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Chapter 9

CONDUCTING SOUND ECOLOGICAL STUDIES AT THE LANDSCAPE SCALE: RESEARCH CHALLENGES

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1. ABSTRACT

Landscape ecology is maturing as both a traditional natural science and an integrative field. It strives to meet the demands of traditional science through incremental scientific achievements realized via experimentation and hypothesis testing, while working at scales not conducive to the paradigm of controlled experiments. At the same time, landscape ecology is the intersection of many older scientific disciplines (geography, forestry, wildlife ecology, etc.) and applied fields (landscape planning, conservation), each contributing independent views and unique concepts to studying the ecology of landscapes. As such, a unifying theory or paradigm under which to evaluate and design sound ecological studies at the landscape scale is still maturing. This chapter explores these paradoxes and the nature of research in landscape ecology. Through this book, we have identified five challenges in the ecology of landscapes that highlight and synthesize current approaches, issues, challenges, and successes. We place these challenges: process dynamics; scaling; landscape experimentation; modeling and visualization; and research transfer and application, within a knowledge creation framework to identify how work in these areas is advancing landscape ecological science.

2. INTRODUCTION

"We cannot solve the significant problems we face at the same level of thinking we were at when we created them." Albert Einstein

The practice of normal science is the cumulative process of building upon the knowledge gained by others through small but incremental steps. This puzzle-solving activity is successful in its steady extension of the scope and precision of scientific knowledge (Kuhn, 1996). The aim has little to do with producing major novelties of fact or theory, and when successful, finds none. Yet new and unsuspected phenomena are repeatedly uncovered by scientific research leading to radical new theories and approaches. Specialized knowledge in any field cannot remain still. Rather, each field grows and evolves as its member scientists advance frontiers of knowledge and question existing subject boundaries (Tress et al., 2005).

Newer, less mature fields of inquiry are not likely to have a unified theory to guide research. Instead, research in young fields is initially dominated by exploratory studies. More quantitative but descriptive analyses become prevalent as theories are built and disciplines are defined; eventually a discipline moves into more experimental and theory-testing stages as it matures (Cresswell, 2003). Some suggest that landscape ecology still lacks a conceptual and theoretical basis on which to frame the science (e.g., Wu and Hobbs, 2002; Saunders et al., Chapter 7). Yet foundational principles and concepts have guided growth of the discipline over the past two decades.

In the early 1980s landscape ecology took root as a convergence of many fields operating on different theories. In 1984, landscape ecology pioneers in the United States defined principles and direction for the field (Risser et al., 1984). Their paper stated "Landscape ecology focuses explicitly upon spatial patterns. Specifically, …considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchange across heterogeneous landscapes, influences of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity." Early landscape studies in North America tended to focus on pattern description and analysis (Turner, 2005). Wiens (1992) reviewed the first five issues of the *Landscape Ecology* journal and found that the 99 articles were predominantly descriptive or conceptual, with either no quantitative results, or results that were presented without statistical or mathematical analysis. Close to half were concerned with landscape structure. In other words, the first steps were to devise tools and methods for measuring landscape pattern, and to collect some baseline data. For example, Turner and Ruscher (1988) measured changes in the spatial patterns of land use in Georgia. Their work was straightforward and descriptive, but very important at the time. In fact, the authors (Silbernagel et al., 1997) followed on this work to quantify landscape structure in a northern Great Lakes region. In this way, we incrementally built upon the methods and application developed previously. Development and testing of landscape metrics was a pivotal stage, coincident with advancements in geographic information systems (GIS) and information technology. Now, more than twenty years after the initial attempt to define principles, landscape ecological studies have made great progress in both theory and applications. Practitioners have especially honed methods for quantifying landscape structure, for applying remote sensing and GIS tools, and for developing spatial models. Landscape ecology has transformed into a global science, influencing how ecologists view and study the world. Its approaches and perspectives have been widely embraced both in university curricula and environmental resource management worldwide (Turner, 2005).

Assessing the state of the field in 2002, a team of leading scholars in landscape ecology identified 10 areas of research that are reflective of where landscape ecology is now, and where it needs to go to advance our knowledge of landscape ecosystems (Wu and Hobbs, 2002; Table 1). The present book has addressed at least three of the 10 points in more detail, including relating landscape metrics to ecological processes, scaling, and developing new research methods.

