ECOLOGICAL ECONOMICS

Ecological Economics 32 (2000) 217–239

www.elsevier.com/locate/ecolecon

ANALYSIS

The concept of scale and the human dimensions of global change: a survey

Clark C. Gibson [a,*], Elinor Ostrom [b], T.K. Ahn [b]

[a] *Department of Political Science, Center for the Study of Institutions, Population, and Environmental Change, Indiana University, Woodburn Hall 210, Bloomington, IN 47405, USA*

[b] *Workshop in Political Theory and Policy Analysis, Department of Political Science, Center for the Study of Institutions, Population, and Environmental Change, Indiana University, 513 North Park, Bloomington, IN 47405-3895, USA*

Received 9 February 1999; received in revised form 12 July 1999; accepted 14 July 1999

Abstract

Issues related to the scale of ecological phenomena are of fundamental importance to their study. The causes and consequences of environmental change can, of course, be measured at different levels and along multiple scales. While the natural sciences have long understood the importance of scale, research regarding scale in the social sciences has been less explicit, less precise, and more variable. The growing need for interdisciplinary work across the natural/social science divide, however, demands that each achieve some common understandings about scaling issues. This survey seeks to facilitate the dialogue between natural and social scientists by reviewing some of the more important aspects of the concept of scale employed in the social sciences, especially as they relate to the human dimensions of global environmental change. The survey presents the fundamentals of scale, examines four general scaling issues typical of social science, and explores how different social science disciplines have used scale in their research. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Environmental change; Human dimensions; Level; Scale; Social science

Countless human activities — from the cutting of firewood in rural Uganda to the production of hydrocarbons by oil refineries in southern California — have causes and consequences measured at different levels along multiple scales. The multilevel/multiscale nature of the problems related to the human dimensions of global change demands that researchers address key issues of scales and levels in their analyses. While natural scientists have long understood the importance of scale, and have operated within relatively well-defined hierarchical systems of analysis, social scientists have worked with scales of less precision and of greater variety.[1] With the growing realization that

* Corresponding author. Fax: + 1-812-8552027.

[1] Although ecologists understand the importance of scale in their research, Norton (1998) argues that they misunderstand the importance of scale when trying to affect the policy process.

PII: S0921-8009(99)00092-0

Table 1
Definitions of key terms related to the concept of scales[a]

Term	Definition
Scale	The spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon.
Extent	The size of the spatial, temporal, quantitative, or analytical dimensions of a scale.
Resolution (grain)	The precision used in measurement.
Hierarchy	A conceptually or causally linked system of grouping objects or processes along an analytical scale.
Inclusive hierarchy	Groups of objects or processes that are ranked as lower in a hierarchy are contained in or subdivisions of groups that are ranked as higher in the system (e.g. modern taxonomic classifications — kingdom, phylum, subphylum, class, family, genus, species).
Exclusive hierarchy	Groups of objects or processes that are ranked as lower in a hierarchy are not contained in or subdivisions of groups that are ranked as higher in the system (e.g. military ranking systems — general, captain, lieutenant, sergeant, corporal, private).
Constitutive hierarchy	Groups of objects or processes are combined into new units that are then combined into still new units with their own functions and emergent properties.
Levels	The units of analysis that are located at the same position on a scale. Many conceptual scales contain levels that are ordered hierarchically, but not all levels are linked to one another in a hierarchical system.
Absolute scale	The distance, time, or quantity measured on an objectively calibrated measurement device.
Relative scale	A transformation of an absolute scale to one that describes the functional relationship of one object or process to another (e.g., the relative distance between two locations based on the time required by an organism to move between them).

[a] Sources: Turner et al., 1989a, p. 246; Mayr, 1982, p. 65; Allen and Hoekstra (1992).

the insights of social science are crucial to understanding the relationships between people and the natural environment, it is necessary for social scientists to identify more clearly the effects of diverse levels on multiple scales in their own analyses, to comprehend how other social scientists employ diverse kinds of levels and scales, and to begin a dialogue with natural scientists about how different conceptions of scales and levels are related.

We seek to facilitate this dialogue among researchers by surveying the concepts of scale used in the social sciences, especially as they relate to the human dimensions of global environmental change. In Section 1, we begin by discussing some of the fundamental concepts that relate to scale. We start with definitions and explore concepts such as level, resolution, hierarchy, and emergence. In Section 2 we argue that scale is important to the social sciences in four fundamental areas: (1) identification of patterns and problems; (2) explanation of observed patterns; (3) generalization of propositions made at one level of a scale and applied to another level of the same scale; and (4) optimization of some process or function. In Section 3 we offer brief reviews of some specific social science disciplinary contributions to scale (from geography, ecological economics, urban studies, sociology, and political science). We begin this section, however, by discussing scaling issues in ecology because this field has a long history of dealing explicitly with scaling issues. Finally, in the last section we offer some concluding remarks about scale.

1. The fundamentals of scale

It is clear that terms such as level and scale are frequently used interchangeably and that many of the key concepts related to scale are used differently across disciplines and scholars. Thus, we present in Table 1 definitions of key terms that we have come to use after reading the literature cited in our bibliography and struggling with the confusion created by different uses of the same word.

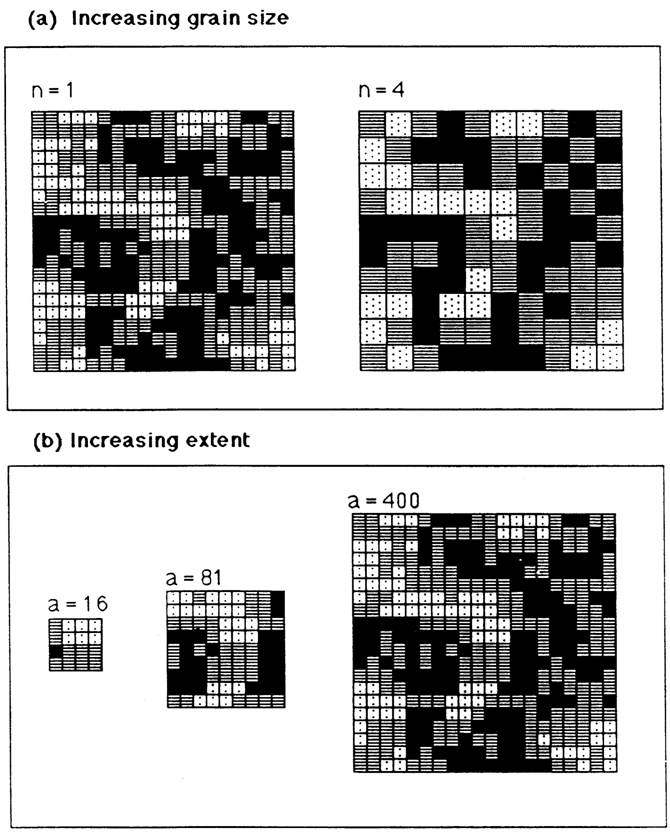

Fig. 1. Schematic illustration of (a) increasing grain size and (b) increasing extent in a landscape data set. The number of cells aggregated to form a new data unit are indicated by n; total area is indicated by a; see Methods for complete explanation. Source: Turner et al. (1989b): 154).

1.1. Definitions of key terms

We use the term scale to refer to the spatial, temporal, quantitative, or analytical dimensions used by scientists to measure and study objects and processes (see Table 1). Levels, on the other hand, refer to locations along a scale. Most frequently, a level refers to a region along a measurement dimension. Micro, meso, and macro levels refer broadly to regions on spatial scales referring to small-, medium-, and large-sized phenomena. Levels related to time, for example, could involve short, medium, and long durations. Scaling problems can be related to issues of scale and/or level.

