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PERSPECTIVES

Design in science: extending the landscape ecology paradigm

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Abstract Landscape ecological science has produced knowledge about the relationship between landscape pattern and landscape processes, but it has been less effective in transferring this knowledge to society. We argue that design is a common ground for scientists and practitioners to bring scientific knowledge into decision making about landscape change, and we therefore propose that the pattern–process paradigm should be extended to include a third part: design. In this context, we define design as any intentional change of landscape pattern for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values. We see both the activity of design and the resulting design pattern as opportunities for science: as a research method and as topic of research. To place design within landscape ecology science, we develop an analytic framework based on the concept of knowledge innovation, and we apply the framework to two cases in which design has been used as part of science. In these cases, design elicited innovation in society and in science: the design concept was incorporated in societal action to improve landscape function, and it also initiated scientific questions about pattern–process relations. We conclude that landscape design created collaboratively by scientists and practitioners in many disciplines improves the impact of landscape science in society and enhances the saliency and legitimacy of landscape ecological scientific knowledge.

Keywords Adaptation · Landscape change · Interdisciplinary · Transdisciplinary · Innovation · Sustainable development · Landscape planning

Problem and aim: applying landscape ecological knowledge

While the science of landscape ecology has made fundamental advances in describing landscape pattern and in understanding pattern:process relationships, it has made less profound gains in affecting landscape decision making. Landscape ecology has always identified humans as intrinsic to conceptual understanding of landscape and ecosystem dynamics (e.g. Golley 1987), but the state-of-the-art provokes only incomplete application of environmental knowledge in practice (Prendergast et al. 1999; Brody 2003). Environmental benefits have been part of the intent of

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design in landscape architecture and planning since the 19th century (e.g., Zube 1986), and academic examinations of various conceptions of ecological design have burgeoned over the past decade, along with influential methodologies for measuring the environmental consequences of design (e.g., US Green Building Council 2007), However, these inquiries and systems have not substantially incorporated progress in research on biogeochemical and ecological processes in landscapes across scales (Termorshuizen et al. 2007). We argue that more active, integral links between landscape science and landscape design are required—in both the world of science and the world of practice—to achieve vitally important societal needs.

This gap between knowledge and practice is particularly poignant for landscape ecology because perceptions of landscape pattern may influence human volition for action to effect landscape change (Nassauer 1992; Gobster et al. 2007). In this context, we define "landscape" as a heterogeneous mosaic of ecosystems that is constantly being adapted by humans to increase its perceived value. Human volition complements sustainability, then, only to the extent that perceived value is aligned with, rather than diverging from, protection of earth's life support systems (Nassauer 1997). From this definition of landscape, in which human adaptation is integral, landscape ecology is positioned to contribute to sustainability science (Clark and Dickson 2003) by framing scientific questions that can guide landscape change to be perceived as valuable in society and to be environmentally sustainable (Kates et al. 2001).

As society is confronted with mounting environmental problems, why has there been only incomplete application of environmental science? An overriding cause may be societal evolution away from the modernist "Sputnik Era", in which conventional science institutions were granted societal authority for the creation of knowledge, toward post-modernist societies in which different forms of scholarly knowledge compete, and the primacy and even the credibility of scientific knowledge is questioned (Jackson 2005; Nowotny 2005). This evolution is evident where governance structures have become complex multi-layer processes involving a variety of actors with different backgrounds, interests, and different spheres of influence (Healy 1996; Agrawal 2005).

Shedding light on how science and technology can be employed to protect the earth's life support system within these complex societal systems, Cash et al. (2003) concluded that the effectiveness of scientific information in societal decision-making is related to three characteristics of science: *saliency* (relevance to decision making), *legitimacy* (fair and unbiased information production that also respects stakeholders' values), and *credibility* (scientific adequacy). They stress that saliency and legitimacy are often in tension with credibility. Their conclusions are the basis for our analysis of why science knowledge has not been sufficiently applied to landscape change. For example, even interdisciplinary landscape ecological knowledge may lack the appropriate integration of disciplines and professions required to be salient for complex, real world problem solving, or it may lack credible methods to anticipate and address surprising problems (Tress and Tress 2001; Nassauer and Corry 2004; Palmer et al. 2004a). Saliency and legitimacy also may suffer when scientific tools are considered too complex, too prescriptive, too demanding of resources, or not flexible enough to support place-specific decisions (Prendergast et al. 1999; Theobald et al. 2000; Pullin et al. 2004; Azerrad and Nilon 2006). Furthermore, if science is not attentive to stakeholder knowledge, research may lack legitimacy because it appears to be irrelevant to place-specific landscape issues.