Table 1. Top ten research topics in landscape ecology (from Wu and Hobbs, 2002)

	Topic
1	Ecological flows in landscape mosaics
2	Causes, processes, and consequences of land use and land cover change
3	Non-linear dynamics and landscape complexity
4	Scaling
5	Methodological development
6	Relating landscape metrics to ecological processes
7	Integrating humans and their activities into landscape ecology
8	Optimization of landscape pattern
9	Landscape sustainability
10	Data acquisition and accuracy assessment

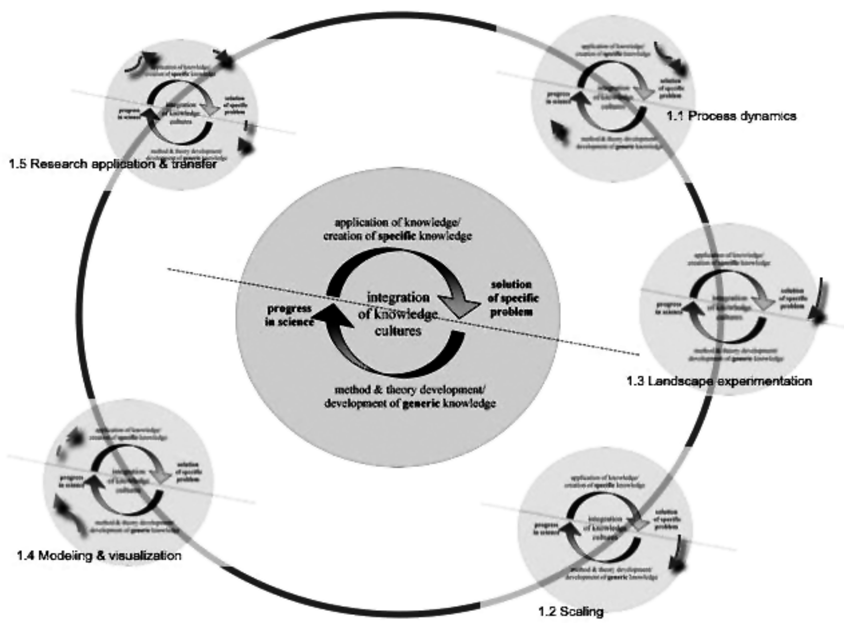

Figure 1. The circle of knowledge creation (center circle - used with permission, © Tress et al. , 2005). The circle illustrates the use of specific knowledge to the right (3 o'clock), which, by accumulation, leads to general theory at the bottom (6 o'clock), the progress of science with acceptance of new theory to the left-hand side (9 o'clock), and eventual application of new theory to specific applications as the circle is completed again (12 o'clock). Subsection diagrams and headings around the periphery of the circle indicate a suggested position for each of the five research challenges discussed in this chapter (adaptation by the authors).

While existing and new knowledge might be used to solve a context-specific problem or application, ultimately science must seek knowledge that has relevance and validity beyond a specific context (Tress et al., 2005). Generic knowledge created through integrated research advances method and theory development in interdisciplinary fields and leads to progress in the science, and then to new applications of that science. Tress et al. (2005) created a diagram (Figure 1) to illustrate the cyclical process between research and application. At the top of this circular framework, working clockwise to the right illustrates the use of specific knowledge for specific problems, including individual studies or applications. From the right (3 o'clock) toward the bottom of the circle we see how accumulation of specific solutions can eventually lead to general knowledge and theory development, or an understanding that transcends individual relationships and settings. Continuing upward around the circle (toward 9 o'clock), shows that as general knowledge and theory become supported and accepted, science moves forward; progress has been made. Finally, the cycle makes its way back to the top. Once progress is accepted and transferred, it is likely to be applied back to specific settings and management problems. In this concluding chapter we use this knowledge creation framework to examine the recurring challenges to landscape ecology as a scientific discipline and to consider successful examples of landscape-ecological studies. In the next section we organize these challenges into five broad categories. Each category captures two or more themes covered in the previous chapters of this book.