All scales also have extent and resolution, although these may not be explicitly noted in a particular study. Extent refers to the magnitude of a dimension used in measuring a phenomenon. In regard to time, extent may involve a day, a week, a year, a decade, a century, a millennium, or many millennia. In regard to space, extent may range from a meter to millions of square meters or more. In regard to quantity, the number of individuals considered by the observer to be involved in a social relationship may vary from two to billions, as may the quantity of goods and the other entities of interest to social scientists. The extent of a measurement fixes the outer boundary of the measured phenomenon (see Fig. 1). Resolution refers to the precision used in measurement; often grain is used in the same way. In regard to time, social scientists rarely use a resolution of less than an hour to divide the time of an observation, but may do so when timing individuals or groups performing particular tasks. In regard to space, social scientists use a variety of resolutions ranging from a meter or less (anthropological studies of household activities) to coarser measurements running to the thousands of kilometers (studies of the impact of international treaties). The resolution used to observe quantity depends on the extent involved, e.g. when an analysis involves a larger quantity, measurements normally use a larger aggregation of individual units than when a smaller quantity is studied. In this paper, we will consistently use the term ‘small scale’ to refer to phenomena that are small in regard to scales of space, time, or quantity. Thus, ‘large scale’ refers to big items, quantities, or space. This conforms well to the everyday usage of this term (but is exactly the opposite of the way the term is used by cartographers).[2]

Many scales are closely related to the concept of hierarchy. A hierarchy is a conceptually or causally linked system for grouping phenomena along an analytical scale. For political scientists, the concept of hierarchy is frequently limited to a system of personnel ranking that defines the authority of individuals dependent upon their formal position within a hierarchy. Generals command captains who command lieutenants and so on, down to the privates who can be commanded by anyone of higher rank. This is an example of an exclusive hierarchy, whereby the objects at the higher level do not contain the objects at a lower level, i.e. they are not nested. There are many other examples of exclusive hierarchy where the concept of command and control is absent. One example — shown in Fig. 2 — is that of the organisms ranked in the food chain whereby the top carnivores eat carnivores who eat grazers who eat plants (Allen and Hoekstra, 1992, p. 33).

In contrast, there are two types of nested hierarchies: inclusive and constitutive. Inclusive hierarchies involve orderings whereby phenomena grouped together at any one level are contained in the category used to describe higher levels, but having no particular organization at each level.[3] Major analytical classification systems are usually inclusive hierarchies. One of the best-known examples is the Linnaen hierarchy of taxonomic categories. Most inclusive hierarchies are classificatory rather than explanatory devices: the units at a lower level (e.g. the species of a genus) do not interact configurally to produce emergent properties of a new higher-level unit.

The second type of nested hierarchy — most characteristic of complex systems — is a constitutive hierarchy. In this type of hierarchy, the lower

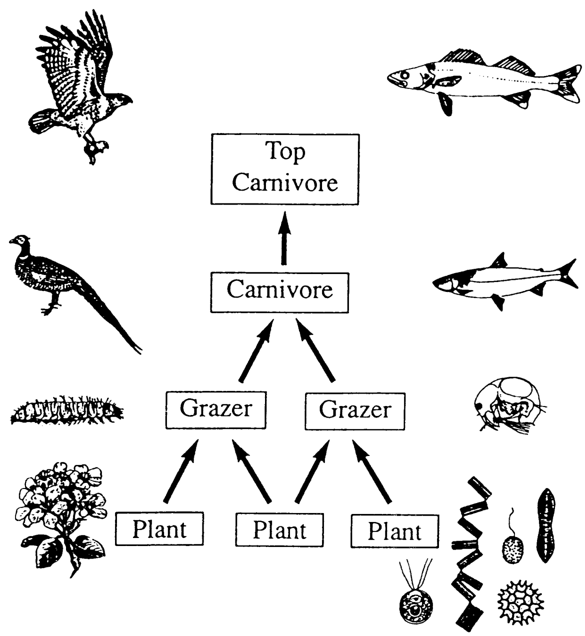

Fig. 2. The food chain as an example of an exclusive hierarchy. Source: Allen and Hoekstra (1992): 33.

[2] For someone reading maps, large entities, such as a continent or the globe, must be measured with a very coarse resolution in order to cover the great extent. One unit on the map corresponds to a very large terrain. The grain is referred to by cartographers as small scale because of the relationship of this small cartographic representation for an immense region. As the map maker focuses on domains of ever smaller extent, the ‘scale’ of what is represented by a unit on the map grows larger. Thus, a cartographer will refer to a very small region as one characterized by a large-scale map. We hope that those trained in cartography who read this article will understand our use of the term in a different manner than their use.

[3] Inclusive hierarchies are also referred to as aggregational hierarchies (Mayr, 1982, p. 64).

level can combine into new units that have new organizations, functions, and emergent properties (Mayr, 1982, p. 65). All living organisms and most complex, nonliving, systems are linked in constitutive hierarchies, e.g. molecules are contained in cells that are contained in tissues that are contained in organisms that are contained in populations.[4] These levels are on a conceptual scale based on functional relationships rather than on a spatial or temporal scale.

The concept of emergence is important when trying to understand constitutive hierarchies. In complex, constitutive hierarchies, characteristics of larger units are not simple combinations of attributes of smaller units, but can show new, collective behaviors.[5] According to Baas and Emmeche, 1997, p. 3), some important examples of emergent properties include the general situation of a client and a server (with the interactive help from the server, the client may perform tasks that none of them could do separately); and consciousness (not a property of individual neurons, it is a natural emergent property of the interactions of the neurons in the nervous system) (Baas and Emmeche, 1997, p. 3; see also Baas, 1996).

Many phenomena associated with global change are linked together in constitutive hierarchies. Individual humans are contained in families that are contained in neighborhoods, which are contained in villages or cities, which are contained in regions, which are contained in nations, which are contained in international organizations. In such systems, there is no single 'correct' level to study. Phenomena occurring at any one level are affected by mechanisms occurring at the same level, and by levels below and above. Thus, research on global change processes should examine the world from a multilevel perspective.

We use these definitions of scale, levels, hierarchy, and emergence throughout the remainder of this article.

2. Issues related to scale

The most important issues related to scale can be grouped into four theoretical areas, each of which is fundamental to the task of explanation in all sciences: (1) how scale, extent, and resolution affect the identification of patterns; (2) how diverse levels on a scale affect the explanation of social phenomena; (3) how theoretical propositions derived about phenomena at one level on a spatial, temporal, or quantitative scale may be generalized to another level (smaller or larger, higher or lower); and (4) how processes can be optimized at particular points or regions on a scale.

2.1. Scale and identification

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. These choices over scale, extent, and resolution critically affect the type of patterns that will be observed, because patterns that appear at one level of resolution or extent may be lost at lower or higher levels.

Overt choices of particular scales to identify specific patterns are generally taken more consciously in the natural sciences than in the social sciences. Natural scientists are accustomed to working with hierarchical systems with levels that are explicitly named within a discipline. Scientists share a common understanding of these levels and agree upon their usefulness. Thus, the choice to work in subatomic physics or cellular biology restricts the extent and resolution of patterns to be studied. Social phenomena, on the other hand,

[4] 'At each level there are different problems, different questions to be asked, and different theories to be formulated. Each of these levels has given rise to a separate branch of biology; molecules to molecular biology, cells to cytology, tissues to histology, and so forth, up to biogeography and the study of ecosystems' (Mayr, 1982, p. 65).

[5] Morgan (1894) was among the early scholars to point out that 'at various grades of organization, material configurations display new and unexpected phenomena and that these include the most striking features of adaptive machinery' (cited in Mayr, 1982, p. 63).

may or may not include clear hierarchical systems. The existence of particular social science disciplines or subdisciplines may help researchers somewhat to restrict their inquiry for patterns and their causes (e.g. psychologists generally study individuals, anthropologists small communities, etc.). However, economists, geographers, historians, political scientists, and sociologists analyze households, neighborhoods, cities, landscapes, regions, countries, international relations, and global patterns depending on the subdiscipline of their work or their particular substantive interest. The domain of disciplines and subdisciplines and their constituent parts affects a social scientist's unconscious choice of scale, but does not determine it completely.

Less consensus exists among social scientists about the appropriate extent and resolution of the scales they use, as we will see in Section 3. Social science is driven generally by the search to explain social problems or issues. Because these phenomena include causes and consequences that range over scales, levels, extent, and resolutions, their explanation may need to range more broadly.

2.2. Scale and the explanation of causal processes

Scale and level help to identify patterns, but they do not explain them. Making causal statements about particular patterns, however, explicitly or implicitly invoke a scale and level. The crucial issue linking scale and level to explanation is whether the variables used to explain a pattern are themselves located at the same level as the pattern or at different levels. Downward causation refers to a key variable or variables being used in an explanation that occurs at a higher level than the pattern or dependent variable(s) being explained. Upward causation refers to the variable or variables used in an explanation that occurs at a lower levels than that of the dependent variable(s) (see Campbell, 1974).[6]

2.3. Scale and generalizability

In addition to the explanations derived for phenomena at any one level, scale is central to attempts to generalize from one level or scale to another, i.e. to use theoretical propositions discovered about entities interacting at one level to explain relationships operating at a different level. Scaling up applies findings from lower levels to higher levels (Young and Underdal, 1996). Scaling up in space, for example, is a matter of applying findings derived from the analysis of small scale or microlevel systems to mesoscale or even macroscale systems.