Nowotny et al. (2001) concluded that for scientific knowledge to be effective in society, science and practice must interact in a continuous exchange of knowledge. They argue that scientists need to participate in application and make it part of their scientific approach. This would mean a change in science—from an emphasis on analysis and reductionism toward a goal of synthesis and integration that challenges conventional norms of scientific adequacy. Transdisciplinarity, collaborative production of knowledge by scientists and practitioners (Fry et al. 2007), has been put forward as a potentially effective means of addressing complex societal problems (Wu and Hobbs 2002; Horlick-Jones and Sime 2004; Knight et al. 2006; Fry et al. 2007; Liu et al. 2007). Undoubtedly effective transdisciplinarity will require that new norms, not solely dependent on disciplinary conventions, evolve for credible research.

Palmer et al. (2004b) also assert that "scholarly inquiry and tacit and experiential knowledge of practitioners need to be connected at some point in the knowledge chain," and they point out that a common ground is needed for communication. The common ground that they describe clearly includes landscape design. They call for ecologists to engage in "a research agenda centered on ecosystem services and the science of ecological restoration and design", saying that ecological restoration must be supplemented by ecological design that will blend familiar components of indigenous ecosystems with cultural patterns. They describe that, where indigenous ecosystems have been fundamentally displaced, ecological design occasionally must create wholly new landscape patterns de novo, "synthetic systems consciously created to meet ecological, societal, and/or economic goals".

To examine the relationship between design and landscape science, we use *knowledge innovation* as an overarching rationale for more specific criteria of saliency, legitimacy, and credibility, and the indicative characteristic of transdisciplinarity. Knowledge innovation broadly encompasses essential characteristics of design: creativity and application to achieve societal values. Amidon (1997) defined knowledge innovation as "the creation, evolution, exchange and application of new ideas into marketable goods and services, leading to the success of an enterprise, the vitality of a nation's economy and advancement of society". Dvir and Pasher (2004) defined it as the process of turning knowledge and ideas into value. In the context of landscape ecology, innovation is turning knowledge about interactions among pattern–process into designs that add value for society. More specifically, innovation is turning knowledge into design for landscape change that protects earth's life-support system for the long term while respecting societal values. By definition, innovation based on new knowledge adds value to society.

In this paper, we explore whether and how design of the landscape can be a common ground for landscape ecologists in many disciplines along with practitioners involved in landscape change to work together in knowledge innovation. In this context, we define design as *intentional change of landscape pattern, for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values*. *Design* is both a *product*, landscape pattern changed by intention, and the *activity* of deciding what that pattern could be.

Our hypothesis is that landscape design can effectively link science and society in knowledge innovation for sustainable landscape change. We examine whether landscape design enhances the credibility, saliency and legitimacy of scientific information in society, and whether it provides a common ground for practice and science. We also examine whether design can advance transdisciplinarity, which may support knowledge innovation for sustainable landscape change. We explore our hypothesis by reflecting on case studies in which we participated: the design method for robust corridors (Vos et al. 2007) and the alternative futures/integrated assessment method (Nassauer and Corry 2002; Scavia and Nassauer 2007). We conclude that the landscape ecology paradigm of pattern: process must be expanded to incorporate design, both as a design science method, an activity within the science of landscape ecology, and as a common product of scholars and practitioners.