3. Research Challenges and Approaches in Landscape Ecology

3.1 Generalizing Process Dynamics

A fundamental challenge in landscape studies, linking pattern to process, has been a target of many researchers for several years. Turner (1989) highlighted the roles of landscape disturbances (wind, fire, and other disturbances) in shaping landscape patterns. Chen and Saunders (Chapter 1) also emphasize that while it is important to understand how disturbances modify landscape structure, it is equally critical to examine the consequences of patterns on these processes. For example, they discussed a study by Robinson et al. (1995) that assessed the impacts of fragmentation on migrant bird populations. This study demonstrated how spatial patterns play a critical role in population dynamics, not only through habitat availability, but also through behavioral dynamics such as nest predation and brood parasitism. Similarly, Brosofske (Chapter 2) discussed the influences of spatial pattern on plant distributions, including the effect of habitat corridors and matrix properties on plant dispersal. A synthesis of 13 research papers in a special issue of Biological Conservation (Collinge, 2001) noted the conservation implications of landscape spatial configuration and change and the responses to this landscape structure of populations, species, and communities. Together these studies showed that the responses vary according to the species being considered, its life history, it vulnerability to habitat edges, the character of the landscape interspersed with the preferred habitat, and the particular spatial configuration of the habitat. The impact of varying habitat configuration for native populations may occur along a continuum from devastating to relatively benign. Being able to derive general process dynamics from specific studies like those summarized in Collinge (2001) would better position ecologists to resolve the consequences of landscape pattern and change.

Chen and Saunders (Chapter 1) explained that elucidating the pattern-process relationship presents both conceptual and methodological challenges. These include: (1) robustly linking landscape pattern metrics to ecological processes; (2) appropriately matching quantification of pattern to scales of associated landscape processes; and (3) assessing whether changes in landscape indices with time or spatial scale represent meaningful process dynamics, or are artifacts of data discrepancies. They emphasize that hierarchy theory and scaling approaches may offer the best avenues for grasping the mechanistic underpinnings of pattern and process in hierarchical systems. Brosofske (Chapter 2), for example, clearly demonstrated that conclusions regarding plant species diversity made at one scale could be completely different at another scales. We reflect on some of these scaling tools in the next section.

Euskirchen et al. (Chapter 3) discussed the need for a unifying theory to link edge influences to landscape structure and function. They argued that to advance the general theory of edges, it is important to go beyond the interactions that take place at a single edge and focus on how edges influence the functioning of the greater landscape mosaic. Using the example of plant responses to edges between adjacent ecosystems, the authors pointed out knowledge gaps in the scientific understanding of edge structure, especially regarding areas of multiple edge influence and the influence of the edges on biogeochemical cycling across a landscape. Environmental factors (e.g., surface roughness, wind, light, temperature) that tightly regulate biogeochemical cycles may be altered near edges. For plant communities, processes such as carbon and nutrient cycling are dependent on the complexity of underlying landscape structure, which often includes areas of multiple edge influence and varying contrast.

It is essential to comprehend the dynamic way in which edge features modify key ecosystem and landscape processes, particularly for elucidating biogeochemical processes across edges. Case studies from the Chequamegon-Nicolet National Forest (CNNF) landscape supported proposals for including edges and areas of multiple edge effects in analyzing landscape structure and synthesizing landscape function. In fact, Chen and Saunders echoed Sanderson and Harris (2000) and asserted that the area of edge influence (AEI) should be considered as unique landscape elements with special emphasis on multiple edge effects (Fletcher, 2005; Harper et al., 2005). They suggested seeing the landscape as not just a simple mix of patches, corridors, and a matrix, but rather a complex mosaic that includes the transitional zones, or AEI, between ecosystems. Enough research has now been done on the influence of forest edges that a generalized theory of edge influence is developing for forested landscapes (e.g., Harper et al., 2005; Figure 1.1). However, most previous studies did not consider areas that are influenced by multiple edge zones or lower contrast edges. It is complicated enough to relate ecological processes to the structure of a simple patch-corridor-matrix model; considering single or multiple edge transitions dimensionally adds to the problem of quantifying landscape function. There is even less information about edge-dependent gradients in biogeochemical processes than there is for biophysical (microclimate) variables. Data on these processes are necessary to understand basic ecological productivity and decomposition patterns, and to develop spatial understanding of how these processes scale up or down.

