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Linking ecological and social scales for natural resource management

6.1 Introduction

Natural resource management has moved from a single disciplinary and one resource management approach to an interdisciplinary and ecosystem-based approach. Many conceptual models are being developed to understand and implement ecosystem management and forest certification initiatives that require an integration of data from both the social and natural systems (Vogt *et al.*, 1997, 1999a,b). These changed approaches to natural resource management arose from a perception that variables critical in controlling the health and functioning of an ecosystem could only be determined by integrating information from both the social and the natural sciences (Vogt *et al.*, 1997). However, it has been difficult to take many of the theoretical discussions and the frameworks or conceptual models that they have produced and to operationalize or put them into practice on the ground.

Despite these discussions and the recognition of their importance, social and natural science data have been ineffectively incorporated into the management and trade-off assessments of natural resources (Berry and Vogt, 1999). We hypothesize that some of this has occurred because of the distinct spatial scales being used by different disciplines which have not allowed for integration of information to occur at a causal level. The complexity and uncertainty of data needed to understand ecosystems by both social and natural scientists have also made it difficult for managers to recognize when the wrong indicators are being monitored or whether a system could degrade due to management (Larson *et al.*, 1999; Vogt *et al.*, 1999c). The need to link data causally from both disciplines as part of ecosystem management has given greater impetus to develop practical tools that would allow this integration to be accomplished. However, today much of that integration has been mainly occurring at the level of conceptualization and development of frameworks of analysis.

Table 6.1. *The smallest to large-scale levels of analysis existing in the social and natural sciences*

Natural sciences	Social sciences
Biotic individual approach	*Biotic individual approach*
1. Genes	1. Individual
2. Protoplasm	2. Household
3. Cells	3. Kin, clan, caste
4. Tissues	4. Neighborhood
5. Organs	5. Village or city
6. Organ systems	6. Watershed
7. Individual (e.g., producers, consumers, carnivores, omnivores, decomposers – fungi, bacteria, etc.)	7. County
8. Family	8. State
9. Population	9. Region
10. Community	10. Society
	11. Country
Functional ecosystem approach	*Functional ecosystem approach*
1. Inorganic or organic substrate	1. Social order identity (age, gender, class, caste, clan) hierarchy (wealth, power, status, knowledge, territory)
2. Patch or microsite	2. Social order and cycles (a) physiological (b) individual (c) social norms or rules for behavior (d) institutional
3. Stand or plot	3. Social institutions health, justice, faith, commerce, education, leisure, government, sustenance institutional cycles
4. Vegetative type	4. Cultural resources (organizations, beliefs, myths)
5. Ecosystem type	5. Socioeconomic resources (information, population, labor, capital)
6. Soil type	6. Environmental cycles energy, land, water, materials, nutrients, flora, fauna environmental cycles (natural disturbances)
7. Watershed	
8. Landscape	
9. Region	
10. Biome	
11. Globe	

Note:
The scale of analysis increases from a smaller to a larger scale with increasing category numbers – the smallest scale starts with category number 1. Only within the functional ecosystem approach in the social sciences does each category potentially not have the ability to contain scales ranging from the smallest to the largest.

Sources: Odum (1959); Burch (1988); Grove (1996); Machlis *et al.* (1997); Vogt *et al.* (1997).

The focus of this chapter will be to discuss one issue, the spatial scales of analyses, that we feel is a significant constraint reducing the ability of managers to conduct holistic analyses of their resources. The spatial scales commonly used in assessments are defined by the boundaries of the management unit (see Table 6.1 for the typical scales used by researchers). To satisfactorily achieve holistic management of natural resources, implicit consideration of spatial scale and identification of what scales are appropriate need to become an integral part of the suite of tools used by a manager. The primary objective of this chapter is to further advance the dialogue on scale issues and to discuss more explicitly how consideration of scale would allow for more effective management. Several points will be considered that have constrained integration in natural resource management. First, each discipline tends to utilize its own spatial scales of analyses which are generally different from other disciplines. Second, there is a tendency within each discipline to identify the most sensitive spatial scale of analysis for each natural resource problem as determined by the dominant scales of analyses particular to that discipline. Finally, there is a tendency of the scale of analysis in the social sciences not to match the scale used in the natural sciences. If these assumptions are correct, they suggest a need for managers to identify relevant scales of analyses for each management unit that should vary based on the spatial characteristics of the management unit and the matrix landscape within which it is imbedded. This would require the manager to select a scale based on causal or mechanistic relationships that are sensitive at the selected scale and may even suggest the need to examine several scales simultaneously.

This chapter will not summarize much of the previous scientific discussion that has occurred on scale but will emphasize how managers should use spatial scale when integrating social and natural science sides of management. A case study of the Baltimore Ecosystem will be used to highlight some of the points being made with respect to scale and to demonstrate how scale can be used to resolve natural resource problems at different scales of analysis.

6.2 Spatial scales relevant for natural resource managers

Any discussion of spatial scale issues in the social and natural sciences should begin with an examination of how scale has been incorporated into research and an understanding of why particular scales were selected. This discussion will begin to inform a manager of the appropriate scales to consider when linking social and natural science information and whether it is realistic to assume that this integration should occur at the same spatial scale. The dominant and sensitive spatial scales relevant in the different subdisciplines in ecology, conservation, and the social sciences will be analyzed in the next section. This will be followed by a discussion of scaling and scale issues that must be considered when integrating social and natural science data to achieve ecosystem management.

6.2.1 Dominant scale uses assessed from publications in the social and natural sciences

It is informative to review the literature and determine what similarities and differences exist in the typical scales of analyses used by the dominant disciplines germane to natural resource management. We documented the spatial scale of analysis used by researchers who published in two ecological journals (i.e., *Conservation Biology*, *Ecology*) and two social science journals (i.e., *Human Ecology*, *Society and Natural Resources*). Journals were selected for inclusion in this analysis that published interdisciplinary papers, but were written primarily for audiences in the natural or social sciences, since the purpose of this exercise is to inform ecosystem managers. The results of this survey are given in Table 6.2 for the year 1996.

A surprisingly high number of articles published in the social and natural sciences do not even give the spatial scale of their study (the exception is *Human Ecology*). For example, spatial scale was not mentioned in 60.7% of the articles published in *Conservation Biology*, 38.2% of the articles in *Ecology*, and 66.6% of the articles in *Society and Natural Resources* (Table 6.2). In articles where scale was not reported, scale was not considered relevant in half of the studies and was not "place-based" for the other half. *Human Ecology* had a higher percentage of the articles having clearly defined spatial scale – only 14.4% of the articles did not specify a scale. The tendency for studies not to give the scale at which their research is being conducted suggests a perception that the spatial scale is not a critical factor for understanding the system. Since many studies did not mention scale nor define their spatial scale of analysis, it suggests that researchers have (1) alternative conceptualizations of what scale is and how to define it, and (2) different perceptions of the importance of locating their analysis unit (e.g., village ecosystem) within the landscape.

Summarization of the scale data by groupings for the four journals also shows a lack of a common spatial scale of analysis among them (Table 6.2). In general, this small survey of a few journals suggests that most social science studies were conducted at larger scales than what was commonly used in the natural sciences.