The conceptual basis for design in the landscape ecology paradigm

To help landscape science affect landscape change, we propose to broaden the landscape ecology paradigm beyond *pattern: process* to explicitly incorporate intentional human action: *design*. This paradigm (Fig. 1) requires three parts: *process: pattern: design*. Directly related to our hypothesis, it suggests that scientific understandings of process: pattern: design relationships could usefully affect landscape planning (broadly defined as design practice to change landscapes), and that landscape planning can usefully affect science. It positions "design" as a common ground for technology transfer: where practitioners and scientists conceptualize landscape innovations, where practice can influence scientific questions in landscape ecology, and where scientists can discern relevant directions for developing new knowledge. It also suggests that design research, investigating what landscape patterns and compositions are valued by society, can contribute to framing landscape science to be more salient and legitimate, and consequently to have a greater effect on landscape change. Viewed from the perspective of societal planning for landscape change, the paradigm also suggests that invention of novel *pattern:design* relationships may be useful in scientific investigations of

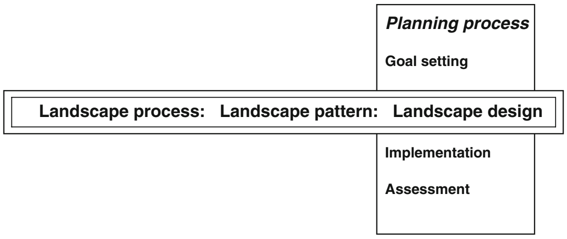


Fig. 1 Extending the landscape ecology paradigm by including design as a link to landscape planning in society

ecological processes. Design methods that invent novel patterns can help to anticipate and address surprising circumstances (Palmer et al. 2004a; Liu et al. 2007). Making such surprises amenable to scientific analysis may enhance legitimacy, and making surprising futures accessible to public comprehension may enhance saliency.

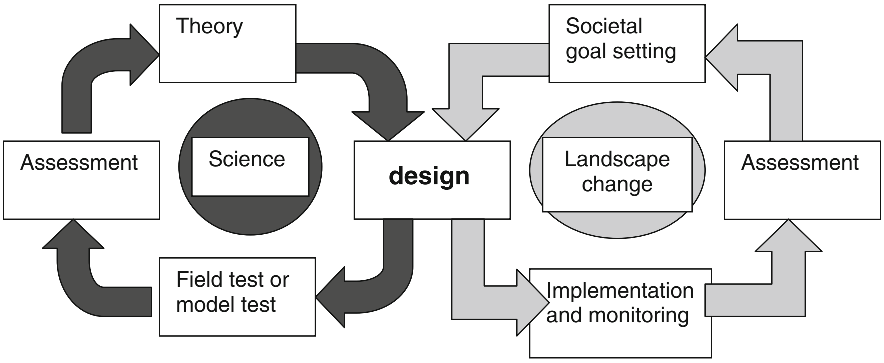
If we include landscape design as part of scientific knowledge creation, we have a common link between the science and practice of landscape change (Fig. 2). This design link is both a product and an activity. The changed landscape pattern and composition, i.e., design as a product, can be a shared basis for scientific and societal assessment of landscape change. This relationship also can be described as two knowledge creation activities linked by design as the common activity, in which scientists and practitioners work together to create and revise knowledge to guide landscape change. Note that in this model, scientists from many disciplines including design and ecology, may participate in the intentional landscape change process, and may develop and test scientific tools or design concepts in practice. Alternatively, questions born during practice can link back into the science cycle.

To bring this model into an analytical framework suggested by the concept of knowledge innovation and literature we review above, we identified the following problems that could interfere with design as a link between practice and science:

1. *Science disciplines* may not be sufficiently integrated, broad, and appropriate to societal issues. Knowledge from different disciplines may not be sufficiently integrated, and this lack of transdisciplinarity may prevent new knowledge from being salient. Disciplinary barriers, especially fear of losing credibility within one's own discipline, may cause scientists or practitioners to reject knowledge or tools that are salient but unfamiliar to them
2. *Knowledge tools* may not be perceived as legitimate or may not be salient to societal decision making process. Models or other tools may be too narrow, too resource or data intensive, or too prescriptive to be adapted to particular places. Or science tools may lack the capability to address uncertain or surprising future conditions that are of concern to society.
3. *Communication processes* among scientists, practitioners, and society stakeholders may be inadequate to achieve credibility, saliency and legitimacy, and ultimately, to support innovation.
4. *Feed back from practice to science.* If scientists are not involved in practical applications of scientific knowledge, they may not learn how they could improve the effectiveness of their science, staying unaware of new problems or new solutions that demand scientific investigation.