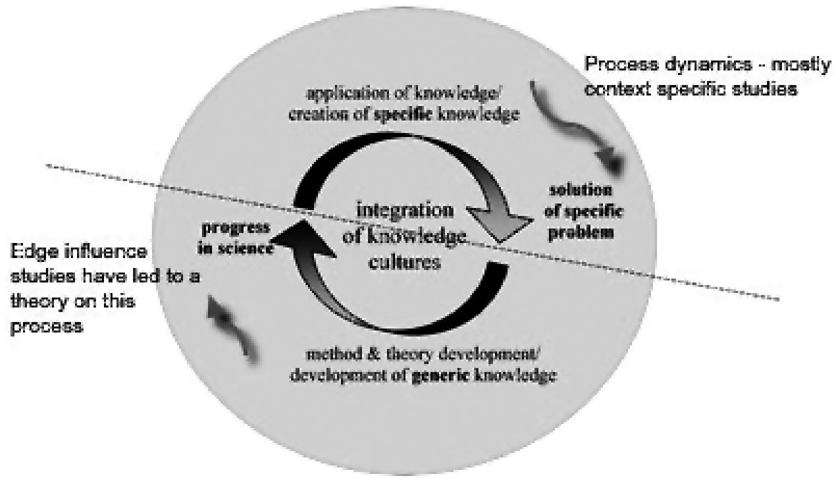

Figure 1.1. The current state of landscape ecological science concerning pattern-process dynamics is positioned near 3 o'clock in that most work is around specific relationships or settings, although some areas (e.g., edge influences) may have developed a general theory for that portion of the topic (adapted from © Tress et al., 2005).

Together the Chapters by Chen and Saunders, and Euskirchen et al. 1 and 3 have demonstrated the continued challenge for landscape ecological studies to rigorously deal with ecosystem processes and to robustly link these process dynamics to landscape structure measures. Our synthesis suggests that research on certain specific pattern-process relationships, such as edge influences on forest processes, may have established generalized knowledge leading toward progress in science. Overall however, understanding of process dynamics is still rather limited to specific situations from which generality is yet to be determined.

Turner (2005) concurs that landscape ecology should continue to "push the limits of understanding of the reciprocal interactions between spatial patterns and ecological processes and seek opportunities to test the generality of its concepts across systems and scales." In terms of the knowledge circle (Figure 1.1) we place Process Dynamics near the right (3 o'clock position), in that landscape ecological science has tested several specific pattern-process relations (e.g., nest predation, dispersal, decomposition) but has not thoroughly synthesized specific studies to form general knowledge on the topic.

3.2. Scaling Tests

Understanding pattern-process dynamics and detecting changes in the structure and function of landscapes also requires matching scales of spatial patterning with scales of associated processes, and often translating these relationships among different organizational levels and scales of study (Chapter 1). This is another fundamental challenge for landscape ecology; although this issue has been recognized for some time, operational tools for handling multi-scale analyses are still not well developed. Examining process dynamics most often requires studies that cross scales, considering multiple levels of organization (Levin, 1992).

For example, landscape structure at one scale may influence dynamics such as hydrological flows at broader scales (see also Chapter 2 for diversity changes with scale). Likewise, Euskirchen et al. (Chapter 3) reported a need to cross scales in the study of bioegeochemical processes across edges. In Chapter 4 Noormets et al. discussed the effects of landscape-level heterogeneity, driven by natural and anthropogenic disturbance, on scaling using two case studies in Wisconsin. The authors argued that the central role of scaling for ecological research is to help us formalize our understanding of processes that drive the behavior of broader systems and of interactions between processes acting at different scales. Because ecologists are often asked to contribute to solutions for broad-scale problems, they have to project or extend current knowledge, or *extrapolate,* to new or larger areas (Miller et al., 2004). In a literal way, scaling is a way of moving from specific problems to more general knowledge (Figure 1.2).

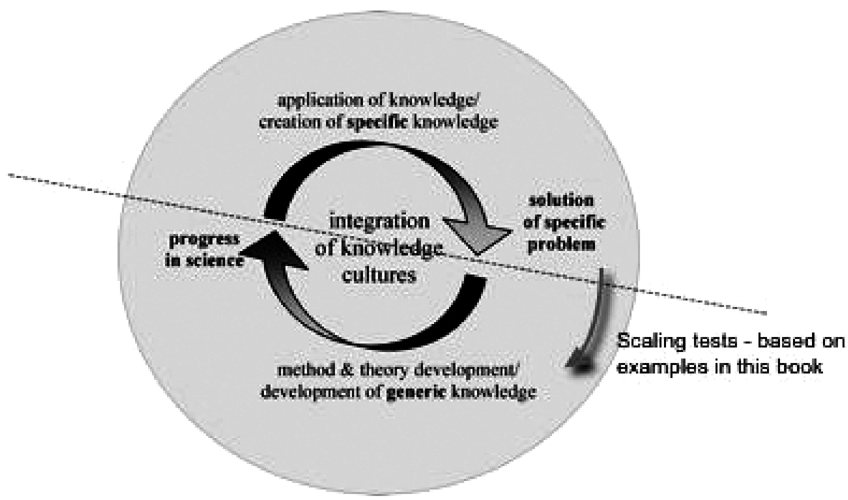

Figure 1.2. Examples and synthesis from this book indicate that specific scaling tests from a number of contexts are accumulating toward general knowledge. As scaling up is, in effect, the process of extending site-specific knowledge to new, larger, or more general areas, it translates literally to this position on the knowledge circle.