Conservation Biology was characterized by having no one scale being the dominant unit of analysis – the smallest scale (<0.01 ha) was equally represented (7.1%) as was the largest scale (>10 000) (5.7%) (Table 6.2). This reflects the tendency of this discipline to undertake plot studies to understand smaller

Table 6.2. *Scale of analysis used by studies published in four journals* (Conservation Biology, Ecology, Human Ecology, and Society and Natural Resources) *for a one-year period in 1996*

Spatial scale (ha)	Number of times cited in 1996 (% of total citations in each spatial scale category by journal) Conservation Biology	Ecology	Human Ecology	Society and Natural Resources
<0.01	10 (7.1%)	95 (39.9%)	0 (0%)	1 (2.1%)
>0.01 to <0.1	6 (4.3%)	6 (2.5%)	0 (0%)	0 (0%)
>0.1 to <1	6 (4.3%)	14 (5.9%)	0 (0%)	1 (2.1%)
>1 to <10	4 (2.9%)	13 (5.5%)	10 (37.0%)	2 (4.2%)
>10 to <100	6 (4.3%)	7 (2.9%)	2 (7.4%)	0 (0%)
>100 to <10 000	7 (5.0%)	4 (1.7%)	6 (22.2%)	5 (10.4%)
>10 000 to <100 000	8 (5.7%)	1 (0.1%)	4 (14.8%)	5 (10.4%)
>100 000	8 (5.7%)	7 (2.9%)	1 (3.7%)	2 (4.2%)
Not given[a]	40 (28.6%)	55 (23.1%)	2 (7.4%)	16 (33.3%)
Scale not relevant[b]	45 (32.1%)	36 (15.1%)	2 (7.4%)	16 (33.3%)
Total number articles	136	219	23	38

Notes:

[a] Many of these articles may have given scales in terms of household, village, national park, etc., but did not give an explicit mention of the areal measurement unit.

[b] Articles not spatially based (e.g., models, conceptual theory oriented articles, measurements taken from "populations" without saying where).

animals or bounded activities as well as landscape studies to understand the territory necessary for survival of a species. The results from *Conservation Biology* markedly contrasted with the *Ecology* journal. *Ecology* showed a dominance of the smallest scale of analysis (<0.01 ha, e.g., 10 m × 10 m plot) with 40% of the total studies being conducted at this scale. The *Ecology* journal publishes many articles by population and community ecologists who tend to conduct their research on small plot sizes.

Human Ecology did not record any studies that had research plot sizes less than 1 hectare in size (Table 6.2). In 1996, *Human Ecology* had 37% of the articles having study plot areas that were greater than 1 but less than 10 hectares in size (e.g., 100 m × 100 m to 316.2 m × 316.2 m). Most of the studies in this journal were at the household or village level. The scales in the two social science journals, if mentioned, were given in terms of socially determined areas, e.g., village, province, rather than landscape or ecosystem differentiations. *Human Ecology* also showed that 22.2% of the studies used study areas 100 to 10 000 ha in size and 14.8% used study area sizes of 10 000 to 100 000 ha. Similarly, *Society* *and Natural Resources* had over 20% of the articles reporting their research areas to vary between 100 and 100000 ha in size. At least during 1996, *Society and Natural Resources* published no studies that were conducted at the second smallest size grouping (0.01 to 0.1 ha) and in a middle-level spatial area (10 to 100 ha).

6.2.2 Scale delineation rationale in the sciences contributing to natural resource management

Many of the scales selected for use by different disciplines are based on the selection of those scales that are the most sensitive to answering the question being pursued by each researcher in their field of specialty. For example, the smaller scale of analysis selected by an ecophysiologist is the only scale at which a physiological process in particular tissues of a plant can be detected mechanistically. Clarification of study area sizes selected by scientists implementing ecosystem management or conservation follows below.

The past tendency by ecologists to study systems using a biotic or functional approach (Vogt *et al.*, 1997) have reinforced a few spatial scales of analysis (see Table 6.1). Early in ecology, the biotic approach was the dominant tool being used to study ecological systems (Clements, 1916; Whittaker, 1953; Billings, 1985; Ashton, 1992). In the 1980s, the importance of the ecosystem and functional approaches was finally recognized (Vogt *et al.*, 1997). Since ecosystem ecologists generally used larger spatial scales than the biotic approach, the scale of system analysis increased with the adoption of the ecosystem approach. Researchers using the biotic approach focus on individual interactions with nature. Those using a functional approach are ecosystem based and frequently the individual is not a relevant unit of analysis and therefore not ever explicitly considered. Natural scientists using the biotic approach focus on smaller scales of analysis compared to those who use a functional research focus where the spatial scales of analysis are larger (Table 6.1).

In ecosystem ecology, the spatial scale is identified by the boundaries of ecosystems where the function of the system changes. However, determining the exact boundaries of an ecosystem is a subjective process because the scale at which the system is being observed influences this decision (Giampietro, 1994). By definition, the boundaries of the ecosystem should be demarcated where there is a significant change in the rate at which energy or materials move between two systems (Allen and Hoekstra, 1992). In practice, it is impractical to study the entire ecosystem so representative areas are identified within that larger ecosystem for study. Ecosystem ecologists have used two dominant spatial scales of analysis within this larger system – the stand or plot, and the watershed. The stand typically varies from 0.05 to 1.0 ha in size and is a small fraction of the total ecosystem under study. Site selection becomes crucial at the stand scale since the heterogeneity of the system may mask the processes being studied. When selecting replicate stands, ecosystem ecologists spend a considerable amount of time locating plots that are similar to one another and representative of the ecosystem but distant enough to decrease chances of pseudo-replication. Plot-size choices often reflected the assumption that the processes and patterns examined are indifferent to scale (Wiens, 1989). The other scale used by ecosystem ecologists is the watershed where there is no subjectivity in site selection because the scale is clearly defined by the boundaries of the watershed. Watersheds selected for scientific study (vs. all watersheds) are typically <100 ha in size (Bormann and Likens, 1979; Hornbeck and Swank, 1992). Traditionally, the watershed was defined as a topographically specific area where all the precipitation falling into that area drained into one stream. Since a watershed-scale approach does integrate the heterogeneity that can be found within its bounded space, some researchers use the word watershed as an equivalent term to a landscape.

More recently, landscape ecologists have also focused on the landscape as a spatial unit of measure. Landscape ecology looks at broad spatial scales and attempts to understand the development and dynamics of spatial heterogeneity, interactions and exchange across heterogeneous landscapes, and the influences of spatial heterogeneity on processes (Turner, 1989; Forman, 1995). The landscape scale contrasts the watershed approach because it explicitly incorporates the heterogeneity in the system. It also does not limit studies to an area necessarily linked by flows of water, nutrients, and other materials.

Conservation Biology has focused on the species of interest and defined the scale of analysis by the habitat requirements for that species so that no fixed spatial scale is common (see Table 6.2). Out of all of the subdisciplines in ecology, conservation biology has most explicitly dealt with spatial relationships since the early 1960s when the relationships between the amount of habitat area and number of species were converted to mathematical relationships (Preston, 1962). MacArthur and Wilson further developed these relationships between species and habitat area in 1963 when they published their *island biogeography theory* (MacArthur and Wilson, 1963). These ideas are still an important element of conservation biology although the patterns predicted by the island biogeography theory are not always supported by subsequent studies (Smith, 1990). Species–area relationships focused conservation biologists into explicitly examining the spatial scale of their management area as defined by the species of conservation priority. For example, the scale of interest can vary significantly since the habitat area for a salamander is a stand while for a bear it is a landscape. This lack of a specific spatial scale of analysis compared to other disciplines was quite apparent from the data summarized in Table 6.2.

