IHDP WORKING PAPER NO. 1
MAY 1998

Scaling Issues in the Social Sciences

A Report for the International Human Dimensions Programme on Global Environmental Change by

Clark Gibson
Elinor Ostrom
Toh-Kyeong Ahn

IHDP
INTERNATIONAL HUMAN DIMENSIONS PROGRAMME ON GLOBAL ENVIRONMENTAL CHANGE

ICSU

CISS ISSC

IHDP Working Paper No. 1:
Scaling Issues in the Social Sciences
May 1998

IHDP Working Papers

The Working Papers is an IHDP publications series to draw attention to emerging issues in the field of Human Dimensions of Global Environmental Change. The Papers represent preliminary material circulated to stimulate discussion and comments. They represent the view(s) of the author(s) and do not necessarily represent those of the IHDP nor its sponsors ICSU and ISSC

The Authors:

Clark Gibson
Assistant Professor, Department of Political Science
Research Associate, Center for the Study of Institutions, Population, and Environmental Change, Indiana University, Woodburn Hall 402, Bloomington, IN 47405
Phone: 812-855-6473 / Fax: 812-855-2027 / Email: cgibson@indiana.edu

Elinor Ostrom
Arthur F. Bentley Professor of Political Science; Co-Director, Workshop in Political Theory and Policy Analysis; Co-Director, Center for the Study of Institutions, Population, and Environmental Change, Indiana University, 513 North Park, Bloomington, IN 47408-3895
Phone: 812-855-0441 / Fax: 812-855-3150 / Email: ostrom@indiana.edu

Toh-Kyeong Ahn
Research Assistant, Department of Political Science, and Workshop in Political Theory and Policy Analysis, Indiana University, 513 North Park, Bloomington, IN 47408-3895
Phone: 812-855-0441 / Fax: 812-855-3150 / Email: tahn@indiana.edu

The paper was prepared as part of the IHDP project on the Institutional Dimensions of Global Envrionmenta! Change (IDGC). Support from the IHDP and the National Science Foundation (Grant # 5BR-952-1918) is gratefully acknowledged. Patty Dalecki's skill in helping us edit this report has improved the draft paper immensely.

WORKSHOP IN POLITICAL THEORY AND POLICY ANALYSIS
Indiana University, 513 North Park; Bloomington, IN 47408-3895 U.S.A.; Telephone: 812-855-0441; Fax: 812-855-3150; E-mail: workshop@indiana.edu

International Human Dimensions Programme on Global Environmental Change (IHDP)

IHDP Secretariat	Telephone:	+49-(0)228-739050
Wa!ter-Flex-Str. 3	Fax:	+49-(0)228-739054
53113 Bonn	E-mail:	ihdp@uni-bonn.de
Germany	Web:	www.uni-bonn.de/ihdp

sponsored by:

Contents

Preface

This paper was selected as an IHDP Working Document because although it was prepared as a contribution to the IHDP Institutional Dimensions of Global Environmental Change Project (IDGC), it also may be relevant to many other researchers within the IHDP's growing network.

The authors, the IDGC Scientific Planning Committee and the IHDP would welcome any comments, proposals and exchanges with researchers interested in the issues raised in this document. The goal of IHDP Working Documents is to promote the early and wide dissemination of emerging research related to human dimensions of global environmental change with a view to promoting enhanced synergies and networking within the human dimensions research community.

We look forward to receiving your comments and suggestions for the future.

Professor Eckart Ehlers,
Chair
Scientific Committee of IHDP

Dr. Larry R. Kohler
Executive Director
IHDP Secretariat

Foreword

As part of a proposal to create a scientific program regarding the Institutional Dimensions of Global Change, Arild Underdal and Oran R. Young asked us in June 1996 to prepare a literature review on scaling issues in the social sciences. The review was to focus on three broad questions:

Where in the social science literature or the research community do we find interesting studies examining the scaling question?

What are the main hypotheses, propositions, and findings that have emerged or can be extracted from these studies?

What seems to be major gaps in the present state of knowledge, or particularly interesting and promising areas of future research?

During the fall semester of 1996, we conducted an extensive search of the literature and review of the most relevant books and articles on this topic. Analysis and write-up have taken place during the first half of 1997.

We have organized this report into four sections. In the Introduction (Section I), we broadly identify the many ways that scales and scaling issues arise in the social sciences. We begin with a definition of scale: *Scale is the dimension used in any effort to measure a phenomenon.* The three most obvious types of scales used by all scientists are space, time, and quantity. The relative importance placed on these three scales varies among disciplines. Space is the dominant scale used in geography and the most prominent in ecology. Time is used more widely across disciplines to separate static from dynamic analyses. Quantitative scales are important in all of the social sciences; the number of actors, for example, is a crucial theoretical variable in economics, political science, and sociology. In addition to space, time, and quantity, many important conceptual scales are used by social scientists, including measures of equity and types of governance. Not only do social scientists utilize different scales, 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 II of this report, we describe how disciplines outside the physical sciences employ scale and related concepts. The most obvious uses of scale are found in ecology, landscape ecology, geography, economics, sociology, and political science. In Section III, we discuss some of the issues related to the generalization of hypotheses and propositions across levels. There are many kinds of hierarchies, and not all propositions can be applied across levels. Section IV will be devoted to a discussion of collective-action theory as a potentially fruitful theory to unify some central questions studied throughout the social sciences, allowing an integrated view of conflict and cooperation at international, national, regional, and local levels. 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. Many social scientists and philosophers of science (e.g., Giddens, 1984; Bueno de Mesquita, 1985; Popper, 1968) have also advocated the development of a unifying theory "capable of explaining political behavior at various scales of social activity" (Clark, 1996: 284). We will evaluate the potential role of collective-action theory to accomplish this goal—especially as related to the role of institutions in the study of human impacts on global phenomena.

1. Introduction

Numerous 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 small, medium, and large levels on spatial and temporal scales. The multilevel/multi-scale nature of the problems relating 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 scales, and have operated within relatively well-defined hierarchical systems of analysis, social scientists have worked with scales of less precision and greater variety. With the growing realization that 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.

This report seeks to facilitate this dialogue among researchers by reviewing the concept of scale in the social sciences. After reading extensive numbers of articles and books related to the broad concept of scale, one of the key problems that we have come to recognize is 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 1.1 definitions of key terms that we have come to use after reading the literature cited in the bibliography and struggling with the confusion created by many different uses of the same word.

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 1.1). *Levels 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 phenomenon. Levels related to time, for example, could involve short, medium, and long duration. *Scaling problems* can be related to issues of scale and level. All scales 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 phenomena. 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 phenomena (see Figure 1.1).

Table 1.1 Definitions of Key Terms Related to the Concept of Scale

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	The precision used in measurement.
Grain	The finest unit of resolution possible using a particular scale.
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).

Sources: M. Turner, Dale, and Gardner (1989: 246); Mayr (1982: 65); T. Allen and Hoekstra(1992).

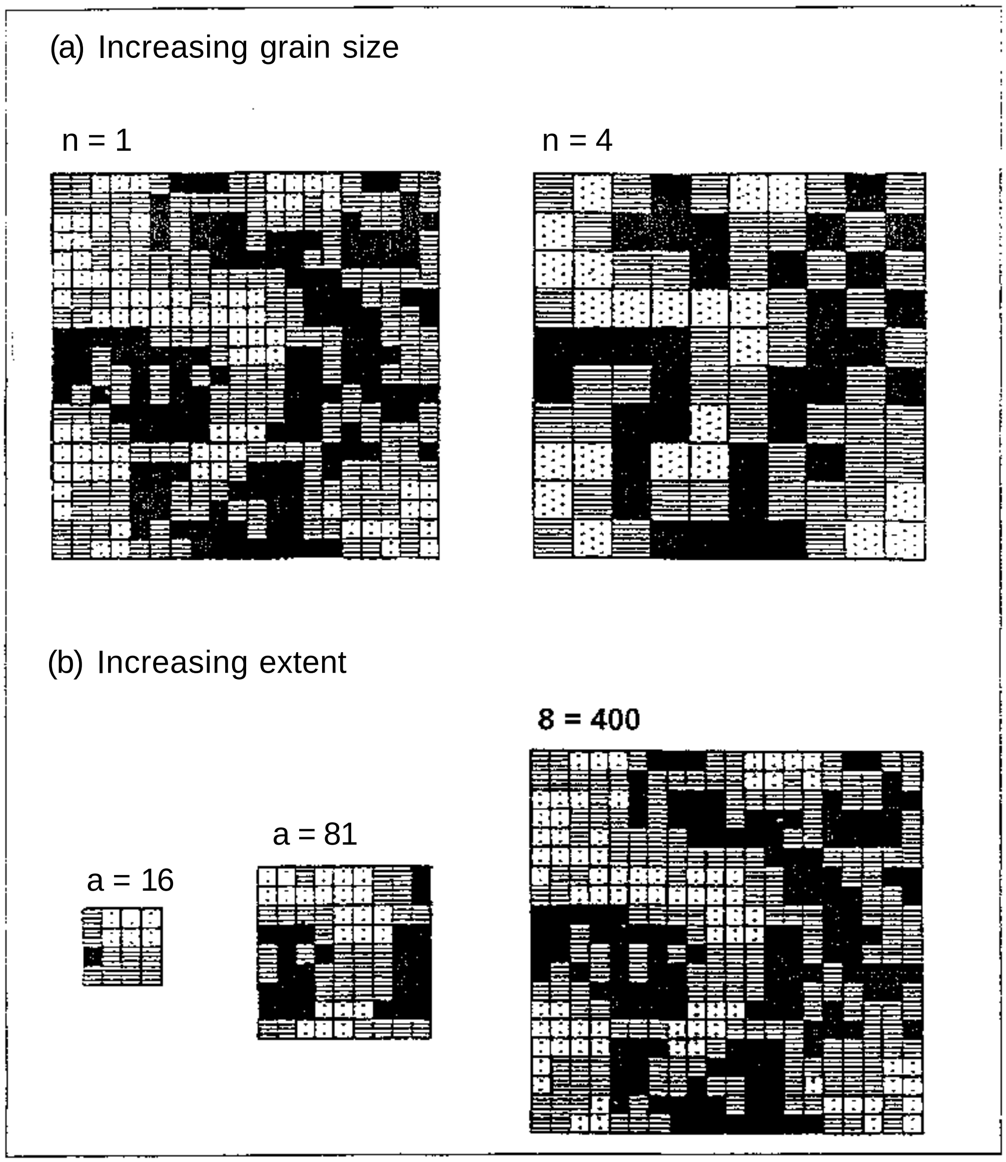

Figure 1.1 Schematic illustration of (a) increased grain size and (b) increased extent in a landscape data set. The number of cells aggregated to form a new data unit are indicated by n; total area is indicated by a; see Methods for complete explanation.
Source: M. Turner et al (1989: 154).

Resolution refers to the precision used in measurement and *grain is the finest unit of resolution* along a particular scale. 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. Many sources of data used by social scientists provide observations on an annual or decadal basis. In regard to space, social scientists use a variety of resolutions ranging from a meter or less (anthropological studies of household activities) to coarser measurement 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).[1]

Many scales are closely related to the concept of hierarchy. *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 where their formal position lies on an exclusive 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. There are many other examples of exclusive hierarchy where the concept of command and control is absent. One example—shown in Figure 1.2—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, 1*992:* 33).

Exclusive hierarchies include levels that are not nested within one another. 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 throughout the defined hierarchical system, but there is no particular organization at each level. Inclusive hierarchies are also referred to as aggregational hierarchies (Mayr, 1982: 64).

Major analytical classification systems are usually inclusive hierarchies. The best-known example *is* the Linnaen hierarchy of taxonomic categories. All species are contained in a particular genus that is contained in a particular family, and so on, up through the kingdoms of biological life. In an inclusive hierarchy, however, 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. They are primarily classificatory devices.

[1] 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 paper will understand our use of the term in a different manner than their use.

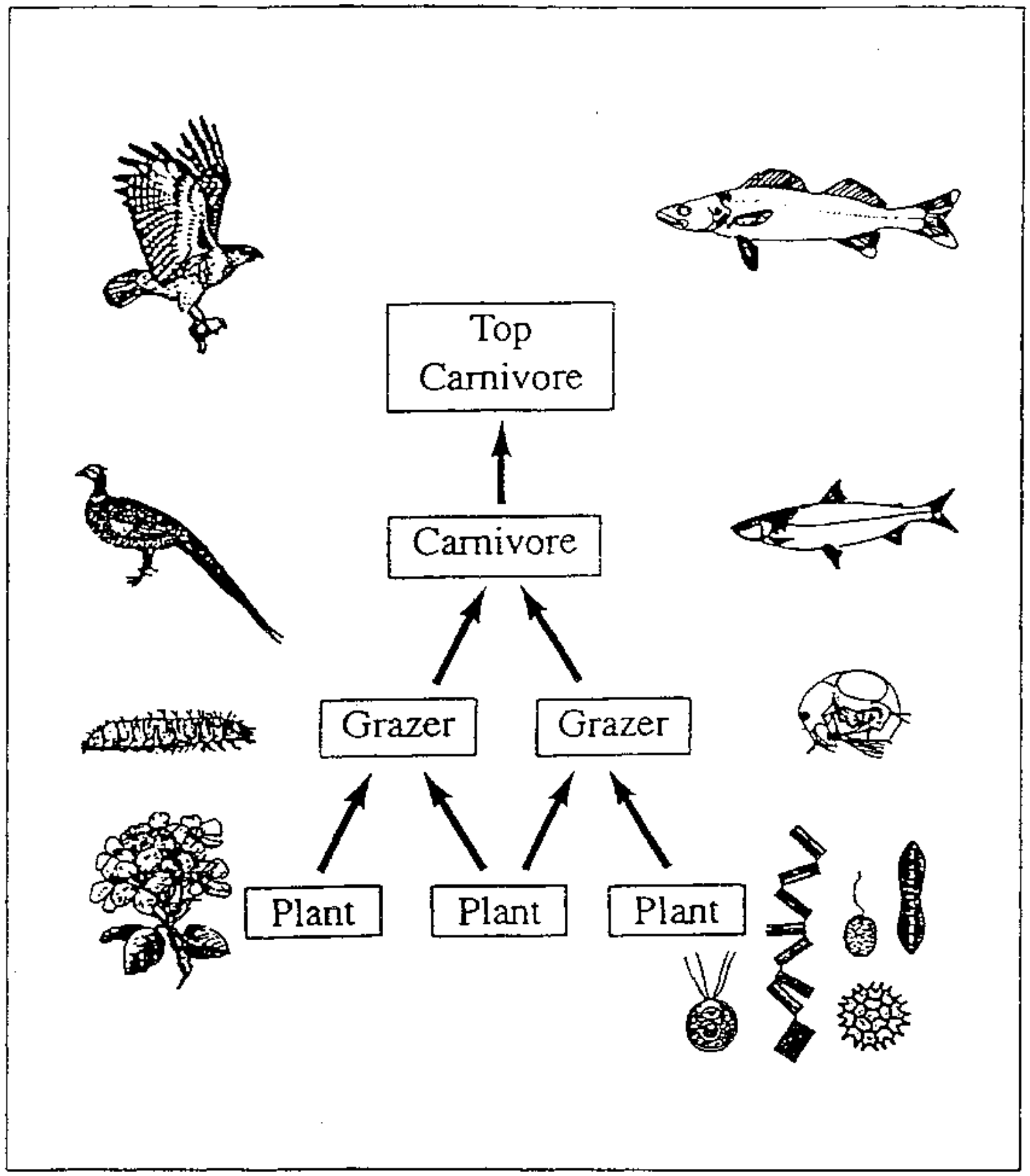

Figure 1.2 The food chain as an example of an exclusive hierarchy.
Source: T. Allen and Hoekstra (1992: 33)

The second type of nested hierarchy—most characteristic of complex systems—is a *constitutive* hierarchy. "In such a hierarchy the members of a lower level, let us say tissues, are combined into new units (organs) that have unitary functions and emergent properties" (Mayr, 1982: 65). Organization exists at each level. All living organisms and most complex, nonliving, systems are linked in constitutive hierarchies. Molecules are contained in cells that are contained in tissues that are contained in organisms that are contained in populations. "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" *(Idem).* These levels are on a conceptual scale based on functional relationships rather than on a spatial or temporal scale.

As we will discuss in Section III, many phenomena—but not all—associated with global change are linked together in constitutive hierarchies. Individuals 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, by the level immediately below, and the level immediately above. Thus, much of the research on global change processes must examine the world from a multi-level perspective.

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. Combinations of individual units frequently show collective behavior. Lloyd 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: 63). According to Baas and Emmeche *(1997:* 3), some important examples of emergent properties include:

- Functionality of biomolecules in cells: The self-maintenance of a living cell is based on the structure of the cell and the functionality of its molecules. Though, in general, each type of macromolecule in virtue of its chemical properties . . . can enter into reactions with an infinite set of possible molecules, in the living cell each molecular species is committed to one or a small number of reactions that define its specific *function* within the cell's metabolic system.

- The general situation of a client (C) and a server (S). With the interactive help from the server, the client may perform tasks that none of them could do separately. Hence, we get a second-order agency (CS) that again may serve as a client in a new context

- Consciousness is not a property of individual neurones, it is a natural emergent property of the interactions of the neurons in the nervous system of the body in an environment. It makes a structure that is related to lower-level interactions as well as higher-level thoughts, and it represents a new observational mechanism of the entire system (Baas and Emmeche, 1997: 3; see also Baas, 1*996).*

The definitions of scale, levels, hierarchy, and emergence will be utilized throughout the remainder of this paper.

1.2 Issues Related to Scale

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 and its extent and resolution affect the identification of patterns;

(2) how diverse levels on a scale affect the explanation of social phenomenon;

(3) how theoretical propositions derived about phenomenon 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.

1.2.1 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: Patterns that appear at one level of resolution may be lost at lower or higher levels; patterns that occur over one extent of a dimension may disappear if the extent is increased or decreased.

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 sub-atomic physics or cellular biology restricts the extent and resolution of patterns to be studied to a certain domain. Social phenomena, on the other hand, 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. For example, psychologists normally restrict their attention to the behavior of individuals, and anthropologists generally study small communities over certain periods of time. However, economists, geographers, historians, political scientists, and sociologists may all 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, thus, affect a social scientist's unconscious choice of scale, but do not determine it completely.

Less consensus exists among social scientists about the appropriate extent and resolution of the scales they use. Social science is driven generally by the search to explain social problems or issues. Yet these phenomena may include causes and consequences that range over scales, levels, extents, and resolutions. Thus, while the object of inquiry for a social scientist may occupy one level of a particular scale, the search for its explanation may need to range more broadly.

1.2.2 Scale and the Explanation of Causal Processes

Scale alone does not explain patterns. Making causal statements about particular patterns, however, explicitly or implicitly invokes scale. The crucial issue linking scale 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. A valid explanation of patterns occurring at any one level can be based on variables that also occur at that level or at scales with greater or smaller extent. *Downward causation* refers to a key variable or variables being used in an explanation that occurs at a larger level than the pattern or dependent variable^) being explained. *Upward causation* refers to the variable or variables used in an explanation that occur at a smaller level than that of the dependent variable(s) (see Campbell, 1974).

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 improperly impute the cause of higher-level (or macro) patterns to be the same as those operating at a lower (or micro) 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.

1.2.3 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 to another, i.e., use theoretical propositions discovered about entities interacting at one scale to explain relationships operating at a different scale. "Thus, scaling up in space is a matter of applying findings derived from the analysis of small scale or micro-level systems to meso-scale or even macro-scale systems. Conversely, scaling down is a process of bringing findings about large-scale systems to bear on the analysis of meso-level or micro-level systems" (Young and Underdal, 1996). Scaling issues are equated by some scholars with the problem of generalizing across levels. In this literature review, we have included the issue *of* generalizing across levels as one of four key issues related to scaling found in the social science literature.

Theory plays a key role in the process of generalizing. After observing and describing processes occurring in one or more settings, scientists develop theories, and models from their theories, to explain why observed patterns occur. A very recent effort to generalize across levels is illustrated by an example from the pages of *Science.*

The resemblance immediately caught his eye, Bruce Remington recalls. Images in two different journals depicted daisy like patterns, formed when small ripples on a ball of plasma -- or ionized gas ~ bloomed explosively into long, turbulent spaces. But the floral analogy was not what glued the Lawrence Livermore National Laboratory researcher to the pages; it was the gulf between what the look-alike images actually showed. One depicted the mixing of a speck of plasma less than a tenth of a millimeter across as a converging array of powerful laser beams at the Livermore's Nova facility slammed into it The other was a computer model - much simplified - of mixing in a supernova blast, millions of kilometers across (Glanz, 1997: 351).

Similarities across such an extreme difference in the levels of a scale could be a fluke. But when Bruce Remington worked out some of the numbers generated by both systems, he established for himself that the physics were identical. This generalization across levels is now providing a mechanism at the Lawrence Livermore National Laboratory that, while originally designed to examine plasma relationships, is now being used to "mimic the roiling, radiating, three-dimensional (3D) dynamics of exploding stars" *(Idem).* Being able to generalize across levels is one of the most powerful tools of modern science. In this instance, experiments conducted at a nano level are increasing the understanding of phenomena occurring at an extreme size and distance from the observer. Given this size and distance, there is no way of doing experiments or even making detailed observations of the large phenomenon, but given the capacity to generalize experiments can be conducted on the small-scale phenomenon that are relevant for understanding the large.