Theory plays a key role in attempts to generalize across levels or scales. After observing processes occurring in one or more settings, scientists develop theories and models to explain why observed patterns occur. Theories may originally develop to explain phenomena that occur primarily among small (large) groups, or in a small (large) spatial extent, or within a short (long) time frame. Many theories overtly make the number of actors, space, or time a key theoretical variable within the theory rather than a limiting factor affecting the applicability of the theory. Once the theory has been well developed and used to explain phenomena at one or another level of a scale, it may then be applied to phenomena at dramatically different levels. Scientists may discover that additional variables are needed in an explanation based on a general theory in order to apply that theory to similar processes at a different level. They may also discover that the key explanatory variables change substantially as one attempts to explain phenomena at a substantially smaller or larger level.

[6] When researchers employ variables occurring at a different level to explain phenomenon at a particular level, they must avoid several well-known explanatory fallacies. Individualistic fallacies may occur when a researcher imputes the cause of higher-level (or macro) patterns to be the same as that causing lower-level (or micro) patterns. Ecological fallacies are those that impute the cause of lower-level (or micro) patterns to be the same as those operating at a higher (or macro) level. Such fallacies can reflect a lack of theoretical awareness and/or a lack of data available at the appropriate levels. Inappropriate explanations can also occur using variables at the same level; cross-level fallacies may occur when results from one subpopulation at a certain level are applied to another subpopulation at the same level without ascertaining that the same initial conditions and processes exist in multiple settings.

2.4. Scale and optimization

Choices over scale and level are explicit in all studies that explore questions regarding optimization because, by definition, optimization concerns processes of known extent. Optimization questions are used extensively in economics, in urban studies, in studies of federalism, and in ecology.

Work in the economics of production seeks to determine the optimal level for a production unit. Level in this case refers to the quantity of outputs produced in a facility, i.e. 'flow-through.' The optimal level of production is where the marginal cost of the nth unit of a product is equal to the marginal return achieved from that unit. Scholars and policy makers ask similar optimization questions regarding phenomena related to the public sector, e.g. What is the optimal size for a city? What is the optimal distribution of cities within a region? What is the optimal size of a provision unit for a public good? In many of these questions, the scale used is either the spatial extent of a political unit or the number of factors involved. While economists tend to focus on minimizing long-term production costs, urban scholars tend to focus both on the costs of producing urban services as well as the distance involved between various types of activities that are considered essential aspects of urban life.

Optimization processes lie at the core of evolutionary biology. Evolutionary theory predicts that processes of mutation and natural selection optimize the fitness of individual organisms to particular niches.[7] Ecologists work at a different level, and tend to think of optimization in terms of carrying capacity, i.e. given a particular ecological niche, the optimal number and type of species that could make use of that niche. Ecologists employ another type of optimization when using maximum sustainable yield (MSY), i.e. the maximum number of organisms that can be harvested without threatening a given level of stock.[8]

[7] Fitness is defined as the number of offspring that an animal can produce that themselves mature to reproduce.

[8] MSY has been a major contribution of earlier ecologists. It is currently being challenged by practitioners and scholars on grounds that relate to the lack of information we have regarding population dynamics.

Despite the shared technique of optimization, disciplines employ different objective functions in their optimization problems. Economists judge optimality using cost efficiency as their criteria. Urbanists are concerned with efficiency and productivity, but often include normative criteria such as equity. Political scientists are concerned about mixtures of governmental units to achieve both high levels of equity and efficiency. Ecologists' objective functions tend to be concerned with issues of species and system sustainability.

3. Scale in ecology and the social sciences

Although this paper focuses on the social sciences, we begin with an exploration of scaling concepts in ecology because: (1) ecologists have confronted scaling issues directly in their work; (2) ecology as a discipline focuses on complex, multiscale systems; (3) ecology is a discipline central to the study of human dimensions of global change; and (4) social scientists are increasingly drawing upon ecological ways of thinking.

3.1. Scale issues in ecology and landscape ecology

While the topics that interest ecologists are diverse — ranging from population dynamics and coevolution to environmental change — scale issues are at the core of this discipline (Levin, 1992). Scale became increasingly important to ecologists with the growth of landscape ecology, which seeks to investigate the relationship between ecological processes and spatial patterns, the interactions found between adjacent spatial units, and the causes and effects of spatial heterogeneity (Pickett and Cadenasso, 1995). Regardless of the specific foci of ecologists, the concept of scale remains fundamental to their enterprise because ecologists typically try to understand the dynamics at one level of an ecological system as an aggregation of interactions among lower-level units.[9]

[9] Reductionism is typical of most of ecology, but some ecologists such as Eugene Odum and C. S. Holling argue that holistic phenomena can be just as fundamental. See also Bormann and Likens (1979).

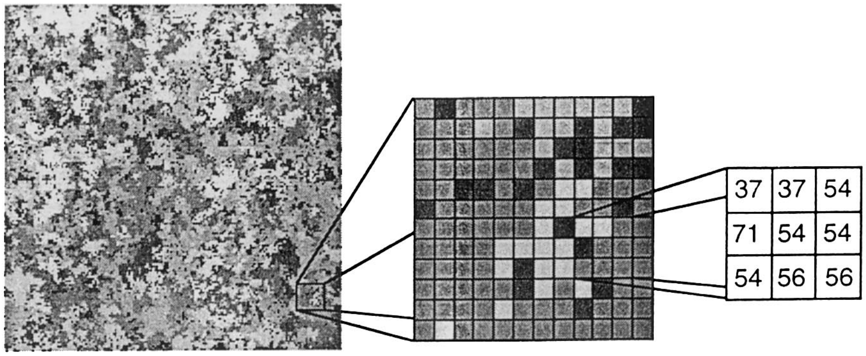

Fig. 3. A sample output of a forest landscape model composed of a matrix of sites. Fire organizes and maintains the landscape as a mosaic of patches composed of even-aged sites. The sites making up the landscape are each shaded by age. Young sites are lightly shaded while old sites are black. At the right of the figure the ages, in years, of a set of sites are shown. Source: Holling et al. (1996): 355).

Ecologists are well aware that the identification of patterns depends on the spatial scale at which they are measured. A pattern detected as relatively homogenous on a scale with coarse resolution might disappear when a finer resolution is applied or vice versa. Ecologists are also deeply aware that extent and grain affect the nature of the patterns observed and the type of information that can be conveyed (see Fig. 3).

In their exploration of scale issues, ecologists have come to question the traditionally defined levels of cell, organism, population, community, ecosystem, landscape, biome, and biosphere that have been the major organizing concepts in biology. In this scheme, higher levels on a conceptual scale also tend to be larger on a spatial scale. A larger size, however, does not always correspond to a higher level on a conceptual scale.[10]

Some ecologists have recently tried to define levels based strictly on absolute temporal and spatial scales instead, arguing that conventional levels are just ways of 'telling foreground from background, or the object from its context' (Allen and Hoekstra, 1990, p. 5). As part of this effort, ecologists have noted that nature does not seem to operate in a seamless web, which would require a full understanding of processes at all levels in order to explain and predict the outcomes of natural processes. Many processes produce clusters of entities, generated by a small set of self-organizing processes, as found in marine (Steele, 1978), freshwater (Carpenter and Kitchell, 1987), and terrestrial ecosystems (Solomon et al., 1980). Thus, one way to explain natural processes is to use the natural scales and frequencies that may emerge (Wessman, 1992; Levin et al., 1997).

Hierarchy theory, a framework that attempts to confront directly the problems of scaling, builds on this idea of natural scales (see Simon, 1962; Allen and Starr, 1982). The starting point for hierarchy

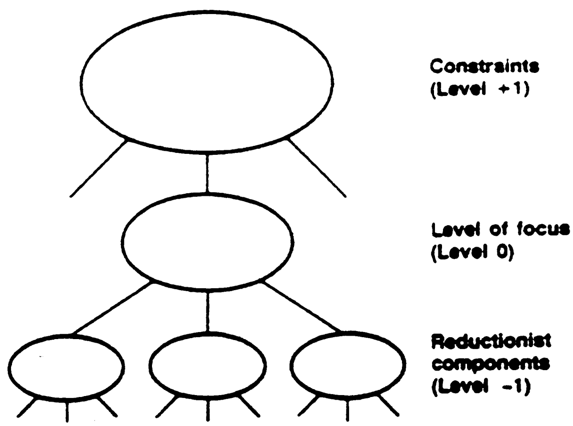

Fig. 4. Schematic of hierarchy theory constraints. This approach may be applied to any level of scale. (Adapted from Dyer and Vinogrodov, 1990: 20). Source: Fox (1992): 291).