Noormets et al. also discussed the need for different scaling strategies (non-spatial, spatially implicit and spatially explicit). Depending on the process of interest and the transition in scale, different scaling techniques are appropriate to realistically represent landscape dynamics. Thus, when modeling processes across multiple scales one must find spatial and temporal dimensions that are common to different organizational levels and that could provide relevant data for the question of interest.

Points made by Chen and others in this book on the importance of edge influences were also brought out by Noormets et al. in terms of scaling. Current challenges in scaling ecosystem processes to landscapes, they argue, include more dynamic representation of spatial gradients in environmental drivers and fluxes. Rather than parameter differences based on crisp boundaries between patches, new spatially explicit approaches should allow these parameters (fluxes) to be characterized as transitions across the landscape.

Another potential scaling strategy discussed by Euskirchen et al. is the use of meta-analysis to examine general trends for specific parameters. Meta-analysis can help overcome limitations of small sample sizes and may be used if common methods are employed across field studies of varying spatio-temporal dimensions. This may be quite valuable since field studies themselves can be problematic and limited at landscape scales (Miller et al., 2004; Saunders et al., Chapter 7).

3.3. Landscape Experimentation

Natural science is typically advanced by formulating hypotheses, designing experiments, and synthesizing the results for generalization. Developing and testing hypotheses with sound experiments or observational data is probably the most fundamental, but most challenging component for advancing modern sciences. Yet in parallel with the search for sound, defensible statistical methods, the challenges presented by landscape ecology have led to development of analytical approaches that allow us to effectively use the data we have. For certain types of landscape analysis, information-theoretic approaches offer advantages over traditional hypothesis testing, especially where multiple hypotheses are plausible or multiple predictors are considered in combination. Information theory approaches are being used effectively in many other areas of ecology already, yet there are situations where null hypothesis tests are still most appropriate (Stephens, 2005).

Testing hypotheses that relate process to pattern has been limited by the difficulty of setting up large, long-term landscape experiments. Designing experiments to address cross-scale phenomena may be even more challenging. One feasible approach for large field studies is to use existing landscapes with varying pattern to explore the underlying mechanisms that influence and are influenced by their structure. For example, Brosofske (Chapter 2) took advantage of four contrasting patch patterns within the CNNF to capture changes in spatial structure and species diversity of understory plants. Because heterogeneity in soils, topography, and presettlement vegetation was minimal in the study area, with landscape structure imposed primarily by the effects of current disturbance and management regime on overstory vegetation, the study area provided an exceptional opportunity for studying the relationships between patterns that are inherent to and imposed on the landscape, and processes that are associated with these patterns at multiple scales.

In the CNNF study area, the forest managers have been managing specifically for different structural outcomes in a relatively homogeneous landscape, which provided a fantastic opportunity to study the effects of the different patterns on plant distribution or other processes in an almost experiment-like setting. Even so, unanticipated issues arose because of the fine-scale structural complexity of the landscapes, which tended to reduce the differences among them (Brosofske, Chapter 2). For example, a high density of roads throughout the study area broke up large tracts of forest and open areas in all landscape units, reducing patch size, decreasing the structural differences among landscape units, and sometimes confounding the results when located spatially adjacent to another type of edge. In addition, only a single transect could be placed through each landscape unit because of the time, effort, and monetary expense involved. This eliminated the possibility of statistical testing at the landscape level and limited the generality of conclusions that could be made. Nevertheless, making use of existing landscape setups is a feasible way to obtain valuable, relevant field data for landscape ecology. Experience from CNNF suggested that there are approaches to conducting landscape experiments given the right setting (e.g., an existing assemblage of varying landscape patterns within otherwise similar environments) but there are barriers to drawing statistical conclusions and generalizations (Figure 1.3).