A theory is always considered to be more powerful if it explains phenomena that occur in widely disparate settings that differ from one another in terms of many situational variables but share important underlying causal relationships. As in the above example, 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 scale, it may then be applied to phenomena at dramatically different scales. This effort may prove to be successful or unsuccessful, but the effort to generalize occurs in all of the natural sciences and is becoming a more frequent occurrence in the social sciences. 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 size. They may also discover that the key explanatory variables change substantially as one attempts to explain phenomena at a substantially smaller or larger scale.

One example of considerable relevance to the study of the institutional dimensions of global change is whether the evolving theory of collective action is relevant to more than one scale of human organization. Are propositions about the variables that explain cooperation in social dilemmas derived from the study of small groups relevant to the study of larger groups and vice versa? Currently, scholars of international relations apply theories of collective action as much as scholars of national or local efforts to overcome social dilemmas. Can findings from analyses of smaller-sized common-pool resources (CPRs), such as the design principles derived by Ostrom (1990) to explain the robustness of smaller-scale institutional arrangements, be applied to explain the robustness of institutional arrangements for larger CPRs? McGinnis and Ostrom (1996) apply the design principles to problems related to large-scale CPRs. Young (1995) and Snidal (1995), however, raise important questions about how easy it is to apply theoretical propositions developed to explain robustness of institutions organized to govern smaller spatial extent and use them to explain phenomena at a large spatial scale involving many more individuals.

One of the puzzles in addressing the question of generalizability of collective-action theory relates to the relative importance of the number of actors, spatial extent, and time. Are the representatives of sovereign nations the actors related to global commons? In regard to making some major constitutional rules and collective-choice rules, the relevant actors may indeed be corporate bodies represented by delegates to international meetings. If the problems of solving collective-action problems are more severe when the relevant time horizons extend to a century in length, is time a more relevant variable for scaling than either space or number of actors? We will return to this particular generalization in Section IV as it is of considerable importance in studying the relationships between institutional arrangements and global change.

1.2.4. Scale and Optimization

Choices over scale are explicit in all studies that explore questions regarding optimization since, by definition, optimization concerns processes of known extent. Optimization questions are used extensively in economics, in urban studies (drawing on economics, geography, and political science—particularly studies of federalism), and in ecology.

Work in the economics of production seeks to determine the optimal scale for a production unit. Scale in this case refers to the quantity of outputs produced in a facility, i.e., "flow-through." When the first few units of a product are produced by a plant, the cost of each unit is very high. The average cost of unit of a product tends to fall, however, as more and more units are produced. For most "normal" economic products, the theory of diminishing marginal productivity applies. After a certain number of products have been produced, the marginal cost of the nth unit of a product starts to rise. Average costs will also rise. 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 policymakers 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 diverse kinds of public goods? in many of these questions, the scale used is either the spatial extent of a political unit or the number of actors 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. Scholars particularly interested in federal political systems focus on how best to design nested political units ranging in size from an urban neighborhood to an entire nation. For these scholars, the costs and accuracy of information that flow from citizens to public officials are central variables in the optimization of governance.

For biologists, optimization processes lie at the core of their theoretical foundations. Evolutionary theory predicts that processes of mutation and natural selection optimize the fitness of individual organisms to particular niches.[ii] Ecologists work at a different level, and tend to think of optimization in terms of carrying capacity, i.e., given a particular ecological niche, what is 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.[iii].

Despite the shared technique of optimization and the concern with scale, different disciplines employ different standards for 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 are primarily concerned with the sustainability of species and systems.

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

[iii] 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.

2. Scale in Ecology and the Social Sciences

Although this literature review of scale focuses on the social sciences, we begin with an exploration of scaling concepts in ecology since

(1) ecoiogists 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.

2.1 Scale Issues in Ecology and Landscape Ecology

While the topics that interest ecoiogists are diverse—ranging from population dynamics and coevolution to environmental change—scale issues remain at the core of this discipline. In fact, scaling may be the fundamental conceptual problem in ecology, if not in all of science (Levin, 1992). Scale became increasingly important to ecologists with the growth of landscape ecology, which seeks to investigate the relationship between ecological process and spatial patterns, the interactions found between adjacent spatial units, and the causes and effects of spatial heterogeneity (Pickett and Cadenasso, 1995). Applied ecologists have begun to focus on global environmental change and use new technologies such as the analysis of data from remote sensing. 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 (Levin, 1992).

Ecoiogists 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. Therefore, identifying patterns depends on the resolution of the spatial scale used. O'Neill and his colleagues (1991) conducted an experiment that clearly demonstrated the dependence of pattern on spatial resolution. They took a 1600 meter transect on a field that had a mixture of species. At each .1 meter interval, they measured all plants that were taller than a specified vertical measure. Using diverse statistical methods they then analyzed the existence of similarity or differences between segments that varied in terms of spatial resolution. They found multiple scales at which distinct patterns of plants are found (see Figure 2.1). Further, ecologists are deeply aware that extent and grain affect the nature of the patterns observed and the type of information that can be conveyed (see Figure 2.2).

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. 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.

Some ecologists have recently tried to define levels based strictly on absolute temporal and spatial scales, arguing that conventional levels are just ways of "telling foreground from background, or the object from its context" (Alien and Hoekstra, 1990: 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. For example, such scaled structures have been 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 (Levin et al., 1997; Wessman, 1992).

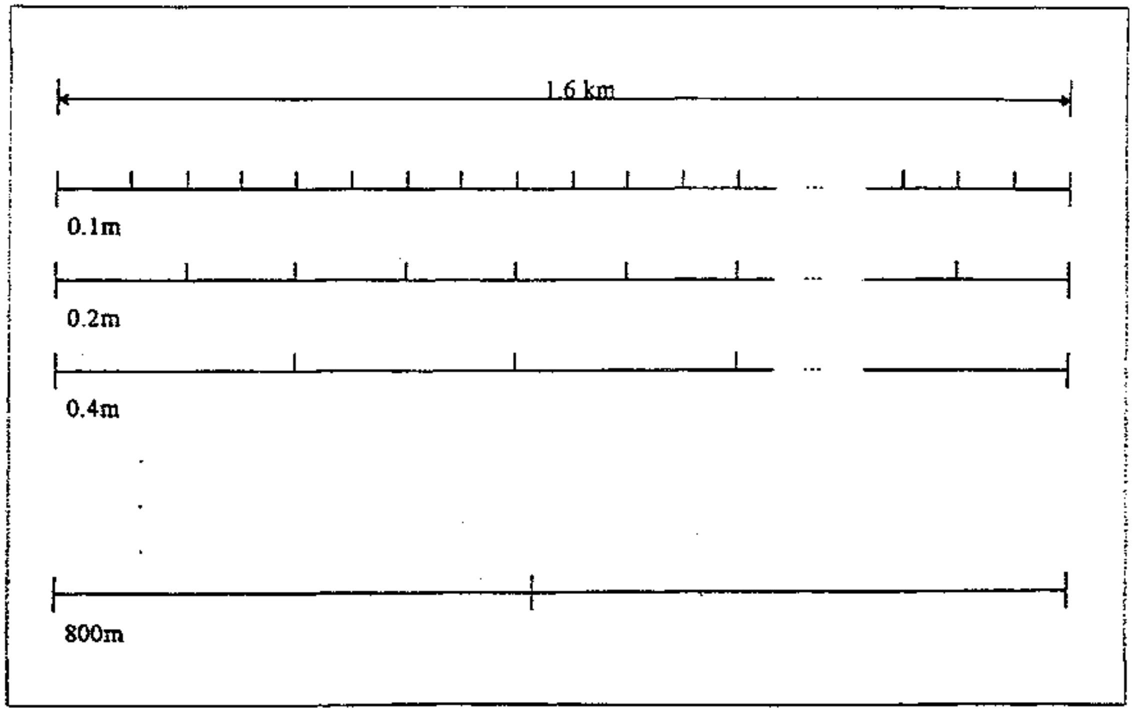

Figure 2.1 Identification of pattern and scale: An example.
Along the same transect, measurements were taken at different intervals and yielded different patterns.
Source: Based on discussions found in O'Neill et al. (1991).

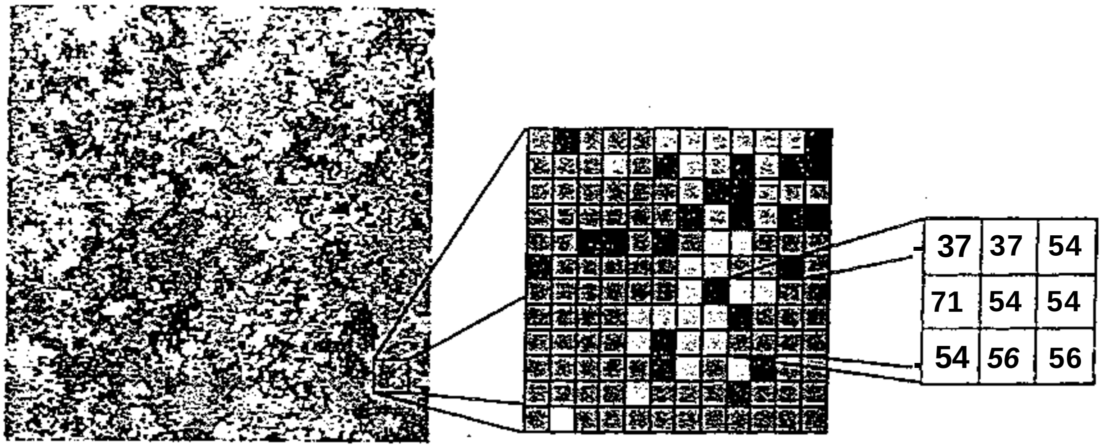

Figure 2.2 A sample of a forest landscape model composed of a matrix of sites. Fire organizes and maintains the landscape as a mosaic of patches composed of even-aged sites. The sites making up the landscape are each shaded by age. Young sites are lightly shaded while old sites are black. At the right of the figure the ages, in years, of a set of sites are shown.

Source: Holling et al. (1996: 355)

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 theory is to dissect any complex system of processes as a series of hierarchical entities as shown in Figures 2.3 and 2.4. 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 present at the higher and lower levels of spatial-temporal resolution. It is assumed that levels lower than -1 produce changes that are either too small or too fast to be much more than background noise in measurements of processes at level 0. Similarly, levels above +1 are presumed to be too large and too slow to affect measurement and understanding at level 0. The levels immediately above and below the referent level provide environmental constraints. These constraints produce a constraint "envelope" in which the process or phenomenon must remain (O'Neill, Johnson, and King, 1989; Norton and Ulanowicz, 1992: 244). The constraint envelope may contain both physical and biological components as shown in Figure 2.5. Hierarchy theory, thus, uses both bottom-up and top-down explanations but assumes that it is extremely difficult to generalize across levels of analysis largely due to the existence of emergent properties.

While conceptually appealing, hierarchy theory demands a great deal of knowledge in order to be useful. 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 parameters 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 (M. Turner, Dale, and Gardner, 1989; Wessman, 1992; O'Neill et al., 1991).

Even in cases where hierarchy theory is used to identify the patterns of certain natural processes, the explanation of those patterns remains difficult: 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 (Stohlgren, 1995; Wessman, 1992; B. Turner and Meyer, 1991); the complex web of interrelations and feedbacks often contain lags and/or discontinuities; and living systems are generally far from any stable equilibrium state (Folke, Holling, and Perrings, 1996).

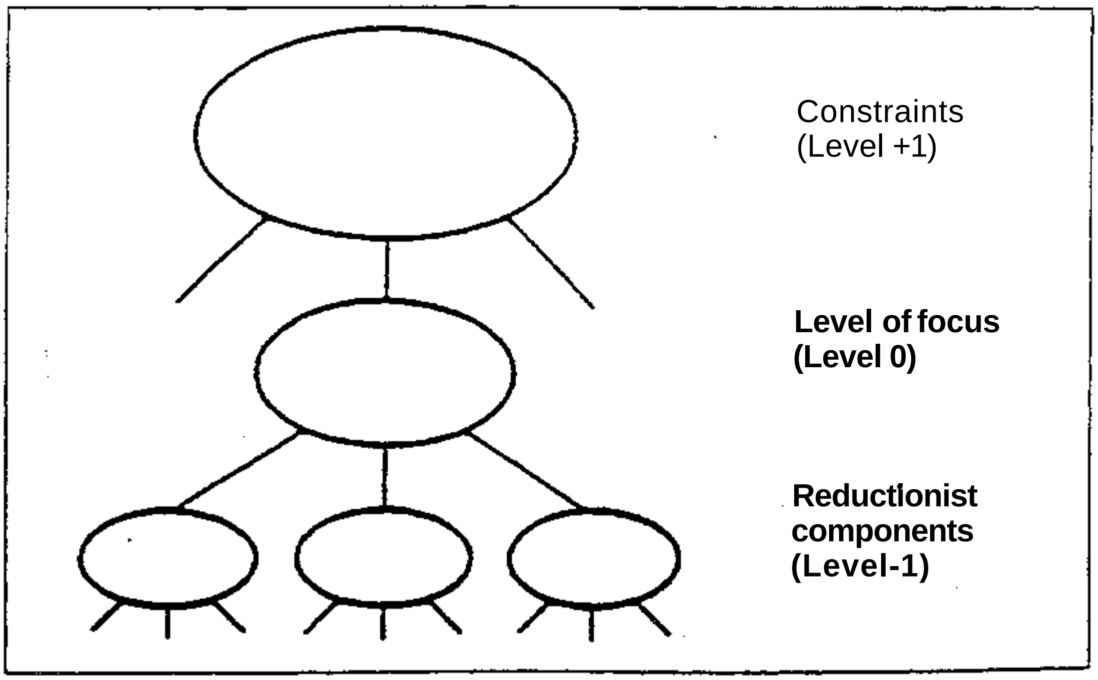

Figure 23 Schematic of hierarchy theory constraints. This approach may be applied to any level of scale. (Adapted from Dyer and Vmogrodov, 7 990:20).
Source: Fox (1992: 291).

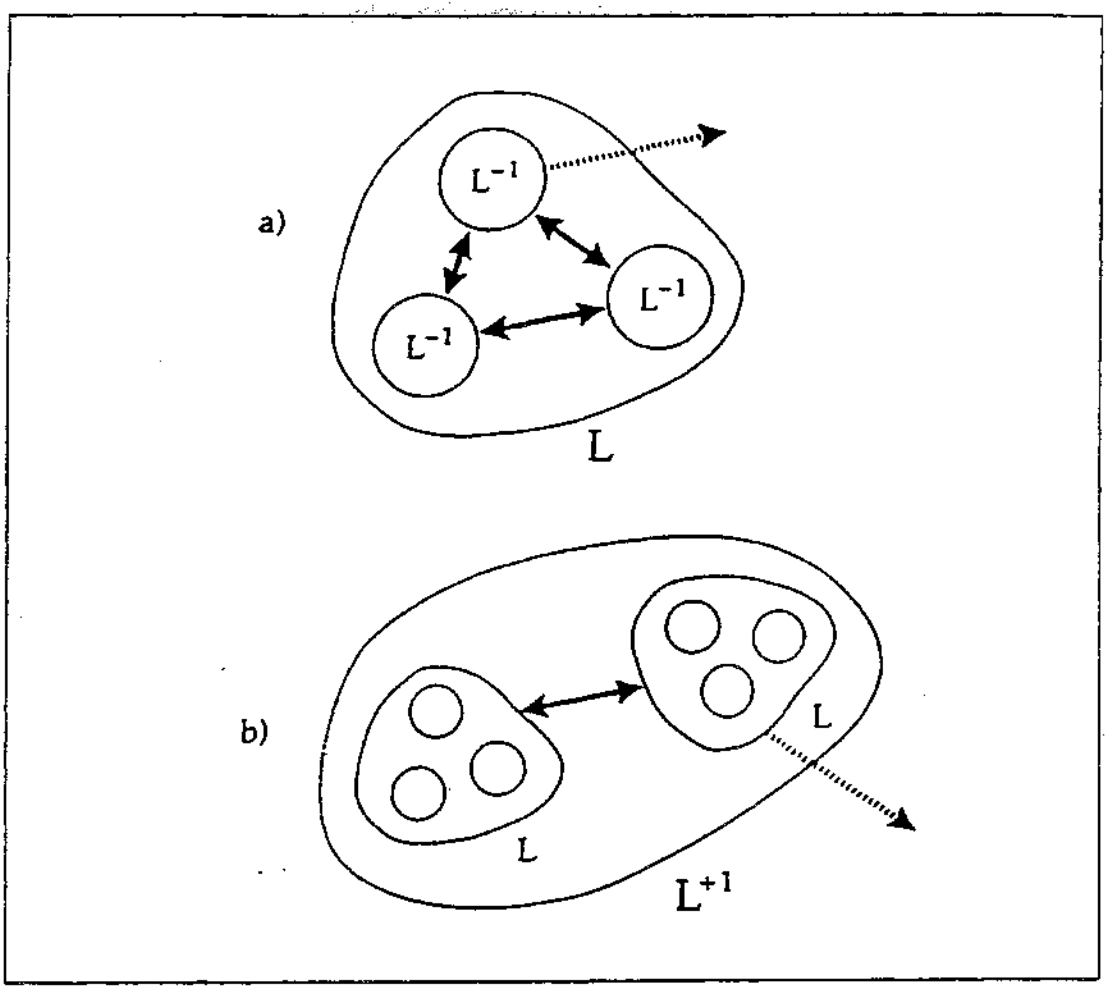

*Figure 2.4 L is the level in question; L-1 is the next level down; L+*1 *is the level above. The weak connections of L-1 to the outside world beyond L become the strong connections whithin level L+* 7.
Source: Allen and Hoekstra (1992: 30).

Since these natural processes are normally complex, nonlinear, discontinuous systems, arriving at top-down or bottom-up generalizations is far from trivial (O'Neill and Rust, 1979; Rastetter et al., 1992). 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.

The work of C S. Holling and his colleagues (Holling, 1973, 1986; Hailing 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: 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.

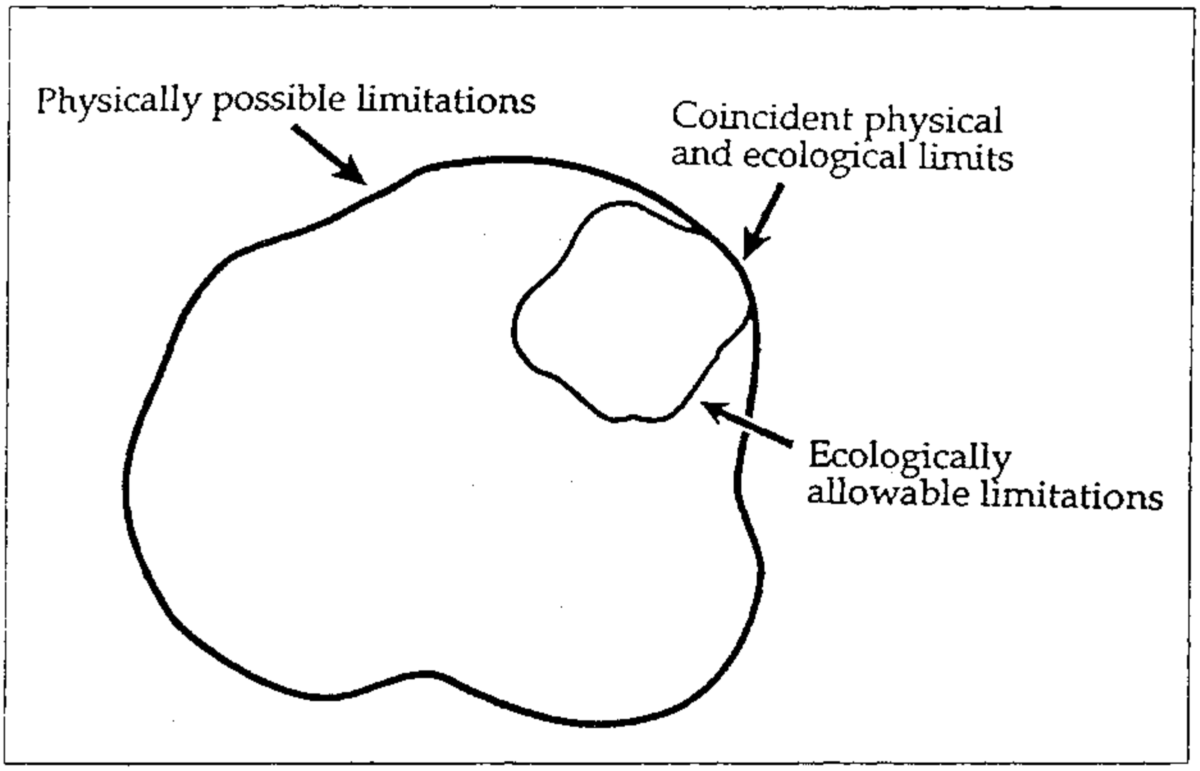

Figure 2.5 Only occasionally is what is observed in ecology directly the result of a physical limitation. More usually what is ecologically allowable a subset inside what is physically possible.
Source: T. Alien and Hoekstra (1992: *49).*

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)" (ibid.: 7). As shown in Figure *2.6,* ecosystems with several levels of ecological structure facilitate multitaxa food guilds to reduce competition by spreading their members along separate body mass clumps. Different levels are exploited by the set of species in each body mass clump. The redundancy produced by such processes is more like the diverse portfolio strategies of investors than the redundancy built into engineering systems. Diversity of species and body masses generates substantial robustness to the functioning of ecosystems through an overlapping set of reinforcing influences. Each of the processes may not be fully efficient, but together they operate in a robust manner.

