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Scaling Issues With Social Data in Integrated Assessment Modeling

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ABSTRACT

The issue of scale is critical to the understanding of data collection, data representation, data analysis and modeling in the social and biophysical sciences. Integrated assessment models must acknowledge these scale issues in order to evaluate the utility and results of these models. This awareness of scale has been widely recognized in the physical sciences and a variety of tools have been developed to address these scale issues, although there is no general consensus on what tools to apply in what situations. Scale issues have been less widely addressed in the social sciences, but recent literature suggests an increasing awareness. This paper addresses the importance of scale issues to social data as they are related to integrated assessment modeling. A review of terminology related to scale issues is presented to address the vagueness and lack of consensus in this terminology. Scientists from a variety of social disciplines have addressed scale issues from different perspectives and these are briefly reviewed.

Keywords: scale, spatial analysis, social science, integrated assessment.

1. INTRODUCTION

The importance of scale issues is widely recognized. Methods of dealing with the effects of scale are not, however, universally accepted. Cohesive theories of scale, with a few isolated exceptions, have not yet been developed, widely applied or widely accepted. Because scale issues pervade data collection and representation efforts, spatial data modeling, including integrated assessment modeling (IAM), is dramatically affected by these scale issues [1]. Both social and natural scientists acknowledge the importance of scale effects and how relationships and processes operate differently at different scales [2, 3]. Because of the varying nature of social-biophysical interactions as a function of scale [4], many researchers have concluded that a multi-scale approach is necessary to understand the relationships between variables or the function of social and biophysical processes [2, 5]. While scale effects are widely acknowledged, a considerable amount of research in integrated assessment and global change research is still conducted at a single scale of analysis using data collected at single scales. Important conclusions are drawn about the relative impact of different factors using only household, regional or global scale analysis.

This dependence on a single scale is understandable. In some cases, data availability may limit the ability to examine relationships across scales, particularly for regional and global extents. In other cases, labor resource limitations may make a multi-scale approach infeasible. A continent-scale examination of the impact of population growth on deforestation can hardly expect to use household-level data as a social unit of analysis for such a large geographic extent. Yet, it is critical that researchers pursue research questions that operate at large scales where these data availability problems and resource limitations predominate. In these cases, researchers must attempt to hypothesize about the impact of different operational scales on the phenomenon they are studying.

This paper explores how some social scientists have acknowledged the importance of scale issues, the various meanings of scale in different social science disciplines and the implications of scale issues to social science within the realm of IAM. The first section of this paper discusses the various terminology related to scale issues from different social science disciplines. The second section of this paper reviews how different disciplines have developed different meanings of ‘‘scale,’’ drawing from Gibson et al. [3]. Section three discusses the implications of scale on social data collection focusing on individual, household, community and regional levels of aggregation. The following two sections review specific methods of dealing with scale developed from the fields of the social and natural sciences.

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The paper closes with a discussion of how these components relate to data collection and representation for integrative assessment and integrated assessment modeling.

2. SCALING TERMINOLOGY

The vagueness of the terms ''scale'' and ''level'' contribute to the difficulty of developing universal theories of scale effects [6]. While the meaning of ''scale'' varies across (and within) disciplines, there are common threads within these different meanings. Scale can be referred to as the spatial, temporal, quantitative, or analytical dimensions used by scientists to measure and study objects and processes [3].

Levels refer to a region along a measurement dimension. For example, the terms micro, meso, and macro refer in general to regions on spatial scales referring to small-, medium-, and large-sized phenomena. To be precise about the concept of scale, one needs to refer to the concepts of extent and resolution. Extent refers to the magnitude of a dimension used in measuring some phenomenon. Spatially, extent may range from a meter or less, to millions of square meters or more. Temporally, extent may involve a second, an hour, a day, or even a century, a millennium, or many millennia. The extent of a scale establishes the outer boundary for what is being measured.

Resolution refers to the precision used in measurement. The term ''grain'' is used to refer to the smallest unit of resolution along a particular scale. Social scientists use a variety of resolutions in their measurements. In regard to time, physical scientists frequently use extremely small units of time when measuring physical processes. Most social scientists, on the other hand, rarely use a resolution of less than an hour. Such a unit would only be used when timing groups of individuals performing particular tasks such as labor allocation. Many types of social science data are recorded on an annual or decennial basis. In this paper, we will use small scale to refer to phenomena that are limited in their spatial, temporal, or numerical extent and large scale to refer to big quantities or space. This is how many people understand the term in everyday usage, but it is exactly the opposite of the way the terms are used by cartographers.

For integrated assessment modeling, choices about scales, levels, extent, and resolution affect what data is collected, how it is calibrated, what data can be used for validation, and what are the basic units that can be used in a model of a process. For example, a researcher must determine what the appropriate level of analysis is when examining the relationship between changes in agricultural production and climate change. In developing countries, land management decisions are often made at a household level, yet most climate-change models are focused at a regional level of analysis. It is these cross-scale issues that need to be reconciled within integrated assessment modeling.

It is important to distinguish between how scale issues relate to data collection versus data representation and how scale-related terminology refer to both areas in the social sciences. In terms of data collection and cartographic representation, scale implies a representative fraction related to portraying data in the real world on a map (e.g., topographic maps showing village locations and road features). The implications of map scale are common across disciplines and well documented. For example, scale affects the representation of a road used for market accessibility in the same way scale affects the representation of a stream or contour line.

In the social sciences, scale can also refer to the social unit of analysis. For example, socio-demographic data are collected at the individual, household and community levels. This social unit of analysis is critical in the observation of certain processes. For example, in many rural environments, land-use decisions are made at the household level within a regional context. Individual migrant decisions are made within the context of the household. Both cases are examples of lower-level agents or actors being affected by higher-level forces or factors. While social data are commonly collected at one of the above social units of analysis, it should be noted that these terms (individual, household, community) mean different things in different areas. For example, the meaning of a household differs dramatically between cultures. Land settlement patterns and institutional regimes affect how a community is defined and what the implications of a community arrangement are for decision making and vice versa.