In the social sciences, the spatial scale of analyses frequently varies from the small to the large scale within one study. The small scale typically consists of household surveys while the large scale assesses the condition and changes in the natural resource-base across a village or other defined area utilized by the people in question. Conway (1986) included a hierarchy of information needs in both the social (e.g., the family to kin group and tribe) and natural systems (e.g., village to mini-watersheds and to the valley). Freudenberger (1997) also used the larger scale of the landscape (e.g., remote sensing to identify locations with significant land-use changes) to identify locations of her more in-depth small-scale studies at the household level. The focus in Table 6.2 on the larger scales of analyses in the two social science journals reflects the inclusion of the natural system to identify the largest scale of assessment. Many social scientists conduct research at the household or community/village level as these are seen to be the most fundamental units of productivity and social order (Moran, 1984; Siralt *et al.*, 1994). Traditional data-gathering techniques in the social sciences are geared towards these two scales (Molnar, 1989). Broader political and economic issues have only recently been included as important factors influencing smaller-scale decision-making, and social and natural systems (Moran, 1984; Fox, 1992).

Other social science studies require information to be collected at several different scales. In order to conduct impact assessment for their human ecosystem model, Machlis *et al.* (1994) recommended analyses that would include the family unit, the community, country, region, nation, and eventually the globe. The study by Grove and Hohmann (1992) was a landscape study that used social data collected at the household, community, regional, state, and national levels.

The use of similar scales and theoretical frameworks by social and natural sciences can be found in the literature. Use of similar scales was *not* the result of social and natural scientists working in interdisciplinary teams or reading each other's literature. These frameworks evolved from each discipline attempting to deal with their own problems. Excellent examples showing the development of similar conceptual frameworks by social and natural scientists is the research on urban expansion (Burgess, 1925; Park *et al.*, 1925) and the design of biosphere reserves. Burgess (1925) did not consider the environment as part of his theory on urban expansion but emphasized the relations between humans and the artificial construct of a city. That study defined specific activities occurring within concentric circles that radiated out from the center of the city. The center of the city was dominated by the business sectors and radiated out to the urban parts of the city. The key unit of analysis for Burgess (1925) was the city. The concept of the human community articulated by Burgess (1925) is similar to the reserve design adopted by the Man and the Biosphere (MAB) program.

The MAB reserve concept does not use the city analog but instead focuses on the interactions of humans with the surrounding environment (typically forests). The MAB reserve concept consists of a core area in the center of a reserve that is not to be utilized by humans, but should remain as habitat for native animals and plants. The next concentric circle located adjacent to the core area is defined as areas where humans can harvest products from the forest but this utilization should not visibly change the character of the forest. The last outer circle is the zone of intensive human activity (e.g., villages, agricultural fields) and has few, if any, of the characteristics of the core area. Both the city model and the biosphere reserve model define zones of human activity using the concentric circle concept. This separation of activities by spatial scale is very artificial and in practice does not typically occur (e.g., human activities are difficult to exclude from the MAB reserve core areas).

6.2.3 Scaling issues

Scaling is an important research topic because most of our past data collection has occurred at smaller scales and not at the larger scale where natural resource decisions and policy need to be formulated (Levin, 1992). Scaling issues are further compounded by the fact that different scales (given in Table 6.2) are also not discrete or disjointed in time and space (Magnusen, 1990) so that temporally distinct activities can feed back to affect a different scale relative to where the activity was originally generated. Several factors have contributed to making it difficult for managers to translate information collected at smaller scales to make practical decisions at larger scales. Three of these factors will be briefly discussed here: (1) changing amount and type of data with scale, (2) preference by scientists to study smaller scales because of the ease of experimentation and use of controls for the experimental system (see section 6.2.1), and (3) the loss of predictive ability (i.e., causal relationships) when transferring information between scales.

In the 1980s, much attention began to be placed on producing tools to scale data from the small to the larger scales of the landscape and the globe in the natural sciences. Developing scaling tools was important to allow the significant volumes of data already collected by physiologists as well as community and ecosystem ecologists to be used (Running and Coughlan, 1988; Running and Nemani, 1988; Ehleringer and Field, 1993; Running and Hunt, 1993). At the same time, model development in the social sciences began to integrate information from different scales (Burch, 1988; Fox, 1992; Cortner *et al.*, 1996). This need for linking data between small and large scales was an impetus for the development of hierarchy theory.

Already in the 1980s, hydrologists realized the problems resulting from modeling watershed dynamics as uniform. This realization stimulated research to link hydrologic models with geographic imformation systems (GIS) to spatially analyze a watershed to incorporate its heterogeneity (Beasley *et al.*, 1982; Young *et al.*, 1989; Arnold *et al.*, 1990; Fraser, 1999). Hydrologists have also accepted the importance of the spatial resolution of input variables in determining the results of their modeling efforts (Fraser, 1999). This conclusion resulted from the use of non-linear equations in models so that "their statistical properties (mean and variance) for a given area will change if input data are aggregated to a coarser resolution" (Fraser, 1999). Dubayah *et al.* (1997) demonstrated this phenomenon when they obtained different results from input variables aggregated at a 1-km compared to a 10-km resolution. This last example again demonstrates the importance of identifying the most sensitive scale of analysis for each natural resource problem.

Scientists generally accept the statement that the type and amount of data needed to assay the resistance and resilience characteristics of an ecosystem are sensitive to scale of analysis. As a generality, the smallest scale has the largest data requirements to explain how that ecosystem functions (Gosz, 1993). Other variables and, in most cases, fewer variables are needed to predict ecosystem characteristics as one progresses up to larger scales. Each scale also has different stresses that are important in regulating processes at that scale (Turner *et al.*, 1995). Therefore, there is an inability to automatically sum up the parts of a system at one scale and then examine that system from a larger scale. In addition, each scale itself may have many linked scales (e.g., forested landscape to a drainage basin or watershed to a forest stand or ecosystem to gaps within the forest and individual trees). Therefore when analyzing landscapes at different scales, it is important to recognize that each organism defines and perceives patches differently within that landscape (Wiens, 1989; Levin, 1992; Milne, 1992; Turner *et al.*, 1995).

The difficulties of transferring data between scales have generated much of the discussion related to hierarchy theory (O'Neill *et al.*, 1986, 1989). Unfortunately, the tools or good examples demonstrating the implementation of hierarchy theory have been slow to develop (Turner *et al.*, 1995). Some of this difficulty is a result of the non-linear transformations of process and relationships that occur when making transitions among scales (Walters and Holling, 1990). The existence of "chaos" or the loss of predictive capability between different scales of analysis creates problems for global-scale policy analyses when utilizing information generated at smaller scales (Stern *et al.*, 1992; Nilsson and Schopfhauser, 1995; Lele and Norgaard, 1996). Depending upon what data from the lower scale are used may skew the results synthesized at the higher scale. This is especially relevant when the scaled-up data results are associated with data from a lower scale that has a large degree of variation.