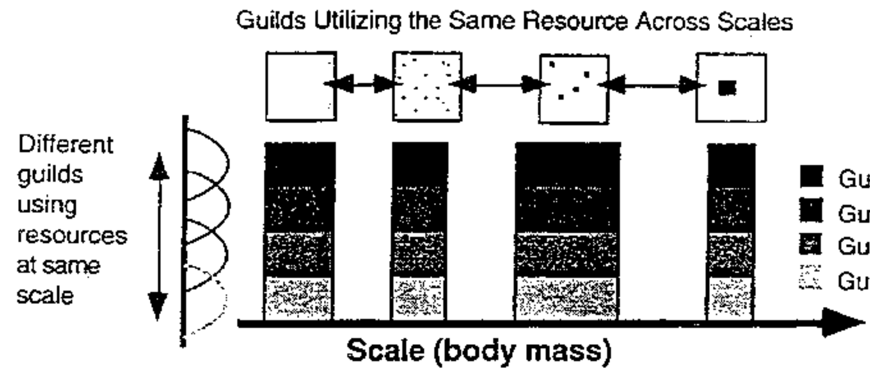

Figure 2.6 Animal species belonging to different ecological guilds exist at different body sizes. For example, there are both small and large insectivores. This distribution provides two forms of resilience. At the same scale, animals from different guilds can utilize the same resources with lower efficiency. Also, animals that utilize the same resources can begin to utilize resources from a lower level if they form large enough aggregations. For example, if insectivores were removed from a group, insects would become easier to catch and it would become worthwhile for animals at the same scale to switch from their normal food to insects, and it may become worthwhile from larger insectivores to eat prey items they normally would not eat.
Source: Gunderson et al. (1997:26).

Such systems also produce substantial surprise, however. Given their non-linear structure, they can flip from one pattern to another and thus one set of controls to another. Losing just a few species may not make much difference while many other species still exist. As the number of interacting species is reduced still further, a flip in system behavior may occur suddenly that requires substantial reorganization and investment to regain its former behavior. Hoiling (1992) has studied the relationships between four key processes, shown in Figure 2.7: exploitation, conservation, release, and reorganization. In an *exploitation* process, species that are rapid colonizers move into recently disturbed areas. In a *conservation* phase, energy is stored and there is a slow accumulation of species and material. When biomass and nutrient have become so tightly connected that they are highly susceptible to external disturbance, such as forest fires or infestation of pests, one can enter a *release* phase. *Reorganization* processes involve new restructuring of capital and elements into a new system. The time spent in each of these processes may vary dramatically. From exploitation to conservation may involve a long period of time with only small changes, but the shift from conservation to release may be very rapid. Under some conditions, reorganization and exploitation may then take place rapidly. Thus, the importance of studying systems over time—and not just at set intervals—is one of the key lessons to be learned from this research program.

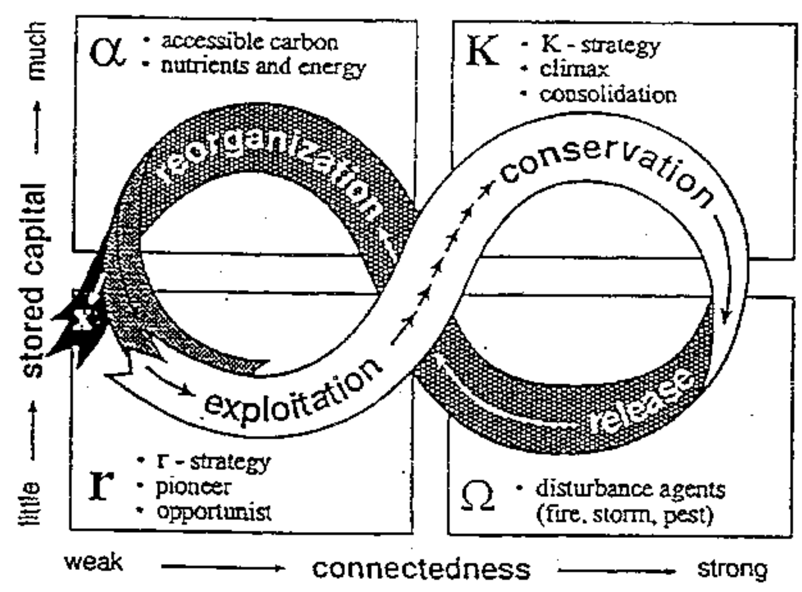

Figure 2.7 The four ecosystem functions (r, K, Ω, α) and the flow of events among them. The arrows show the speed of that flow in the cycle, where arrows close to each other indicate a rapidly changing situation and arrows far from each other indicate a slowly changing situation. The cycle reflects changes in two attributes, (1) Y axis: the amount of accumulated capital moment and (2) X axis: the degree of connectedness among variables. The exit from the cycle indicated at the left of the figure indicates the stage where a flip is most likely into a less more productive and organized system, i.e., devolution or evolution as a revolution! (From Holling 1992, 1995).
Source: Gunderson et al. (1997: 27)

Further, in many field settings "there is a nested set of such cycles, each occurring over its own range of scales" (Gunderson et al., 1997: 11). Some cycles occur annually, some take around a decade, and still others may take a century. "The result "*is* an ecosystem hierarchy, in which each level has its own distinct spatial and temporal attributes. A critical feature of such hierarchies is the asymmetric interactions between levels. In particular, the larger, slower levels constrain the behavior of faster levels" *(Idem,* see also Allen and Starr, 1982; O'Neill, 1988). But the causal direction is not always from the larger to the smaller. When a system has been in its conservative growth phase for some time, it can become brittle and all of its accumulated capital is available to stimulate a major structural change. "The system is very stable, but that stability is local and narrow. A small disturbance can push it out of that stable domain into catastrophe" (Gunderson et al., 1997: 12). At this point, a change in a lower-level phenomenon may cascade throughout an overly connected system leading to a reorganization of the larger system. Alternatively, when a system is in the transition from reorganization to exploitation, chaos may characterize much of the patterns of interaction. A lower-level change can create a center of order around which the available resources grow exponentially.

Scientists have engaged ecological problems at enormous scales (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, Risser and Mankin, 1986; Rosswal, Woodmansee, and Risser, 1988; Powell and Steele, 1995; Steele, 1978, 1989). 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 (Costanza, et al., 1997; M. Turner, Dale, and Gardner, 1989). Such a challenge is particularly acute for those analysts who focus on large heterogeneous systems, like landscape ecologists (Forman and Godron, 1986; B. Turner, 1989). Despite the goal of finding interscaie models, many scientists working in areas such as physiological ecology (Jarvis and McNaughton, 1986), population interactions (Addicott et al., 1987), soil processes (Sollins, Spycher, and Topik, 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 (M. Turner, Dale, and Gardner, 1989; Wessman, 1992) and that a single mechanism rarely explains patterns found at different levels (Gueron and Levin, 1995; Menge and Olson, 1990)

2.2 *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: 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 Figure 2.8).

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.

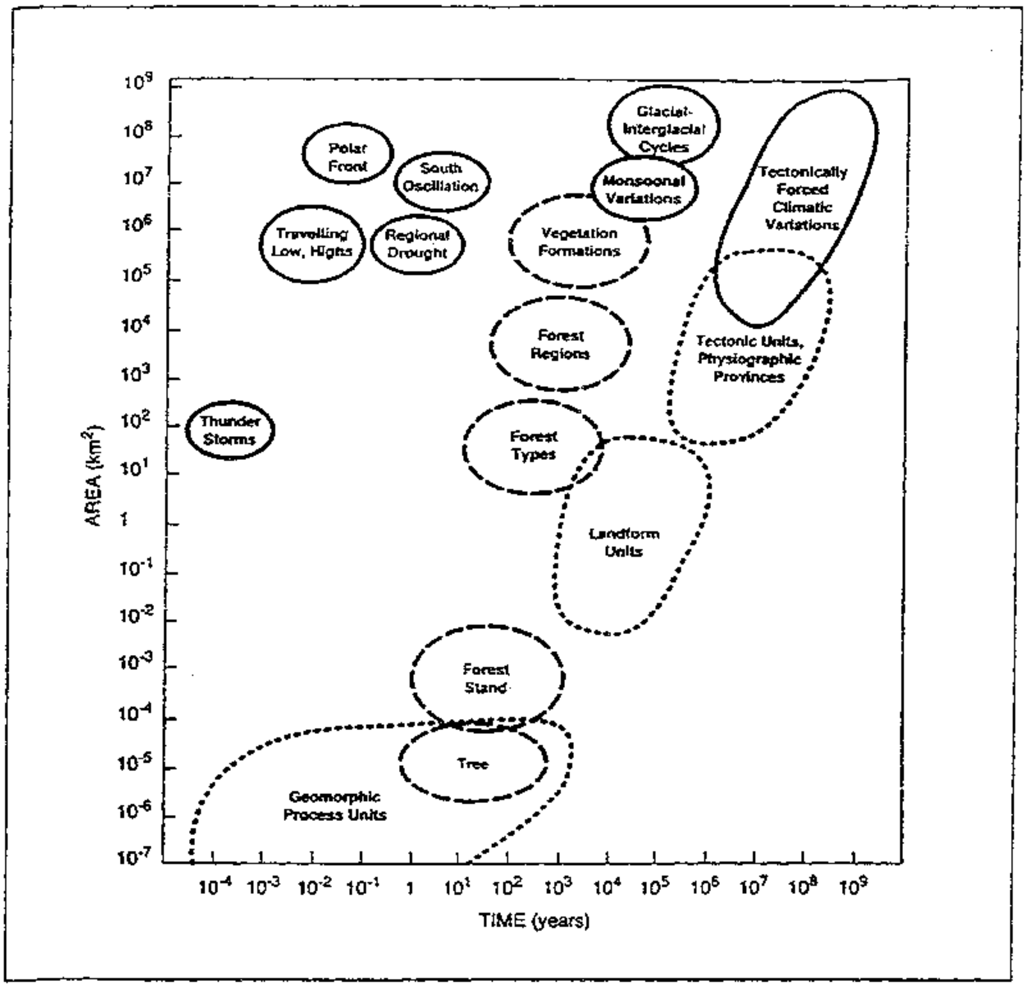

Figure 2.8 Some important features of the atmosphere, biosphere, and lithosphere shown in space-time.. Climatic units are shown by solid outlines, ecological units by dashed outlines, and geomorphic units by dotted lines. Ecological terms are functional rather than spatial in concept (Allen and Hoekstra 7 990), but because only one ecological system (forest vegetation) is represented here, relative scale differences can be shown.
Source: Meyer et al. (1992: 268). Based on McDowell, Webb, and Bartlein (1990: 144, 151, 155)

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 micro-level 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 Figure *2.9,* even the direction faced by a location changes as the extent of the measurement changes. 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: 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).*

Behavioral geographers examine the correlation between spatial and temporal scales in individual activities. Figure 2.10 illustrates that spatial scale, temporal scale, and the degree of routinization are highly correlated in many human activities. As in ecology, scale has a significant effect in identifying geographical patterns. 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 (ibid.: 168).

When the generalization of propositions is made across scales and levels in geography, it can result in the common fallacies of inference discussed earlier. These erroneous inferences have often been attributed to poor theory, but in fact they may often reflect lack of data, or the limits in gathering data at multiple levels. Consequently, the incorporation of multiple levels in a hierarchical model is not as easy as it might appear. For geography, data-rich variables are usually found at "near global level," while few data exist at finer levels. Meentemeyer (1989: 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, 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.

---

iv Minute to hour: local convection and dew point depression. Hour: wind speed and feeder clouds. Day: synoptic events, vorticity, and short wave patterns. Year: precipitable H_2O, upper-level divergence, baroclinic zones , SST and ENSO.

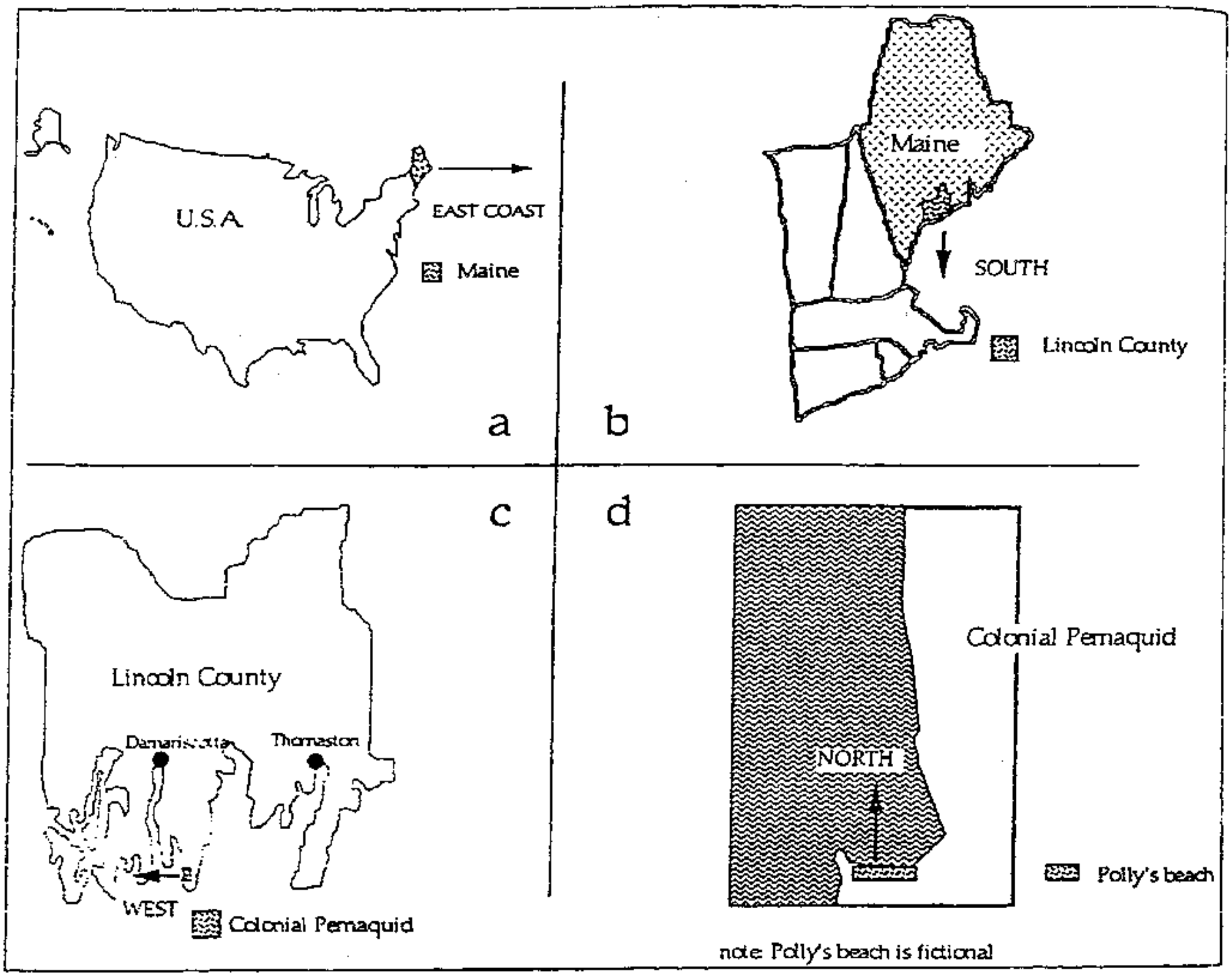

Figure 2.9. The orientation of the coast of Maine can change dependent on scale selected. a. Maine is located on the east coast of the United States, so its coastal line primarily faces east. b. Lincoln County, which is in Maine, has its coastal line directed toward the south. c. The village of Colonial Pemaquid, in Lincoln County, has its coastal line facing west. d. There is likely to be a beach, which I refer to as Polly's beach, in Colonial Pemaquid that has its shore oriented toward north.
Source: Giampietro (1994: 678).

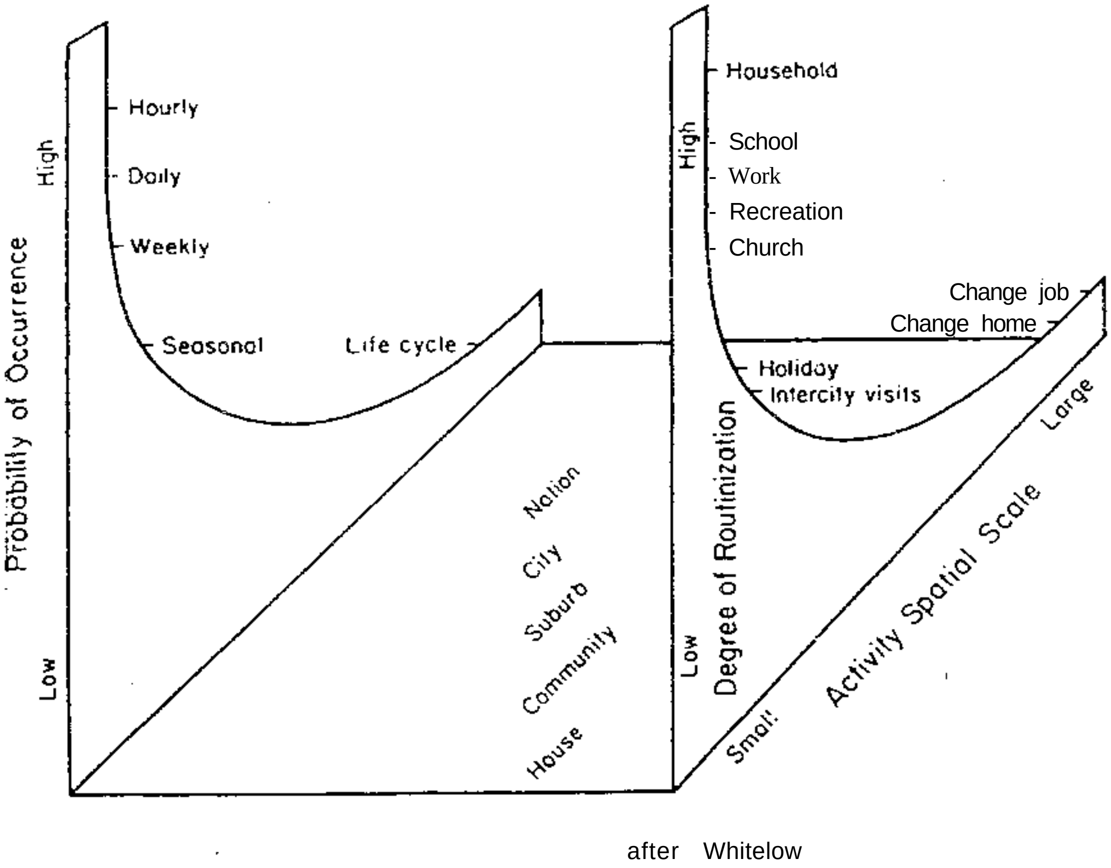

Figure 2.10. The activity space of individuals as it relates to time involved, distance traveled, degree of routinization, and probability of occurrence.
Source: Meentmeyer (1998: 165).

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). Remote sensing and G15 use absolute scales almost exclusively as they attempt to fill out a given space with information. In other words, an absolute scale exists before, and is defined independently of, any objects or processes.

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 under study. Jammer (1954) first contrasted absolute and relative concepts of space in his review of the history of the concept of space in physics. 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: 195; see also Jammer, 1954). 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).

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: 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: 164). For example, when one is dealing with processes and mechanisms, space and time become properties of those processes or mechanisms under investigation. Therefore, the study of a process cannot *a priori* assume certain spatial and temporal scales. An example of such a relative scale can be found in Figure 2.11, which shows the volume of retail sales in the United States (1948) arrayed spatially with each billion dollar of sales equated with a defined spatial unit.

Relative space is 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. When this happens, it is not easy to "map the processes in terms of absolute" scale (Meentemeyer, 1989: 164). Accessibility or isolation does not always depend on absolute distance, but on the cost in terms of time and resources, or mileage through a transportation system (Holt-Jensen, 1982). 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 Figure 2.12).

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: 256). As a spatial scale also implies a temporal scale in physical geography, so too does space link with conceptual scale in human geography.

2.3 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. No distinction is made in neoclassical theory between individual behavior and the behavior of an organized entity—the firm—even if the firm employs one person or thousands of employees working in widely dispersed locations. 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 have attempted to link these two distinct levels of theory.

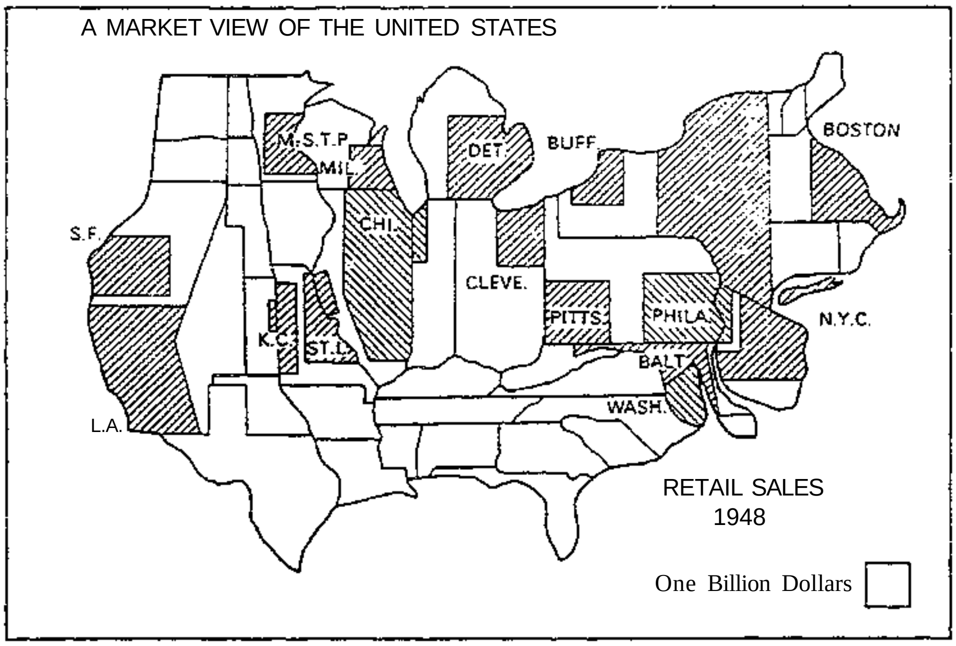

Figure 2.11 An elementary map transformation in the form of a cartogram of United States retail trade with the area state equated with its volume of retail trade (from Harris, 1954).