It is also important to understand how the terms ''scale-up'' and ''scale-down'' apply to social science data. Curran et al. [6] has identified how these terms alone are vague and that specifying between what scales data are being transformed is a more precise method of description. Household-level data are commonly scaled up to a regional-level representation such as with census enumeration units. Household-level data are also commonly scaled up to a community level. With this scaling-up, data variability is clearly lost as with any data aggregation procedure. It should also be noted that different social variables are affected by this scaling-up differently. For example, household size scales-up to the community-level population totals with little impact on the precision or accuracy of those data (assuming no households are excluded in the household survey). In contrast, data on ethnic composition or religious affiliation does not scale-up well as these are nominal data attributes. In addition, scaling-up or aggregating data on labor allocation and land-use from the household to the community level loses the complex household dynamic that exists between these variables.

Social science researchers also sometimes use data at a higher scale to represent a social unit at a lower scale. For example, social data at the census block or block-group level (U.S. census enumeration units analogous to groups of city blocks) can be mapped to households within those enumeration units. For example, hospitals collect address information for patients and address-matching procedures allows these addresses to be spatially located. The socio-economic characteristics of the census unit an address falls within, such as educational background or median family income, can be assigned to a patient as a prediction of that patient's characteristics. However, this down-scaling or disaggregation clearly risks mis-representing households because the higher-scale census block-group data does not indicate the variability within the census unit. Fuzzy data techniques, for example, can be used to represent with what reliability the data can be mapped to lower scales or the boundaries within which a data value may likely fall, but these techniques still do not provide a level of accuracy or reliability were the data initially collected at the household level.

3. CONTEXT OF SCALE ISSUES IN SOCIAL RESEARCH

Following Curran et al. [6], who conducts a similar review of scale issues relating to biology and ecology, we use the following propositions to discuss how scale issues relate to social science. Here we explore a set of statements revolving around social-biophysical relationships to establish a context for scale issues in IAM. In this discussion, we address where these statements hold for different types of social data and where they break down.

3.1. The Small Things Are the Ones That Determine the Characteristics of the Living World

The complexity in social and natural systems is beyond the ability of researchers to represent completely. Yet these systems can be modeled through simplifications and generalizations of these systems. All systems can be broken down into components. Researchers strive to identify the components in the living world and the relationships among these components. One of the most difficult tasks in integrated assessment modeling is how to determine what level of complexity is needed in a model and what model components need more or less complexity. Just as the landscape-scale pattern and composition of forests can be broken down into the physiological characteristics of the individual species within the forest, the economic structure of a society can be broken down into the household dynamics of labor decisions and financial management.

Likewise, it is the aggregate condition and situations of the households, communities and businesses within a region that determine the regional economy of that area. All land-use decisions are affected by the individual level in some way. In environments where subsistence agriculture is the major mode of production this is particularly the case. But even in areas with a higher degree of economic development, agricultural landholdings (e.g., large farms practicing agriculture with high inputs) may be managed by a relatively small number of individuals. One notable exception to this rule are publicly managed lands where land management decisions are made in the context of a set of political institutions regulating how that land may be managed. But, (1) public lands comprise a relatively small proportion of the earth's surface and (2) while many institutional regulations are not necessarily the product of individual decisions, individual-level decision making does enter into the land-use equation at other points, such as where within a forest stand to selectively cut trees. For an integrated assessment model with a biodiversity/ecological function component these lower-level individual decisions made within the context of institutional regulations at a higher level are important. It is these lower-level decisions that create landuse/landcover outcomes that in aggregate produce higher-level patterns and processes.

3.2. The Small Things Are the Ones Most Amenable to Study by the Methods of Science

Regional economies are characterized by a summary of statistics for the businesses and individuals in that region. The mean cost of new housing in different regions is the product of the costs in different areas composing each region. While data are often reported at coarse scales, it is fine-scale measurements that allow the generation of this coarse-scale reporting. This statement can be extrapolated to temporal scales of analysis as well. With the exception of dramatic changes in landcover such as that associated with colonization in the Midwest United States in the 1800s or the Brazilian Amazon in the 1970s, landcover changes generally operate over long periods of time. An examination of an area over the course of one or two years yields a very different process than an examination over the course of a decade or several decades. Likewise, examining an area using a monthly interval yields dynamic relationships that are not observable using a coarser time interval such as five or ten years.

3.3. The Large Things Are the Ones That Have the Most Profound Effect on Humans

While small-scale phenomena frequently lend themselves to easier data collection, it is often larger-scale phenomena that attract major interest among global change researchers. Such large-scale phenomena include global temperature changes, acid rain, tropical deforestation, carbon sequestration, and regional-global species diversity. It is also the case that large-scale government policies have an impact over the opportunities and constraints faced by many peoples. Current patterns of extending markets to a global extent are the result of major international treaties. Similarly, restrictions on the trade of rare and endangered species have come about through national legislation as well as international treaties. For all the importance of large-scale phenomena, there are many small-scale phenomena that also impact large numbers of people. The tragic consequence of the spread of the HIV virus is but one example of how many small-scale processes add up to large-scale disasters.