[10] A simple example is that of an ant colony found in a tree. In this case, a single organism (the tree) is larger than a community containing many organisms (the ant colony). Thus, ecological concepts like organism and community tend to be functional units that are ordered on a conceptual scale that are not necessarily correlated with a spatial scale.

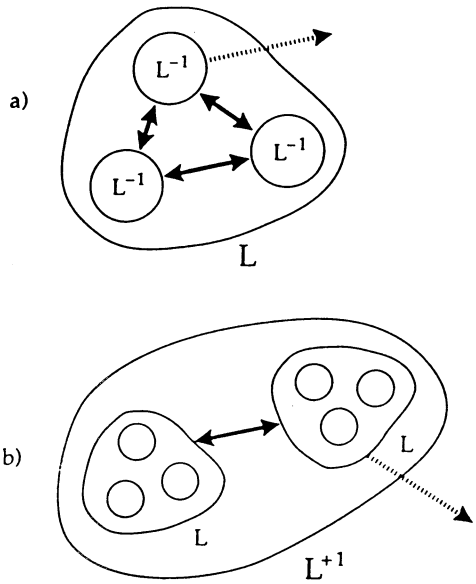

Fig. 5. L is the level in question; L − 1 is the next level down; L + 1 is the level above. The weak connections of L − 1 to the outside world beyond L become the strong connections within level L + 1. Source: Allen and Hoekstra (1992): 30).

theory is to dissect any complex system of processes as a series of hierarchical entities as shown in Figs. 4 and 5. The system of interest is considered for the purposes of analysis to be level 0, which is a component of some higher level (level + 1) and has component systems at a lower level (level − 1).

The central idea of hierarchy theory is that to understand any complex system depends on understanding the constraints at higher and lower levels of spatial-temporal resolution. The levels immediately above and below the referent level provide environmental constraints and produce a constraint 'envelope' in which the process or phenomenon must remain (O'Neill et al., 1989; Norton and Ulanowicz, 1992, p. 244).

While conceptually appealing, hierarchy theory quickly runs into problems related to scale. To characterize a constraint envelope accurately, the analyst must: (1) clearly identify the scale and level of the study and their appropriateness for the phenomenon; (2) know the important variables impacting on the phenomenon at different scales and levels; (3) know when one is translating levels or scales and to recognize issues involved in top-down or bottom-up thinking; and (4) sample and experiment across scales and levels (Turner et al., 1989a; O'Neill et al., 1991; Wessman, 1992). Further, the causes and effects of any phenomenon may occur on levels above or below the one analyzed (Lambin, 1994); some processes may be isolated at one level, while others may not be (Wessman, 1992); the intensity of response to perturbations may vary at smaller levels (Stohlgren, 1995); the process under study may not be linear in time or space (Turner and Meyer, 1991; Wessman, 1992; Stohlgren, 1995); the complex web of interrelations and feedbacks often contains lags and/or discontinuities; and living systems are generally far from any stable equilibrium state (Folke et al., 1996). Since these natural processes are normally complex, nonlinear, and discontinuous systems, arriving at top-down or bottom-up generalizations is far from trivial (O'Neill and Rust, 1979; Rastetter et al., 1992).[11]

The work of C. S. Holling and his colleagues (Holling, 1973, 1986; Holling et al., 1996) on resilience also addresses several key issues related to scale. In dynamic systems, an engineering concept of resilience that is used in both ecology and economics is the speed with which a system returns to a stable equilibrium or a steady state upon being disturbed (Pimm, 1984; Varian, 1992). A second concept — called 'ecological resilience' — is the 'magnitude of the disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behavior' (Gunderson et al., 1997, p. 3). Scholars who are primarily interested in engineering resilience will ask scientific questions about the behavior of a system when it is near to its stable state. Those interested in ecological resilience examine the possibility of multiple stable states and how systems transform from one to another.[12]

[11] Sonnenschein (1973) and Debreu (1974) have shown that, unless one makes very strong and unrealistic assumptions about individual units, the aggregate relations between variables may have no resemblance to the corresponding relations on a smaller level.

[12] Resilience is frequently affected by a small set of 'keystone processes' that produce a discontinuous distribution of structures in ecosystems, yet allow for immense diversity of plant and animal organisms. 'While animals that function at the same scale are separated by functional specialization (e.g. insectivores, herbivores, arboreal frugivores, etc.), animals that function at different scales can utilize similar resources (e.g. shrews and anteaters are both insectivores but utilize insects at different scales)' (Gunderson et al., 1997, p. 7).

Ecological scientists have engaged ecological problems at enormous levels (e.g. greenhouse gases, regional and global biodiversity) and broad ranges over the past two decades (Allen and Starr, 1982; Addicott et al., 1987; Meentemeyer and Box, 1987), and the need to consider the issues regarding scales and scaling in ecological analyses is increasingly important (see, for example, Steele, 1978; Risser and Mankin, 1986; Steele, 1989; Powell and Steele, 1995). Consequently, ecologists continue their active search for guiding principles that would allow them to combine data and models at different spatial and temporal scales, and to extrapolate information between scales and levels (Turner et al., 1989a; Costanza et al., 1997). Despite the goal of finding interscale models, many scientists working in areas such as physiological ecology (Jarvis and McNaughton, 1986), population interactions (Addicott et al., 1987), soil processes (Sollins et al., 1983), vegetation analysis (Getis and Franklin, 1987), aquatic ecology (Steele, 1985), paleoecology (Solomon et al., 1980), and landscape ecology (Meentemeyer and Box, 1987) realize that their predictions are scale and level dependent and that a single mechanism rarely explains patterns found at different levels (Turner et al., 1989a; Menge and Olson, 1990; Wessman, 1992; Gueron and Levin, 1995).

3.2. Scale issues in geography

One of the major foci of geographers is to describe and to explain spatial patterns. Depending on what in a space matters to particular researchers, geography is divided into subdisciplines that parallel most of the major disciplines across natural and social sciences, e.g. physical geography includes geomorphology, biogeography, and climatology; human geography includes economic, political, and urban geography. But what gives geographers their disciplinary identity is their explicit consideration for spatial relationships. Spatial scales are thus critically important in this discipline, and span in their extent from 'a single point to the entire globe' (Meentemeyer, 1989, p. 163). As geographers have addressed more questions related to global change, they have also been increasingly aware of linkage between spatial and temporal scales (see Fig. 6).

The choice of extent and resolution that conveys relevant information most efficiently has always been the central problem of topography. Discussions of the problem of scale in a more methodological and abstract fashion did not start in physical and human geography until mid-century, when geomorphologists began to address the problem. Now, scale issues are found at the center of methodological discussions in both physical and human geography. Regional scales were used prominently during the first half of the twentieth century until new research technologies, combined with a need for a more scientific mode of explanation, led to more microlevel studies. Until recently, most geographic studies gathered data at the microlevel that could ultimately contribute to larger geographic goals. However, given an increasing interest in global phenomena, geographic studies are shifting more to the direction of meso- and macroscale studies (Meyer et al., 1992).

Like ecologists, geographers have found that the consideration of scale problems is fundamental to the identification of patterns and their explanation. In spite of the ongoing debate on the appropriate scale on which geographic processes should be analyzed, a widespread agreement exists that explanatory variables for a given phenomenon change as the scale of analysis changes. As illustrated with Fig. 7, even the direction faced by a location changes as the extent of the measurement changes.[13]

[13] Human migration is a phenomena that may occur at different spatial scales: within an urban area, within a region, within a nation, or across national boundaries. The patterns of intraurban migration are related to individual-level variables such as age, education, and individual family income. Intrastate migration, on the other hand, is explained mainly by aggregate variables such as 'labor demand, investment, business climate, and income' (Meentemeyer, 1989, p. 165). If the spatial scale or level is fixed, variables may also change according to a temporal scale. For example, different variables related to patterns of precipitation in and around mountains vary over temporal levels of hours, days, and years (ibid.: 166).