To analyze the role of design in our case studies, we focused on the problems above. Specifically, we

Fig. 2 Design as a link between science and landscape change



addressed the following questions for each case study:

1. *Did design enhance saliency through knowledge integration?* Were the relevant disciplines active in developing and assessing the design? What broadly applicable generalizations or rules of thumb were developed, and what knowledge was integrated through guidance by the common design?
2. *Did the design process offer legitimate, salient knowledge tools for decision-making?* How did the landscape design affect the transfer of scientific knowledge into the landscape planning process, the transfer of technology to decision-making, or the transfer of design inventions into scientific inquiry? How was scientific knowledge made salient and legitimate for the application?
3. *Did design invoke communication and innovation?* For design to contribute to innovation, it must enhance communication between science and practice. How did the landscape design enhance communication, and did this communication allow scientific concepts to affect landscape change?
4. *Was the design brought back into science?* For example, were the science and society premises underpinning the design sufficiently credible to frame future scientific investigations? The design may have initiated new pattern:process studies, new scientific concepts for knowledge integration, or the development of methods that enhance the saliency of scientific knowledge for practical application.

Case studies: the role of design

Case 1: design of robust ecological corridors

In 1990 the Dutch government launched the National Ecological Network NEN (MANFS 1990), composed of existing nature areas extended with additional areas (to be purchased and restored by the national government) and interconnected by local scale ecological corridors. The NEN was an answer to habitat loss and fragmentation, which were considered prime causes of the observed loss of biodiversity (Lammers and Zadelhoff 1996). Based on island biogeography and metapopulation theory, habitat networks were thought to offer conditions for long-term conservation where individual areas were no longer large enough for persistent populations (Opdam et al. 1995; Opdam 2002; Hobbs 2002). Selected ecosystem types and species were targeted as objectives of national policy (Bal et al. 2001). In 1998, the first evaluation of the 30-year implementation process proved that the predicted spatial cohesion (Opdam et al. 2003) of the NEN would be insufficient because extensions were inappropriately located and corridor development was ineffective (Bal and Reijnen 1997; Vos et al. 2007). At this point, a design process was initiated to make the NEN effective to meet national policy objectives for ecosystem types and species. This process involved scientists from Alterra, a large Dutch research institute connecting academic and applied research in the fields of soil and water science, ecology, landscape ecology, governance and planning. Other participants were nature conservation NGO's, civil servants of the Ministry of Agriculture, Nature Conservation and Food Quality, as well as provincial governmental bodies (Pelk et al. 1999). The process occurred in three phases.

In the first phase, Alterra organized several workshops in which representatives of all parties defined the most important problems and explored alternative solutions. As a result, a new interpretation of the corridor concept, called the "robust ecological corridor", was proposed. Robust corridors were intended to connect the most important agglomerations of fragmentation prone ecosystems at an extent over tens of kilometers. Alterra researchers developed a preliminary design of the NEN with robust corridors, and this was adopted by the secretary of state to start negotiations for implementation (MANFS 2001). This design merged generic scientific knowledge (metapopulation ecology, ecosystem network ecology, environmental conditions etc) and practitioners' context-specific knowledge (e.g. about appreciation of the current state of nature and the acceptability of alternative options in the political arena). This first phase design was a new concept for connectivity nationwide, the robust corridor, and a mapped proposal for its location.

In the second phase, Alterra helped the national Ministry of Agriculture structure a negotiation process among the governments of the 12 provinces (which were responsible for implementation) to agree upon quantifiable goals for the corridors. The nationwide robust corridor locations, was unevenly distributed corridor length among the provinces, and the implied unequal allocation of national funds was a likely complication in the decision-making process. Based on ecological knowledge and arguments of ecological functionality, Alterra organized a common learning process for provincial representatives in which goals for each corridor were agreed upon by all parties. Goals were specified by species that could benefit from developing corridors in each location. With this process, location decisions made in the first phase design became more specific in the second phase by using species goals. From species goals, the required area coverage and costs for purchase were derived.