3.4. There is a Feeling That We Should be Able to Use Our Knowledge of Small Things to Predict and Manage These Large-Scale Phenomena

Because of the difficulty and expense of collecting detailed and comprehensive data at the regional and global scales, researchers often rely on finer-scale data to characterize social-biophysical relationships. Much of the research in human ecology, an arena where social-biophysical relationships have been studied from a systems perspective, has concentrated at local-scale relationships. Examples include fallow periods in swidden agricultural systems, nutrient loss, soil erosion and other forms of environmental degradation. These observations at the local scale have been used widely to inform policy makers whose decisions affect regional and global change. Yet it is unclear to what extent local-scale phenomena scale up to regional- and global-scale effects. Can the behavior of individuals modeled at a local scale be represented at a higher scale? Can the outcomes of the behavior of those individuals modeled at the local scale be adequately depicted by a higher-scale representation? Many economists would argue that a macro-scale representation can adequately represent the function of a system that is composed of a set of individuals. But in terms of policy prescriptions it is important to understand what the impact of high-scale (e.g., national or regional) policies will be at lower scales. The impact of a specific policy prescription in a region with a highly homogenous ethnic composition can be quite different from the impact of that policy prescription in a region with a highly heterogeneous ethnic composition.

3.5. Although the Small Things are Easier to Study and Understand, They are More Numerous

Social data collection is expensive and time consuming whether the data is household data, demographic data, or agriculture prices from regional co-ops. While remote sensing provides the ability to characterize the landcover or meteorologic conditions of an area (at specific scales), no such method exists to rapidly assess the condition of human systems across broad spatial extents at any scale. The resources necessary to collect full data at the finest scale possible for a large spatial extent are beyond the capabilities of researchers and governments alike. Even mammoth efforts such as the U.S. Census make compromises in data collection. While every household is included in the survey, there are two different forms for data collection. A short form is used for the complete census, and a longer form sent to approximately one-sixth of all households provides still further information for a subsample of the population. Beyond this, there are households and individuals missed by the census, such as migrant and transient populations.

In addition, the questions included in national-level censuses are generally broad and not focused on a specific research question. Therefore, researchers interested in focused areas of research understandably limit the spatial extent of their research and focus on specific scales of analysis. These compromises allow researchers to examine relationships that would otherwise be undiscovered or poorly understood. Yet the compromises in research design limit the researchers' ability to fully document and characterize the nature of the relationships at work.

3.6. The Large Scale is Likely to Have at Least Some Characteristics We Cannot Predict at all from a Knowledge of the Small Scale

One of the major intellectual breakthroughs of the 18th Century was the work of Adam Smith and his recognition that studying a single firm was not sufficient to understand the consequences of exchange among a variety of firms in an open competitive market. Thus, most of modern economics is based on a study of the competitive dynamics among many firms rather than the internal organization and decision making of a single firm. All processes that involve some levels of competition are likely to generate phenomena at a larger scale that is not fully predictable from a focus strictly on the smaller scale.

3.7. The Small Scale is Likely to Have at Least Some Characteristics We Cannot Predict at all from a Knowledge of the Large Scale

Similarly, examining some data or processes at a large scale removes considerable variation in what is happening at a smaller scale. For example, it is frequently thought that population change leads to rapid deforestation. For countries as a whole, population density does appear to be related to the amount of forested land remaining in the country. At a micro-level, however, many studies have shown that increases in population either do not affect the extent and composition of forests in a smaller region or actually lead to an enhancement [7, 8]. Thus, while some areas are adversely affected by increases in population located nearby, or in other regions of a country, other areas are able to use an increase in population to invest more labor in protecting a forest.

In addition, large-scale processes and relationships mask the variability that exists at smaller scales. While an overall population growth rate can be determined for an entire region, there are households with both low and high fertility within that region. The household dynamics are what will inform the researcher about what the factors are contributing to the overall level of fertility, whether they be income, education or access to contraception.

3.8. Scaling-Up is Not Part of Our Scientific Tradition

Despite the acknowledgement in both the social and physical sciences of the importance of scale effects, most theoretical progress has been made while disregarding this importance. For example, the theories about demographic transition, agricultural intensification [9], collective choice theory [10] are major contributions but do not acknowledge the operation of these theories across scales. Hierarchy theory arguably comes the closest to a conceptual framework for addressing scale issues, but this theory is not widely applied and methods of addressing this theory in research are lacking.

4. SCALE ISSUES IN SOCIAL SCIENCE DISCIPLINES

With this context for scale issues established, we now turn to a discussion of how scale has been approached from different social science disciplines drawing on Gibson et al. [3]. The content of this earlier work is adapted and modified in the following section. This discussion demonstrates that many social science disciplines are cognizant of scale-related problems in data collection and data representation. The different approaches that different disciplines adopt are partly products of the nature of the data associated with a particular discipline and partly related to the inter-disciplinary nature of certain disciplines and the ability for ideas and techniques to cross-fertilize.

4.1. Scale Issues in Geography

A major focus of geographers is to describe and 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. Geographers gain their disciplinary identity by their explicit consideration of spatial relationships. Spatial scales are thus critically important in this discipline, and span in their extent from "a single point to the entire globe" [11]. As geographers have addressed more questions related to global change, they have also been increasingly aware of linkage between spatial and temporal scales.

Discussions of the problem of scale in a more methodological and abstract fashion did not start in physical and human geography until mid-century, when geomorphologists began to address the problem. Now, scale issues are found at the center of methodological discussions in both physical and human geography. Regional scales were used prominently during the first half of the twentieth century until new research technologies, combined with a need for a more scientific mode of explanation, led to more microlevel studies. Until recently, most geographic studies gathered data at a microlevel for the purpose of contributing to larger geographic domains. However, given the increasing interest in global phenomena, however, geographic studies are shifting to more meso- and macroscale studies [12].

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.

Behavioral geographers examine the correlation between spatial and temporal scales in individual activities. Spatial scale, temporal scale, and the degree of routinization are highly correlated in many human activities. Patterns that appear to be ordered at one level may appear random at another.[1] 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 [11].