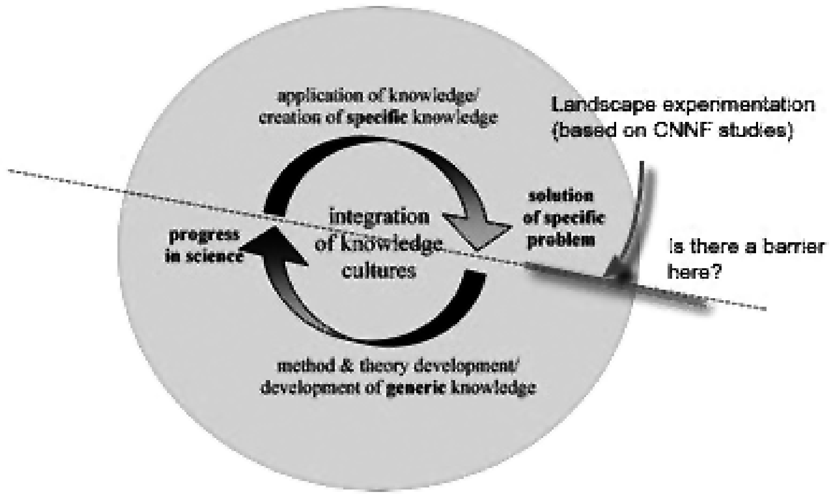

Figure 1.3. Like the illustration of process dynamics (Figure 1.1), our synthesis suggests that landscape experimentation has had some success in specific settings, but there are barriers to drawing statistical conclusions or generalizations. It has been difficult to develop generic knowledge from landscape experiments to date.

It is also quite common that results and conclusions made from a case study cannot be extrapolated to broader spatial and temporal scales, although scientists are consistently expected to deliver such generalizations. Miller et al. (2004) suggested that extrapolations not be viewed as an end point, but rather as part of an iterative cycle in understanding ecological processes. Learning from extrapolation successes and failures can advance scientific methods for landscape experimentation and its potential generalization. In a sense, Miller et al.'s claim would place extrapolation within the lower half of the knowledge circle, whereby extrapolations from specific studies (3 o'clock) are an attempt to make generalizations (6 o'clock). The outcome of those extrapolations may advance science (9 o'clock), and/or may feed lessons back to future studies (3 o'clock; Figure 1.3).

3.4. Modeling and Visualization

Models and visualization tools have been developed to examine landscape questions in lieu of large experiments. These tools offer an alternative means to test treatments that cannot be adequately controlled for in the field, and that are limited by the availability and accessibility of good empirical data. As a data collection tool, remote sensing offers the advantage of repeat sensor coverage for a given area, which is often the only practical means of mapping and monitoring whole landscapes. In the most reliable extrapolations, Miller et al.

(2004) claim environmental features captured through remote sensing tend to be the best response variables. Combining remotely-sensed data and other spatial data with landscape modeling is a promising and efficient approach to illustrate and predict spatio-temporal patterns of ecological process and properties of interest. On the other hand, landscape researchers should realize that remotely-sensed data are an interpretation of only certain features of the landscape, which may or may not be those relevant to the process being studied.

Zheng et al. showed in Chapter 5 that spatial modeling is a particularly powerful tool for landscape analysis because it can provide repeated measurements and it represents a system or process in abstract terms. Scenarios can be tested that would be impossible to implement in the field. By running multiple simulations for a given pattern-process dynamic, models can not only aid decision-makers about future landscape alternatives, they can also lead scientists to generate vigorous hypotheses about landscape dynamics. However landscape researchers should be aware that models represent expected relationships and can assess the robustness of these relationships, but cannot directly test associated hypotheses (Miller et al., 2004).

Like modeling, 3D visualization is a powerful tool that can visually portray not only the structure and composition of forest landscapes, but also the spatial and temporal changes of a forest landscape related to different disturbances or management treatments, and therefore can be an important tool for land management decisions and research (Song et al., Chapter 6). It is a specialized form of modeling that creates visual pictures or landscape scenes based on different scenarios (Wang et al., 2006). 3D visualizations of forest landscapes are quantitative information-based techniques that can be used for interpreting projections of stand succession, landscape transformation, and regional planning. The tool allows observation of forests and landscapes at multiple time sequences, including future and past scenarios. It facilitates evaluation of management alternatives and promotes better understanding of natural and human disturbances among researchers, forest managers, and the public. Short- and long-term visualizations may even be used to increase public involvement in natural resource management decisions. Song et al. clearly demonstrated that the combination of visualizations with traditional research methods will enable the decision making process to become more convincing and reliable. The generalized methods in modeling and visualization are well developed, have contributed toward progress and are, in fact, being applied (Figure 1.4). 3-D visualizations helped in forest planning and decision-making, by allowing users to evaluate local and regional changes based on a set of expectations. As the examples in Song et al. show, 3-D visualizations allow planners and decision-makers to anticipate the forest growth and landscape changes both historically and prospectively (Wang et al., 2006). In this realm, applied landscape ecology moves around the top of the knowledge creation circle back to specific solutions (Figure 1.4). These applications can help researchers and managers come together to find common ground to develop landscape-level "experiments" within the context of existing policy and management requirements.