Global warming and carbon sequestration in forests (Schroeder, 1992; Brown *et al.*, 1993; Houghton, 1996) also illustrate problems arising from aggregating incomplete data collected at lower scales to address a problem at a larger scale. We suggest that some global warming debates are being analyzed at the wrong scale because the final scale of analysis is not sensitive to the variables initially used to drive the analyses. This lack of sensitivity at the global scale results from inadequate data summarization and how existing data are being scaled to the globe. When scaling data, any errors in the synthesis of the data will strongly affect the conclusions that are reached. For example, most of the global warming studies cited above did not adjust their data analyses to account for the selectivity of data from a few study sites. They also did not adjust their analyses to compensate for missing information. Vegetative community classifications and aboveground biomass data have been used as the main data to scale-up plot specific data to address global warming issues. However, belowground vegetative biomass and soil organic matter can sequester carbon at levels two to three times higher than the aboveground biomass (see Lugo and Brown, 1993; Vogt *et al.*, 1996). Therefore, the synthesis and scaling of ecological information to produce the global value should be highly suspect. These analyses result in an assumption that particular management practices will be useful for counteracting global warming when in fact averaging and lack of data on several ecosystem components means that the suggestions may not be supported by data. Instead of assuming the need to scale-up to answer global environmental questions, it may be more important to identify which scale is most sensitive in reflecting the processes relevant for policy-makers and for which credible data can be produced.

Tools and approaches to scale information from the smaller to the larger scale are evolving and mathematical models are an integral part of these analyses. For example, ecophysiologists have used process-based models for addressing scaling issues from leaf to canopy levels and from stand to ecosystem levels (Ehleringer and Field, 1993). These models have used either a bottom-up or a top-down approach (e.g., Reynolds *et al.*, 1993; Running and Hunt, 1993). Bottom-up modeling, scaling from smaller to higher scales, involves extending calculations from an easily measured and reasonably well understood unit to processes at a more encompassing scale. The most familiar bottom-up models have taken knowledge at leaf or sub-leaf scales, combined these with environmental information, and derived descriptions of how a stand functions under a range of circumstances (Jarvis, 1993). A major problem with the bottom-up models is the complexity of information needed, especially in heterogeneous systems. Bottom-up models can thus be too complicated to be of general use in scaling to higher levels. Furthermore, the output from bottom-up models is open-ended, which makes the models more sensitive to input errors (Jarvis, 1993). In contrast, top-down approaches have been constrained totally through an experimentally determined relationship with a crucial driving variable. The empirical relationships that have been derived prevent the extreme predictions that may result from the bottom-up models. Top-down models have, however, less mechanistic insight and are thus limited in their application to scaling information up to another level. Dawson and Chapin (1993), Reynolds *et al.* (1993), and others have argued that these two modeling approaches are interdependent and should be used concurrently for addressing scaling issues. In order to simplify the task of scaling without losing predictive power, Dawson and Chapin (1993) also suggested that the plants within a community should be grouped together according to their form–function relationships.

6.2.4 Ecological and social systems and their integration

The disciplinary focus of scientists and the use of specific scales by discipline have resulted in the development of constraints to integrating ecological and social systems (see Tables 6.1, 6.2). A historical precedence exists for natural scientists to consider spatial scales in their study system that was not as prevalent in the social sciences. It is only recently that social scientists have been explicitly making their data scale dependent. Although natural scientists considered scale explicitly, their use of a few scales by discipline (see section 6.2.1) have also created problems for integrating ecological and social scales. For example, the current integration of ecological and social scales is being conducted at larger scales than the study system was originally studied, necessitating the development of new scaling tools that are still evolving (section 6.2.3). The following section will present a brief introduction on how researchers have linked social and natural systems and how each perceives spatial scale.

The types of data collected by social and natural scientists have contributed to difficulties in integrating information from different disciplines. The quantitative type of data collected by many natural scientists has been easier for policy-makers to utilize compared to the more qualitative data collected in the social sciences (Rifkin, 1996). Frequently, social science data was ignored in past policy-making decisions because of the difficulty of using qualitative data. The predominant use of economics as a natural resource assessment tool is based on its ability to give quantitative results. Since natural scientists appear to give more credibility to quantitative data, this has made it difficult for both the social and natural scientists to interact and integrate their studies. The rise of the Rapid Rural Appraisal and the more broadly focused Participatory Rural Appraisal (Chambers, 1994) approaches have partly been an effort by social scientists to decrease the need to conduct cumbersome surveys to obtain quantitative results that are easily transmittable and utilizable in policy-making. These approaches allow meaningful results to be obtained, since there is an ability to quantify multiple activities and patterns even if they cannot be analyzed statistically. Rifkin (1996) suggested that the value of the Rapid Rural Appraisal approach for social scientists has been to provide a framework for data collection and analysis that is spatially explicit.

Several decades ago, social scientists recognized the interactions and constraints placed by the ecological system on the social system (Hawley, 1950; Duncan, 1961; Young, 1974; Rambo, 1983; Rosa and Machlis, 1983; Vayda, 1983; Hawley, 1986; Burch, 1988; Grove and Burch, 1997). However, although they recognized the importance of these linkages, they did not explicitly address or produce a model to deal with the spatial relationships between humans and natural resources (Machlis *et al.*, 1997). This means that the social sciences did not deal with the issues of scale and hierarchy theory in any way comparable to the high attention given to these topics by the natural sciences. Although the social sciences have not explicitly dealt with the issue of scale and hierarchy theory (Fox, 1992), scale probably drives the conflicts perceived to exist between the different disciplines in the social sciences. For example, the arguments and differences existing between psychologists (Lynch, 1960; Sommer, 1969), sociologists (Firey, 1945; Schnore, 1958; Bailey and Mulcahy, 1972; Young, 1974, 1992; Field and Burch, 1988; Catton, 1992, 1994), geographers (Agnew and Duncan, 1989), and political scientists (Masters, 1989) may be attributed more to the use of different scales and criteria (Allen and Hoekstra, 1992) than questions of who is right or wrong. For instance, psychologists and sociologists argue about whether individual behavior creates social structures or whether social structures determine individual behavior. Rather than seeing this as a mutually exclusive dichotomy, it may be more appropriate to conceive of such a question as a matter of scale and to ask about the relative relationship between individual behavior and social structure for a given question. With this approach, research questions are more resolvable by actually promoting discussions between scientists.

Natural scientists historically did not incorporate people into their analysis of a natural system but focused on finding ecosystems to study that were "virgin" (e.g., minimal human influence) and that could be isolated from the social system (Vogt *et al.*, 1997). The philosophy was that there was a need to understand the natural system first and that most human activities could be treated more as harvesting or removal of products from that system. The approach taken by most natural scientists was to link human communities with the natural resources by measuring the impact of a particular human activity (e.g., chemical pollution) on a defined natural resource area (Bormann and Likens, 1979). This approach maintains the idea that ecological systems are mostly constrained by the natural system and that the social system is a minor constraint to its functioning. Only recently has the importance of the social system as a driver of natural resource conditions been articulated (Stern *et al.*, 1992). Other natural scientists have moved beyond these strictly ecological approaches to assessing the health of natural resources by attempting to see what concepts can be derived from comparing natural systems to human health (Rapport *et al.*, 1985; Levin, 1989; O'Laughlin *et al.*, 1994). However, these ecosystem health assessments have been mainly driven by satisfying the human desired values/products from a natural system and not from understanding the constraints of the ecological system (Vogt *et al.*, 1999c). The importance of human legacies, other than chemicals or land-use patterns, in controlling or constraining ecosystem function has been only recently addressed by natural scientists (Vogt *et al.*, 1999b).