When the generalization of propositions is made across scales and levels in geography, it can result in the common inferential fallacies. These erroneous inferences have often been attributed to poor theory. In fact, they often reflect lack of data, or the limits in gathering data at multiple levels. Meentemeyer [11] 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

[1]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" [11: p. 165]. If the spatial scale or level is fixed, variables may also change according to a temporal scale. For example, different variables related to patterns of precipitation in and around mountains vary over temporal levels of hours, days, and years [11: p. 166].

system, to define an object's location and to measure its size. An advantage of using absolute scales is that hierarchical systems can easily be created when a larger (or longer) entity contains several smaller (shorter) ones (e.g., Nation-City-District-Neighborhood; Century-Decade-Year-Month-Week).

Geographers have paid increasing attention to relative space as they try to conceptualize the processes and mechanisms in space rather than the space itself. Relative scales are defined by, rather than define, the objects and processes under study.[2] 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" [13, 14].[3] Relative space is particularly important in studies of behavioral geography that focus on individual perception of space. When we need to measure distance in terms of the time and energy needed for an organism to change its position from one place to another, absolute distance rarely corresponds with the relative distance. The plasticity of space is represented by the work of Forer [15] 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.

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" [12]. As a spatial scale also implies a temporal scale in physical geography, so too does space link with conceptual scale in human geography.

4.2. Scale Issues in Economics

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

Recently, Partha Dasgupta [16] addressed a concern with the problem of linking across spatial and temporal scales within economic theory. Dasgupta suggests that economics at its core tries to explain "the various pathways through which millions of decisions made by individual human beings can give rise to emergent features of communities and societies" [16: p. 1]. By emergent features he means "such items as the rate of inflation, productivity gains, level of national income, prices, stocks of various types of capital, cultural values, and social norms" [16: p. 1]. He points out that individual decisions at any particular time period are affected by these emergent features (which themselves result from very recent individual decisions). Some of the emergent features are fast-moving variables (e.g., changes in national income and rate of inflation) and some are slow-moving variables (e.g., changes in cultural values, institutions, and norms). When economists have studied short periods of time, they have simplified their analyses by taking slow-moving variables as exogenous and focused on the fast-moving variables. This has been a successful strategy for many economic questions, but Dasgupta [16] points to the repeated findings in ecology, on the other hand, that it is the interface between fast- and slow-moving variables that produces many important phenomena.

Scale is most overtly addressed by microeconomists interested in the question of economies of scale and optimization problems. Economies of scale refer to the phenomena in which an increase of inputs within some range results in more or less than proportional increase of outputs [17]. The quantity or magnitude of objects in both the input and output streams of a productive process represents certain levels of the process. Many propositions found in economics are expressed in terms of the relationship between the level of inputs and outputs, followed by suggestions on how to make decisions that optimize results. The law of diminishing returns refers to the diminishing amount of extra output that results when the quantity of an input factor is successively increased (while other factors are fixed). The law of increasing costs refers to the ever-increasing amount of the other goods that tend to be sacrificed in order to get equal extra amounts of one good [17: p. 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 [18].

The issue of generalizability is also studied in microeconomic theory. Paul Krugman [19] examines the generalizability of theoretical propositions developed at one scale of interactions to another. Theories based on competitive

[2]Jammer [13] first contrasted absolute and relative concepts of space in his review of the history of the concept of space in physics. In fact, the absolute concept of space is a rather modern development that accompanied Newtonian physics in which relations of objects were represented in absolute terms [14].

[3]The classical reference for geographers, [14], starts with the psychological, cultural, and 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" [14: p. 192]. The early geographers relied more on Kant and Newton and thus on absolute scales. The construction of noneuclidean geometry in the nineteenth century and the development of Einstein's theory of relativity challenged the absolute concept of space. Since the mid-twentieth century, geographers have included more measures of relative space in their studies. Here, space does not exist by itself but "only with reference to things and processes" [11: p. 164].

markets are not useful when attempting to explain the structure and behavior of firms under the conditions of monopoly and less than perfect competition.

4.3. Scale Issues in Ecological Economics

Ecological economists study economic phenomena using a broader perspective than traditional economics by overtly incorporating ecological processes. 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 [20]. 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'' [20] or ''the physical dimensions of the economy relative to the ecosystem'' [21]. They take the ecosystem as a relatively fixed entity and argue that the economy grows by exploiting the ecosystem. This approach shifts the focus of economic study from economies of scale to the scale of the economy, i.e., the scale of ''all enterprises and households in the economy'' [21]. 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.

4.4. 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 [22].

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 [23]. 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 [24], often posed as ''the problem of determining the optimal spatial distribution and hierarchy of cities of different sizes'' that maximizes per capita income. Urban researchers also consider noneconomic, but no less significant, factors in their models of optimum city size, including the physical layout (accessibility to the countryside), health, public safety, education, communication, recreation, churches and voluntary associations, family life, and psychosocial characteristics. Researchers have found no general relationship between the size of city and these desired conditions [23].

4.5. Scale Issues in Sociology

While scaling issues have always been implicit in sociology, the publication of Charles Tilly's book in 1984, *Big Structures, Large Processes, Huge Comparisons* [25] put the importance of explicitly dealing with scale squarely on sociologists' agenda. Tilly criticizes many aspects of traditional sociological theories because they address social processes in abstraction, without specifying temporal or spatial limits. His method is to specify the scale of analysis first and then to find fundamental processes and structures within that scale (or, in our terms, level). The implication of his work is that multiple processes exist and some are more fundamental than others for a given level of spatial and temporal scales. For example, he argues that from the fifteenth through the nineteenth centuries in the Western world, the forms of production and coercion associated with the development of capitalism and nation states ''dominated all other social processes and shaped all social structure'' [25] including urbanization and migration.

For Tilly, the proper problem of studying historical processes should start with ''locating times, places, and people within those two master processes and working out the logics of the processes'' [25]. If one were to accept his argument for the study of integrated assessment modeling, one would start by (1) defining the question of which temporal and spatial scale is crucial in affecting a particular environmental change process; (2) identifying fundamental processes (such as commercialization, industrialization, or population growth) that drive the process; (3) examining how these fundamental processes relate to one another; and

(4) addressing how systematic, large-scale comparison would help us understand the structure and processes involved.