In the third phase, the provinces were asked by the national Ministry to explore feasibility by making a rough design for each corridor. To assist the provinces, Alterra developed a manual with guidelines for corridor design that integrated species specific knowledge into spatial characteristics (Broekmeijer and Steingröver 2001). For the manual, Alterra developed a tool called "ecoprofiles", in which species were categorized by spatial dimensions of corridors. The manual distinguished functional building blocks like key patches, stepping stones and corridor zones, seven ecosystem types, and approximately 10 ecoprofiles for each ecosystem type. It also included rules for combining building blocks into ecologically effective corridor designs in different landscape contexts. This enabled a variety of combinations for design of particular places (Vos et al. 2007). An instructional design tool on CD guided the provinces' designers through the procedure.

During the development of the manual, the Ministry organized workshops in which Alterra, provinces and landscape design bureaus discussed the credibility of the underlying science and other features constraining the application of the method. Subsequently, the manual was supported and used by professional landscape architect practitioners.

Alterra also was asked by the Ministry to conduct an assessment of the use of the manual in each corridor design. The outcome of this design process led to a decision by the national government to develop robust corridors, specifying the total area by which the NEN would be expanded and the distribution of budgets over the provinces. This decision was supported by the national Parliament, and the map of the NEN with robust corridors is now part of national spatial policy, with robust corridors moving toward implementation.

Did the design enhance saliency through knowledge integration? In inventing the corridor pattern, scientists from many disciplines were forced to make generalizations based upon a variety of fragmentation studies, and they had to interpret the variety of responses of species to fragmentation patterns in relation to the variation in corridor pattern. Also, because robust corridors were meant to be used for recreation purposes, literature and expert knowledge about recreation was incorporated to investigate how recreation could be combined with habitat use and how the corridor design could be adapted for potential impact of recreation on its ecological effectiveness. The transdisciplinary method is discussed in detail in Vos et al. 2001, 2007; Verboom et al. 2001; Opdam et al. 2003.

Did design process offer legitimate, salient knowledge tools for decision-making? Because the provinces had been involved from the first phase of the design process, they understood it, and they knew what types of tools they wanted in the third phase, when the provinces and the landscape architects they had commissioned were involved in the production of the manual, for example in the decision to distinguish three aspiration levels of conservation goals, linked to an increasing level of investment. This provided them with flexibility in the negotiation process. At the same time, they understood that the link between species goals and spatial dimensions was necessary to achieve ecological sustainability (Termorshuizen et al. 2007). An important tool in knowledge transfer was the classification of 400 target species into a simplified matrix, with spatial features of the corridor as axes (the ecoprofile matrix, see Opdam et al. submitted).

Did the design invoke communication and innovation? The design of the corridor map was a strong instrument for communicating the need to improve the connectivity of the NEN. The robust corridors were a designed invention based on the known relationship between ecological processes and ecosystem pattern. In the linked design process conducted in the workshops, scientists learned how to express this information in a way that was relevant in the political arena, and actors in the policy domain learned to use the information. The design invoked discussions in the national Parliament, and in 2005, the robust corridor concept became national spatial policy. The provinces and the nature conservation NGO's became strong supporters of the robust corridors, and were able to prevent loss of political support in periods when a government had no interest in nature conservation.

Was the design brought back into science? The decision to implement the plan for robust corridors pointed to the need to improve underlying ecological knowledge. Research was begun to check the logic of the design rules with a modeling research method, and to conduct a meta-analysis of published empirical knowledge on corridor effectiveness. Another project explored how the flexibility of the design guidelines could be increased by combining varying matrix characteristics of the wider landscape with the varied dimensions of the robust corridors.

Case 2: design of alternative landscape futures to affect agricultural landscape change

This project began as interdisciplinary research funded by the US Environmental Protection Agency (Santelmann et al. 1997). Scientists from more than 10 disciplines, including agronomy, several areas of ecology, economics, hydrology, and landscape architecture, conducted the project, and they were joined by expert practitioners in other disciplines within agriculture, conservation and forestry. Design was explicitly both a research activity and a product of the research, as implied by the title of the research proposal: *Modeling Effects of Alternative Landscape Design and Management on Water Quality and Biodiversity in Midwest Agricultural Watersheds*. While immediate application of results was not a goal of the research, anticipated policy relevance powerfully influenced the research questions and the.design of the alternative landscape futures.