Already in 1994, Miller suggested that part of the data analysis problems encountered between integrating social and natural sciences can be traced to how each discipline measures and records spatial data. For example, it is not unusual to collect georeference data in the natural sciences. In contrast, the social sciences had not previously considered georeferenced data important to collect (Fox, 1992). In fact, many of the important driving variables studied by social scientists (e.g., cultural, political, institutional, and economic conditions) do not appear to be driven by spatial scale processes (Miller, 1994). This suggests that social scientists did not explicitly consider space itself as a factor that affected the resistance and resilience characteristics of human ecosystems (see Table 6.1). However, each social science variable listed in Table 6.1 has an implicit scale inherent to itself even when no scale is implied. For example, each institutional structure has a zone of authority that it influences which can be spatially expressed. This zone of influence becomes the spatial scale at which the impacts of an institution should be examined. In fact, social scientists have typically defined spatial scales to include the political boundaries that constrain the activities occurring in the area being studied. However, in most cases the political boundaries do not track the ecological boundaries as identified by ecologists so that the scales of analysis are distinctly different (Lee *et al.*, 1990; Miller, 1994) (Table 6.2). In fact, boundaries generated by social variables have not been typically analyzed by natural scientists. Natural scientists have been historically more interested in understanding the processes and functions occurring at the scales of vegetative communities or soil types (see Vogt *et al.*, 1996).

Increasingly, social scientists are beginning to realize the need for the adoption of a hierarchical or multi-scale approach to their research. This approach has been adopted for use in several interdisciplinary research projects where natural scientists are adapting and integrating approaches from various disciplines to understand a specific phenomenon (Pickett *et al.*, 1989; Grimm *et al.*, 2000). Watershed-scale research (e.g., hydrological studies) has been especially amenable to linking social and ecological data in human-dominated landscapes (see section 6.3.). Hydrologists had already developed the tools needed to combine GIS technology with modeling to examine how abiotic attributes of different areas within a watershed contribute variable amounts of water and nutrients to stream flow (Hewlett and Nutter, 1969; Dunne and Leopold, 1978; Black, 1991). Recently, these techniques have been successfully used to link the biotic attributes of a watershed with their social attributes (e.g., indirect effects from land-use change and forest/vegetation management and direct effects from inputs of fertilizers, pesticides, and toxins). By spatially linking social and ecological information within a watershed and determining how these related to different types of allocation mechanisms, the differential flows and cycles of critical resources within the watershed could be understood (Burch and DeLuca, 1984; Zonneveld, 1989; Parker and Burch, 1992; Grove and Burch, 1997).

6.3 A multi-scale approach to social ecological research: The case of the Baltimore Ecosystem Study

The Baltimore Ecosystem Study (BES) is one of 21 long-term ecological research sites (LTER) of the National Science Foundation. The BES is distinguished from nearly all the other LTER sites because it is one of only two urban sites (the other being the Central Arizona Project, Phoenix, Arizona) where integration of information from the social and natural sciences was a primary focus for establishing these LTERs. Research scientists for these two urban sites have been recruited from both the social and biophysical sciences and have adopted integrated, multi-scale approaches from the inception of the research.

The research described here was conducted for the Gwynns Falls Watershed of the BES. The Gwynns Falls Watershed (76° 30′W, 39°15′N) is approximately 17,150 ha in size. This watershed lies in Baltimore City and Baltimore County, Maryland and drains directly into the Chesapeake Bay. The research briefly described here illustrates the usefulness of a multi-scale approach to link social (e.g., social stratification) and natural science variables (e.g., vegetation structure) to understand what regulates the health of this watershed.

6.3.1 Description of the research

The Baltimore Ecosystem Study LTER has adopted a multi-scale (e.g., within and between watersheds) approach to its research that considers social and natural science variables at several, broad scales of ecological analyses:

organismal, population, community, ecosystem, and landscape (Grove and Burch, 1997; Pickett *et al.*, 1997). Both biophysical and social drivers and endogenous and exogenous change can drive the system dynamics. For instance, endogenous change in a neighborhood may include changes in demographic structure, housing conditions, or vegetation, while exogenous change may include changes in financial markets, regional transportation, or climate.

This multi-scale approach focuses purposefully on different social and ecological scales. Some social scales include different levels of social organization such as individuals, families, communities, and societies. BES uses a hierarchical, multi-scale approach because it attempts to understand the strong and weak ties within and among scales in order to uncover the ways that components at different scales are related to one another. Thus, lower-level units interact to generate higher-level behaviors and higher-level units control those at lower levels. For instance, a hierarchical approach to urban ecological systems may attempt to understand the ways that the interactions among households within a neighborhood may affect the ability of a neighborhood to attract public and private investments (Grove, 1996). At another level, the competition among neighborhoods in terms of relative political power subsequently affects the quality of government services that each household receives (Grove, 1996).

Some examples of theory that that may be used in this hierarchical approach are:

- Regional variations: Urban–rural dynamics (Morrill, 1974; Cronon, 1991; Rusk, 1993) (Fig. 6.1a, color plate).
- Municipal variations: Distribution and dynamics of land-use change (Burgess, 1925; Hoyt, 1939; Harris and Ullman, 1945; Guest, 1977) (Fig. 6.1b, color plate).
- Neighborhood variations: Power relationships between neighborhoods (Shevky and Bell, 1955; Timms, 1971; Johnston, 1976; Agnew, 1987; Logan and Molotch, 1987; Harvey, 1989) (Fig. 6.1c, color plate).
- Household variations: Household behavior within communities (Fortmann, 1986; Fortmann and Bruce, 1988; Fox, 1992; Grove and Hohmann, 1992; Burch and Grove, 1993; Grove, 1996) (Fig. 6.1d, color plate).

The answer to whether one scale is more dominant or sensitive than another will vary in relationship to the research or management question. Thus, it is crucial that researchers and managers begin to conceive of their questions in terms of scale.

A particular area of interest has been to understand how social stratification of groups (i.e., power structures) affects green investments made by private firms and public agencies in neighborhoods within the watershed (Grove, 1996) (Fig. 6.1b, color plate). The theoretical foundation for this question comes from Logan and Molotch's (1987) political economy of place theory. Logan and Molotch argued that patterns and processes of social stratification between people and place have significant environmental implications. According to Logan and Molotch's theoretical framework, the key social variables affecting access to power, the allocation of private and public resources, and subsequently the biophysical characteristics of wealthy residential areas include: (1) The presence of homeowners and the absence of renters or absentee landowners, (2) residents who are either able to migrate to more desirable and healthy areas, who are effective at community organizing, or who are willing to become involved in local politics, (3) elites who have differential access to government control over public investment, pollution control, and land-use decision-making. Conversely, low income and heavily populated minority areas are disproportionately in or next to polluted areas, have residents who are unable to migrate to more desirable and healthy areas, and have fewer human resources in terms of leadership, knowledge, tactical and legal skills, and communication networks to manipulate existing power structures.

Logan and Molotch (1987) and Choldin (1984) described these sociocultural and biophysical interactions as a dynamic process. In this process, residents act individually and collectively to control and maximize the exchange and use values of their neighborhood. This results from residents restoring, maintaining, or improving their current place or migrating to a more desirable place. Some of these acts of restoring, maintaining, or improving include changing the biophysical characteristics of residential areas (e.g., planting trees, parks, lawns, and community gardens, and keeping clean streets). These restoration activities produce an environment that is both socially and biophysically heterogeneous.