Tilly's [25] work also focuses on the concept of the levels of analysis – a higher level corresponds to a larger temporal and spatial scale. He argues that the crucial structures and processes vary as one changes the level of analysis. While he indicates that the number of levels between the history of a particular social relationship and the history of the world system is an arbitrary number, he proposes four levels as being useful: (1) at *world-historical level*, the rise and fall of empires, interaction of world systems, and changes in the mode of production are the relevant processes to investigate; (2) at *world-system level*, the world system itself and its main components, such as big networks of coercion and exchange, are the foci of analysis; (3) at *macrohistorical level*, major structure and processes of interest to historians and social scientists such as proletarianization, urbanization, capital accumulation, and bureaucratization become effective foci of investigation; and (4) at *microhistorical level*, the task is to make a linkage between the historical processes and the experience of individuals and groups.

Coleman [26] also directly addresses the problem of analyzing multilevel social systems. Coleman critiques Weber's [27] 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 [27] (and others who follow this method) omit how lower-level phenomena react to macrolevel phenomena, and then may act to change it. For Weber's argument, this would mean that new religious doctrines affect the values of individuals, leading to changed values about economic phenomena, new patterns of interaction between individuals, and finally, a new economic system.

4.6. Scale Issues in Political Science and Political Economy

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

Although the concept of scale within the subdisciplines of political science is rarely addressed explicitly, some of the most important substantive and methodological issues addressed by political scientists relate essentially to problems of scale and level – especially the number of individuals involved. One important discussion regarding democracy concerns the differences of scale and level between the image of the original, small Greek city-states and the conditions of large, modern nation-states. In a major study of this question, Robert Dahl [28] concludes that there are major consequences of increases in the size of democratic polities, including limited participation, increased diversity in the factors relevant to political life, and increased conflict. Sartori [29] argues that democracy is still possible because competition among politicians for election and re-election more or less guarantees their responsiveness to citizens. Vincent Ostrom [30, 31], who is more cautious, sees modern democracies as being highly vulnerable precisely because of problems related to the scale of interaction among citizens.[4] And Benjamin Barber [32] fears that the technocratic and bureaucratic orientations of monolithic multinational corporations seriously challenge the access of citizens to information and participation in effective decision making.

Scholars in political economy, public choice, or social choice focus on the relationship between individual and group preferences, with scale and level issues at its core. The path-breaking work of Kenneth Arrow [33], which has been followed by several thousand articles on what is now referred to as social choice theory (for a review, see Enelow [34]), proved that it was impossible to scale up from all individual preference functions to produce a group preference or ''general will'' or ''public interest'' function that satisfied what appeared to be an essential set of axioms of desirable properties of an aggregation process. Plott [35] demonstrated that when there were more than two dimensions involved in a policy choice, majority rule rarely generated a single equilibrium except when the preferences of individual members were balanced in a particularly optimal, but unlikely, manner. McKelvey [36] and Schofield [37] proved that an agenda could be constructed to include every potential outcome as a majority winner unless there was a single outcome that dominated all others. These ''impossibility theorems,'' combined with Arrow's earlier

[4]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, Ostrom [30, 31] 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.

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.[5] Like the Arrow paradox, the theory of collective action has also demonstrated a fundamental discontinuity between rationality at the individual and group level in the face of a social dilemma.[6] Olson [10] and hundreds after him have explored the ramifications that in social dilemmas, group outcomes are worse when individuals choose their own best strategies.

The relationship between scale, government, and the delivery of public goods and services has also been an important part of political science. This tradition of work starts with an awareness of market failure in regard to the provision of public goods and services. If free riding leads to an underprovision of a good through voluntary arrangements, some form of governmental provision will be necessary. Different configurations of governments may be more efficient and responsive depending upon the nature of the goods and services in question [42, 43, 44]. 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 [45, 46]. The approach is similar to that of ecologists who study the patterns of interactions among a large number of organized units within a spatial terrain and discover emergent properties resulting from the way that individual units work together. Scholars have found that in many cases a multilevel, polycentric system is more efficient than one large, metropolitan-wide governmental unit or only a single layer of smaller units [47, 48].

In addition to recognizing that governmental units operating at diverse spatial levels are potentially more efficient than any single-unit operation at one level, scholars in this tradition have also recognized that there are several conceptual levels involved in any governance system. At an operational level, individuals engage in a wide diversity of activities directly impacting on the world, such as the transformation of raw materials into finished goods. There is a set of operational rules that provides structure for these day-to-day decisions made by government officials and citizens interacting in a wide diversity of operational situations (teachers in a classroom with students; welfare workers processing applications of those seeking welfare benefits; police giving a ticket to a speeding driver). These operational rules are the result of decisions made in a collective-choice arena. The structure of that collective-choice arena is itself affected by a set of collective-choice rules that specify who is eligible to make policy decisions, what aggregation rule will be used in making these decisions, and how information and payoffs will be distributed in these processes. At a still different conceptual level, collective-choice rules are the outcome of decisions made in constitutional arenas structured by constitutional rules [48, 49, 50].

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

[5] Kenneth Shepsle [38, 39] 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.

[6] The term "social dilemma" refers to an extremely large number of settings in which individuals make independent choices in an interdependent situation with at least one other person and in which individual incentives lead to suboptimal outcomes from the perspective of the group [40, 41]. The reason that such situations are dilemmas is that there is at least one outcome that yields higher returns for all participants, but rational participants making independent choices are predicted not to achieve this outcome. Thus, there is a conflict between individual rationality and optimal outcomes for a group.

Table 1. The relationships of analytical levels of human choice and geographic domains.