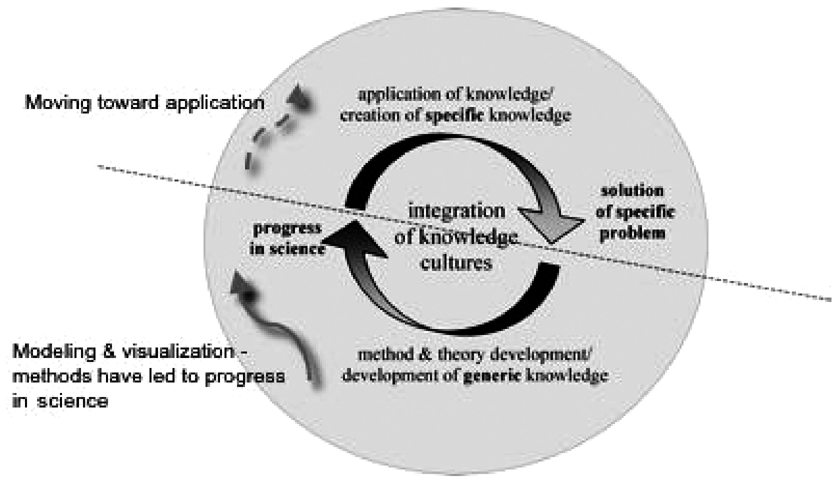

Figure 1.4. The generalized methods in modeling and visualization are well developed, and have contributed toward progress in landscape ecological science. In some cases, modeling and visualization methods are now being applied in management. Thus, applied landscape ecology moves around the top of the knowledge circle back to specific solutions.

3.5. Research Application and Transfer

The research program in Rhinelander, Wisconsin (Crow et al., Chapter 8) has emphasized development of practical models and tools to advance ecological thinking in landscape management. It has helped managers move beyond a piecemeal approach to managing resources, and to provide a basis for a more comprehensive, integrated, and spatial approach to managing ecosystems at landscape levels. Collaborations with natural resource management agencies and planning associations over the past 15 years have led to more accurate and more accessible data, models, and visualization tools (e.g., the Great Lakes Assessment, HARVEST, and LANDIS models, improved landscape change assessments).

Internationally, regional planners and natural resource managers have been applying landscape-ecological knowledge and theory across large landscape areas. Saunders et al. (Chapter 7) point out that landscape ecology principles have been paramount to the implementation of initiatives such as ‘ecosystem management’ that attempt to use landscape ecology as a framework for management. Many on–the-ground projects have been implemented through these initiatives over the past 10 or more years. When applied carefully, specific projects may offer empirical data for refining research models, or they could serve as large field experiments. Such cross-transfer of knowledge is very important to overcoming some of the challenges to advancing the science of landscape ecology. Researchers could exploit opportunities afforded by existing projects that have or could utilize landscape ecological theory. In other words, this would allow scientists to work from existing solutions (3 o’clock in knowledge circle), collecting findings from several in place, to build general knowledge (6 o’clock). To date, the research transfer trend seems to have been stronger near the top of the knowledge circle (applying research knowledge), and weaker at taking advantage of these projects to develop theory (Figure 1.5).