Logan and Molotch's theory was applied to one of the watersheds of the BES study area. The selection of variables and indices of social stratification for the classification of social areas or neighborhoods used the theoretical parameters identified by Logan and Molotch (1987), Choldin (1984) and Bullard (1990). These variables and indices were also further adjusted to incorporate recent adjustments recommended by Johnston (1976), Murdie (1976), and Hamm (1982). These indices of residential social stratification included a socioeconomic index (income and education), a household index (homeownership), and an ethnicity (race and ethnicity) index.

A classification of vegetation structure was developed using Bormann and Likens's (1979) theory of vegetation regulation of watershed hydrology and the data requirements of various hydrologic ecosystem models. At the ground surface, areas were classified as impervious or pervious. At the canopy level, areas were classified as having or not having a vegetation canopy layer. The four classes of vegetation structure included: (1) Impervious surfaces/no canopy cover, (2) impervious surfaces/canopy cover, (3) pervious (vegetation cover) / no canopy cover, and (4) pervious (vegetation cover)/canopy cover. Statistical analyses of data were conducted for residential land uses only. In addition, the research included a temporal component (1970–90) to explore possible time lag or non-linear relationships.

6.3.2 Results of the interdisciplinary watershed analysis

The results indicated a significant relationship between two of the three indices of social stratification – socioeconomic factors and ethnicity – and vegetation structure. Further, a time lag was found between independent variables and dependent variables (1970 social data and 1990 biological data) (Fig. 6.2, color plate). In retrospect, these results were realistic considering that the primary response variable being measured – tree canopies – takes time to grow and die. This highlighted the importance of considering the rate at which response variables may change and the time frames necessary to measure that change thus demonstrating the linkage between spatial and temporal scales that needs to be considered when determining what scale is appropriate to study for a given problem.

The absence of a relationship between indices of homeownership and vegetation structure was puzzling since the literature suggested such a relationship should exist. Extensive literature from rural forestry has indicated the importance of ownership and property regimes to land cover (Coase, 1960; Hardin, 1968; Ciriacy-Wantrup and Bishop, 1975; Fortmann and Bruce, 1988; MacPherson, 1989; Raintree, 1985; Ostrom, 1990; Bromley, 1991). Further, community foresters and community organizers in Baltimore City reported the significance of ownership to their activities. Thus, alternative explanations needed to be explored.

The spatial structure of the three social stratification indices was re-examined to try to tease apart the lack of a relationship between ownership and land cover. It was apparent that there was strong spatial structure for socioeconomic status and ethnicity, but not for homeownership on a watershed or city/county basis. These results suggested the need to examine these data at a different scale – that the data were reflecting a scale phenomenon. Perhaps, the relationship between homeownership and vegetation structure was effective at an alternative scale. Based on an initial exploratory data collection, scale-dependency for this relationship was verified (McManus and Steer, 1998). The relationship between ownership and vegetation structure occurred at a neighborhood level (i.e., Fig. 6.1d, color plate: vegetation structure varied in relation to household ownership patterns within a neighborhood).

The research described for the Baltimore Ecosystem Study illustrates the significance of scale for deductive and inductive (exploratory) research, particularly for interdisciplinary research. In particular, it highlights the need for researchers to be explicit about the relationships among theory, methods, and measures within an hierarchical context and to consider specific tools and techniques to assess the spatial and temporal structure of their research question (Grove, 1999; Gustafson, 1998). The results also have significant implications for natural resource management. The results from this research have helped planners and community foresters to recognize and understand the importance of a multiple-scale approach, particularly the idea that different processes occur at different scales. For instance, strategies for targeting community forestry activities, community organizing, and local capacity building are important considerations at a citywide scale (Fig. 6.1c, color plate) while community participation is related to ownership patterns at a neighborhood scale (Fig. 6.1d, color plate). Therefore, community forestry activities need to focus on the development of private or community ownership of open access/abandoned lands at a neighborhood scale. These findings provide an example of how natural resource managers may develop more comprehensive and effective strategies by knowing what to do, where to do it, *and at what scale.*

6.4 Integration of social and natural science spatial scales for management

Adequately incorporating spatial scales into natural resource management requires a practical approach that can be easily implemented but where decisions are based on specific guidelines that will allow non-subjective identification of the scale or scales of analysis. Managers need to recognize the large contrast that exists between scientific research conducted by academia and the research needed to inform management, that the information and analytical needs are different, and that these differences need to be taken into account when planning research to be used to answer management questions. It is also important to recognize that the problem definition is itself linked to a scale. So in contemplating issues of scale for management, managers must take one step backwards and use scale as part of an analysis to ensure the right question is being answered.

Few research investigations have integrated the social and natural sciences. Even if the hurdle of deciding to include both social and natural sciences in the same investigation was removed, their integration is formidable because of the propensity of each to use different spatial scales of analysis (Table 6.2). It is important to identify what types of environmental problems can be dealt with at the same social and natural science scales and what type of problems require different scales of analysis. Answering these points will begin to allow us to use "scale" as one of the common integrating tools to link the social and natural sciences. At the same time, it is also important to understand that no one scale will automatically address all environmental issues. Fox (1992) found that determining the appropriate scale of analysis is an iterative and not a one-step process, especially when conducting interdisciplinary research. This finding also reinforces the possibility that the social and natural science scales will differ so that the best approach should be decided on a case-by-case basis. If this generalization is correct, it can be a useful tool for integrating research from the social and natural sciences.

To determine the most appropriate scale(s) to use, the first step would be to ask if the study's hypothesis dictates the scale that should be used (Fig. 6.3). If this is the case, this scale must be used regardless of the specific disciplines required to answer the question. Usually the scale will not be dictated by the hypothesis alone and must be selected using a procedure like that shown in Fig. 6.3.

Now the most important question becomes which discipline is most suitable for proving or disproving the hypothesis (Fig. 6.3). The most suitable discipline, whether from the social or natural sciences, should have the greatest impact on the quality of the conclusions. Each discipline prefers particular scales of analysis as shown in Tables 6.1 and 6.2. Traditionally the focus has been on which discipline has a better approach for evaluating the problem, but the discussion should be shifted to which particular discipline is more important for solving the particular problem. Once the evaluator determines which discipline is best suited for solving the specific environmental problem, the selected discipline will dictate the scale of analysis. It is impossible to separate the question of the most appropriate scale for the analysis from the question of the discipline having the greatest impact on the conclusion.

After choosing a discipline, other factors must be considered (Fig. 6.3). Is the primary scale of analysis used by this discipline incompatible with the scales used by the other disciplines relevant to the problem? If there is no incompatibility, then the scale selected by the appropriate discipline should also be used for all other disciplines. If there is incompatibility, one must determine if the primary scale can be modified. If it is impossible to eliminate this incompatibility, multiple scales must then be utilized.