Spatial levels of political jurisdictions	Conceptual levels of human choice		
	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 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 non-governmental organizations (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 public property, building infrastructure, providing services, monitoring and sanctioning

Paul Peterson [51], 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.

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

5. SCALE, SOCIAL SCIENCE DATA COLLECTION, REPRESENTATION AND ANALYSIS

Social science data is most frequently collected at one of the following levels: individual, household, neighborhood, urban jurisdiction (e.g., cities or counties), larger political jurisdictions (e.g., states or regions of a country), or nation. Recently, more studies have involved data collection for more than a single country and more than a single time period. The levels at which data are collected and aggregated most frequently may not be useful to the research question at hand. This is particularly the case with secondary data such as census data and national summary data. For many purposes where the process under study does not conform to the levels described above, data must be scaled up or down which involves the introduction of error to the analysis. Further, the operational processes in a smaller geographic domain may be simultaneously affected by several levels of analytical processes in that same domain as well as in larger domains (Table 1). And, as social scientists begin to address policy issues related to ecological processes, the problems of aggregating data to fit the processes under study becomes ever more important. Earlier methods of data collection and analysis frequently are not sufficient for the major environmental questions being addressed currently.

Several recent studies conducted in Indiana as well as in Nepal [52, 53] have shown the usefulness of creating institutional landscapes that conform to the governance and management units of those responsible for forest resources in a particular geographic region. To understand forest change over time, for example, it is necessary to understand the legal rules that affect forests that are owned by national as well as by state governments [54], but also the internal policies adopted by a forest owner (whether a government or an individual person) toward specific stands of forests. Rarely do forests conform to any of the levels identified above. Most state and federal forests in the U.S. cross county borders and frequently include portions of several cities. In his study of state and federal forests, Schweik [55] identified new geographic units that represented the institutional landscapes relevant to forest property manager's operational decision making and activities (as a result of a study of the collective choice and constitutional levels of choice affecting these operational-level activities). He was then able to identify the institutional incentives they faced and to map the relevant geographic domains of diverse forest-stand policies and how these changed over time. Schweik then used Spectral Mixture Analysis to convert the raw digital numbers that MSS images provide to at-surface reflectance values for three time periods. This enabled Schweik to trace changes in management practices (e.g., opening areas for recreation, changing timber harvesting practices, restricting all harvesting activities) as measured by changes in the reflectance values. By conducting this kind of multi-scale analysis (from the pixel, to a stand, to a forest owner, to a region), Schweik was able to show that many of the forest stands owned by both state and national governments were showing substantial patterns of regrowth over the past twenty years, but that the difference in collective choice rules governing the two types of government-owned forests could be detected in the spectra. The stronger collective choice mandate facing state foresters to generate income from state land can be detected when comparing the spectra from federal and state forests over time.

Recent studies using dynamic modeling techniques, have also enabled scholars to address problems of spatial misperceptions as they affect public policy. Wilson et al. [56] examine the domain of regulatory actions related to inshore fisheries and ask whether the spatial extent of the regulation is appropriate given the spatial differentiation in the ecological processes affecting fishery dynamics. The presumption underlying much of contemporary policy is that the domain of regulation should be as large as possible for any resource where there is some movement among local ecological niches. In this view, all members of the same species are part of a panmictic population and harvesting practices adopted in one location will eventually affect and be affected by practices adopted in other locations. If the population is indeed panmictic, then regulation at the largest level is indeed appropriate. Gilpin [57] and others have argued, however, that many fisheries are characterized by metapopulations where local populations are relatively discrete. When a species is appropriately characterized as a metapopulation, a local extinction may not be re-colonized by other fish and regulation that does not take into account smaller-scale processes may lead to an unintended collapse of key segments of the larger population. By using a series of dynamic models, Wilson et al. [56] are able to identify when having regulatory regimes at a smaller level (complemented by more limited regulation at a larger level) leads to greater sustainability of a fishery. In particular, the level of variability that occurs within and across sub-systems affects the likelihood that a regulatory system organized at too large a scale will lead to extinctions of local populations and a consequent overall reduction in the sustainability of the fishery.

Entwisle et al. [58] used the integration of community-level socio-demographic data and remotely sensed imagery to explore the relationship between demographic factors (fertility, migration) and the rate of deforestation in northeast Thailand. Deforestation in northeast Thailand is the product of household level decisions made within the context of community-level institutions such as those rules imposed on a community by a village headman and group of village elders.[7] In order to enable this linkage, the social unit of analysis, a community, was linked to the landscape by creating a spatial partition around each community representing the area affected by the socio-economic composition of the community. While communities did have distinct administrative boundaries associated with them, community-level land tenure patterns did not coincide with these boundaries, making the administrative boundaries alone inadequate to capture the spatial extent affected by households in a particular village.

In an extension of this work, Walsh et al. [4] explore how the relationship between demographic factors and forest cover changes as a function of scale and specifically the cell size used for spatial data representation. Using a set of different cell resolutions and tests of significance, it was found that the statistical results (e.g., sex-ratio and land-cover composition) changed as a function of data aggregation and the cell resolution used to represent those data. In other words, the scale at which data are collected and represented affect what relationships are found between variables in subsequent analysis. This study is one of many that demonstrate the importance of not relying on a single scale of analysis.

[7]The study area of Nang Rong is characterized by a nuclear village settlement pattern where households are aggregated in a common area and land holdings are dispersed around the village area. The administrative areas around a village are comprised of private landholdings and community land whose management is controlled by village headmen and village elders.

Perhaps even more fundamentally, a researcher must determine if a specific level of analysis is of relatively little importance in a social-biophysical system. For example, in some areas community-level institutions have relatively little affect on the way land is managed and household dynamics are far more important. In this case a model of land-cover change may appropriately exclude a specific community-level component while still adequately capturing the key social-biophysical interactions. The difficulty lies in determining the relative importance of different levels prior to data collection.