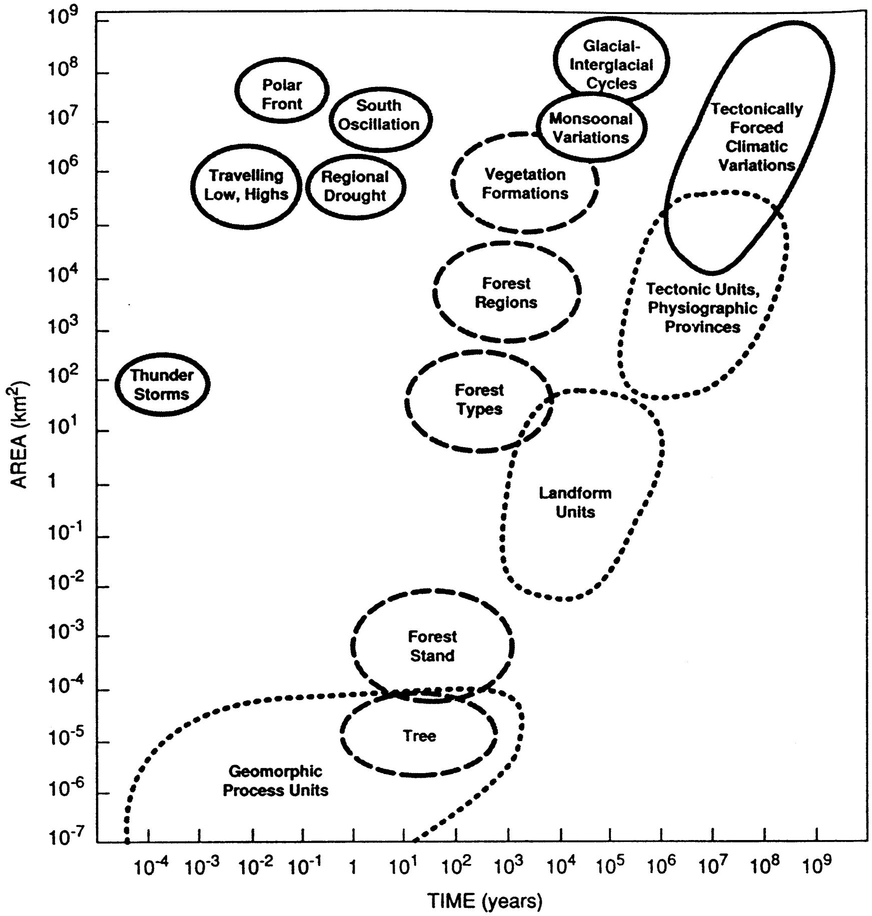

Fig. 6. Some important features of the atmosphere, biosphere, and lithosphere shown in space-time. Based on McDowell, Webb, and Bartlein 1990: 144, 151, 155. Climatic units are shown by solid outlines, ecological units by dashed outlines, and geomorphic units by dotted lines. Ecological terms are functional rather than spatial in concept (Allen and Hoekstra, 1990), but because only one ecological system (forest vegetation) is represented here, relative scale differences can be shown. Source: Meyer et al. (1992: 268).

Behavioral geographers examine the correlation between spatial and temporal scales in individual activities. Spatial scale, temporal scale, and the degree of routinization are highly correlated in many human activities. Patterns that appear to be ordered at one level may appear random at another. For example, shoe stores show clumping patterns to attract more customers, but each store in a clump tries to place itself as far as possible from the others (Meentemeyer, 1989, p. 168).

When the generalization of propositions is made across scales and levels in geography, it can result in the common inferential fallacies. These erroneous inferences have often been attributed to poor theory. In fact, they often reflect lack of data, or the limits in gathering data at multiple levels. For geography, data-rich variables are usually found at 'near global level,' while few data exist at finer levels. Meentemeyer, 1989, p. 170) suggests using data-rich, higher-level variables as theoretical constraints on lower-level processes to help predict lower-level phenomenon.

The issues posed by the growing interest in globalized phenomena have led some human geographers to discuss new types of scaling issues. In postmodern interpretations of globalization,

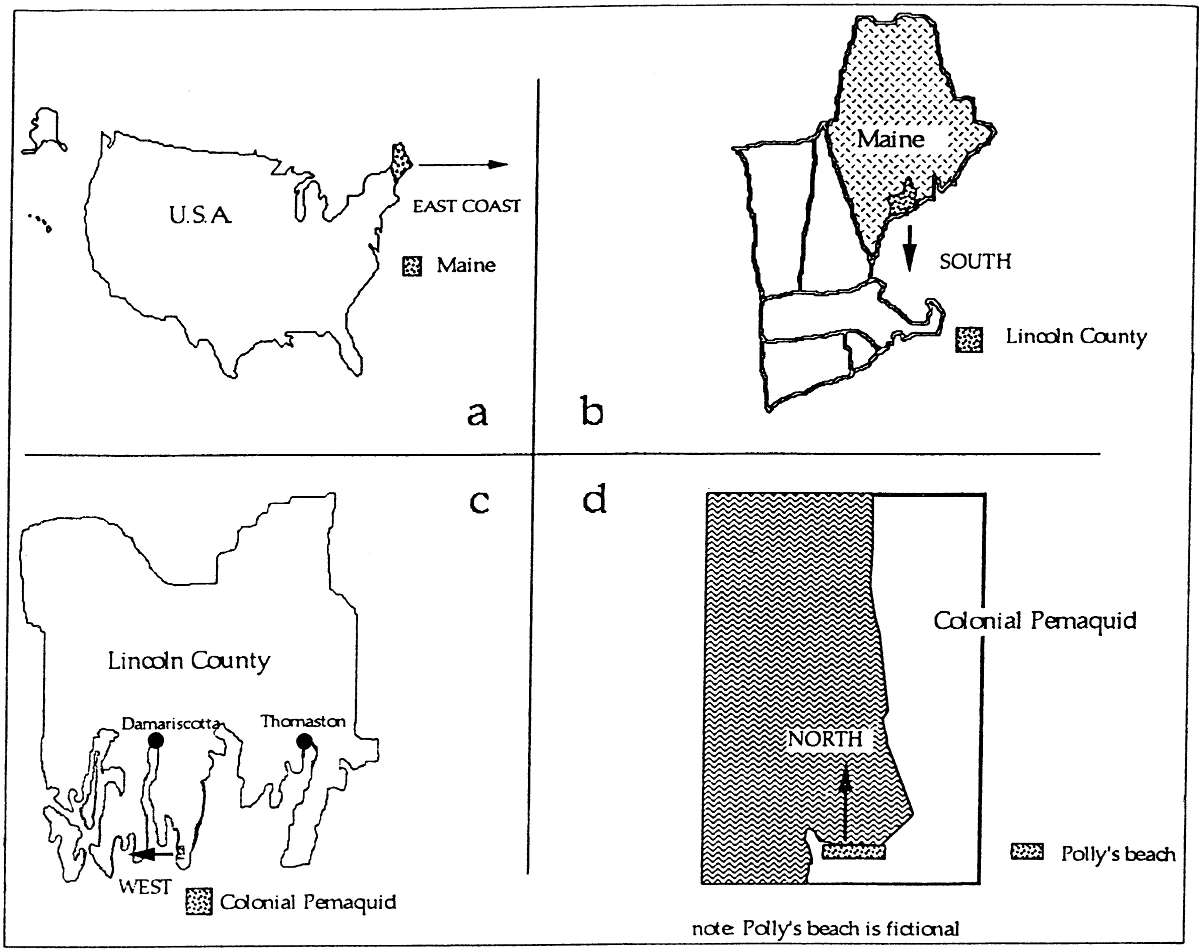

Fig. 7. The orientation of the coast of Maine can change dependent on the scale selected. (a) Maine is located on the east coast of the United States, so its coastal line primarily faces east. (b) Lincoln County, which is in Maine, has its coastal line directed toward the south. (c) The village of Colonial Pemaquid, in Lincoln County, has its coastal line facing west. (d) There is likely to be a beach, which is referred to as Polly's beach, in Colonial Pemaquid that has its shore oriented toward north. Source: Giampietro (1994: 678).

human geographers assert that the scale of the relationship between the dimension and object is important. Three types of scales involve different relationships: absolute, relative, and conceptual. An absolute scale exists independently of the objects or processes being studied. Conventional cartography, remote sensing, and the mapping sciences use absolute spatial scales, usually based on a grid system, to define an object's location and to measure its size. An advantage of using absolute scales is that hierarchical systems can easily be created when a larger (or longer) entity contains several smaller (shorter) ones (e.g. Nation-City-District-Neighborhood; Century-Decade-Year-Month-Week).