Some natural resource problems can be studied at the scale of a substrate or small plots. For example, a piece of coarse wood, hedgerows and even soil aggregates can be meaningful ecological scales for management when conserving microbes and soil animals whose life cycles occur at micro-site scales

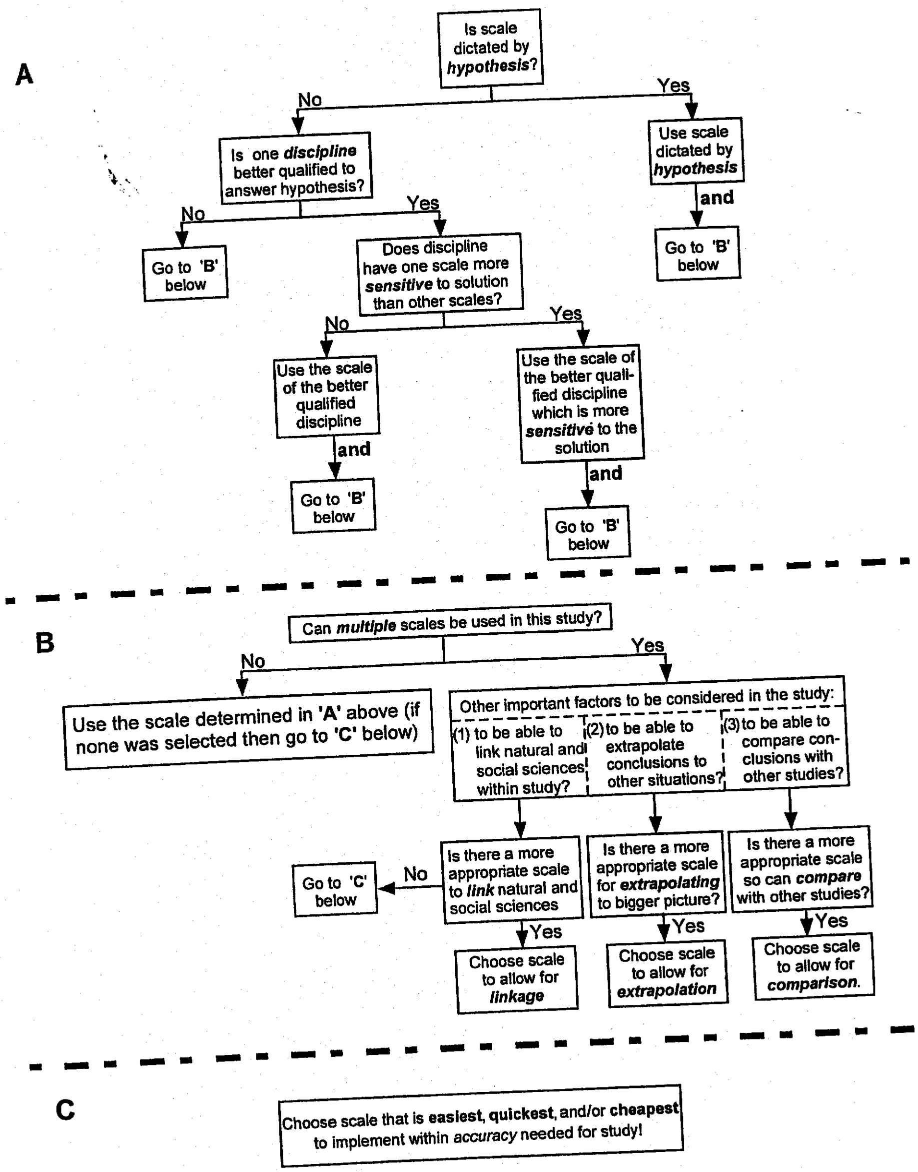

FIGURE 6.3
A conceptual model of one decision-matrix approach to determine what scale of spatial analysis is appropriate for any natural resource problem.

(Franklin, 1993). When human use has to be factored into this management, however, the small scale will not be adequate as a study scale. For example, if the microbes produce sporocarps harvested by humans, the scale of analysis will have to be a landscape. In this example, it will be important to understand the distribution of the successional stages of the vegetative communities that are the sources of spores needed to reinoculate and maintain the sporocarps in each management unit.

Managers may want to routinely consider multiple scales of analysis whenever dealing with a management problem because of the complexity of natural resource issues. Although one scale may ultimately be identified as the most sensitive scale for a particular problem, the initial approach should include multiple scales so that a manager can be confident that the appropriate scale is ultimately selected. No consistent rules have been reported in the literature that would allow a manager to link natural resource problems with their sensitive scales of analysis. For example, Farmer (1981) suggested the landscape level was too large when conducting macro-scale planning of agricultural development and the intervillage variation was more important to monitor. However, Moran (1984) suggested that hypotheses should be restricted to one level but that it is important to understand how other levels affect the process. For example, Moran (1984) recommended studying resource use in the Amazon using a nested approach involving a systematic sampling of localities, districts, and sub-regions, because information flows through each level of analysis. Spaling and Smit (1995) suggested that assessing the health of agroecosystems needs a watershed management plan that combines landscape analysis with examination of fields.

Managers in the past used the boundaries of the management unit as the spatial scale of analysis. However, using property boundaries to define the spatial scale can be flawed. This type of approach assumes that there is no impact of the management unit on adjacent systems. It also assumes the management unit is, or is not, influenced by the landscape within which it is imbedded. Agrosystems are a good example of the problems in defining the spatial scale by ownership boundaries (Conway, 1986). The activities occurring on the farm are not restricted to the human-defined borders. Depending on the type of agriculture being practiced, the zone needing to be analyzed may expand considerably outside the zone of the fields themselves. For example, the impacts of applying pesticides and/or fertilizers can be frequently measured outside the boundary of the farm itself and change how systems outside of the farm function (Spaling and Smit, 1995).

At times, the largest scale of analysis as defined by political or institutional boundaries may be insufficient to manage a resource when a resource cannot be contained within the defined boundaries or where there is an overlap of institutional control over a given resource. Many examples of the defined boundaries being inadequate as a management scale can be found in the literature (Clark and Minta, 1994). For example, the park boundaries for Yellowstone National Park are defined as the core area of what is needed for the conservation of the grizzly bear (*Ursus arctos*), however the administrative boundaries of the park are inadequate to conserve the grizzly bear. Likewise, property boundaries are insufficient in the Everglades National Park where the park boundaries do not match the jurisdictional boundaries that control local and regional uses within the landscape (Harwell *et al.*, 1996). Therefore, the scale of the Everglades needs to be larger than the park boundaries in order to study the drivers of ecosystem health.

There is a need to produce the tools to determine what scale is most appropriate to measure in any system. This is greatly facilitated if a formal process will allow the scales of analysis to be determined in a non-subjective manner. Past studies can be used as examples to direct us to understand what scale of analysis was considered most relevant or sensitive. They are useful to consider because they suggest the scale that was most successful in addressing a specific natural resource problem.

A decision matrix that can be used by managers to determine what scales of analysis are appropriate for them to consider is diagrammed in Fig. 6.3. A flow diagram similar to this can be used as a tool or guide to help determine the most appropriate scale(s). For the diagram to be useful, one must focus on the relationship of the disciplines to the solution and the linkage of disciplines using scales. With a tool such as this, one can more effectively manage natural resources and determine their relevant spatial scales for analysis.