Scientific research at different scales of levels of analysis invariably yields different findings [4]. This disparity is in part due to the scale dependence of certain relationships but also the availability and representation of data at different scales. For example, Wood and Skole [59] completed a large study of deforestation in the Brazilian Amazon to examine the factors related to the rate of deforestation. This research relied on regional-level census data and remotely sensed imagery and found that population density was a major factor related to deforestation rates. This regional-level analysis is critical in determining the rate of deforestation over a broad spatial extent. However, the findings relating social variables to deforestation are limited to the variables available in the census data.

Household-level analyses of the Brazilian Amazon show a more complex set of relationships in relating socio-economic and biophysical factors to deforestation [60, 61, 62]. For example, access to credit, wage labor availability, distance to roads, topography, and soil characteristics have all been shown to be important factors at this household level of analysis. These more complex relationships are apparent because of the use of a household-level survey to address the specific question of deforestation, and so this distinction between household and regional-level analysis is more a question of data availability. Yet researchers developing IA models need data to calibrate and validate their models. Furthermore, IA models typically operate at a single scale of analysis. Data availability issues might lead modelers to develop models at specific scales of analysis not because that is the proper scale at which the system should be modeled but because of the scale at which validation data are available.

6. SOCIAL SCIENCES METHODS ADDRESSING SCALE

Much of the progress made towards understanding the nature of scale has been made in the physical sciences [3]. However, these methods developed in fields such as ecology and hydrology do not necessarily address the particular problems scale effects introduce in social science research. A variety of methods have been developed in fields such as geography, epidemiology and sociology that are well suited to addressing scale questions related to social data.

6.1. Contextual Analysis

One of the interesting scale-related questions that political scientists face is whether there are “neighborhood” effects on individual political behavior. For example, is it the case that individuals who start out with a Democratic Party identification continue to vote for Democratic Party candidates in all elections over time when they are living in a neighborhood that is predominantly Republican as contrasted to predominantly Democratic? In other words, what is the effect of the context at a neighborhood level on the voting behavior of individuals with particular political orientations? This is a question that has now been addressed by the development of a sophisticated form of data analysis referred to as contextual analysis [63, 64]. Recently scholars interested in educational performance have used contextual analysis to address questions related to the impact of classroom composition on individual student performance. Again, the question is phrased whether students who come into a classroom with an initial score on a standardized test progress more rapidly or more slowly depending on the test scores of others in the classroom or other individual attributes of students aggregated up to the classroom level. In all forms of contextual analysis, the hypothesis is that the aggregation of individual characteristics that make up a relevant group affect the impact of individual characteristics on individual behavior.

6.2. Multi-Level Modeling

Socio-economic data that are collected at the individual, household and community levels are in turn aggregated to regional and then national levels of data representation. Scientists have recognized the importance of relationships that operate at only specific scales. For example, land management decisions are commonly made at the household level in the context of a regional economy. Individual migrant decisions are made by individuals in the context of a household and region. The importance of these multiple levels has been managed methodologically using multi-level modeling, where variables from multiple levels are used in empirical analyses. Much of this multi-level modeling research grew from the health sciences. In particular, epidemiologists would use multi-level modeling to look at both household and neighborhood characteristics as risk factors.

6.3. Hierarchy Theory

One theory particularly relevant to scaling both social and biophysical data is hierarchy theory [65, 66]. The central idea of hierarchy theory is that the understanding of a complex system depends on understanding the constraints at higher and lower levels of spatial-temporal resolutions. The levels immediately above and below the referent level provide environmental constraints and produce a constraint ‘‘envelope’’ in which the process or phenomenon must remain [67, 68]. For example, households are a common unit of social data analysis and in many environments are the level at which land management decisions are made. Community-level institutions and characteristics provide a context within which household decisions are made as with the example from northeast Thailand [4, 58]. The difficulty in applying this theory is that the researcher must first decide what the bounding levels with constraints are, something difficult to do without the availability of multi-scale data. However, hierarchy theory comes closest to providing a conceptual framework within which scale issues can be explicitly addressed regarding the spatial representation of social and biophysical processes and the interactions between them.

6.4. Modifiable Areal Unit Problem

A common method of spatial data integration is by using simple overlays of different polygonal units representing homogenous areas for particular variables. Overlaying polygonal units from different sources (e.g., census tract polygons and watersheds) often creates polygon intersections that can change the nature of the spatial data representation. These changes occur because of the method of the somewhat arbitrary method of delineating polygonal units. This problem, referred to as the Modifiable Areal Unit Problem in Geography [69, 70] has been well documented and a variety of researchers have presented research suggesting various solutions to this problem (see for example Green and Flowerdew [71]). However, a universal solution has not yet been forthcoming and the modifiable areal unit problem addresses only one particular manifestation of scale effects.

7. SCALE, SOCIAL SCIENCE AND INTEGRATED ASSESSMENT MODELING

A central problem in integrated assessment modeling and the calibration and validation of IA models is data availability. The lack of social data (longitudinal and cross-scale) precludes the ability to perform robust time series analysis, hindering the ability to look at the dynamic nature of social and biophysical processes. For example, county- or state-level price data are often available in rich time series and at multiple temporal resolutions (e.g., daily, monthly, yearly) but demographic data is more commonly available at much coarser temporal resolutions (e.g., decadal, five years). Some might argue that demographic indicators are less variable then economic indicators and thus the relative intervals for data collection is thus justified. However, while fertility and mortality rates are slow to change, very dramatic changes in in-migration and out-migration rates can occur within very short periods of time. These disparities between datasets from different sources are major obstacles to model calibration and validation and no solution to this problem is evident.