Source: Harvey (1969: 221)

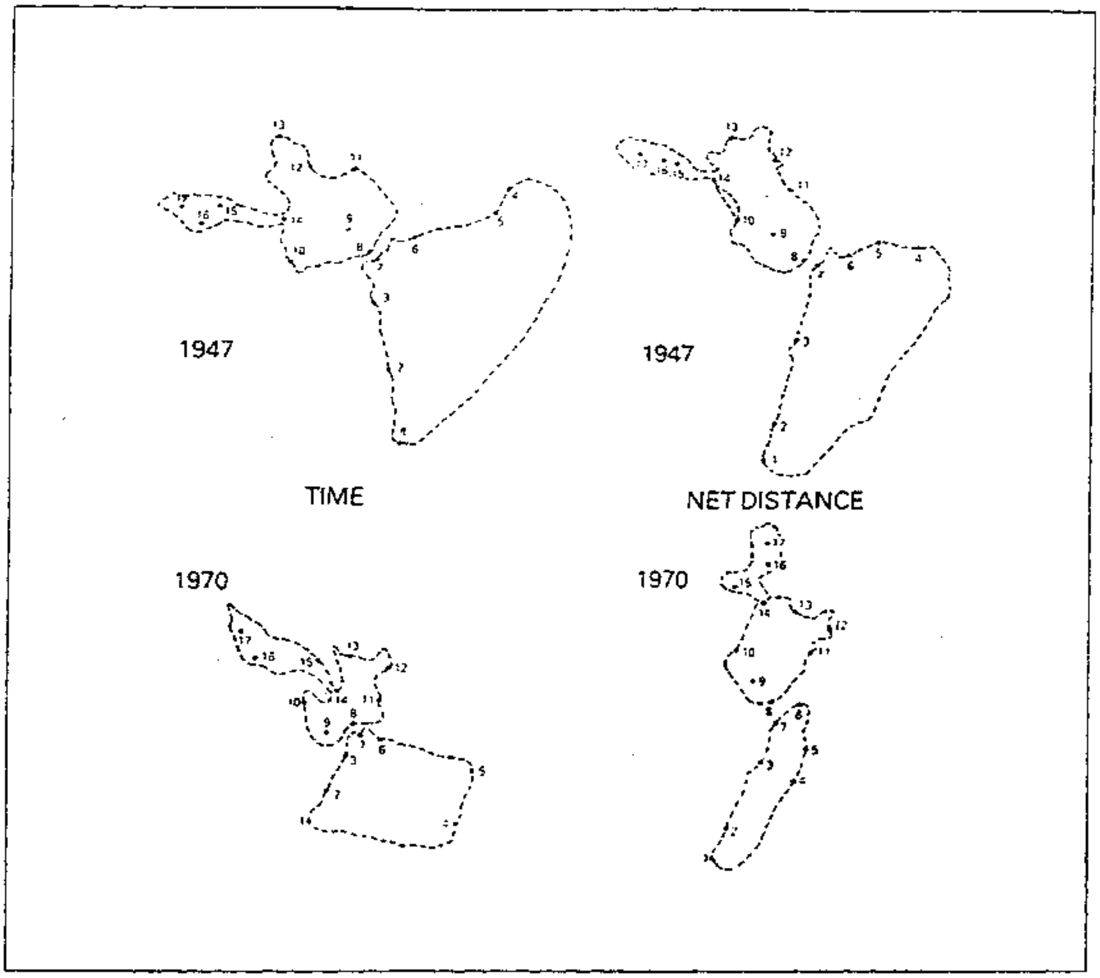

Figure 2.12 A demonstration of the plasticity of space. The four maps have been constructed from data on the New Zealand airline system and its changes from 1947 to 1970. The two maps on the left show how distance measured in time has changed as the airline network has grown and the speed of travel has increased. The maps on the right show how the net distance traveled has changed with the network. (From Forer 7 978).
Source: Holt-jensen (1982: 65).

In a recent note, however, Partha Dasgupta addresses a concern with the problem of linking across spatial and temporal scales within economic theory. Dasgupta points out 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" (1997: 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 are the results of individual decisions that happened very recently). 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 sim*pUfied* 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. 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. He proposes to undertake a research program that involves the development of economic models that have both a sound microeconomic foundation but that also examine the interactions between fast- and slow-moving variables in the economic system and the environmental systems in which an economy is embedded.

Scale is most overtly addressed by macroeconomists interested in the question of economies of scale and optimization problems. Economies of scale (or increasing returns to scale) refer to the phenomenon in which an increase of inputs within some range results in more than proportional increase of outputs (Samuelson, 1973[1955]: 28). The quantity or magnitude of objects in both the input and output streams of a productive process represent 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 get 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[1960]: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). Scholars of industrial organization attempt to deal with economic interactions among firms under these conditions of imperfect competition. Industrial organization theories are focused on explaining the modes of competition (quantity versus price), the production and sales strategies (quality differentiation, limit pricing, or price discrimination), and the internal structure of firms located in the same industry (see Tirole, 1988). 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. Krugman points specifically to models of monopolistic competition, the effects of tax and quotas, price discrimination (dumping), and the effects of government policy on oligopolistic competition.

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 due to transportation costs still engage in trade.

The theoretical model, as mentioned above, does not make any particular assumptions about the *size* of the firms involved or the size of the market. Industrial organization models tend to assume a relatively closed economy, but that economy could be operating at a metropolitan, regional, or national scale. The Cournot model assumes that no borders distort the patterns of interaction among the two duopolists. Applied to the international level, the two countries are not two closed models but are reconceptualized as an economy composed of two distant geographic units. As the international market expands its scope, it is highly likely that more models based on within-country cases will be developed to explain industrial organization between countries. And where international trade is a relatively open, competitive process, the theory of competitive markets developed to explain behavior and outcomes within domestic markets will be applied to international markets.

2.4 *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: 185) or "the physical dimensions of the economy relative to the ecosystem" (Foy and Daly, *1992: 296).* They take the ecosystem as a relatively fixed entity, and argue that the economy grows by exploiting the ecosystem. The scale or level of the economy therefore may serve as an important indicator of how economic subsystems affect the larger 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.). Neoclassical economists were able to avoid the scale of economy issue by assuming that either (1) natural resources are infinite or (2) nature is just another sector of the economy. Consequently, the question of the proper or optimal amount of natural resource use is included in typical marginal cost analysis. 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. An optimal scale of economy is "at least sustainable, but beyond that it is a scale at which we have not yet sacrificed ecosystem services that are at present worth more at the margin than the production benefits derived from further growth in the scale of resource use" (Daly, 1992: 187).

2.5 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 controversy 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: 32), often posed as "the problem of determining the optimal spatial distribution and hierarchy of cities of different sizes" that maximizes per capita income. The functional form of the aggregate income over city size was usually assumed to be concave (meaning increasing returns to scale) to some point and convex later (Tisdell, 1975). In Figure 2.13, for example, P is the optimal size for a certain city. But if the slope of CD exceeds that of OB, the optimal size of the largest city for a given region is greater than P. In this neoclassical regional growth model, the cost of transportation (or the cost of surmounting distance) is the key explanatory variable.

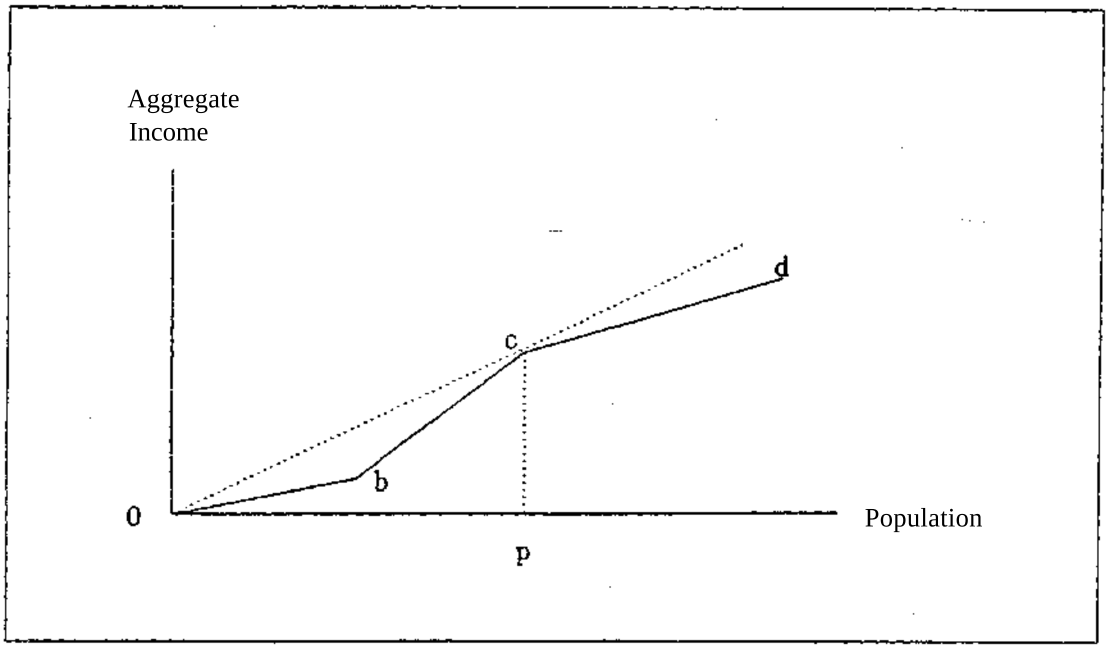

Figure 2.13 Optimum city size.
Source: Adapted from Tisdell (1975: 64).

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 psycho-social characteristics. Researchers have found no general relationship between the size of city and these desired conditions (Duncan, 1980).

2.6 Scale Issues in Sociology

Until recently, scale has not been a major area of discussion or controversy in sociology. With the publication of Charles Tilly's book in 1984, *Big Structures, Large Processes, Huge Comparisons,* however, the issue has been placed 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: 15) including urbanization and migration. This argument differs from those of ecologists in that it assigns one process along one scale a dominant role in affecting all other processes at other scales within a particular time frame. Tilly points to the difficulties involved in understanding social organization during this era since many of the structures related to capitalism and the centralization of power in nation states were new and had not existed before that time outside that space.

For Tilly, the proper problem of studying historical processes in that temporal and spatial extent should start with "locating times, places, and people within those two master processes and working out the logics of the processes" (Tilly, 1984: 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; (4) addressing how systematic, large-scale comparison would help us understand the structure and processes involved; and (5) asking whether it is still appropriate to rely on the intellectual frame we have inherited from the past.

Tilly's work also focuses on the concept of the levels of analysis—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 focus 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: 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 macro-level 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. Though Coleman is not explicit, Weber's analysis could also include more than only two levels (individual and society), such as organizations of merchants or workers.

2.7 *Scale Issues in Political Science*

In a fundamental sense, scale divides 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. Other analytical dimensions also affect what political scientists study—particularly the distinction between individual and group behavior. A large number of political scientists study "political behavior" and tend to focus on the behavior of individuals and their choices concerning participation with a special emphasis on voting. Still others focus on group behavior, particularly that of 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. A major exception to this tendency has been scholars studying federalism that is at its heart a theory of multilevel, linked relationships. The Institutional Analysis and Development (IAD) framework, developed by colleagues associated with the Workshop in Political Theory and Policy Analysis, is another exception due to the focus *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. First, many discussions regarding democracy refer to the contradiction between the image of the original, small Greek city states and the conditions of large, modern nation states. Second, the number of participants has been of major concern to modern political economists who have established fundamental discontinuities between individual and group preferences. Third, spatial relationships are crucial to researchers focusing on the provision of public goods and services in a federal system where a central question is how to define the scale of the public goods and how to organize governmental entities to fit the scale of the good. Fourth, a conceptual scale distinguishing levels of rules *is* part of a general framework developed by political scientists. Fifth, research on the strategies adopted by contending parties, classes, and groups has shown that these entities seek to define and implement policies at the scale that generates most favorable outcomes to them. Thus, the scale at which political activities are undertaken is subject to choice rather than being determined by the scale. Each of these approaches will be discussed below.

Political theorists have addressed the problem of modern democracy as being fundamentally related to the scale of interactions among democratic citizens. Modern democracies are far larger in both demographic and geographic scale than the Greek city states to which their origin is traced. In Greek city states, where the number of citizens was small enough, "government by the people" was generated through direct citizen participation. In modern democracies, however, the conditions of small populations and restrictions on citizenship no longer exist In a major study of this question, Robert Dahl (1989: 215-20) concludes that there are eight major consequences of increases in the scale of democratic polities: (1) representation as an application of the equality principle to large-scale political order, (2) unlimited extension of the scale on which (representative) democracy is possible, (3) limited participation, (4) increased diversity in the factors relevant to political life, (5) increased conflict, (6) polyarchy as "a set of political institutions necessary to the democratic process on a large scale/' (7) social and organizational pluralism, and (8) the expansion of individual rights.

Is democracy possible on the scale of nation-state? Sartori (1987), one of the optimists, argues that democracy is possible because competition among politicians for election and re-election more or less guarantees their responsiveness to citizens. He suggests a redefinition of the meaning of democracy as an output of a political system. Democracy is best understood, then, as "demo-distribution." If the system works effectively, the benefits of a democratic system are equally distributed among citizens. Vincent Ostrom (1991, 1997), who is more cautious, sees modern democracies as being highly vulnerable precisely because of problems related to the scale of interaction among citizens. 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. Benjamin Barber (1992) has also raised serious questions related to the survival of democratic citizenship and high levels of participation as global markets become even more important. He fears that the technocratic and bureaucratic orientations of the more monolithic multinational corporations seriously challenge the access of citizens to information and participation in effective decision making.

Within a broad definition of political science—including scholars from multiple disciplines who focus on political economy, public choice, or social choice questions—theoretical work focuses on scale as a crucial variable. The pathbreaking work of Kenneth 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), first demonstrated that there was a fundamental breaking point in the way that individuals dealt with their own personal preferences and the way that individual preferences are aggregated at a group level. For many centuries, political scientists have referred to concepts like "the public interest," "the general welfare," "social welfare function," or "the general will" with an assumption that there were mechanisms that translated individual interests into a knowable, logically consistent, ordering. Arrow proved that it was impossible to scale up from individual preference functions to produce a group preference function that satisfied what appeared to be an essential set of axioms of desirable properties of an aggregation process. Instead of producing a single equilibrium, it was possible for decisions to cycle between multiple alternatives—each producing a majority vote but no outcome dominating all of the others.

Further, 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. Even more depressing were the proofs by McKelvey (1976) and Schofieid (1978) that unless there was a single outcome that dominated all others, an agenda could be constructed to include every potential outcome as a majority winner. In other words, it is possible for an agenda setter to devise an agenda whereby any policy outcome Under consideration could be achieved. 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 legitimate.

After close to half a century of intensive work, scholars in this tradition recognize that it is impossible to predict simple majority rule outcomes from knowing individual preferences in a manner similar to predicting market outcomes from knowing buyer and seller preferences. Much more detail about the specific institutional rules used to arrive at a decision is needed before a prediction can be made. Thus, instead of a general theory of elections to predict and explain outcomes, one must construct models that involve considerable institutional detail. The importance of this literature for the study of global change processes is the robust finding that the particular institutions used to aggregate choices affect the outcomes to be achieved. Thus, in any nested system, the outcomes achieved at any one level are strongly affected by the institutions used to organize decision-making processes at that level. In turn, the institutional rules used at any one governance level are affected by decisions made at other analytical levels.

The theory of collective action—like the Arrow paradox—also has demonstrated a fundamental discontinuity between rationality at the individual level and the problem of achieving a "rational" outcome for a group facing a social dilemma problem. 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 (Dawes, 1980; R. Hardin, 1982). Social dilemmas abound in human affairs. In many situations, a group of individuals could jointly provide a benefit, such as the reduction of carbon emissions into the stratosphere. Such benefits are automatically received by all individuals living in the world whether or not they contribute. Appropriators using an open-access CPR, such as the ocean fisheries, could jointly harvest at a rate that maximizes economic returns to the group (or the sustainability of the resource), but the incentives facing each appropriator lead to an equilibrium of substantial overharvesting. Many of the problems related

---

[v] Kenneth Shepsle (1979a, 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.

to the study of global change turn out to be social dilemmas upon close examination.

If each individual in these situations selects strategies based on individual, short-term rational calculations, all individuals are predicted to receive an equilibrium outcome that has less value (however this is measured) than one or more alternative outcomes that the individuals could obtain if they had somehow cooperated with one another. In other words, a set of individuals is involved in a game where the Nash equilibria for a single iteration of the game yields less than an optimal outcome for all involved. The optimal outcome could be achieved if those involved "cooperated" by selecting strategies other than those prescribed by a Nash solution to a noncooperative game. Since the less valued outcome is an equilibrium, no one is independently motivated to change their choice, given the choices of all other participants. 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.

Time has become a key variable in efforts to understand why many groups seem to achieve group outcomes not predicted by the initial theory. If a social dilemma game is finitely repeated, and everyone shares complete information about the structure of the situation, the predicted outcome for each iteration is the Nash equilibria for the constituent game. If uncertainty exists about the time or the number of rounds involved, or if the repetition is infinite, the number of possible equilibria explode (Abreau, 1988). Among the predicted equilibria are strategies yielding the deficient Nash equilibria, the optimal outcome, and everything in between. The problem of collective action raised by social dilemmas is finding a way to avoid deficient equilibria and to move closer to optimal outcomes. In Section IV of this paper, we will return to the issue of whether it is possible to generalize across levels drawing on the growing body of theory focused on the problem of collective action.

A closely related body of work in political science focuses on local, regional, and national public economies nested in polycentric governance systems. 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. But simply because market arrangements fail does not make it necessary for national governments to provide all public goods and services. Different configurations of governments may be more efficient and responsive depending upon the nature of the goods and services in question. V. Ostrom, Tiebout, and Warren (1961: 833) define the scale of public goods as "the geographic domain and the intensity or weight of the externality," and suggest four criteria that should be considered in providing and producing such public goods: The criterion of *control* requires that "the boundary conditions of a political jurisdiction include the relevant set of events to be controlled." *Efficiency* requires "the modification of boundary conditions so as to assure a producer of public goods and services the most favorable economy of scale." *Political representation* requires all relevant interests should be included in the arrangement of decision making. The criterion of *local self-*

determination requires that all three of the above considerations should be decided by the citizenry in a relevant community that may be relatively small or may be relatively large (ibid.: 835-36). Given the very large number of goods and services that are provided in most polities and the array of appropriate scales, an effective public economy will depend on the capability of multiple units of government to exist in a polycentric system (see V. Ostrom and E. Ostrom, 1977; E. Ostrom, Parks, and Whitaker, 1978).

The work of Ronald Oakerson (ACIR, 1987) and Roger Parks (Parks and Oakerson, 1993) has examined how local public economies work in metropolitan areas like St. Louis and Pittsburgh. Since most metropolitan areas contain a very large number of units of government, they have been treated by many political scientists as pathologically fragmented and chaotic. 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. 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. Oakerson, Parks, and E. Ostrom—and others working in this tradition—have discovered that public agencies have frequently found ways to contract with each other so as to move production processes characterized by considerable economies of scale to larger units, while keeping many processes subject to diseconomies of scale to smaller units. The overall multilevel, polycentric system is more efficient than having only one large, metropolitan-wide governmental unit or only a single layer of smaller units (see E. Ostrom, 1983; V. Ostrom, Bish, and E. Ostrom, 1988; E. Ostrom, Parks, and Whitaker, 1978).

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, however, do not exist in a vacuum. They 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 themselves are the outcome of decisions made in constitutional arenas structured by constitutional rules (Kiser and Ostrom, 1982; E. Ostrom, Gardner, and Walker, 1994: ch. 2).

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 do change more slowly than collective-choice rules which, in turn, change more slowly than operational rules. And 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 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 2.1 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. Paul Peterson (1981), for example, argues that since 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 which level of political organization will be the most appropriate one for introducing proposals for policy change in collective-choice arenas. This is frequently referred to as "forum shopping." 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 U.S. 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 rela

Table 2.1 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.

tionships 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.

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 different, but enforceable, agreements. Trying to understand what is the impact of dealing with diverse "global change phenomenon" at diverse levels of organization will be one of the central tasks of institutional theorists studying global change processes.

3. Scales, Levels, and Generalizations

The previous review reveals that social scientists offer a variety of propositions important to the understanding of issues of scale. Not all of these propositions involve scaling in the sense of "the transferability of both empirical generalizations and causal inferences from one level to another" (Young and Underdal, 1996: 21). In fact, the propositions that emerge from the social sciences demonstrate the existence of different types of scaling problems that confront those social scientists interested in global change. In this section we discuss aspects of the relationship between scale and generalization. We argue that the global change agenda will need to focus both on the search for propositions that can be transferred between levels, as well as an understanding of how processes may be nested between levels within a hierarchical system (an approach similar to ecology's hierarchy theory).