Geographers have paid increasing attention to relative space as they try to conceptualize the processes and mechanisms in space rather than the space itself. Relative scales are defined by, rather than define, the objects and processes

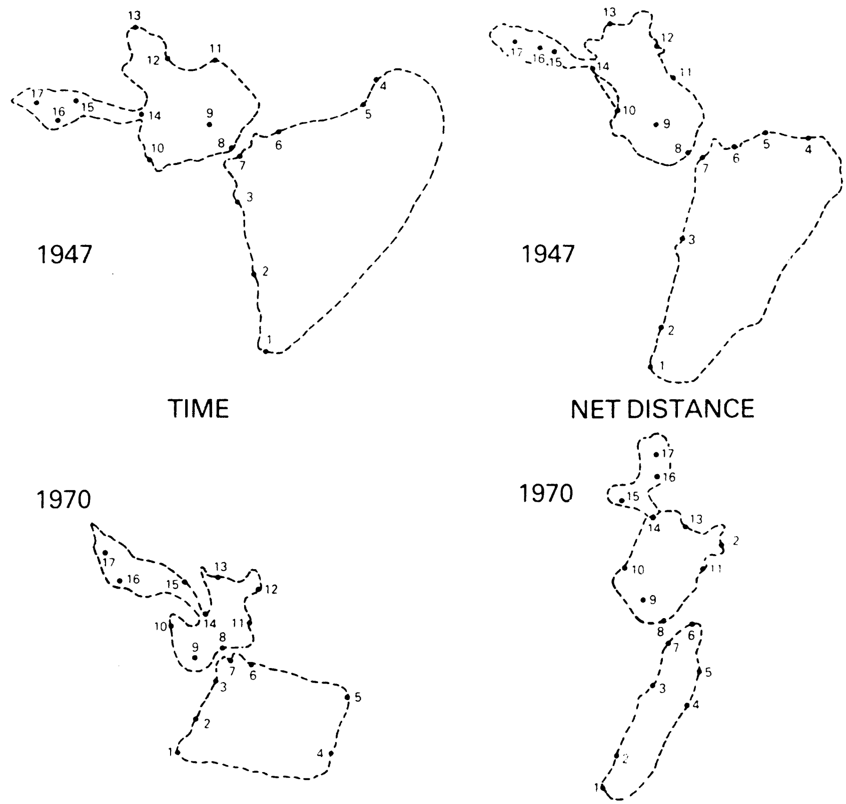

Fig. 8. A demonstration of the plasticity of space. The four maps have been constructed from data on the New Zealand airline system and its changes from 1947 to 1970. The two maps on the left show how distance measured in time has changed as the airline network has grown and the speed of travel has increased. The maps on the right show how the net distance traveled has changed with the network. (From Forer, 1978). Source: Holt-Jensen (1982: 65).

under study.[14] A relative concept of space regards space as 'a positional quality of the world of material objects or events,' while an absolute concept of space is a 'container of all material objects' (Harvey, 1969, p. 195; see also Jammer, 1954).[15] Relative space is particularly important in studies of behavioral geography that focus on individual perception of space. When we need to measure distance in terms of the time and energy needed for an organism to change its position from one place to another, absolute distance rarely corresponds with the relative distance. The plasticity of space is represented by the work of Forer (1978) who examined both the time and the net distance that it took to reach diverse locations within New Zealand in 1947 as compared to 1970 after growth in the airline network (see Fig. 8).

[14] Jammer (1954) first contrasted absolute and relative concepts of space in his review of the history of the concept of space in physics. In fact, the absolute concept of space is a rather modern development that accompanied Newtonian physics in which relations of objects were represented in absolute terms (Harvey, 1969).

[15] The classical reference for geographers, *Explanation in Geography* by David Harvey (1969), starts with the psychological, cultural, and the philosophical problems of understanding the concept of space, which he then connects with issues of measurement and spatial representation. For Harvey, a central question is 'how concepts of space arise and how such concepts become sufficiently explicit for full formal representation to be possible' (1969, p. 192). The early geographers relied more on Kant and Newton and thus on absolute scales. The construction of noneuclidean geometry in the nineteenth century and the development of Einstein's theory of relativity challenged the absolute concept of space. Since the mid-twentieth century, geographers have included more measures of relative space in their studies. Here, space does not exist by itself but 'only with reference to things and processes' (Meentemeyer, 1989, p. 164).

Finally, in addition to spatial denotations, geographers also use terms like global and local scale to stress conceptual levels. Global and local may correspond to the conceptual levels of 'totality, comprehensives' and 'particularity, discreteness, contextuality' (Meyer et al., 1992, p. 256). As a spatial scale also implies a temporal scale in physical geography, so too does space link with conceptual scale in human geography.

3.3. Scale issues in economics

Economics has developed two distinct types of theories — microanalytic and macroanalytic. Microtheories tend to examine the incentives faced by producers, distributors, retailers, and consumers as they are embedded in diverse market structures. Macroeconomists study large-scale economic phenomena, such as how various economic forces affect the rate of savings and investment at a national level. Few economists attempt to link these two distinct levels of theory.

In a recent note, however, Partha Dasgupta addresses a concern with the problem of linking across spatial and temporal scales within economic theory. Dasgupta suggests that economics at its core tries to explain 'the various pathways through which millions of decisions made by individual human beings can give rise to emergent features of communities and societies' (Dasgupta, 1997, p. 1). By emergent features he means 'such items as the rate of inflation, productivity gains, level of national income, prices, stocks of various types of capital, cultural values, and social norms' (idem). He points out, however, that individual decisions at any particular time period are affected by these emergent features (which in many instances result from very recent individual decisions). Some of the emergent features are fast-moving variables (e.g. changes in national income and rate of inflation) and some are slow-moving variables (e.g. changes in cultural values, institutions, and norms). When economists have studied short periods of time, they have simplified their analyses by taking slow-moving variables as exogenous and focused on the fast-moving variables. This has been a successful strategy for many economic questions, but Dasgupta points to the repeated findings in ecology, on the other hand, that the interface between fast- and slow-moving variables produces some of the important phenomena.

Scale is most overtly addressed by microeconomists interested in the question of economies of scale and optimization problems. Economies of scale (or increasing returns to scale) refer to the phenomena in which an increase of inputs within some range results in more than proportional increase of outputs (Samuelson, 1973[1955], p. 28). The quantity or magnitude of objects in both the input and output streams of a productive process represents certain levels of the process. Many propositions found in economics are expressed in terms of the relationship between the level of inputs and outputs, followed by suggestions on how to make decisions that optimize results. The law of diminishing returns refers to the diminishing amount of extra output that results when the quantity of an input factor is successively increased (while other factors are fixed). The law of increasing costs refers to the ever-increasing amount of the other good that should be sacrificed in order to obtain equal extra amount of one good (ibid.: 25–29). The optimal combination of inputs is a combination of input factors that minimizes the cost of a given amount of output and is achieved by equalizing marginal productivity of every input factor. The optimum population for a society is the size of population that maximizes per capita income for given resources and technology of the society (McConnell, 1969, p. 352).

The issue of generalizability is also studied in microeconomic theory. Paul Krugman, in his influential article 'Industrial Organization and International Trade' (1986), addresses the generalizability of theoretical propositions developed at one scale of interactions to another. Theories based on competitive markets are not useful when attempting to explain the structure and behavior of firms under the conditions of monopoly and oligopolistic (and less than perfect competition). Krugman (1986) argues explicitly that models of imperfect competition can be usefully applied to the study of international trade — therefore recommending that generalizations made about the structure and behavior of firms located in one (domestic) market can be applied to questions at the international level.[16]

3.4. Scale issues in ecological economics

Ecological economists study economic phenomena on a broader perspective than traditional economics by incorporating not only human society but ecological processes as well. Many ecological economists reject the myopic and human-centered viewpoint of mainstream neoclassical economics. They also differ with environmental economics in that the latter is seen merely as an application of neoclassical economics to environmental issues. Instead, ecological economists adopt a broader and more holistic analytical scale: conceptually larger in spatial scale and longer in terms of temporal scale (Daly, 1992). Ecological economists criticize the 'methodological individualism' of neoclassical economics as the theoretical expression of myopic economic thinking that treats the ecological environment only as an exogenous constraint on human economic activity. And they argue that this narrow scale of economic analysis is responsible for the disturbances of ecosystems and the overexploitation of natural resources that destroy the foundations of human existence.

The quantitative dimension of economic objects is also an important scale issue in ecological economics. Ecological economists' discussion of scale centers on 'the physical volume of the throughput' (Daly, 1992, p. 185) or 'the physical dimensions of the economy relative to the ecosystem' (Foy and Daly, 1992, p. 296). They take the ecosystem as a relatively fixed entity and argue that the economy grows by exploiting the ecosystem. This approach shifts the focus of economic study from economies of scale to the scale of the economy, i.e. the scale of 'all enterprises and households in the economy' (ibid.). Ecological economists argue that the scale of economy should not be reduced to allocation analysis but should be addressed at the outset as a constraint on human economic activity — something that should not be determined by the price system but by a social decision that would take into account sustainability.

3.5. Scale issues in urban studies

In urban studies, the primary dimension of scale used is population. Scale or size of a city, unless otherwise specified, is equated to the number of people living within a given territory. Urban researchers also use alternative measures of scale such as a city's active labor force, number of households, value added in production process within the territory, and spatial area (Reiner and Parr, 1980).