The decisions being made in forest management highlight the utility of the decision matrix diagram presented in Fig. 6.3. Forest management decisions need to be addressed at different scales depending on the questions and objectives. Furthermore, the questions being asked are best addressed by certain disciplines and each of these disciplines uses different scales. For example, problems in analysis emerge if the questions being asked change. One example is intensive management of plantations. If the question concerns tree growth and timber yield, the relevant disciplines are tree physiology and biometrics and the resulting appropriate scale is a single tree or a small plot of trees. If questions arise concerning treatment effects on site productivity, the scale may be the forest stand because the appropriate disciplines are soil science and community ecology. If, however, the effects of intensive management on the total ecosystem were questioned, ecosystem ecology would be the relevant field and an area much larger than the forest stand must be studied.

In forest management, the issue of appropriate scale becomes more interesting if the question involves a social science component. If the economic value of the intensive management is questioned, then mixed scales might have to be used because timber yield studies must be used in conjunction with regional price studies. In some cases, the answer will be much more sensitive to price fluctuations than tree growth so that economics might be the dominant discipline for the analysis at the regional scale.

If natural forest dynamics are expected to occur in areas with less intensive management, it might be necessary to study landscape size areas to study the impact of these dynamics. To address questions of biodiversity, the landscape will have to include the different developmental stages relevant for maintaining that biodiversity (Oliver and Larson, 1996). The relevant disciplines might be forest stand dynamics or landscape ecology, and the scale necessary for study would depend on which discipline most sensitively reflects the problem.

This same decision matrix can be used to define the relevant scales in the social sciences as well (Fig. 6.3). Identifying social science scales is further complicated by some social variables appearing to not have an inherent scale or to have multiple scales embedded within each variable (see Table 6.1). Identifying a discipline to focus on does not necessarily facilitate scale determination in the social sciences. For example, even if the dominant discipline is constant (e.g., political science), the appropriate scale can vary. Governments at several different scales control how natural resources are managed (Machlis *et al.*, 1997) and which scale of government is most important should determine the scale of analysis even when political science has been identified as the relevant discipline. The impacts of policies are felt at different scales (Walters and Holling, 1990) – a fact that is important to keep in mind when determining the scale of investigation. The government boundary will probably not be the sensitive scale of analysis for many natural resource problems. For example, Freudenburg and Gramling (1994) suggested that the government level is not sufficient to explain poverty occurring at the smaller scales of resource-dependent communities.

6.5 Summary

Since the acceptance of the ecosystem management and sustainable development paradigms as the management philosophy of many federal agencies that manage natural resources, there has been an impetus to determine how to link social and natural systems. Yet, frameworks or models that integrate the natural and social sciences have been difficult to operationalize for natural resource management. We propose that the explicit incorporation of scale can be used as a critical and effective means for integrating different social and biophysical disciplines to address specific natural resource problems. The ecosystem management paradigm does require the explicit delineation of the spatial scales and boundaries of the management unit (Vogt *et al.*, 1997, 1999c). However, the definition of the scale of the management unit has created problems because it tries to define the scale by the natural system and as the spatial extent of the management unit (Fox, 1992). The social system has not been used by natural scientists to influence the scale-dependency of an analysis for ecosystem management. In practice, identifying the spatial scale of analysis appears to be somewhat arbitrary. Researchers in both disciplines have tended to use concrete, uniform definitions of what spatial scales are relevant for research (Table 6.2) that followed disciplinary lines.

The watershed scale has been generally accepted as the relevant scale for implementing ecosystem management (FEMAT, 1993; Montgomery, 1995). It is not clear if resource managers recognize the implications of choosing this scale of analysis for their management unit. On the surface, selecting this scale appears to simplify the decisions that have to be made by a natural resource manager because the problems of scale identification are eliminated. This approach also reflects the shift from, for example, managing forests from a product-based approach to the management of processes. Acceptance of the watershed scale as a unit of measurement sets limits on the type of questions that can be addressed because only certain measurement variables are sensitive at this scale (Conway, 1986; King, 1993).

The landscape scale appears to be one scale where the natural and social sciences can link because data collection is compatible with the existing tools utilized by both disciplines (Miller, 1994; Grove, 1996). Care must be taken to avoid the assumption that this is the only scale at which effective linking of the social and natural sciences can occur. The dominance of few scales of analyses in both the social and natural sciences (Table 6.2) will probably limit future integration of both fields if one scale is accepted as the primary scale of analysis. This scale of analysis is relevant for particular types of environmental problems but is not the universal answer for those questions where the sensitive variables exist at smaller scales.

Frameworks and tools will need to be developed to identify the sensitive scales of analysis that are disciplinary- (Table 6.2) and ecosystem-based and able to integrate information from both the social and natural sciences (such as shown in Fig. 6.3). Managers will have to recognize the limitations of aggregating information from smaller scales to elucidate patterns across larger scales more typical to natural resource management problems (Levin, 1992). Since the scales selected for data collection by each discipline are those that have been found to be the most sensitive to address their question (see section 6.1), scaling research data between scales should result in the loss of the causal relationships that were developed at that scale. Therefore, the implications of using different scales and how the scales are defined as shown in Table 6.1 are important to understand when managing natural resources.

Making scale relevant for management will require the development of causal (e.g., mechanistic) relationships between the management unit and natural and social science factors that will identify the appropriate scale(s) for each site. This will require managers to avoid using the wrong scale of analysis just because it is convenient and because data has been collected in the past at that particular scale (the idea being that the most sensitive scale may not have been identified then). It will also require managers to avoid scaling information from the small to the large scales unless there is a clear link between the information and the different scales; information may be lost with scaling so that sensitive variables may no longer be monitored.

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

Many of the tools being currently used to study natural resource uses and the trade-off between different uses within human-dominated landscapes assume that scale should be similar for both the social and natural sciences (Montgomery, 1995; Driver *et al.*, 1996). It is important to understand that the sensitive scales of analysis may differ between the social and natural sciences. However, the existence of different scales by discipline is not a valid argument for not integrating the two fields. It is interesting to analyze whether social and natural sciences can be mechanistically linked using spatial scales even when the appropriate scales of analysis might differ for each.

This chapter has shown how the appropriate scale for studying social and ecological systems often varies depending on the scale at which the most sensitive variables are most strongly expressed and can therefore be easily measured. Currently, different disciplines have their preferred scales of analysis where they concentrate their research efforts and therefore indirectly the scales of analysis used for management. This type of approach has been more prevalent in the natural sciences since individual researchers by necessity have scales in which they are specialists. The social scientists until recently did not explicitly deal with scale even though their research did encompass several different scales of analysis. There is a need to acknowledge that different disciplines have spatial scale preferences and that these will constrain the integration of the social and natural sciences since they are not asking questions at the same scale. These incompatibilities in the scales of analysis are major detriments to successfully implementing ecosystem management, conservation planning and sustainable development.

There is also a need to recognize that focusing on one scale of analysis will not allow management to integrate those social and natural science factors constraining management activities. The Baltimore case study presented in this paper showed the importance of using several scales of analysis when attempting to link the social and natural systems in management. Once the most sensitive scale of analysis has been identified, it is important that management does not emphasize that scale alone to identify all the parameters or indicators that would sensitively reflect that scale. The Baltimore case study also demonstrated how the generation of data at one scale provided important information determining how the identified scale of interest should be assessed. It becomes crucial that information obtained at different scales and about different systems is continually exchanged and evaluated through a parallel and interactive research approach. Unfortunately, this essential step of integrating information is often not addressed until after the research is completed and the results are presented. At this point, policy-makers and managers often face difficulties in drawing coherent and unified conclusions since an understanding of how their different study systems were interrelated was not incorporated in the research process nor in the results.

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