Generalizations can be made when two phenomena are similar. Such a similarity may be generated by the attributes of the phenomena themselves, or the causal processes in which the phenomena are located, or both. Similarities may be empirically verifiable or assumed.[vi] In chemistry, for example, the similar parts of compounds are not just assumed but have been subjected to replicable and public measurement and verification. Macroeconomists, on the other hand, assume that individuals possess similar motivations, i.e., individuals are utility maximizers, and sometimes seek to support this with data. Followers of each discipline can generalize because of these similarities.

The relationship between generalization and scale, however, is not straightforward. As illustrated in Figure 3.1, researchers may have to understand multiple processes with different levels, e.g., studies of the global hydrological cycle must integrate across units of the earth system with vastly different spatial and temporal dimensions. Figures 3.2-3.9 help illustrate this argument. In each figure, the geometric shapes denote some process or phenomenon that can be considered distinct from another process or phenomenon (or group of processes or phenomena). Innumerable processes exist, so the schema could be extended in both levels and numbers. Processes differ both within and along any particular scale, e.g., the same "low" level of the scale found in Figure 3.2 has two processes, a rectangle and a circle; the figure also has different processes along its scale, e.g., a star, a triangle, and a rectangle.

[vi] It is easier to identify real similarities when phenomena have fewer attributes, can be isolated from other phenomena, and can be used in experiments.

Figure 3.3 displays a situation in which a process at one level helps determine a second process at the same level. The process depicted by the rectangle influences the circle process in some way. This is the type of explanation found most commonly, since any increase in the number of levels will increase the number of processes involved in an explanation. Since these processes occur only at one level, and since they are not similar sui generis, both scaling issues and generalizations can be ignored in this example.

Comparing similarities across one scale is the simplest form of generalization. In Figure 3.4, one process (the rectangle) is very similar to another (the square). Both rectangles can be considered functional units, like an organism or a community (in hierarchy theory, these are not necessarily correlated on a spatial scale). Examples of this type of generalization abound in relationship to global change issues. The process of providing a public good may share many attributes whether the public good is strictly local (e.g., preventing the spread of a disease vector like mosquitos), national (providing national defense), or international (reducing the level of atmospheric carbon dioxide).

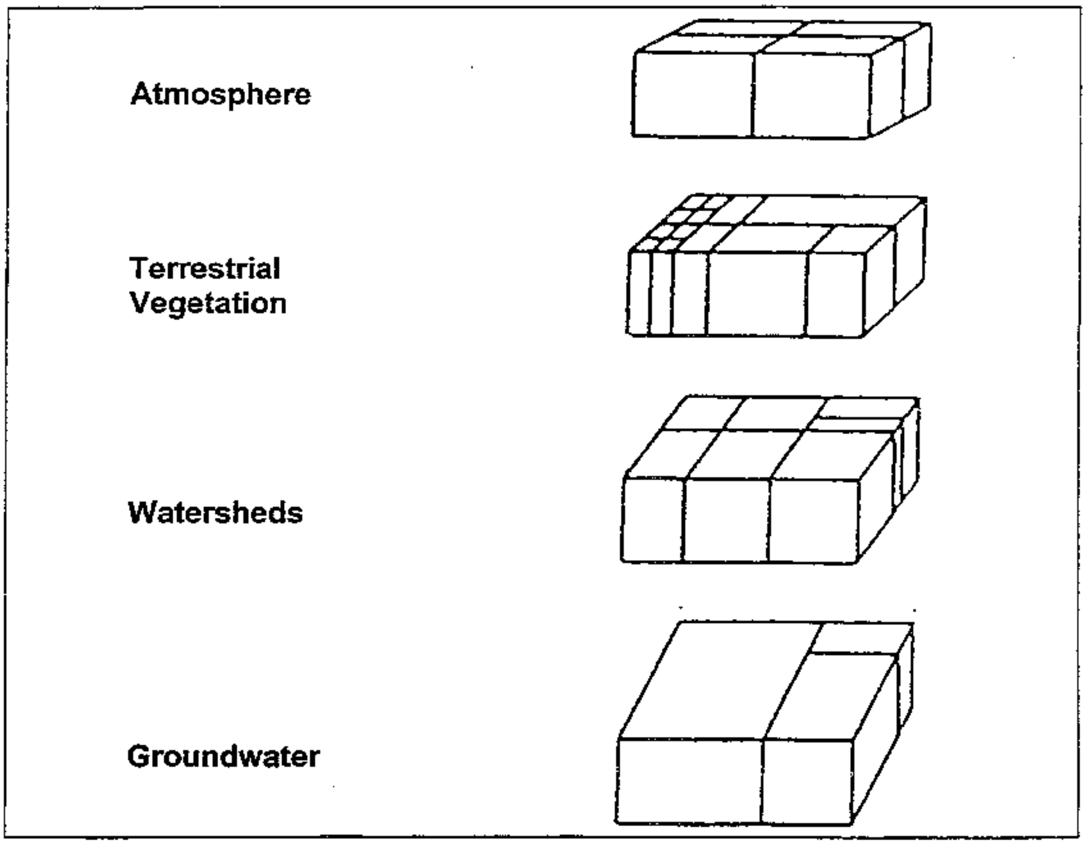

Figure 3.1 Study of global hydrological cycle must integrate cross units of the earth system that have different spatial and temporal dimensions. (Adapted from van der Heijde 1988.)
Source: M. Turner, Dale, and Gardner (1989: 246).

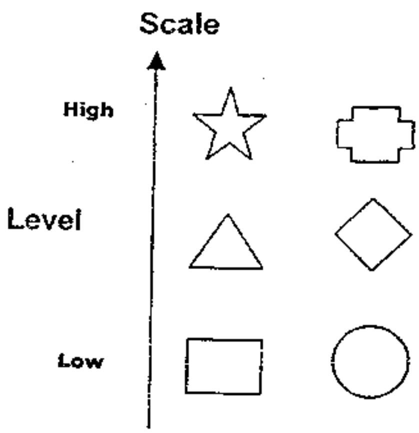

Figure 3.2 Different processes, denoted by geometric shapes, occuring at different levels along a particular scale.

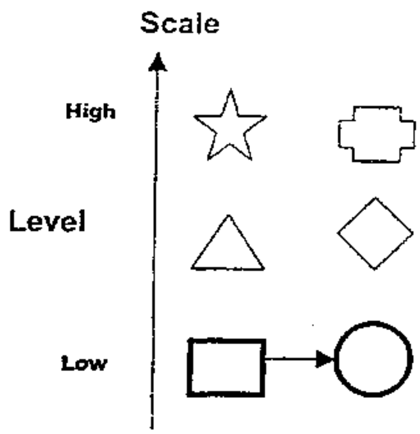

Figure 3.3 One process influencing another process at the same level of scale.

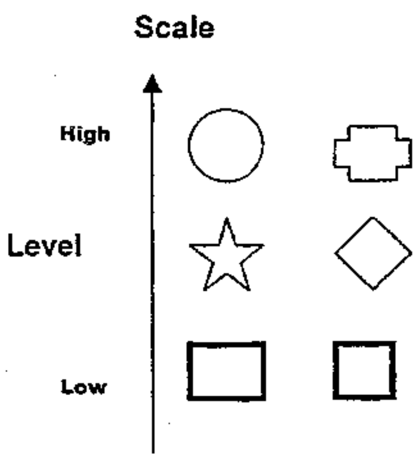

Figure 3.4 Two similar processes at the same level.

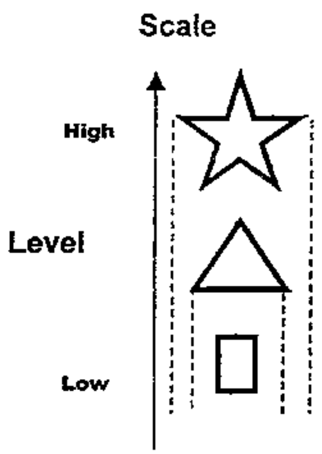

Figure 3.5 An exclusivele hierarchy. Levels arre linked not by the simiarity of processes but by a hierarchical raltionship, e.g. military organizations. No causation is implied.

The application of duopoly theory to international trade by Krugman (1986) is another good example of this type of generalization. Krugman extends a theory of the behavior of firms across the levels of governance, i.e., from domestic to international. In an important sense, Krugman has identified a functional unit—a market with two firms operating in it. Krugman's contribution is to see that two different processes have similar underlying structures while assuming exactly the same type of actors. An example more directly related to the environmental aspects of global change is the work done on forest frontiers (Brondizio et al, 1996). The behavior of individuals with respect to clearing forest for land occurs at roughly the same spatial and temporal level. The general similarities in the conditions and motivations of frontier people across cultures and time (e.g., midwestern United States of a hundred years ago versus contemporary Amazonia) make it a topic ripe for further exploration (Schweik, 1997; Moran et al., 1994; McCracken, Safar, and Green, 1997). These are all examples of generalizations along one level of a scale.

Focusing at a single level possesses the advantages of being the most analytically tractable. This helps to explain why so much work in the social and natural sciences remains at a single level: anthropologists generally confine their studies to the level of the community, political scientists to the level of a specific political level, chemists to subfields of chemical types, etc.

But single-level analyses have two weaknesses when considering the global change agenda. First, unless they employ theoretical foundations that are not scale specific (an important point to which we will return), single-level studies are unlikely to account for outcomes at levels different from themselves. It is reasonable to assume, like hierarchy theory, that processes and phenomena at any one level are likely to possess substantially unique attributes and processes, making simple comparisons across levels a dubious enterprise. Second, unless linked directly to a problem or issue dealing with global change, the knowledge gained at any one level may or may not help explain those processes more central to the global change agenda.

Because of the numerous and multilevel processes that are the object of much of the human dimensions of global change agenda, researchers cannot avoid the scaling issue. Global changes occur at numerous spatial, temporal, and quantitative scales and levels, as do the human activities that are part of such changes. The difficulty of explanation increases with the number of levels involved. For example, explanations of deforestation at the national level (i.e., population, per capita income) do a poor job at explaining the variation of deforestation at sub-national levels (P. Turner, 1995). At the same time, the processes at the national level may have substantial impacts on those processes at the regional and local levels and vice versa.

It is important to note that not all multileveled frameworks confront these challenges. Some conceptual frameworks use multiple levels only to order processes or phenomena. In Figure 3.5, for example, the multiple levels are related through some relationship, not by causation. A good example of this exclusive hierarchy is the system of rank used by the armed forces: each lower-level member is linked in an authority relationship with people above in the hierarchy. The members at different levels share some attribute(s) (e.g., being in the military and having authority distributed according to rank) but may not share others (they may not be in the same division or unit). In Figure 3.6, in contrast, the processes or phenomena do share attributes. An example of this inclusive hierarchy is the Linnaen system of scientific names that we give to plants and animals. Each belongs to several inclusive groups within a hierarchy (family, genus, species). Like an exclusive hierarchy, the primary effort is classification. Modern classification efforts have tried to classify based on the concept of a common ancestor, so evolutionary theory has affected the classification system. Still another form of hierarchy is the constitutive inclusive form shown in Figure 3.7. In this hierarchy, the processes or phenomena at one level can be aggregated into a process or phenomena at another. An example of this hierarchical type can be found in biology, where cells make up organs; organs make up organisms, and organisms make up groups. The levels in an inclusive constitutive hierarchy can be analyzed for some purposes independent of higher or lower levels, but what happens at any one level is affected by what happens at the level above or the level below.

Explanations of processes or phenomena at different levels, however, require different frameworks than inclusive or exclusive hierarchies. We assert that at least two approaches can help overcome the multilevel problem. The first is to adopt a theoretical framework that can transcend levels. In Figure 3.8, the rectangular process at the top of the first column is similar to the process at the bottom of the column. Notice that they are not exactly the same process, since they occupy different levels of a scale. Yet their structure may be similar enough that a generalization can be made either by moving up or down levels. This is precisely the type of generalization attempted by McGinnis and Ostrom (1996). By employing theories of collective action to international relations, they help to account for some behavior at a different level. In doing so, however, they had to assume some fundamental similarities for the attributes of the actors and the causal processes involved. The increasing use of rational choice theory, especially in institutional analyses, can also be seen as an attempt to transcend levels (North, 1990; Eggertsson, 1990). By assuming that actors are fundamentally similar in their behavior, and by confining their analyses to similar processes, scholars are able to explore phenomena at the same level or across levels.

The assumptions that have to be made to generalize across levels or scales, however, may decrease the usefulness of the generalization. Economists make the strongest assumptions in their models, and their results have been roundly critiqued for their lack of fit to the real world. Institutional analysts make less restrictive assumptions in their work, but their attempts at generalization have also been attacked on the grounds of narrow assumptions and poor empirical fit, especially in explanations of voting behavior (Green and Shapiro, 1994).

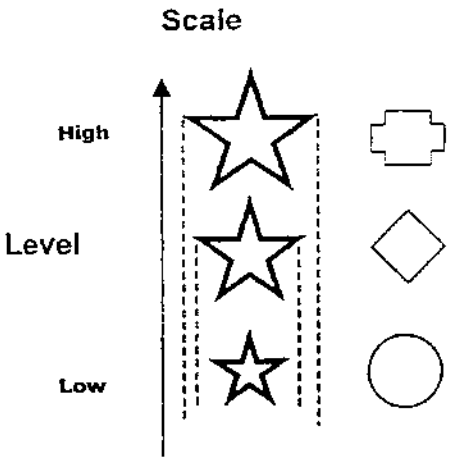

Figure 3.6 An inclusive hierarchy. Processses are included categorically within each other. Rather than linked by their relationship, all higher level processes share a trait(s) with lower level processes, e. g. Linnaen classification system. No causation is implied.

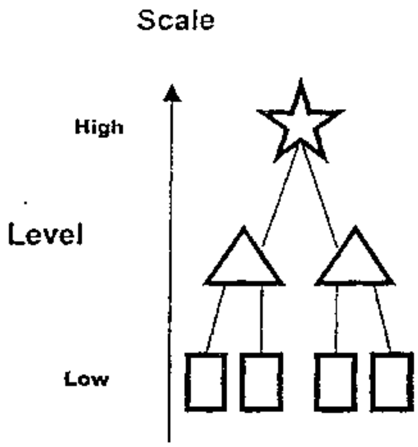

Figure 3.7 Inclusive constitutive hierarchy. Entities at each level combine to form entities at the next, although no direct causation is implied. Aggregation, rather than relationship, is important here.

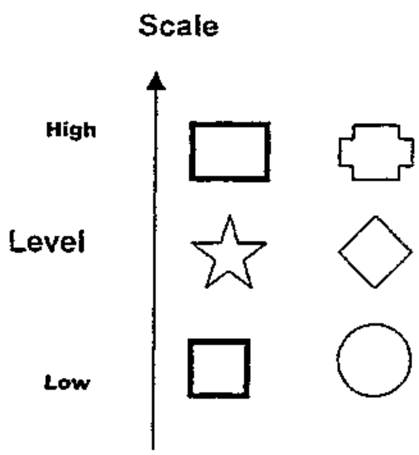

Figure 3.8 Two similar processes at different levels.

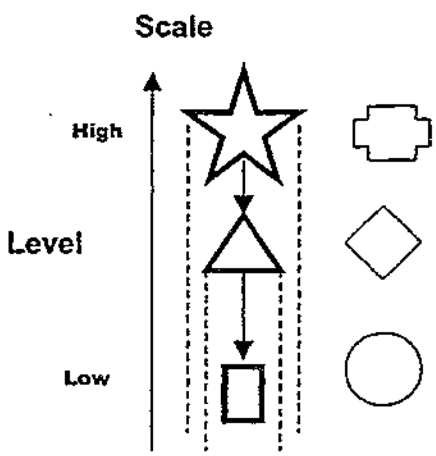

Figure 3.9 A hiearchy of causation. Processes set constraints for the level above or below. Processes at different levels may or may not share traits. This is similar to ecology's hierarchy therory.

Another way to approach multileveled and multiscaled phenomena may be gleaned from ecology's hierarchy theory. As mentioned, any problem or issue important to the global change agenda is likely to entail multiple processes at multiple levels. Figure 3.9 depicts a situation where the rectangle at the low end of the first column of processes is related to different processes at different levels of a scale. In this example, the search for a generalization to explain the rectangle process at a different level will prove fruitless, since all the processes in this example are distinct. Nevertheless, the processes are linked, or nested. Thus, an understanding of the square process, or any of the processes involved with this issue area, requires an understanding of the processes at all levels. The direction of the arrows could be reversed, signifying that lower-scaled processes are critical to processes at higher levels; or the arrows can be double-headed, signifying an interaction between processes.

Tsebelis (1990) takes this approach when he attempts to account for legislative outcomes by exploring individual behavior at two levels. Like McCinnis and Ostrom, he assumes that the motivations of his actors in his analysis are exactly the same, allowing for an easier comparison across levels. But Tsebelis also does something quite different: he uses a two-level or nested game. At each level, individuals operate within different processes. The outcome of processes at one level, however, helps to shape the types of processes at another level. This method allows Tsebelis to explore different phenomena at different levels to explain one outcome. Like hierarchy theorists, Tsebelis understands that processes at one level may set constraints on processes at a different level. Putnam has also explored the concept of nested processes in his work (Putnam and Tarrow, 1978), as has Coleman (1990).

The task in employing this approach is to identify what processes need to be explored to answer certain questions, to identify the levels at which they operate, and to examine both the processes and their links to each other. As proponents of hierarchy theory assert, this approach is more difficult than it appears. And yet it is interesting to note that many social scientists have already explicitly or implicitly adopted this approach in their work. Tilly (1984) has argued that studies of social phenomena must take into account the development of nations and capitalism; thus for Tilly, those two master processes stand at the top of his hierarchy and pose constraints on lower levels. The IAD framework developed by colleagues associated with the Workshop in Political Theory and Policy Analysis argues for three arenas of collective choice, each embedded within the other (see Kiser and Ostrom, 1982; E. Ostrom, Gardner, and Walker, 1994). Gibson (forthcoming) argues that understanding the outcomes of government policy requires a multilevel approach, since the actors and processes at each level of the policy process are different and yet impose constraints on actors at other levels. And, McGinnis (1997) has moved toward this nested view for explanations of international relations.

The effort to understand the processes of global change does require an alteration to the traditional approaches as used by social scientists. First, social scientists must explicitly contend with many processes at many levels. Second, they will likely need to extend their own scales of time and space. Third, social scientists interested in generating theory or extending propositions across levels or scales must ensure that such work includes those processes, levels, and scales that are of central importance to the global change agenda. We contend that one such social science theory that is likely to be fruitful to this endeavor is the theory of collective action.

4. Collective-Action Theory at Multiple Levels

Since many social scientists have organized their subdisciplines using an implicit spatial scale to determine what they study, there has been little serious attention to the types of processes that exist at multiple geographic levels versus those that exist at only one level. As we discussed above, a key finding of hierarchy theory is that functional units are not bounded precisely by either space and time. For ecologists, functional units include organisms, communities, and ecological systems. Many communities of organisms (such as insect communities) are themselves much smaller than the single organism (such as a tree) on which they are located. Since functional units are not themselves scale dependent, many of the theories that explain the structure and behavior of functional units may not themselves be scale dependent. Many of the theories explaining mammalian structure and behavior apply as much to mice as they do to elephants. If one is asking, however, about the impact of the number of a particular species on an ecological system, the response one makes about mice differs from the response made for elephants. Thus, many theories apply to small-scale animals and large-scale animals equally well, but the actual *size* of organisms makes a substantial difference when addressing some particular questions.

In Section III, we illustrated the potential scale independence of similar processes or functional units in Figure 3.8, depicting two rectangles at two distinct levels on the same scale. To the extent that a theory exists for explaining the processes within "rectangles," propositions about these processes derived from observations at one level should generalize to other levels. Thus, it should be possible to scale up and down—at least to some extent—when we are talking about the same kind of process or functional unit. For some questions, however, the particular size, quantity, or temporal extent may be quite relevant to addressing a question.

The problem for social scientists is that the functional concepts similar to "organisms" and "communities" have been difficult to identify. Our organisms and communities are not as obviously self-contained as those studied by ecologists. We have tended to focus more on the conspicuous differences between local, regional, national, and international levels of organization—in terms of their spatial extent—and less on types of processes that may occur at multiple levels. Political scientists, for example, tend to study particular levels of government rather than studying particular processes that are involved in governance at many diverse levels. During the past several decades, however, this has slowly changed. For example, the theory of committee and legislative voting is now applied to a diversity of representative bodies ranging in size from local village councils, to national legislatures, to the United Nations. And recent research on the theory of collective action appears to offer the prospect of being generalizable across local, regional, national, and perhaps, even international levels. We argue that work on collective action should be a central feature of social scientists' efforts to contribute to the global change agenda. Several branches of work regarding collective action exist; here we focus on the two most related to the global change agenda: collective action and the provision of public goods, and collective action and the appropriation of CPRs.

One area where collective action has been widely applied to the study of public goods concerns the provision of a good which, once provided, is available to a set of beneficiaries whether or not they contribute to its provision (but whose consumption does not interfere with one another)—such as the creation and enforcement of a set of rules that helps to regulate a CPR. To generalize from one level to another using this approach, it is quite important to clarify precisely the specific question and process under investigation. If this process is indeed the same process, it should be possible to learn from research conducted at one level about some aspects of the same process at a different level. If, however, one attempts to study loosely related processes at multiple levels, one may be attempting to generalize across entirely different processes. Using figures from Section III, one would be attempting to generalize from a theory of circles to a theory of squares.