The problem of optimal city size is central to urban studies, and is reflected in a variety of secondary research topics such as the planning of new cities, limiting the growth of existing cities, rebuilding destroyed or deteriorated cities, dispersal of cities as a measure of civilian defense, deconcentration of urban populations, and controlling the location of industry. These topics, in turn, depend on different optimization problems, such as the optimum population of a nation, the optimum ratio of urban to rural population, the optimum pattern of different sized cities, the optimum size of a principal city as the service center for its tributary region, the optimum size of residential units, and the optimum sizes of particular cities or of cities of special types (Duncan, 1980). While at first glance these approaches appear straightforward, urban researchers wrestle with a great deal of complexity, and extensive contro-

[16] As an example, suppose two countries each possess a monopoly firm producing the same good at the same general quantity level and marginal cost. Assuming no trade barriers exist, the Cournot duopoly model can be applied to this situation. This theory expects that: (1) each firm exports to the other country, bearing some transportation costs if monopoly price exceeds the sum of production costs and transportation costs; (2) a firm's share in the exporting market is smaller than that in its domestic market due to transportation costs; and (3) a firm's price in the foreign country is lower than that of its domestic market where it monopolizes production. Krugman argues that this variant of the Cournot duopoly model has significantly different implications than the traditional theories of international trade where the explanation for trade strategies focuses on the comparative advantage of the two countries. In the Cournot model of international trade, firms that have a comparative disadvantage because of transportation costs still engage in trade.

versy exists concerning the mensuration and optimization of these phenomena.

Urban researchers addressed the issue of optimal city size most intensively and broadly in the 1970s (Hansen, 1975, p. 32), often posed as 'the problem of determining the optimal spatial distribution and hierarchy of cities of different sizes' that maximizes per capita income. Urban researchers also consider noneconomic, but no less significant, factors in their models of optimum city size, including the physical layout (accessibility to the countryside), health, public safety, education, communication, recreation, churches and voluntary associations, family life, and psychosocial characteristics. Researchers have found no general relationship between the size of city and these desired conditions (Duncan, 1980).

3.6. Scale issues in sociology

While scaling issues have always been implicit in sociology, the publication of Charles Tilly's book in 1984, *Big Structures*, *Large Processes*, *Huge Comparisons*, put the importance of explicitly dealing with scale squarely on sociologists' agenda. Tilly criticizes many aspects of traditional sociological theories because they address social processes in abstraction, without specifying temporal or spatial limits. His method is to specify the scale of analysis first and then to find fundamental processes and structures within that scale (or, in our terms, level). The implication of his work is that multiple processes exist and some are more fundamental than others for a given level of spatial and temporal scales. For example, he argues that from the fifteenth through the nineteenth centuries in the Western world, the forms of production and coercion associated with the development of capitalism and nation states 'dominated all other social processes and shaped all social structure' (Tilly, 1984, p. 15) including urbanization and migration.

For Tilly, the proper problem of studying historical processes should start with 'locating times, places, and people within those two master processes and working out the logics of the processes' (Tilly, 1984, p. 15). If one were to accept his argument for the study of human dimensions on global environmental change, one would start by: (1) defining the question of which temporal and spatial scale is crucial in affecting contemporary global environmental change; (2) identifying fundamental processes (such as commercialization, industrialization, or population growth) that drive the process; (3) examining how these fundamental processes relate to one another; and (4) addressing how systematic, large-scale comparison would help us understand the structure and processes involved.

Tilly's work also focuses on the concept of the levels of analysis — a higher level corresponds to a larger temporal and spatial scale. He argues that the crucial structures and processes vary as one changes the level of analysis. While he indicates that the number of levels between the history of a particular social relationship and the history of the world system is an arbitrary number, he proposes four levels as being useful: (1) at world-historical level, the rise and fall of empires, interaction of world systems, and changes in the mode of production are the relevant processes to investigate; (2) at world-system level, the world system itself and its main components, such as big networks of coercion and exchange, are the foci of analysis; (3) at macrohistorical level, major structure and processes of interest to historians and social scientists such as proletarianization, urbanization, capital accumulation, and bureaucratization become effective foci of investigation; and (4) at microhistorical level, the task is to make a linkage between the historical processes and the experience of individuals and groups (Tilly, 1984, pp. 61–65).

Coleman (1990) also directly addresses the problem of analyzing multilevel social systems. Coleman critiques Weber's (1958) argument in 'The Protestant Ethic and the Spirit of Capitalism' for using macrophenomena at one level to explain other macrophenomena at the same level. By ignoring lower-level phenomena, Weber (and others who follow this method) omit how lower-level phenomena react to macrolevel phenomena, and then may act to change it. For Weber's argument, this would mean that new religious doctrines affect the values of individuals, leading to changed values about economic phenomena, new patterns of interaction between individuals, and finally, a new economic system.

3.7. Scale issues in political science and political economy

As in other sciences, scales and levels divide political science into different subdisciplines. Many political scientists focus on the actions and outcomes of aggregated units of government operating at different geographical levels: local, regional, national, and international. Levels of human aggregation also affect what political scientists study: much research concerns the political behavior of individuals (especially voting); another features the politics of groups, particularly political parties and interest groups. Most research undertaken by political scientists, however, tends to focus directly on a particular level of primary interest to the scholar without much attention to how the phenomena at that level is linked to phenomena at a higher or lower level. Two exceptions worth noting are the study of federalism, which is at its heart a theory of multilevel, linked relationships, and the Institutional Analysis and Development (IAD) framework, developed by colleagues associated with the Workshop in Political Theory and Policy Analysis at Indiana University, which focuses on nested levels of rules and arenas for choice.

Although the concept of scale within the subdisciplines of political science is rarely addressed explicitly, some of the most important substantive and methodological issues addressed by political scientists relate essentially to problems of scale and level — especially the number of individuals involved. One important discussion regarding democracy concerns the differences of scale and level between the image of the original, small Greek city-states and the conditions of large, modern nation-states. In a major study of this question, Dahl (1989), pp. 215–20) concludes that there are major consequences of increases in the size of democratic polities, including limited participation, increased diversity in the factors relevant to political life, and increased conflict. Sartori (1987) argues that democracy is still possible because competition among politicians for election and re-election more or less guarantees their responsiveness to citizens. Ostrom (1991 and 1997), who is more cautious, sees modern democracies as being highly vulnerable precisely because of problems related to the scale of interaction among citizens.[17] And Barber (1992) fears that the technocratic and bureaucratic orientations of monolithic multinational corporations seriously challenge the access of citizens to information and participation in effective decision making.

Scholars in political economy, public choice, or social choice focus on the relationship between individual and group preferences, with scale and level issues at its core. The path-breaking work of Arrow (1951), which has been followed by several thousand articles on what is now referred to as social choice theory (for a review, see Enelow, 1997), proved that it was impossible to scale up from all individual preference functions to produce a group preference or ‘general will’ or ‘public interest’ function that satisfied what appeared to be an essential set of axioms of desirable properties of an aggregation process. Plott (1967) demonstrated that when there were more than two dimensions involved in a policy choice, majority rule rarely generated a single equilibrium except when the preferences of individual members were balanced in a particularly optimal, but unlikely, manner. McKelvey (1976) and Schofield (1978) proved that an agenda could be constructed to include every potential outcome as a majority winner unless there was a single outcome that dominated all others. These ‘chaos theorems,’ combined with Arrow’s earlier impossibility theorem, have deeply challenged the core presumption that simple majority rule institutions are sufficient to translate citizen preferences into public decisions that are viewed as representative, fair, and

[17] The competition for electoral office may be reduced to a media war that trivializes the discussion of public policy issues rather than clarifying important issues. Without a strong federal system and an open public economy, both of which allow for substantial self-organized provision of problem-solving capabilities, V. Ostrom views contemporary state-centered democratic systems as losing the support of their citizens, fostering rent-seeking behavior, and losing capabilities to deal with major public problems.

legitimate.[18] Like the Arrow paradox, the theory of collective action has also demonstrated a fundamental discontinuity between rationality at the individual and group level in the face of a social dilemma.[19] Olson (1965) and hundreds after him have explored the ramifications that in social dilemmas, group outcomes are worse when individuals choose their own best strategies.