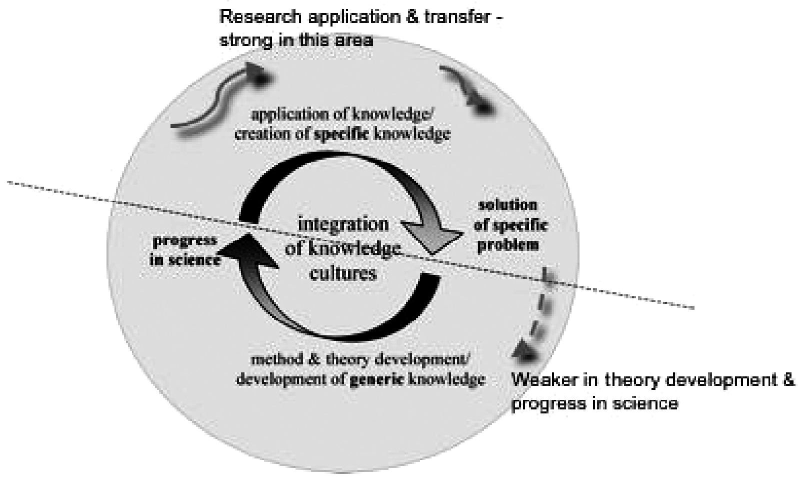

Figure 1.5. To date, the trend in research transfer seems to have been stronger near the top of the knowledge circle (applying research knowledge), and weaker at taking advantage of these projects to develop theory. However, researchers could exploit opportunities afforded by existing projects that utilize landscape-ecological theory. This would allow scientists to build general knowledge from existing solutions.

Saunders et al (Chapter 7) presented their assessment of the information flow between the theoretical and applied aspects of landscape ecology. They concluded that while the theoretical developments may find their way to landscape planning and management, the lessons learned from application of existing theory are not strongly linked to channels through which they can be used to advance landscape ecology theory. The authors argue that conscious facilitation of information transfer would help define landscape ecology in terms of testable hypotheses and help it remain a progressive and dynamic discipline (Figure 1.5). The case study of research planning within the B.C. Coastal Group's Forest Strategy showed that the planning activities were based on careful consideration of theoretical aspects of landscape ecology, and efforts were made to comprehensively address the questions in all their complexity. In analyzing the obstacles to information transfer, Saunders et al. found that often management decisions are made with the understanding that they are based on incomplete information. This could be either due to limited understanding of the complexity of the system or due to limited time or funding that prohibits the collection of all necessary data.

Uncertainty is increasingly recognized as an inevitable part of ecological research and resource management (Taylor, 2000). Managers and policy makers, who have to make decisions on a daily basis, are looking to adaptive management as a proactive approach to managing in the face of uncertainty. As its use becomes more prevalent, adaptive management should strive for a systematic and rigorous approach to learn from actions and accommodate change (Taylor, 2000). The approach therefore, should involve the scientific community and be tested in real landscapes. Future studies in landscape ecology should be designed to support adaptive management, thereby continuing to build and support the connection from scientific progress (9 o'clock) to applications of knowledge (12 o'clock)

(Figure 1.5). Mutual engagement of managers and researchers from the very beginning of the study design and shared ownership of products is critical to adaptive landscape management. To build a 'legacy of knowledge, plans are actively designed to reveal which action is best, rather than making retroactive or passive adjustments. Landscape assessments, such as those presented in Chapter 8 by Crow et al., and the case studies that Saunders et al. considered, can provide templates for practical management considerations in landscape ecological research. Together knowledge exchange between research and application should evolve into a unifying theory for landscape ecology.

4. CONCLUSION

Thus our synthesis of the challenges featured in this book brings us back to the top of the circle of knowledge creation (Figure 1), where the process of generating new knowledge comes full circle only when scientific understanding has been integrated into management and lessons from application are transferred back to validate or inform research studies. It is through this complete process that theories emerge. Landscape studies in particular will be dependent on the knowledge transfer to and from practice because controlled experiments at landscape scales by the research community alone are largely infeasible. The science of landscapes must rely on alternative tools such as modeling, visualization, and long-term alternative management applications to evaluate landscape concepts and build theories.

> "Scientific disciplines are distinguished by their concepts and theories rather than their 'facts'. In a mature discipline, these concepts and theories are unified into a framework that provides a foundation for both research in and applications of the science." (Wiens, 1999)

For the science of landscapes to mature, scholars must consider the process by which new knowledge is created and transferred in the scientific model. As Stephens et al. (2005) remind us, ecological research strives for an ideal: models of general predictive utility. Yet most studies will only identify one small piece of the puzzle at best. Landscape researchers should use the best tools and collaborations available to conduct sound ecological studies at the landscape scale that are hypothesis driven and experimental where possible. Most importantly, this science, like others, is iterative such that research and practice build on each other through long-term cyclical dialogue.

5. AKNOWLEDGMENTS

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