Another main branch of collective-action theory has been applied to the study of CPRs. Such resources share with public goods the problems associated with exclusion, but also have a pernicious appropriation problem: they can be overused or destroyed due to the subtractability of the resource units (see E. Ostrom, Gardner, and Walker, 1994). The theory of CPRs is most relevant when one is studying appropriation processes at an operational level of analysis. The core question addressed when studying appropriation processes is whether the individuals harvesting some kind of resource unit from a CPR will take the externalities of their individual actions into account in deciding when, where, and how to appropriate research units from the resource.

The initial theory of CPRs did focus on the appropriation process and was strongly affected by the early studies of open-access fisheries by Gordon (1954) and Scott (1955).vii Most theoretical studies by political-economists have analyzed simple CPR systems using relatively similar assumptions (Feeny, Hanna, and McEvoy, 1996). In such systems, it is assumed that the resource generates a highly predictable, finite supply of one type of resource unit (one species, for example) in each relevant time period. At the operational level, appropriators are assumed to be homogenous in terms of their assets, skills, discount rates, and cultural views. They are also assumed to be myopic, profit-maximizing actors who possess complete information. In this theory, anyone can enter the resource and appropriate resource units. Appropriators gain property rights only to what they harvest, which they then sell in an open competitive market. The open access condition is a given. The appropriators make no effort to change it Appropriators act independently and do not communicate or coordinate their activities in any way. Thus,

vii This section of this paper draws heavily on E. Ostrom, 1998b.

In this setting, as the incisive analysis of Cordon and Scott demonstrates, each fisherman will take into account only his own marginal costs and revenues and ignores the fact that increases in his catch affect the returns to fishing effort for other fishermen as well as the health of future fish stocks. . . . [E]conomic rent is dissipated; economic overfishing, which may also lead to ecological overfishing, is the result (Feeny, Hanna, and McEvoy, 1996: 189),

Many textbooks in resource economics and law and economics have presented this operational-level theory of appropriation from a CPR as the only theory needed for understanding CPRs more generally (see Dasgupta and Heal, 1979; for a different approach, see Baland and Platteau, 1996). With the growing use of game theory, appropriation from CPRs \s frequently represented as a one-shot or finitely repeated Prisoner's Dilemma game (Dawes, 1973; Dasgupta and Heal, 1979). These models formalize the problem differently, but do not change any of the basic theoretical assumptions about the finite and predictable supply of one resource unit, complete information, homogeneity of users, their maximization of expected profits, and their lack of interaction with one another or capacity to change their institutions.

The initial simple theory was developed to explain the overuse or collapse of relatively small CPRs. It turns out that the initial theory has offered better predictions for appropriation behavior and outcomes related to CPRs with a very large geographic domain and where a large number of individuals are involved who are not able to communicate effectively, do not trust one another, have relatively short-term time-horizons (because they can move on to other resources or other occupations), and have no external authorities that might enhance the problem-solving capabilities of those involved. Thus, the prediction that the appropriators will simply overharvest has been supported by empirical evidence in many large-scale CPRs.viii

During the last decade, extensive research at the local level has demonstrated that in many instances—but certainly far from all cases—the appropriators themselves recognize the joint problem they face, get together to discuss it, and engage in organizational activities to provide themselves with a better set of rules to regulate the use of the resource. The possibility that the

viii Empirical examples exist where the absence of property rights and the independence of actors is the essence of the problem facing appropriators. The desertification of the Saheiian area, the massive deforestation in tropical countries, and the collapse of the California sardine fishery and other ocean fisheries confirmed the worst predictions to be derived from this theory for many scholars. Garrett Hardin's (1968) dramatic article in Science convinced many noneconomists that this theory captures the essence of the problem facing most CPRs in the world. Since appropriators are viewed as being trapped in these dilemmas, repeated recommendations have been made that external authorities must impose a different set of institutions on such settings. Some recommend private property as the most efficient form of ownership (Demsetz, 1967; Posner, 1977; Anderson and Hill, 1983). Others recommend government ownership and control (Ophuls, 1973). Implicitly, theorists have assumed that regulators will somehow act in the public interest and understand how ecological systems work and how to change institutions so as to induce socially optimal behavior (Feeny, Hanna, and McEvoy, 1996:195).

appropriates would attempt to provide new rules was not even contemplated in the initial, simple theory. Organizing at a constitutional level to establish collective-choice rules, and at a collective-choice level to create rules that specify rights and duties of participants, creates public goods. Anyone who is included in the community of users, benefits from these public goods whether they contribute or not. Thus, getting "out of the trap" is itself a second-level dilemma. Further, investing in monitoring and sanctioning activities so as to increase the likelihood that participants follow the agreements they have made also generates a public good. Thus, these investments in governance represent a third-level dilemma.

Since much of the initial problem exists because the individuals are seen as stuck in a setting where they generate negative externalities on one another, it was not consistent with the initial theory that they solve a second- and third-level dilemma in order to address the first-level dilemma under analysis. Since the mid-1980s, however, a substantial body of empirical studies in experimental laboratories and in field settings has begun to challenge the theoretical presumption that only external authorities can effectively change the rules used to govern local CPRs. A wide diversity of resource regimes has been documented where users have successfully managed local natural resources for a long period of time—centuries in some cases. At the same time, empirical studies also document the failure of many resource regimes at the local level as well as at larger spatial extents. The consequence of these empirical studies is not to challenge the empirical validity of the simple theory where it is relevant, but rather its generalizability to all settings.

Thus, instead of presuming that individuals cannot possibly provide the public good of better rules for themselves, scholars have been actively studying a wide diversity of local irrigation systems, inshore fisheries, grazing areas, forest institutions, and other local CPR's. What they have found is considerable variance in the capability of appropriators to organize themselves. Given this variability, the empirical study of multiple resource regimes is an important source of evidence for the still further development of better theoretical integration and understanding. Young and Underdai have identified some of the important related questions to be asked:

Are there certain factors that are common to successful resource regimes regardless of the resources they address or the level of social organization at which they operate? Conversely, are resource regimes highly situation specific in the sense that success depends on tailoring the characteristics of these institutional arrangements with great care to the particular setting in which they are expected to operate? (1996: 62)

As they point out, the answers to these questions "will have far-reaching implications for the efforts of those charged with controlling patterns of land use in the interests of coming to terms with large-scale environmental change" (Idem). We will first address these questions at a local level and then turn to how the evolving theory of providing public goods can then be applied to larger CPRs.

What has been found almost universally is that when individuals are appropriating from a CPR where no effective rules exist limiting who can access and withdraw units from the resource and the resource units generate benefits greater than the costs of appropriation, overuse will be the result. The real question then turns to whether the individuals can overcome the second-level social dilemma involved in providing organization and a new set of rules.

Evidence from a wide diversity of studies has now begun to identify factors that are associated with an increased likelihood that appropriators will halt their continued independent appropriation and invest in the provision of an improved set of rules—either entirely on their own or with the help of external authorities. A fully articulated, reformulated theory does not *yet* exist. On the other hand, scholars familiar with the results of field research substantially agree on a set of variables that enhance the likelihood of appropriators organizing themselves to avoid the socially costly patterns of open-access CPRs (McKean, 1992, 1996; Wade, 1994; Schlager, 1990; Tang, 1992; E. Ostrom, 1990, 1992a, 1992b; Baland and Platteau, 1996; E. Ostrom, Gardner, and Walker, 1994). We will first present the variables that have been consistently identified as being associated with the likelihood that individuals will overcome collective-action problems in smaller-scale CPRs. Then, we will explore how these variables may be relevant for scaling up to larger-scale public good problems.

4.1 Variables Associated with Organizing to Cope with CPR Problems

Drawing heavily on E. Ostrom (1992b: 298-99) and Baland and Platteau (1996: 286-89), Tables 4.1 and 4.2 below summarize the considerable consensus that exists that the following attributes of a resource and of the appropriators using a resource are conducive to an increased likelihood that the appropriators will organize to engage in collective action.

Table 4.1. Attributes of the Resource (A)

A1. Moderate scarcity	Resource units are not so scarce that it is useless to organize, or so abundant that little advantage results from organizing.
A2. Indicators	Reliable and valid indicators of the condition of the resource system are available at a relatively low cost
A3 Predictability	The flow of resource units is relatively predictable.
A4. Spatial extent	The resource system is sufficiently small, given the transportation and communication technology in use, that appropriators can develop accurate knowledge of external boundaries and internal microenvironments.

Table 4.2. Attributes of the Appropriators (B)

Bl.Salience	Appropriators are dependant on the resource system for a mafor portion of their livelihood.
B2 Knowledge	Appropriators have a shared image of how the resource system operates and how their actions affect each other and the resource system.
B3. Discount rate	Appropriators use a low discount rate in relation to future benefits to be achieved from the resource.
B4. Distribution of interests	Appropriators with higher economic and political assets are adversely affected by a lack of coordinated patterns of appropriation and use.
B5. Trust	Appropriators who trust one another to keep promises and relate to one another with reciprocity.
B6. Autonomy	Appropriators are able to determine access and harvesting rules without external authorities countermanding them.
B7. Prior organizational experience	Appropriators have learned at least minimal skills of organization through participation in other associations or learning about ways that other groups have organized.

These tables provide useful lists of empirical findings from studies of smaller-scale settings where individuals face provision problems. To examine the question of how one might scale up from these observations at a local level to address the question of what factors at a large or very large scale would also be conducive to solving provision, one needs first to begin to integrate these observations into a more general theory. The key to further theoretical integration is to understand how these attributes interact to affect the basic benefit-cost calculations of participants. We will begin this task here, but we are aware that much needs to be done to arrive at a fully integrated theory.

Appropriators using a CPR for which no rules have yet been devised—an open-access resource—will compare the expected net benefits of continued harvesting from an ungoverned resource to the increased benefits they expect to achieve with a new set of rules. If they do not expect the new rules to produce a higher level of benefits than their present system, there is no incentive for them to change their harvesting activities. If the expected benefits of a change are positive, then they need to estimate the up-front cost of the time and effort of devising and agreeing upon new rules, the immediate costs of new strategies, and the long-term costs of monitoring and maintaining a self-governed system over time (given the norms of the community in which they live). If the sum of these expected costs for most appropriators exceeds expected benefits, appropriators will not invest the time and resources needed to create new institutions.

For appropriators to provide the collective good of new rules (in other words, for an institutional change to occur as the result of the actions of appropriators), expected benefits must clearly exceed expected costs for that proportion of individuals in a particular setting that is needed to affect a change. The meta rule used to change institutional arrangements in local field settings varies from reliance on the decisions made by one or a few leaders, to a formal reliance on majority or super-majority vote, to reliance on consensus or close to unanimity. (In international settings, we generally see states adopt a base rule of unanimity for constitutional-level decisions.) If expected benefits from a change in institutional arrangements, however, are not greater than expected costs for most appropriators, the costs of designing and enforcing a change in institutions will be much higher than if most participants expect to benefit over time from a change in rules.

The attributes of a resource affect both the benefit and cost sides of an individual's calculus. If resource units are relatively abundant (A1), there are few reasons for appropriators to invest costly time and effort in organizing. If the resource is already substantially destroyed, the high costs of organizing may not generate substantial benefits. Thus, self-organization is likely to occur only after appropriators observe substantial scarcity. The danger here, however, is that when rapid exogenous shocks lead to a change in the relative abundance of the resource, appropriators may not be able to adapt rapidly enough to the new circumstances.

The work of Holling and his colleagues on resource system resilience is quite relevant here. Most unexploited natural resources retain a substantial amount of "conserved" biomass available for harvesting. The withdrawal of initial units may even increase the productivity of a biological common-pool even more productive by taking off units that previously would have been left to compete with the remaining units. As additional units are harvested, however, the negative externalities of each person's actions aggregate, and the resource system may tend toward the r phase (see Figure 2.7). They key problem is whether appropriators (or others) are able to reorganize the rules that govern and manage their use of the system before it loses its resilience and/or loses its productivity. Thus, the feedback of rapid and reliable information about the state of the ecological system (A2), and the sensitivity of the system to being drawn down before new use patterns can be constructed, are fundamental to the process.

A resource flow that is highly predictable (A3) is much easier to understand and manage than one that is erratic. In the latter case, it is always difficult for appropriators (or, for that matter, scientists and government officials) to judge whether changes in the resource stock or flow are due to overharvesting or to random exogenous variables (e.g., Feeny, Hanna, and McEvoy, 1996, discuss these issues in the context of the collapse of the California sardine industry).

Variables AT, A2, and A3 are relatively scale- and level-independent. Scarcity and predictability characterize resource systems in ail size ranges. Developing reliable indicators may be more expensive for large-scale CPRs, but the importance of this variable should apply at both small and large levels. The fourth variable—the spatial extent of a resource (A4)—focuses precisely on spatial scale. This variable depends upon a relative measure of spatial extent, rather than an absolute measure (see discussion of relative measures in Section II). The question is not the size of a resource in absolute terms but rather its size relative to transportation and communication technologies. A forest may be viewed as very large and extensive by forest users who have only mules and dirt trails as their means of transportation (see Becker and Gibson, 1996), while the same size forest might be viewed as relatively small by those using motorized vehicles on tarmac. The key problem is whether the costs of monitoring what is happening in the resource system are relatively low for those who are managing the system, given the transportation and technology available to them.

The attributes of the users also emerge as important to questions regarding scaling. If appropriators do not obtain a major part of their income from a resource (BI), the high costs of organizing and maintaining a self-governing system may not be worth the effort. Similarly, if appropriators do not share the knowledge of how complex resource systems operate (B2), they may not recognize the consequences of their own actions on long-term benefits and costs. Given the complexity of many CPRs—specially multispecies resources in tropical countries—understanding how these systems work may be difficult even for those who make daily contacts with the resource. For resources that are highly variable (A3), it may be particularly difficult to untangle those outcomes stemming from exogenous factors from those resulting from the actions of appropriators. Of course, this is also a problem facing officials as well as appropriators. Appropriators with many options who can discount the importance of future income from a particular resource (B3), may prefer to "mine" one resource without spending resources to regulate it. They simply move on to other resources once this one is destroyed, assuming there will always be other resources available to them.

Appropriators who possess more substantial economic and political assets may be similar to those with fewer assets on other relevant dimensions (B4) or they may differ substantially on multiple attributes. When the more powerful have similar interests, they may greatly enhance the probability of successful organization if they invest their resources in organizing a group and devising rules to govern that group. Mancur Olson (1965) long ago recognized the possibility of a privileged group, i.e., a group of individuals who are sufficiently affected by a situation to desire to bear a disproportionate share of the costs of organizing to provide public goods (such as the organization of a collectivity). On the other hand, if those with more assets also have low discount rates (B3) related to a particular resource and lower salience (BI), they may simply be unwilling to provide the organizational inputs required, or alternatively, interfere with such efforts so that they do not have to reduce their productive activities. We will discuss the importance of heterogeneity of interests—as well as other important variables—in more depth below.

Appropriators who trust one another (B6) to keep agreements and use reciprocity in their relationships with one another face lower expected costs involved in monitoring and sanctioning one another over time. Appropriators who lack trust at the beginning of a process of organizing may be able to build it over time if they initially adopt small changes that most appropriators follow before trying to make major institutional changes. Autonomy (B7) tends to lower the costs of organizing. A group that has little autonomy may find that those who disagree with locally developed rules seek contacts with higher-level officials to undo the efforts of appropriators to achieve regulation. (See Libecap, 1*995,* for a discussion of the efforts to use the courts to challenge the validity of de facto governance of inshore fisheries in the U.S.; see also Alexander, 1982). With the legal autonomy to make their own rules, appropriators face substantially lower costs in defending their own rules against other authorities. Prior experience with other forms of local organization (B7) greatly enhances the repertoire of rules and strategies known by local participants as potentially useful to achieve various forms of regulation. Further, appropriators are more likely to agree upon rules whose operation they understand from prior experience, than upon rules that are introduced by external actors and are new to their experience.

If we move up to the level of an international CPR, we can begin to outline a theory of appropriators that uses the insights generated by community-level work. We can certainly see the incentives provided to actors if they depend heavily on a resource played out at the international level (B1). Although international cartels do break down, those countries whose economies are linked strongly with certain commodities expend a great amount of energy trying to establish agreements that protect their interests. The converse, however, may not be as true at the international level as at the local level: countries with less dependence on a process may still bear the costs of arriving at a collective outcome, i.e., industrialized countries' concern for deforestation in nonindustrialized countries. In some cases, the political benefits that are available for constructing public goods at the international level may be relatively greater than the political rewards available at lower levels. Nevertheless, the theoretical foundations for the importance of dependence—actors' incentives—stand at both levels. The import of attributes B2 through B7 also have salience for the international arena, and a fertile area for research would be the exploration of such linkages.

The growing theoretical consensus related to the above variables does not lead to a conclusion that most appropriators using local CPRs will undertake self-governed regulation. Many settings exist where the theoretical expectation will be the opposite: Appropriators will continue to overuse the resource and will fail to provide an effective level of organization to change the incentives in their ongoing appropriation problem. Unless the variables listed above generate an expectation on the part of those who must agree on new rules that benefits will exceed costs, then the theorists must predict that overuse will continue. If most participants perceive a positive benefit-cost ratio, there is still no guarantee that they will solve their provision problem. Using a game-theoretical approach to this problem, in an indefinitely repeated setting, such a perception of net expected benefits is consistent with achieving a better equilibrium, but many other equilibria are also possible including continued overappropriation. Other factors that can influence the perceived costs and benefits include individuals' time horizon, linkages to other resources, trust, etc. It is exactly some of these that may be crucial, although of different values, to how we understand cooperation or its failure in a very large system. Thus, the theory would make different predictions for different kinds of systems—both resources that are relatively small scale and those that are relatively large-scale. The theory has not changed. The difference between this growing integration and the earlier theory is that now multiple predictions are consistent with the theory rather than there being only one prediction.

There is one additional, major factor that is different between local CPRs and those that exist at an international level. Many of these variables at a local level are in turn affected by the type of larger regime in which users are embedded—as one would expect from hierarchy theory. Larger regimes can facilitate local self-organization by providing accurate information about natural resource systems, providing arenas in which participants can engage in discovery and conflict-resolution processes, and providing mechanisms to back up local monitoring and sanctioning efforts. Macroinstitutional environments can also prevent or extinguish the possibility of lower-level collective action. The probability of participants who live in a supportive macroregime adopting more effective local rules is higher than in regimes that ignore resource problems entirely or, at the other extreme, presume that all.decisions about governance and management need to be made by central authorities. For global *CPRs,* in contrast, there is no political regime that is larger than the set of participants who are affected by a common-pool problem (Snidal, 1995).

Researchers and public officials need to recognize the multiple manifestations of these theoretical variables in the field; i.e., there may be many cases that, while empirically different, support the theoretical proposition. Appropriators may be highly dependant on a resource (B1), for example, because they are in a remote location and few roads exist to enable them to leave. Alternatively, they may be located in a central location, but other opportunities are not open to them due to lack of training or a discriminatory labor market. Appropriators' discount rates (B3) in relation to a particular resource may be low because they have lived for a long time in a particular location and expect that they and their grandchildren will remain in that location, or because they possess a full and well-defined bundle of property rights to this resource (see Schlager and Ostrom, 1992). Reliable indicators of the condition of a resource (A2) may result from activities that the appropriators themselves perform—such as regularly shearing the wool from sheep (see Gilles and Jamtgaard, 1981) or because of efforts to gather reliable information by appropriators or by external authorities (Blomquist, 1992). Predictability of resource units (A3) may result from a clear regularity in the natural environment of the resource or because storage has been constructed in order to even out the flow of resource units over both good and bad years. They may have autonomy to make their own rules (B6) because a national government is weak and unable to exert authority over resources that it formally owns, or because national law formally legitimates self-governance—as is the case with Japanese inshore fisheries. It is highly likely that while the particularities of the cases may differ, they can also support our theories about the relationship between humans can also support our theories about the relationship between humans and natural resources.

When the benefits of organizing are commonly understood by participants to be high, appropriators—lacking the attributes conducive to the development of self-governing institutions—may still be able to construct effective agreements. The crucial factor *is* not whether all attributes are favorable, but the relative size of the expected benefits and costs they generate as perceived by participants. While all of these variables affect the expected benefits and costs of appropriators, it is difficult—particularly for outsiders—to estimate their impact on the expected benefit of individual appropriators. Further empirical analysis of these theoretical propositions requires careful, comparative, and over-time studies of a sufficiently large number of field settings using a common set of measurement protocols (see E. Ostrom, 1998a).

4.1.1 Theoretical Puzzles

In addition to the consensus concerning the variables most likely to enhance self-organization and the design principles characterizing successful, long-term governance arrangements (E. Ostrom, 1990), many theoretical puzzles remain regarding collective action and the governance of CPRs. Two major theoretical questions that need more exploration relate to the effect of number of actors involved and the heterogeneity of those actors. Each of these variables is closely related to scaling issues.

4.1.2 The Number of Actors involved

One of the key theoretical puzzles concerning collective action is directly related to a quantitative scale—the number of actors involved in making decisions about whether or not to provide better rules to govern CPRs. The effect of the number of participants facing problems of collective action related to the management of CPRs is still unclear. Drawing on the early work of Mancur Olson (1*965),* many theorists argue that size of group is negatively related to solving collective-action problems in general (see also Buchanan and Tullock, 1962). The results from many game theoretical analyses of repeated games conclude that cooperative strategies are more likely to emerge and to be sustained in smaller rather than larger groups (see the synthesis of this literature in Baland and Platteau, 1996). Scholars who have studied many user-governed irrigation and forestry institutions in the field have concluded that success will more likely happen in smaller groups (see, for example, Barker et al., 1984; Cernea, 1989).