The relationship between scale, government, and the delivery of public goods and services has also been an important part of political science. This tradition of work starts with an awareness of market failure in regard to the provision of public goods and services. If free riding leads to an underprovision of a good through voluntary arrangements, some form of governmental provision will be necessary. Different configurations of governments may be more efficient and responsive depending upon the nature of the goods and services in question (Ostrom et al., 1961; Ostrom and Ostrom, 1977; Ostrom et al., 1978). The work of scholars focusing on local public economies has tried to understand how local units of government cooperate on the provision and production of some goods and services while competing with one another with regard to others (Parks and Oakerson, 1993; Oakerson, 1999). The approach is similar to that of ecologists who study the patterns of interactions among a large number of organized units within a spatial terrain and discover emergent properties resulting from the way that individual units work together. Scholars have found that in many cases a multilevel, polycentric system is more efficient than one large, metropolitan-wide governmental unit or only a single layer of smaller units (see McGinnis, 1999).

In addition to recognizing that governmental units operating at diverse spatial levels are potentially more efficient than any single-unit operation at one level could achieve, scholars in this tradition have also recognized that there are several conceptual levels involved in any governance system. At an operational level, individuals engage in a wide diversity of activities directly impacting on the world, such as the transformation of raw materials into finished goods. There is a set of operational rules that provides structure for these day-to-day decisions made by government officials and citizens interacting in a wide diversity of operational situations (teachers in a classroom with students; welfare workers processing applications of those seeking welfare benefits; police giving a ticket to a speeding driver). These operational rules are the result of decisions made in a collective-choice arena. The structure of that collective-choice arena is itself affected by a set of collective-choice rules that specify who is eligible to make policy decisions, what aggregation rule will be used in making these decisions, and how information and payoffs will be distributed in these processes. At a still different conceptual level, collective-choice rules are the outcome of decisions made in constitutional arenas structured by constitutional rules (Kiser and Ostrom, 1982; Ostrom et al., 1994, ch. 2; McGinnis, 1999).

Contrary to many presumptions that constitutional rules are made once and only at a national level, the constitution of all organized structures — ranging from the household all the way to international regimes — may be updated by interpretation or self-conscious choice relatively frequently. Constitutional rules change more slowly than collective-choice rules which, in turn, change more slowly than operational rules. Rules that are genuinely constitutional in nature may be contained in any of a wide diversity of documents that do not have the name 'constitution' attached to them. The constitution of many local units of government is embedded in diverse kinds of state

[18] Shepsle (1979a and 1979b), has shown how diverse kinds of institutional rules — including the allocation of particular types of decisions to committees within a legislative body — do lead to equilibria that can be thought of as institutionally induced equilibria.

[19] The term 'social dilemma' refers to an extremely large number of settings in which individuals make independent choices in an interdependent situation with at least one other person and in which individual incentives lead to suboptimal outcomes from the perspective of the group (Dawes, 1980; Hardin, 1982). The reason that such situations are dilemmas is that there is at least one outcome that yields higher returns for all participants, but rational participants making independent choices are predicted not to achieve this outcome. Thus, there is a conflict between individual rationality and optimal outcomes for a group.

Table 2
The relationship of analytical levels of human choice and geographic domains

	Conceptual levels of human choice		
Spatial levels of political jurisdictions	Constitutional-choice level	Collective-choice level	Operational-choice level
International	International treaties and charters and their interpretation.	Policy making by international agencies and multinational firms.	Managing and supervising projects funded by international agencies.
National	National constitutions and their interpretation as well as the rules used by national legislatures and courts to organize their internal decision-making procedures.	Policy making by national legislatures, executives, courts, commercial firms (who engage in interstate commerce), and NGOs.	Buying and selling land and forest products, managing public property, building infrastructure, providing services, monitoring and sanctioning.
Regional	State or provincial constitutions and charters of interstate bodies.	Policy making by state or provincial legislatures, courts, executives, and commercial firms and NGOs with a regional focus.	Buying and selling land and forest products, managing public property, building infrastructure, providing services, monitoring and sanctioning.
Community	County, city, or village charters or organic state legislation.	Policy making by county, city, village authorities and local private firms and NGOs.	Buying and selling land and forest products, managing public property, building infrastructure, providing services, monitoring and sanctioning.
Household	Marriage contract embedded in a shared understanding of who is in a family and what responsibilities and duties of members are.	Policies made by different members of a family responsible for a sphere of action.	Buying and selling land and forest products, managing property, building infrastructure, providing services, monitoring and sanctioning.

laws. Similarly, collective-choice decisions may be made by a diversity of public units, such as city and county councils, local and state courts, and the representative bodies of special authorities, as well as by a variety of private organizations that frequently participate actively in local public economies — particularly in the provision of local social services. Operational choices are made by citizens and by public officials carrying out the policies made by diverse collective-choice arrangements in both public and private organizations. In order to understand the structure, processes, and outcomes of complex polycentric governance systems in a federal system, one needs to understand the conceptual levels of decision making ranging from constitutional choice, through collective choice, to operational choices.

The relationship of these conceptual and spatial levels is illustrated in Table 2, where the conceptual levels are shown as the columns of a matrix while the spatial levels are shown as the rows. The particular focus on operational activities in this table relates to the use of land and forest resources — but almost any other type of CPR or public good could be used instead. Given the importance of international institutions in this realm of activities, as well as the decisions made by households, the geographic domains are arrayed at five levels. This, of course, is an oversimplified view, as there may be several geographic domains covered by community governance units as well as several at a regional level.

One can well expect different types of political behavior as one goes across rows or columns of this matrix. Peterson (1981), for example, argues that because local governments are under the condition of mutual competition, they pursue more developmental and allocative policies than redistributive policies. If they pursue redistributive policies too vigorously, both corporations and private citizens will move to other local governments that do not tax wealthier taxpayers for services delivered primarily to poorer residents. This suggests that redistributive policies will be pursued more often and more successfully at the national level. In terms of interest group politics, Anton (1989) argues that a weak coalition at one level of the government can achieve their desired goal at the higher level, if they can gain enough strength through a vertical coalition. For example, liberal coalitions have been stronger at the national level but they have been less effective at the state level. Further, one can expect various political actors to make choices as to 'forum shop' for a level of political organization that will be the most appropriate one for their policy proposal.[20]

Similar phenomena have evolved during the past two decades in regard to various kinds of environmental policies. Environmentalists seek to engage some policy questions at a strictly local level, some at a regional or national level, and still others within international regimes. At the international level, they may gain considerable public attention, but end up with written agreements that are poorly enforced. At a local or regional level, they may achieve a large number of quite different, but more enforceable agreements. Trying to understand the impact of dealing with diverse 'global change phenomena' at diverse levels of organization will be one of the central tasks of institutional theorists studying global change processes.

[20] Labor management relations, for example, had long been regarded as strictly an individualistic contractual relationship between a worker and a boss. The introduction of the Wagner Act in the US Congress led to a key debate as to whether labor relations have a 'national' character — meaning that the scale of the effects of labor-management relationships is national in character. It was only after the passage of the Wagner Act that workers were allowed to form unions and to negotiate collectively at the level of at least an individual company. Still further developments led to labor organization at the level of an industry. In many respects, this and other policy fields are organized into several constituent hierarchies that then engage in a continuing series of competitive and cooperative relationships with one another at each of the levels in the hierarchies.

4. Conclusion

With increasing amounts of data that demonstrate a clear human 'thumbprint' on small and large ecological phenomena, more and louder calls are being made for the inclusion of the social sciences in the global change research agenda. Although many diagrams of the causes of certain ecological outcomes possess only one large box labeled 'human action,' the marriage between the physical sciences and the social sciences is far from trivial.

In this paper, we survey one of the most important conceptual challenges to that union — the concept of scale. We argue that common definitions do not exist for scale — even within disciplines — and especially in the social sciences. Because the social sciences focus their attention on social phenomena that encompass many scales and many levels, many social scientists' understanding of the importance of scale tends to be underdeveloped. By contrast, some of the fundamental issues related to scale in the physical sciences were resolved with the development of a unified theory of mechanics, explaining the acceleration of small bodies in free fall as well as the orbit of large planetary bodies.

On the other hand, many social scientists have contributed to our understanding of scale in social phenomena. Geographers, urban analysts, sociologists, economists, and political scientists have taken scale seriously as they explore their substantive areas. And interest continues to grow among social scientists and philosophers of science (e.g. Popper, 1968; Giddens, 1984; Bueno de Mesquita, 1985) to develop of a unifying theory 'capable of explaining political behavior at various scales of social activity' (Clark, 1996, p. 284). This interest can only grow with the urgent questions that are emerging from the study of the human dimensions of global environmental change.

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.

Acknowledgements

The authors thank the International Human Dimensions Programme on Global Environmental Change, Bonn, Germany, and the National Science Foundation (Grant # SBR-952-1918) for their crucial support. Comments from Oran Young, Arild Underdal, and three anonymous reviewers, and the editorial skills of Patty Dalecki have greatly improved this work.

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