled Natural and Human Systems programme, in which scale figures prominently. Vogt et al. (2002, p. 168) point out a more theoretical challenge:

To assist in the integration of social and natural sciences for natural resource management, researchers will need to explicitly recognize and address issues of scale differently from their traditional, disciplinary approaches. Instead of emphasizing the need for scale-dependent information that may be associated with their respective disciplines, it may be more important to determine what is the most appropriate scale(s) to address various natural resource issues. Integrating the social and natural sciences will require improving our understanding of how space is currently perceived by each discipline.

Beyond this, of course, lie still deeper philosophical questions. Bruce Rhoads (2006, p. 14) has argued convincingly that geomorphology should embrace a process-philosophical metaphysics, in which 'the nature of reality, including geomorphological phenomena, is fundamentally processual'. This is also where Erik Swyngedouw (1997, p. 140) starts: 'I insist that social life is process-based, that is, in a state of perpetual change, transformation, and reconfiguration'. Obviously, the geomorphological and the social processes in question are likely to unfold on temporal scales that differ by several orders of magnitude – such is the challenge and the potential of the problem of scale. It will also require, as Church (1996, p. 166f.) has argued, a general recognition that 'the scales of enquiry determine the most appropriate mode of explanation', and that some process-scale combinations may not yield to mechanistic, quantitative, or predictive methods.

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