The evidence, however, is by no means conclusive. While most of the 37 farmer-governed irrigation systems studied by Tang were relatively small, ranging in size from 7 to 300 appropriators, he did not find any statistical relationship within that size range between the number of appropriators or the amount of land being irrigated and performance variables (1992: 68). In Lam's (1998) multiple regression analysis of the performance of a much larger set of irrigation systems in Nepal ranging in size up to 475 irrigators, he also found no significant relationship between either the number of appropriators or the amount of land included in the service area with any of the three performance variables he studied. In a systematic study of forest institutions, Agrawal (1 *996)* found that smaller forest user groups were less able to undertake the level of monitoring needed to protect forest resources as moderately sized groups.

One of the problems with a focus on size of group as a key determining factor is that many other variables change as group size increases (Charnberlin, 1974; R. Hardin, 1982). If the costs of providing a public good related to the use of a CPR, say a sanctioning system, remain relatively constant as group size increases, then increasing the number of participants brings additional resources that could be drawn upon to provide the benefit enjoyed by all. Marwell and Oliver (1993: 45) conclude that when a "good has pure jointness of supply, group size has a positive effect on the probability that it will be provided." On the other hand, if one is analyzing the conflict levels over a subtractable good and the transaction costs of arriving at acceptable allocation formulas, group size may well exacerbate the problems of collective action. Since there are tradeoffs among various impacts of size on other variables, a better working hypothesis is that group size is curvilinearly related to the likelihood that individuals will organize themselves and continue to provide the public good of effective and enforced rules.

Snidal (1995) provides a particularly interesting analysis of how group size may affect collective action at both a local and an international level of organization. He observes that the number of participants is not always a strictly exogenous variable, as is frequently assumed in studies of natural resource use. Rather, in some cases individuals can determine the size of group allowed to participate.

Antarctica has been partitioned among a set of states with more or less arbitrary claims, just as the third world was a CPR (from a very ethnocentric Western view) partitioned among imperial rivals in the 19th century. Fishing grounds, navigation rights and seabed minerals all depend heavily on political treatments regarding property rights of individual states (Snidal, 1995: 59).

The most important way that political arrangements affect resource outcomes is through their mechanisms that exclude noncontributors or threaten punishment to induce contributions. Although pure CPRs and public goods models assume exclusion is very difficult, significant exclusion occurs in many real settings. This is the result of conscious efforts (or of evolutionary good fortune) to overcome different collective problems by redefining them through political institutions.

Research concerning the appropriate number of actors and collective success should be extended to other factors as well. The different scales and different levels of human and natural systems help to determine an appropriate institutional "fit" (Gunderson et al., 1997).

4.1.3 Heterogeneity

Many scholars conclude that only very small groups can organize themselves effectively because they presume that size is related to the homogeneity of a group and that homogeneity is needed to initiate and sustain self-governance. Heterogeneity is also a highly contested variable. For one thing, groups can differ along a diversity of dimensions including their cultural backgrounds, interests, and their endowments (see Baland and Platteau, 1996). Each may operate differently.

If groups coming from diverse cultural backgrounds share access to a common resource, the key question affecting the likelihood of self-organized solutions is whether the views of the multiple groups concerning authority, interpretation of rules, trust, and reciprocity differ or are similar. New settlers to a region may simply learn the rules of the established group, and their cultural differences on other fronts do not affect their participation in governing a resource. On the other hand, new settlers are frequently highly disruptive to the sustenance of a self-governing enterprise when they generate higher levels of conflict over the interpretation and application of rules and increase enforcement costs substantially.

When the interests of appropriators differ, solving collective-action problems related to CPR problems is particularly challenging. This problem characterizes some fisheries where local subsistence fishermen have strong interests in the sustenance of an inshore fishery while industrial fishing firms have many other options and may be more interested in the profitability of fishing in a particular location than its sustained yield. The conflict between absentee livestock owners versus local pastoralists has also proved difficult to solve in many parts of the world.

Differential endowments of appropriators can be associated with both extreme levels of conflict as well as very smooth and low-cost transitions into a sustainable, self-governed system. Johnson and Libecap (1982) reason that the difference in the skills and knowledge of different kinds of fishers frequently prevents them from arriving at agreements about how to allocate quantitative harvesting quotas (see also Scott, 1993). In this case, heterogeneity of endowments and of interests coincide. Heterogeneity of wealth or power may or may not be associated with a difference in interests. As discussed above, when those who have more assets share similar interests with those who have less assets (A4), groups may be privileged by having the more powerful take on the higher initial costs of organizing while crafting rules that benefit a large proportion of the appropriators.

Appropriators may design institutions that cope effectively with heterogeneities. Thus, when they adopt rules that allocate benefits using the same formulae used to allocate duties and responsibilities (see E. Ostrom's design principles, 1990), appropriators who differ significantly in terms of assets will tend to agree to and follow such rules.

Even in a group that differs along many variables, if K appropriators from an endangered but valuable resource are dependant on it (A1), share a common understanding of their situations (A2), have a low discount rate (A3), include some with more assets among their members (A4), trust one another (A5), and have autonomy to make their own rules (A6), it is more likely that they will estimate the expected benefits of governing their resource greater than the expected costs. Thus, neither size nor heterogeneity are variables with a uniform effect on the likelihood of organizing and sustaining self-governing enterprises. The debate about their effect is focusing on the wrong variables. Instead of focusing on size or the various kinds of heterogeneity by themselves, it is important to ask how these variables affect other variables as they impact on the benefit-cost calculus of those involved in negotiating and sustaining agreements (Agrawal and Gibson, 1997). Their impact on costs of producing and distributing information (Scott, 1993) is particularly important.

Such heterogeneities have also been explored at the national level, and scholars have come to similar conclusions. Snidal (1995) argues that the variety of forms and consequences of heterogeneity leads to an unprofound finding: the impact of heterogeneity is heterogeneous. According to hegemonic stability theory, the heterogeneity of state capabilities promotes cooperation since larger actors produce a public good whose benefits are joint across all states. Here benefits accrue to all, but costs fall on producers. By contrast, in CPRs, the benefits of appropriation are not joint and do not accrue only to appropriators, yet the costs fall on all actors. In cases where distributional issues are important, and states have different preferences over outcomes (and perhaps different time horizons), cooperation is less likely. However, like local-level situations, heterogeneity and homogeneity can be constructed through institutions.

Bibliography

Abreau, Diiip. 1988. "On the Theory of Infinitely Repeated Games with Discounting." Econometrica *80(4)383-96.*

Addicott, J. F., J. M. Aho, M. F. Antolin, D. K. Padilla, J. S. Richardson, and D. A. Soluk. *1987.* "Ecological Neighborhoods: Scaling Environmental Patterns." Oikos 49(3):340-46.

Advisory Commission on Intergovernmental Relations (Ronald J. Oakerson). 1987. The Organization of Local Public Economies. Washington, D.C.: ACIR.

Agrawal, Arun. *1996.* "Group *Size* and Successful Collective Action: A Case Study of Forest Management Institutions in the Indian Himalayas." Forests, Trees and People Programme, Phase II. Working paper. Rome, Italy: Food and Agriculture Organization of the United Nations.

Agrawal, Arun, and Clark Gibson. 1997. "Community Resources and Development: Beyond Enchantment and Disenchantment." Mimeo. Bloomington: Indiana University, Workshop in Political Theory and Policy Analysis.

Alexander, Paul. 1982. Sri Lankan Fishermen: Rural Capitalism and Peasant Society. Canberra: Australian National University.

Allee, David J. 1993 "Subnational Governance and the International Joint Commission: Local Management of United States and Canadian Boundary Waters." Natural Resources journal 33:133-51.

Allen, P. M., and J. M. McGlade. 1987. "Modelling Complex Human Systems: A Fishery's Example." European Journal of Operational Research 30:147-67.

Allen, Timothy F.H., and Thomas W. Hoekstra. 1990. "The Confusion between Scale-defined Levels and Conventional Levels of Organization in Ecology." Journal of Vegetation Science 1:5-12.

Allen, Timothy F.H., and Thomas W. Hoekstra. 1992. Toward a Unified Ecology. New York: Columbia University Press.

Allen, Timothy F.H., Robert V. O'Neill, and Thomas W. Hoekstra. 1987. "Interlevel Relations in Ecological Research and Management: Some Working Principles From Hierarchy Theory." Journal of Applied Systems Analysis 14:63-*79.*

Allen, Timothy F.H., and T. B. Starr. 1982. Hierarchy: Perspectives for Ecological Complexity. Chicago: University of Chicago Press.

Anderson, Terry L., and Peter J. Hill. 1983. "Privatizing the Commons: An Improvement?" Southern Economic Journal 50:438-50.

Anton, Thomas. 1989. American Federalism and Public Policy. New York: Random House.

Arrow, Kenneth. 1951. Social Choice and Individual Values. New York: John Wiley & Sons.

Baas, Nils A. 1996. "A Framework for Higher Order Cognition and Consciousness." In Towards a Science of Consciousness, ed. Stuart Hameroff, Alfred Kaszniak, and Alwyn Scott, 633-48. Cambridge, MA: MIT Press.

Baas, Nils A., and Claus Emmeche. 1997. "On Emergence and Explanation." Working paper 97-02-008. Sante Fe, New Mexico: Sante Fe Institute.

Baland, Jean-Marie, and Jean-Philippe Platteau. 1996. Halting Degradation of Natural Resources: Is There a Role for Rural Communities? Oxford: Clarendon Press.

Barber, Benjamîn R. 1992. "Jihad v. McWorld." Atlantic Monthly 269 (March): 59-65.

Barker, Randolph, E. Walter Coward, Jr., Gilbert Levine, and Leslie E. Small. 1984. Irrigation Development in Asia: Past Trends and Future Directions. Ithaca, NY: Cornell University Press.

Becker, C. Dustin, and Clark Gibson. 1996. "The Lack of Institutional Supply: Why a Strong Local Community in Western Ecuador Fails to Protect its Forest." Forests, Trees and People Programme, Phase II. Working paper. Rome, Italy: Food and Agriculture Organization of the United Nations.

Bergh, Jeroen C.J.M. van den, and Peter Nijkamp. 1991. "Operationaiizing Sustainable Development: Dynamic Ecological Models." Ecological Economics 4:11-33.

Bird, J. 1989. The Changing Worlds of Geography: A Critical Guide to Concepts and Methods. Oxford: Clarendon.

_____,. 1956. "Scale in Regional Study Illustrated by Brief Comparisons between the Western Peninsulas of England and France." Geography 41:25-38.

Blomquist, William. 1992. Dividing the Waters: Governing Groundwater in Southern California. San Francisco, CA: ICS Press.

Boeckelman, Keith. 1996. "Federal Systems in the Global Economy: Research Issues." Publius 26 (1) (Winter): 1-10.

Brondizio, E. S., E. F. Moran, P. Mausel, and Y. Wu. 1996. "Land Cover in the Amazon Estuary: Linking of the Thematic Mapper with Botanical and Historical Data." Photogrammetric Engineering and Remote Sensing 62(8):921-29.

Buchanan, James M., and Gordon Tullock. 1962. The Calculus of Consent. Ann Arbor: University of Michigan Press.

Bueno de Mesquita, Bruce. 1985. "Toward a Scientific Understanding of International Conflict: A Personal View." International Studies Quarterly 29:121-36.

Campbell, Donald T. 1974. "Downward Causation in Hierarchically Organized Biological Systems." In Studies in the Philosophy of Biology: Reduction and Related Problems, ed. F. J. Ayala and T. C. Dobzhansky, 1 79-186. Berkeley: University of California Press.

Caponera, Dante A. 1993. "Legal Aspects of Transboundary River Basin in The Middle East: The Al Asi (Orontes), The Jordan and The Nile." Natural Resources Journal 33:629-63.

Carpenter, S. R., and J. F. Kitchell. 1987. "The Temporal Scale of Variance in Limnetic Primary Production." American Naturalist 129:417-33.

Cernea, Michael M. 1989. "User Groups as Producers in Participatory Afforestation Strategies." World Bank Discussion Papers, no. 70. Washington, DC: The World Bank.

Chamberlin, J. 1974. "Provision of Collective Goods as a Function of Group Size." American Political Science Review 68(2) (June): 707-16.

Choguill, Charles L. 1989. "Small Towns and Development: A Tale from Two Countries." Urban Studies *26:267-74.*

Clark, W. C. 1985. "Scales of Climate Impacts." Climatic Change 7:5-27.

_____. 1987. "Scale Relationships in the Interaction of Climate, Ecosystems, and Societies." In Forecasting in the Social and Natural Sciences, ed. Kenneth C. Land and Stephen H. Schneider, 337-78. Dordrecht, the Netherlands: D. Reidel.

Clark, William Roberts. 1996. "Explaining Cooperation Among, Within, and Beneath States." Mershon International Studies Review 40:284-88.

Coleman, James S. 1990. Foundations of Social Theory. Cambridge, MA: Harvard University Press.

Costanza, Robert, L. Wainger, Carl Folke, and Karl Gorän Mäler. 1993. "Modeling Complex Ecological Economic Systems: Toward an Evolutionary, Dynamic Understanding of People and Nature." BioScience 43:545-55.

Costanza, Robert, et al. 1997. "The Value of the World's Ecosystem Services and Natural Capital." Nature 387 (May 15): 253-60.

Dahl, Robert. 1989. Democracy and Its Critics. New Haven, CT: Yale University Press.

Daly, Herman E. 1992. "Allocation, Distribution, and Scale: Toward an Economics That *is* Efficient, Just, and Sustainable." Ecological Economics 6:185-93.

Dasgupta, Partha. 1997. "Notes on Slow and Fast Variables in Economics." Gainesville: University of Florida, Department of Zoology, Notes for the Resilliane Network.

Dasgupta, Partha, and Geoffrey M. Heal. 1979. Economic Theory and Exhaustible Resources. Garden City, Nj: J. Nisbet.

Dawes, Robyn M. 1973. "The Commons Dilemma Game: An N-person Mixed-Motive Game with a Dominating Strategy for Defection." Oregon Research Institute Research Bulletin 13:1-12.

_____. 1980. "Social Dilemmas." Annual Review of Psychology 31:169-93.

Dayton, P., and M.]. Tegner. 1984. "The Importance of Scale in Community Ecology: A Kelp Forest Example with Terrestrial Analogs." In A New Ecology: Novel Approaches to Interactive Systems, ed. P. W. Price, C. N. Slobodchikoff, and W. S. Gaud, 457-81. New York: John Wiley & Sons.

Debreu, G. 1974. "Excess Demand Functions." Journal of Mathematical Economics 1:15-23.

Demsetz, Harold. 1967. "Toward a Theory of Property Rights." American Economic Review 57 (May): 347-359.

Dovers, Stephen R. 1995. "A Framework for Scaling and Framing Policy Problems in Sustainability." Ecological Economics 12:93-106.

Duncan, Otis Dudley. 1980. An Examination of the Problem of Optimum City-Size. New York: Arno Press.

Eggertsson, Thráinn. 1990. Economic Behavior and Institutions. New York: Cambridge University Press.

Ehleringer, J., and C. Field, eds. 1993. Scaling Physiological Processes: Leaf to Globe. San Diego, CA: Academic Press.

Enelow, James M. 1997. "Cycling and Majority Rule." In Perspectives on Public Choice, ed. Dennis C. Mueller. New York: Cambridge University Press.

Feeny, David, Susan Hanna, and Arthur F. McEvoy. 1996. "Questioning the Assumptions of the Tragedy of the Commons' Model of Fisheries. Land Economics 72(2) (May): 187-205.

Folke, Carl, Crawford S. Holling, and Charles Perrings. 1996. "Biological Diversity, Ecosystems, and the Human Scale." Ecological Applications 6:1018-24.

Forer, Pip. 1978. "A Place for Plastic Space?" Progress in Human Geography 2(2):230-67.

Forman, R.T.T., and M. Godron. 1986. Landscape Ecology. New York: John Wiley & Sons.

Fox, Jefferson. 1992. "The Problem of Scale in Community Resource Management" Environmental Management *16:289-97.*

Foy, George, and Herman Daly. 1992. "Allocation, Distribution and Scale as Determinants of Environmental Degradation: Case Studies of Haiti, El Salvador and Costa Rica." In Environmental Economics, ed. Anil Markandya and Julie Richardson. New York: St. Martin's Press.

Funtowicz, S. O., and J. R. Ravetz. 1991. "A New Scientific Methodology for Global Environmental Change." In Ecological Economics: The Science and Management of Sustainability, ed. Robert Costanza, 137-52. New York: Columbia University Press.

Geddes, Barbara. 1994. Politician's Dilemma. Building State Capacity in Latin America. Berkeley: University of California Press.

Getis, A., and J. Franklin. 1987. "Second-order Neighborhood Analysis of Mapped Point Patterns." Ecology 68:473-77.

Giampietro, Mario. 1994. "Sustainability and Technological Development in Agriculture: A Critical Appraisal of Genetic Engineering." BioScience 44(10) (Nov.): 677-89.

Gibson, Clark. Forthcoming. Peasants, Poachers, and Politicians: The Political Economy of Wildlife in Africa. Cambridge: Cambridge University Press.

Giddens, Anthony. 1984. The Constitution of Society: Outline of the Theory of Structuration. Berkeley: University of California Press.

Gilles, Jere L, and Keith Jamtgaard. 1981. "Overgrazing in Pastoral Areas: the Commons Reconsidered." Sociologia Ruralis 21:129-41.

Gimblett, Randy. 1997. "RBSim - Recreation Behavior Simulator." Tucson: University of Arizona, School of Renewable Natural Resources.

Glanz, James. 1997. "Bringing the Stars Down to Earth." Science *276* (April 18): 351-52.

Gordon, H. Scott. 1954. "The Economic Theory of a Common Property Resource: The Fishery." Journal of Political Economy 62 (April): 124-42.

Green, Donald P., and Ian Shapiro. 1994. Pathologies of Rational Choice Theory: A Critique of Applications in Political Science. New Haven, CT: Yale University Press.

Groffman, P. G., and G. E. Likens, eds. 1994. Integrated Regional Models: Interactions between Humans and Their Environment. New York: Chapman & Hall.

Gueron, S., and S. A. Levin. 1995. "The Dynamics of Group Formation." Mathematical Biosciences 128(1 -2):243-64.

Gunderson, L H., C S. Holling, L Pritchard, and G. D. Peterson. 1997. "Resilience in Ecosystems, Institutions, and Societies. Propositions for a Research Agenda." Gainesville: University of Florida, Department of Zoology.

Hansen, Niles M. 1975. The Challenge of Urban Growth. Lexington, MA: D.C. Heath & Co.

Hansson L., L. Fahrig, and G. Merriam, eds. 1995. Mosaic Landscape and Ecological Processes. New York: Chapman & Hall.

Hardin, Garrett. 1968. "The Tragedy of the Commons." Science 162:1243-48.

Hardin, Russell. 1982. Collective Action. Baltimore, MD: Johns Hopkins University Press.

Harris, C. D. 1954. "The Market as a Factor in the Localization of Industry in the United States." Annals of the Association of American Geographers 44:315-48.

Harrison, P. 1992. The Third Revolution: Population, Environment and a Sustainable World. Harmonsworth, Middlesex: Penguin.

Harvey, David. 1969. Explanation in Geography. New York: St. Martin's Press.

Hirsch, Werner Z. 1973. Urban Economic Analysis. New York: McGraw-Hill.

Holland, M. M., and P. G. Risser, eds. 1991. Ecotones: The Role of Landscape Boundaries in the Management and Restoration of Changing Environments. New York: Chapman & Hall.

Holling, Crawford S. 1973. "Resilience and Stability of Ecological Systems." Annual Review of Ecology and Systematics 4:1 -23.

_____. 1986. "The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change." In Sustainable Development of the Biosphere, ed. W. C. Clark and R. E. Munn, 292-317. Cambridge: Cambridge University Press.

_____. 1992. "Cross-scale Morphology, Geometry and Dynamics of Ecosystems." Ecological Monographs 62:447-502.

_____. 1995. "Biodiversity in the Functioning of Ecosystems: An Ecological Synthesis." In Biodiversity Loss, ed. Charles Perrings et al., 44-83. Cambridge: Cambridge University Press.

Holling, Crawford S., Garry Peterson, Paul Marples, Jan Sendzimir, Kent Redford, Lance Gunderson, and David Lambert. 1996. "Self-Organization in Ecosystems: Lumpy Geometries, Periodicities and Morphologies." In Global Change and Terrestrial Ecosystems, ed. Brian Walker and Will Steffen, 346-84. Cambridge: Cambridge University Press.

Holt-Jensen, Arild. 1982. Geography: Its History and Concepts. Totowa, NJ: Barnes and Noble.

Israel, Morris, and jay R. Lund. 1995. "Recent California Water Transfers: Implications for Water Management." Natural Resources Journal 35:1-31.

Jammer, Max. 1954. Concepts of Space. Cambridge, MA: Harvard University Press.

Jarvis, P. C, and K. G. McNaughton. 1986. "Stomatal Control of Transpiration: Scaling Up from Leaf to Region." Advances in Ecological Research 15:1-49.

Johnson, Ronald N., and Gary D. Libecap. 1982. "Contracting Problems and Regulation: The Case of the Fishery." American Economic Review 72(5) (Dec): 1005-23.