A core issue related to the scale dependence of social data is the need to reconcile the difference between social units of observation and spatial units of analysis. GIS techniques present a variety of methods of transforming data from one spatial data representation to another allowing these different units to be reconciled. To a large extent, the pattern of land settlement determines what data transformations are necessary to make these social spatial linkages. For example, in Altamira, Brazil, parcels are organized in the widely cited fishbone pattern. Parcels are of roughly uniform size (500×2000 m) and with the exception of recent isolated instances of land consolidation, each parcel is allocated to a single household. This spatial arrangement lends itself to a parcel-level analysis as a one-to-one linkage can be made between the social unit of analysis and a spatial unit of analysis – the parcel.

A similar arrangement exists in many areas in the midwest United States. Here land was surveyed into parcels of regular dimensions and allocated to individual landholders in the early 1800’s. In contrast to Altamira, there has been a high degree of parcel fragmentation as households split parcels and land is transitioned from agricultural uses to residential uses. It is still possible to make a one-to-one linkage between households and a discrete spatial unit of observation, but the ability to conduct longitudinal or multi-temporal analysis is complicated by the fragmentation of parcels over time.

In contrast to Altamira and the midwest United States, northeast Thailand presents a very different pattern of land settlement that dramatically affects the feasibility of making a one-to-one social-spatial linkage. In Buriram Province on the Korat Plateau of northeast Thailand, villages are organized into a nuclear pattern of land settlement. Households are concentrated into a central area and landholdings are distributed around this central village area. Complicating the ability to link households to discrete spatial partitions on the landscape is the fact that households typically have several landholdings that are distributed in different areas around the village. In the absence of digital or hardcopy maps showing landholdings linked to landholders, the effort necessary to spatially reference the landholdings of all the households for a single village is tremendous. This type of linkage would allow researchers to relate household or individual-level characteristics to outcomes on the landscape with a one-to-one relationship between the social unit of analysis (household) and the spatial unit of analysis (parcel). In terms of policy prescriptions it is important to understand the impact of those policies at the household level because different households may be affected differently by the same policy. But, the resources necessary to do this for even a small number of villages makes such a household-level linkage unfeasible for large spatial extents. In this situation data transformations may be used to scale-up social data from the household to the community level. For example, radial buffers can be created around communities allowing a spatial partition to be created within which community-level characteristics can be linked to biophysical data characterizing this spatial partition [58]. Community-level boundaries can be used to partition the landscape, acknowledging certain inconsistencies in these boundaries such as the overlap between adjacent communities. This scaling-up has two major affects. First, some variables do not lend themselves to aggregation. The mean age of males and females can be easily computed, but variables such as ethnicity or religious affiliation are more difficult to scale-up. In addition, this scaling-up necessitates the introduction of some heterogeneity within the social unit. In some cases this heterogeneity is minimal, but in other cases it can have dramatic affects on subsequent analysis.

So what developments in modeling might allow researchers to produce integrated assessment models that are more suited to crossing-scales? Many models exist which do one or two of the following things well: (1) incorporate spatial interactions [56, 72], (2) incorporate dynamic relationships [72, 73], (3) model the human decision-making process [74, 75]. The primary challenge facing researchers now is to develop spatially explicit models that elegantly handle dynamic relationships and human decision making [76].

One type of modeling that shows particular promise is agent-based modeling. Agent-based models explicitly allow interactions between model actors to be represented in a dynamic framework [77]. For example, an agent-based model examining land-cover change can be be populated with the following types of actors: (1) residential smallholders, (2) large-holder agriculturalists, (3) land developers. Interactions within these agent groups and between these agent groups allow for a more realistic environment within which decision making can be modeled. Furthermore, agent-based approaches present a means whereby complex social interactions can be explored such as feedbacks in systems as a result of the transfer of information between agriculturalists or equilibrium states related to crop productivity and inputs. Currently, agent-based models that examine integrated systems are lacking. However, models exist that are approaching this functionality (for example the FLORES model [74] and improvements to the Patuxent ecosystem model [72, 78]) and this linkage between agent-based and spatially explicit approaches shows particular promise for IA models. This linkage involves the reconciliation between individual-based models [79] and large-scale ecosystem approaches [78]. Such a reconciliation is at the core of scale issues in social science and IA modeling.

8. CONCLUSION

An integrated assessment model ideally should incorporate data at multiple scales to calibrate and validate the model. It is possible to use a single scale to observe the impact of a single relationship (e.g., prices and land use, topography and deforestation), but there are likely other factors operating at other scales that are as important, and the nature of relationships change across scales. It is well established that certain phenomena are observable at some scales while unobservable at others. Beyond this, the nature of relationships changes with scale, so that even if a relationship is observable at multiple scales, the magnitude or strength of that relationship may differ across scales. A multi-scale approach will provide a more complete understanding of a system than an analysis focusing on a single scale, but researchers must still determine the individual scales composing this multi-scale approach. What would be ideal would be an analysis not at a discrete set of scales but along a scale continuum, but this is clearly not possible due to data availability issues. The realities of research and modeling dictate that a multi-scale analysis is not always feasible. In these situations it is the researcher's task to understand the situations when scale-dependent relationships may be present through an understanding of the social and biophysical systems under study. If a particular relationship is not evident at one scale, the researcher may explore other scales if there is a certain confidence that relationship exists at other scales or has a different characterization at other scales. Unfortunately this does not lend itself to a rapid appraisal of systems and the impact of scale dependence within those systems.

What is clear from an examination of social science literature is that there is no consensus on how to deal with scale issues in the social sciences and by extension no evident answers in terms of integrated assessment modeling. What the existing literature does provide is evidence of when scale issues are important and to what degree scale issues are important in different situations and methods (albeit not universally accepted) of dealing with scale dependence. While a consensus surrounding scale effects is missing, new developments in modeling present opportunities to explore spatially explicit and complex IA models that cross from the individual to the ecosystem scales. The spatially explicit nature of these new models will allow scale relationships in complex social-biophysical systems to be more easily explored.

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