King, Anthony W. 1993, "Considerations of Scale and Hierarchy." In Ecological Integrity and the Management of Ecosystem, ed. Stephen Woodley, James Kay, and George Francis, 19-43. Delray, FL: Lucie Press.

Kipnis, Baruch A. 1984. "Plant Size and Urban Growth." Urban Studies 21:53-61.

Kiser, Larry L., and Elinor Ostrom. 1982. "The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches." In Strategies of Political Inquiry, ed. Elinor Ostrom, 1 79-222. Beverly Hills, CA: Sage.

Koestler, A. R. 1959. The Sleepwalkers. New York: Macmillan.

Kolasa, J., and S.T.A. Pickett, eds. 1991. Ecological Heterogeneity. New York: Springer-Veriag.

Krakover, Shaul. 1985. "Spatio-Temporal Structure of Population Growth in Urban Regions: The Cases of Tel-Aviv and Haifa, Israel." Urban Studies 22:317-28.

Krugman, Paul. 1986. "Industrial Organization and International Trade." National Bureau of Economic Research, Working Paper no. 1957. Cambridge, MA: National Bureau of Economic Research.

Lam, Wai Fung. 1998. Governing Irrigation Systems in Nepal: Institutions, Infrastructure, and Collective Action. Oakland, CA: ICS Press.

Lambin, E. 1994. "Modelling Deforestation Processes: A Review. Trees Report." Ispra, Italy: Institute for Remote Sensing Applications.

Leven, Charles L. 1991. "Distance, Space, and the Organization of Urban Life." Urban Studies 28:319-25.

Levin, Simon A. 1991. 'The Problem of Relevant Detail." in Differential Equations Models in Biology, Epidemiology and Ecology, ed. Stavros Busenberg and Mario Martelli, 9-15. Berlin: Springer-Veriag.

_____. 1992. "The Problem of Pattern and Scale in Ecology." Ecology 73(6):1943-67.

Levin, Simon A., S. Barrett, W. Baumol, C. Bliss, B. Bolin, N. Chichinsky, P. Dasgupta, P. Ehrlich, C. Folke, 1. M. Gren, C. S. Holling, A. M. Jansson, B.-O. Jansson, K.-G. Mäler, and C. Perrings. 1997. "Resilience in Natural and Socio-economic Systems." Beijer Discussion Papers. Beijer Institute.

Libecap, Gary D. 1995. "The Conditions for Successful Collective Action." In Local Commons and Global Interdependence: Heterogeneity and Cooperation in Two Domain, ed. Robert Keohane and Elinor Ostrom, 161-90. London: Sage.

Lowrance, R. 1992. "Sustainable Agriculture: Research at the Watershed Scale." In Integrating Sustainable Agriculture, Ecology, and Environmental Policy, ed. R. Olson, 105-111. Binghamton, NY: Haworth Press.

Lowrance, R., P. Hendrix, and E. Odum. 1986. "A Hierarchical Approach to Sustainable Agriculture." American Journal of Alternative Agriculture 1:169-73.

Ludwig, D., and C. J. Walters. 1985. "Are Age-Structured Models Appropriate for Catch-Effort Data?" Canadian Journal of Fisheries and Aquatic Sciences 42:1066-72.

Marwell, Gerald, and Pamela Oliver. 1993. The Critical Mass in Collective Action: A Micro-Social Theory. New York: Cambridge University Press.

Mayr, Ernst. 1982. The Growth of Biological Thought: Diversity, Evolution, and Inheritance. Cambridge, MA: Belknap Press.

McCarty, H. H., J. C. Hook, and D. S. Knos. 1956. "The Measurement of Association in Industrial Geography." University of Iowa Department of Geography Reports 1:1-43.

McConnell, Campbell R. 1969[1960]. Elementary Economics: Principles, Problems, and Policies Economics. New York: McGraw-Hill.

McCracken, Steven D., C.A.M. Safar, and Glen Green. 1997. "Deforestation and Forest Regrowth in Indiana, 1860-1990: A Socio-Demographic Perspective." Paper presented at the Annual Meetings of the Population Association of America, Washington, D.C., March 26-28.

McDonnel, M. C, and S.T.A. Pickett, eds. 1993. Humans as Components of Ecosystems: The Ecology of Subtle Human Effects and Populated Areas. New York: Springer-Verlag.

McGinnis, Michael. 1997. "Rent-Seeking, Redistribution, and Reform in the Governance of Global Markets." Working paper. Bloomington: Indiana University, Workshop in Political Theory and Policy Analysis.

McGinnis, Michael, and Elinor Ostrom. 1996. "Design Principles for Local and Global Commons." In The International Political Economy and International

Institutions, Volume II, ed. Oran R. Young, 465-93. Cheltenham, United Kingdom: Edward Eigar Publishing.

McKean, Margaret A. 1992. "Success on the Commons: A Comparative Examination of Institutions for Common Property Resource Management." Journal of Theoretical Politics 4(3) (July): 247-82.

_____. 1 996. "Common Property: What Is It, What Is It Good For, and What Makes It Work?" Forests, Trees and People Programme, Phase II. Working Paper. Rome, Italy: Food and Agriculture Organization of the United Nations.

McKelvey, Richard D. 1976. "Intransitivities in Multidimensional Voting Models and Some Implications for Agenda Control." Journal of Economic Theory 12:472-82.

Meentemeyer, Vernon. 1989. "Geographical Perspectives of Space, Time, and Scale." Landscape Ecology 3(3/4): 163-73.

Meentemeyer, Vernon, and E. O. Box. 1987. "Scale Effects in Landscape Studies." In Landscape Heterogeneity and Disturbance, ed. Monica G. Turner, 15-36. New York: Springer-Veriag.

Menge, B. A., and A. M. Olson. 1990. "Role of Scale and Environmental Factors in the Regulation of Community Structure." Trends in Ecology and Evolution 5:52-57.

Meyer, William B., Derek Gregory, B. L. Turner II, and Patricia F. McDowell. 1992. "The Local-Global Continuum." In Geography's Inner Worlds, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 255-79. New Brunswick, NJ: Rutgers University Press.

Meyer, William B., and B. L. Turner II, eds. 1994. Changes in Land Use and Land Cover: A Global Perspective. Cambridge: Cambridge University Press.

Moran, E. F., E. S. Brondizio, P. Mausel, and Y. Wu. 1994. "Integrating Amazonian Vegetation, Land Use and Satellite Data." BioScience 44(5):329-39.

Neutze, G. 1965. Economic Policy and the Size of Cities. Canberra: Australian National University Press.

Nijkamp, P., and J. Rouwendal. 1988. "Intergenerational Discount Rates in Long-Term Plan Evaluation." Public Finances/Finances Publiques 43:195-211.

North, Douglass C. 1990. Institutions, Institutional Change and Economic Performance. New York: Cambridge University Press.

Norton, Bryan G., and Robert E. Ulanowicz. 1992. "Scale and Biodiversity Policy: A Hierarchical Approach." Ambio 21 (3) (May): 244-49.

Olson, Mancur. 1965. The Logic of Collective Action: Public Goods and the Theory *of* Groups. Cambridge, MA: Harvard University Press.

O'Neill, Robert V. 1988. "Hierarchy Theory and Global Change." In Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes, ed. T. Roswall, R. G. Woodmansee, and P. G. Risser, 29-45. New York: John Wiley & Sons.

O'Neill, Robert V., and A. R. Johnson. 1989. "A Hierarchical Framework for the Analysis of Scale." Landscape Ecology 3:193-205.

O'Neill, Robert V., A. R. Johnson, and A. W. King. 1989. "A Hierarchical Framework for the Analysis of Scale." Landscape Ecology 3:193-205.

O'Neill, Robert V., and B. Rust. 1979. "Aggregation Error in Ecological Models/' Ecological Modeling 7:91-105.

O'Neill, Robert V., S. J. Turner, V. I. Cullinan, D. P. Coffin, T. Cook, W. Conley, J. Brunt, J. M. Thomas, M. R. Conley, and J. Gosz. 1991. "Multiple Landscape Scales: An Intersite Comparison." Landscape Ecology 5(3):137-44.

Ophuls, W. 1973. "Leviathan or Oblivion." In Toward a Steady State Economy, ed. H. E. Daly, 215-30. San Francisco, CA: Freeman.

Ostrom, Elinor. 1983. "A Public Choice Approach to Metropolitan Institutions: Structure, Incentives, and Performance." Social Science Journal 20(3) (July): 79-96.

_____. 1990. Governing the Commons: The Evolution of Institutions for Collective Action. New York: Cambridge University Press.

_____. 1992a. Crafting Institutions for Self-Governing Irrigation Systems. San Francisco, CA: ICS Press.

_____. 1992b. "The Rudiments of a Theory of the Origins, Survival, and Performance of Common-Property Institutions." In Making the Commons Work: Theory, Practice, and Policy, ed. Daniel W. Bromley et al., 293-318. San Francisco, CA: ICS Press.

_____. 1998a. "The International Forestry Resources and Institutions Research Program: A Methodology for Relating Human Incentives and Actions on Forest Cover and Biodiversity." In Forest Biodiversity in North, Central and South America and the Caribbean: Research and Monitoring, ed. F. Dallmeier and J. A. Comiskey, Man and the Biosphere Series, vol. 22. Carnforth, Cancashire, UK: Unesco and the Parthenon Publishing Group, forthcoming.

_____. 1998b. "Self-Governance of Common-Pool Resources." In The New Palgrave Dictionary of Economics and the Law, ed. Peter Newman. London: Macmillan, forthcoming.

Ostrom, Elinor, Roy Gardner, and James M. Walker. 1994. Rules, Games, and Common-Pool Resources. Ann Arbor: University of Michigan Press.

Ostrom, Elinor, Roger B. Parks, and Gordon P. Whitaker. 1978. Patterns of Metropolitan Policing. Cambridge, MA: Ballinger.

Ostrom, Vincent. 1991. The Meaning of American Federalism: Constituting a Self-Govern ing Society. San Francisco, CA: ICS Press.

_____. 1997. The Meaning of Democracy and the Vulnerability of Democracies: A Response to Tocqueville's Challenge. Ann Arbor: University of Michigan Press.

Ostrom, Vincent, Robert Bish, and Elinor Ostrom. 1988. Local Government in the United States. San Francisco, CA: ICS Press.

Ostrom, Vincent, and Elinor Ostrom. 1977. "Public Goods and Public Choices." In Alternatives for Delivering Public Services: Toward Improved Performance, ed. E. S. Savas, 7-49. Boulder, CO: Westview Press.

Ostrom, Vincent, Charles M. Tiebout, and Robert Warren. 1961. "The Organization of Government in Metropolitan Areas: A Theoretical Inquiry." American Political Science Review 55(4) (Dec): 831-42.

Parks, Roger B., and Ronald J. Oakerson. 1993. "Comparative Metropolitan Organization: Service Production and Governance Structures in St. Louis (MO) and Allegheny County (PA)." Publius 23(1) (Winter): 19-39.

Peterson, Paul. 1981. City Limits. Chicago: University of Chicago Press.

Pickett, S.T.A., and M. L. Cadenasso. 1995. "Landscape Ecology: Spatial Heterogeneity in Ecological Systems." Science 269 (July 21): 331-34.

Pimm, S. L. 1984. "The Complexity and Stability of Ecosystems." Nature 307:321-26.

Plott, Charles R. 1967. "A Notion of Equilibrium and its Possibility Under Majority Rule." American Economic Review 57(4) (Sept.): 787-807.

Popper, Karl. 1968. The Logic of Scientific Discovery. New York: Harper & Row.

Posner, Richard A. 1977. Economic Analysis of Law. 2d ed. Boston, MA: Little, Brown.

Powell, T. M., and J. H. Steele. 1995. Ecological Time Series. New York: Chapman-Hall.

Prigogine, I., and I. Stengers. 1984. Order Out of Chaos: Man's New Dialogue with Nature. New York: Bantam Books.

Putnam, R. D., and Sidney Tarrow. 1978. "Between Center and Periphery: Grassroots Politicians in Italy and France." American Political Science Review 72(3):1134-35.

Rastetter, E. B., A. W. King, B. J. Cosby, G. M. Hornberger, Robert V. O'Neill, and J. E. Hobie. 1992. "Aggregating Fine-Scale Ecological Knowledge to

Model Coarser-Scale Attributes of Ecosystems." Ecological Applications 2:55-70.

Reiner, Thomas A., and John B. Parr. 1980. "A Note on the Dimensions of a National Settlement Pattern." Urban Studies 1 7:223-30.

Repetto, R. 1986. World Enough and Times: Successful Strategies for Resource Management. New Haven, CT: Yale University Press.

Risser, P. G., and J. B. Mankin. 1986. "Simplified Simulation Model of the Plant Producer Function in Shortgrass Steppe." American Midland Naturalist U5(2):348-60.

Root, Terry L, and Stephen H. Schneider. 1995. "Ecology and Climate: Research Strategies and implications." Science 269:334-41.

Rosswal, Thomas, Robert G. Woodmansee, and Paul G. Risser. 1988. Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes. New York: John Wiley & Sons.

Samuelson, P. A. 1973[1955]. "A Diagrammatic Exposition of a Theory of Public Expenditure." Review of Economics and Statistics 37:360-66.

Sartori, Giovanni. 1987. The Theory of Democracy Revisited. Chatham, NJ: Chatham House Publishers.

Savory, Alan. 1988. Holistic Resource Management Washington, D.C.: Island Press.

_____. 1991. "Holistic Resource Management: A Conceptual Framework for Ecologically Sound Economic Modeling." Ecological Economics 3:181-91.

Schlager, Edella. 1990. "Model Specification and Policy Analysis: The Governance of Coastal Fisheries." Ph.D. diss., Indiana University, Department of Political Science.

Schlager, Edella, and Elinor Ostrom. 1992. "Property-Rights Regimes and Natural Resources: A Conceptual Analysis." Land Economics 68(3) (Aug.): 249-62.

Schofield, Norman. 1978. "Instability of Simple Dynamic Games." Review of Economic Studies 45:575-94.

Schweik, Charles. 1997. "Toward a Theory of Anthropogenically Induced Forest Change in the Context of Indiana." Working paper. Bloomington: Indiana University, Center for the Study of Institutions, Population, and Environmental Change.

Schumpeter, Joseph A. 1943. Capitalism, Socialism and Democracy. London: Allen & Unwin.

Scott, Anthony D. 1955. "The Fishery: The Objectives of Sole Ownership." journal of Political Economy 63 (April): 116-24.

_____. 1993. "Obstacles to Fishery Self-Govemment." Marine Resource Economics 8:187-99.

Shepsle, Kenneth A. 1979a. "Institutional Arrangements and Equilibrium in Multidimensional Voting Models." American journal of Political Science 23(1):27-59.

_____. 1979b. "The Role of Institutional Structure in the Creation of Policy Equilibrium." In Public Policy and Public Choice, ed. Douglas W. Rae and Theodore J. Eismeier, 249-83. Sage Yearbooks in Politics and Public Policy, vol. 6. Beverly Hills, CA: Sage.

Simon, Herbert A. 1962. "The Architecture of Complexity." Proceedings of the American Philosophical Society 106(6) (Dec): 467-82.

Snidal, Duncan. 1995. "The Politics of Scope: Endogenous Actors, Heterogeneity and Institutions." In Local Commons and Global Interdependence: Heterogeneity and Cooperation in Two Domain, ed. Robert Keohane and Elinor Ostrom, 47-70. London: Sage.

Soja, Edward W. 1989. Postmodern Geographies: The Reassertion of Space in Critical Social Theory. London: Verso.

Sollins, P., G. Spycher, and C. Topik. 1983. "Processes of Soil Organic-Matter Accretion at a Mudflow Chronosequence, Mt. Shast, California." Ecology 64(5) (October): 1273-82.

Solomon, A. M., H. R. Delcourt, D. C West, and T. J. Biasing. 1980. "Testing a Simulation-Model for Reconstruction of Prehistoric Forest-Stand Dynamics." Quaternary Research 14(3):275-93.

Sonnenschein, H. 1973. "Utility Hypothesis and Market Demand Theory.' Western Economic Journal 11(4):404-.

Steele, J. H. 1978. Spatial Pattern in Plankton Communities. New York: Plenum Press.

_____. 1985. "A Comparison of Terrestrial and Marine Systems." Nature 313:355-58.

_____. 1989. "The Ocean 'Landscape.'" Landscape Ecology 3:185-92.

Stohlgren, Thomas J. 1995. "Planning Long-Term Vegetation Studies at Landscape Scales." In Ecological Time Series, ed. Thomas M. Powell and John H. Steele, 209-41. New York: Chapman and Hall.

Suarez-Villa, Luis. 1988. "Metropolitan Evolution, Sectoral Economic Change, and the *City Size* Distribution." Urban Studies 25:1-20.

Szekely, Alberto. 1992. "Establishing a Region for Ecological Cooperation in North America." Natural Resources Journal 32:563-622.

Tang, Shui Yan. 1992. Institutions and Collective Action: Self-Governance in Irrigation. San Francisco, CA: ICS Press.

Taylor, Peter J. 1981. "Geographic Approach within the World-Economy Approach." Review 5:3-11.

Tilly, Charles. 1984. Big Structures, Large Processes, Huge Comparisons. New York: Russell Sage Foundation.

Tirole, Jean. 1988. The Theory of Industrial Organization. Cambridge, MA: MIT Press.

Tisdell, C. 1975. "The Theory of Optimal City-Size: Elementary Speculation about Analysis and Policy." Urban Studies 12:61-70.

Tsebelis, George. 1990. Nested Games: Political Context, Political Institutions and Rationality. Berkeley and Los Angeles: University of California Press.

Turner, B. L. II. 1989. "The Human Causes of Global Environmental Change." In Global Change and Our Common Future: Papers from a Forum, ed. Ruth S. DeFries and Thomas F. Malone, 90-99. Washington, D.C.: National Academy Press.

Turner, B. L. II, Roger E. Kasperson, William B. Meyer, Kirstin M. Dow, Dominic Golding, Jeanne X. Kasperson, Robert C. Mitchell, and Samuel J. Ratick. 1990. "Two Types of Global Environmental Change: Definitional and Spatial-Scale Issues in Their Human Dimensions." Global Environmental Change 1 (Dec.):14-22.

Turner, B. L. II, and W. B. Meyer. 1991. "Land Use and Land Cover in Global Environmental Change: Considerations for Study." International Social Science Journal 43:669-79.

Turner, Monica G., Virginia H. Dale, and Robert H. Gardner. 1989. "Predicting Across Scales: Theory Development and Testing." Landscape Ecology 3(3/4):245-52.

Turner, Monica G., Robert V. O'Neill, Robert H. Gardner, and Bruce T. Milne. 1989. "Effects of Changing Spatial Scale on the Analysis of Landscape Pattern." Landscape Ecology 3(3/4):153-62.

Turner, Paul. 1995. "Explaining Deforestation: A Preliminary Review of the Literature." Working paper. Bloomington: Indiana University, Workshop in Political Theory and Policy Analysis.

Varian, H. R. 1992. Microeconomic Analysis. New York: Norton.

Wade, Robert. 1994. Village Republics: Economic Conditions for Collective Action in South India. San Francisco, CA: ICS Press.

Washington, W. M., and C. L Parkinson. 1986. An Introduction to Three-Dimensional Climate Modeling. New York: Oxford University Press.

Watson, M. K. 1978. "The Scale Problem in Human Geography." Geografiska Annualer 60B:36-47.

Weber, Gregory S. 1995. "Twenty Years of Local Groundwater Export Legislation in California: Lessons from a Patchwork Quilt." Natural Resources Journal 35:657-749.

Weber, Max. 1958. "The Protestant Ethic and the Spirit of Capitalism." in From Max Weber: Essays in Sociology, ed. H. W. Gerth and C. Wright Mills, 302-22. Oxford: Oxford University Press.

Wessman, Carol A. 1992. "Spatial Scales and Global Change: Bridging the Gap from Plots to GCM Grid Cells." Annual Review of Ecology and Systematics 23:175-200.

Whittaker, Robert H. 1975. Communities and Ecosystems. 2d ed. New York: Macmilian.

Wiens, J. A. 1989. "Spatial Scaling in Ecology." Functional Ecology 3:385-97.

Wolf, Steven A., and Timothy F.H. Allen. 1995. "Recasting Alternative Agriculture as a Management Model: The Value of Adept Scaling." Ecological Economics 12:5-12.

Woodward, F. I., and B. G. Williams. 1987. "Climate and Plant Distribution at Global and Local Scales." Vegetation 69:189-97.

Young, Oran R. 1995. "The Problem of Scale in Human/Environment Relationships." In Local Commons and Global Interdependence: Heterogeneity and Cooperation in Two Domain, ed. Robert Keohane and Elinor Ostrom, 27-45. London: Sage.

Young, Oran R., and Arild Underdal. 1996. "Institutional Dimensions of Global Change." A Scoping Report to the International Human Dimensions Program. Hanover, NH: Dartmouth College, Institute on International Environmental Governance.

Zonneveld, Isaak S. 1989. "The Land Unit: A Fundamental Concept in Landscape Ecology, and Its Applications." Landscape Ecology 3:67-86.

IHDP

INTERNATIONAL HUMAN DIMENSIONS PROGRAMME ON GLOBAL ENVIRONMENTAL CHANGE

IHDP, WALTER-FLEX-STRASSE 3, D-53113 BONN, TEL.: +49 - (0)228 / 73-9050, FAX: +49 - (0)228 / 73-9054
E-MAIL: IHDP@UNI-BONN.DE WORLD WIDE WEB: HTTP://WWW.UNI-BONN.DE/IHDP