Facilitating integration of disciplinary knowledge and knowledge transfer between science and design were primary aims of the research process. The landscape architecture scientists organized a highly iterative design process that began very broadly, by using the web to elicit speculative thinking from national experts about policy relevant possible changes in agricultural landscapes, and ended very specifically by designing three future alternative landscape patterns for each of two study watersheds in Iowa, USA, and communicating the futures as coverages for geographic information systems (GIS) modeling and measurement. This process is discussed in detail in Nassauer and Corry (2004).

A key event in the design process was a 3-day transdisciplinary visioning workshop held near the two study area watersheds. For the workshop, the landscape architects organized a sequence of transdisciplinary design activities for the approximately 25 participating scientists, stakeholders and practitioners. The workshop enlisted all the participants in setting the direction for overall policy scenario content, and several options were discussed for their policy relevance. Then, workshop participants were assigned to small transdisciplinary teams that were sent into the field to develop designs for study area landscapes. Each team was required to make *transdisciplinary proposals* for alternative landscape patterns that would improve water quality or biodiversity while maintaining agriculture in particular study area locations. After the workshop, the landscape architects synthesized many of these design proposals into three different futures for each study watershed. Then, over the course of a year, these futures were iteratively vetted with all members of the science team and went through several revisions, often after the landscape architects sought more information from practitioners and stakeholders who were familiar with the study area. The final landscape designs, or alternative futures, were expressed as replicable design rules by which the present landscape could be transformed into each of the futures, as shown in GIS coverages and digital imaging simulations. These GIS coverages and simulations were then used to conduct an integrated assessment of the performance of each future including: financial return to land, farmer perceptions, multiple biodiversity and habitat measures, and hydrology (Santelmann et al. 2004; Nassauer et al. 2007b).

Shortly after the completion of this research project, it became apparent that the realism of the futures and their rigorous integrated assessment would complement an independent interdisciplinary and interagency integrated assessment of the causes and consequences of the so-called "dead zone" of hypoxia in the Gulf of Mexico at the mouth of the Mississippi River Basin that had been conducted as mandated by US federal law (Harmful Algal Bloom and Hypoxia Research and Control Act of 1998). Consequently, scientists from the two projects decided to join their results with the aim of informing US federal agricultural policy (Nassauer et al. 2007b), and the work was presented to members of the US Congress as a consideration for the federal farm bill in 2007.

Did design enhance saliency through knowledge integration? Three aspects of this project were key to achieve saliency by knowledge integration: the transdisciplinary design process, the designed patterns described by explicit rules—which created a single, shared basis for assessment from several disciplinary perspectives, and the integrated assessment of the designs. While the transdisciplinary visioning workshop was the most obvious means of accomplishing knowledge integration, the entire iterative design process involved scientists and expert stakeholders in offering and integrating their knowledge. The design product enhanced knowledge integration by producing a single, shared set of landscape patterns. Because the designed pattern was robust, fully representing all relevant characteristics of the future landscapes, and the design rules underlying landscape transformation and management were explicit, an integrated assessment was possible. Finally, comparing measurements of a wide array of ecological, economic, and societal landscape functions in the integrated assessment inherently integrated science knowledge.

Did the design process offer legitimate, salient knowledge tools for decision-making? Legitimacy and saliency of this research was enhanced by both the integrated assessment, because it gave credible quantified measures for comparing the performance of the designs, and by the digital imaging simulations of the designs. The simulations, showing the designs as they would have looked in photographs from the ground and from 1000’ above, were essential for Iowa farmers to understand and evaluate the designs, and the farmers’ evaluations appeared to be of great interest to NGO’s and members of the US Congress when the project was used for discussion of the federal farm bill in 2007. However, the simulations could have undermined the credibility of the science if there had been any question about whether these “pretty pictures” accurately represented the designs that had been measured by the other scientists in the project. Because the simulations had been carefully derived from the same GIS data shared by the other scientists, decisionmakers could trust that the farmers’ responses were to the same designs as had been assessed for their hydrologic, ecological, and economic performance. For example, the decisionmakers were interested to learn that farmers valued the design that had also provided the greatest water quality and biodiversity benefits (Nassauer et al. 2007a).

Did design invoke communication and innovation? The Corn Belt watershed landscape design products and method helped to make unfamiliar and as yet unknown future landscape patterns, knowable and potentially valued by stakeholders and decisionmakers. The designs invoked communication and innovation in three ways; by designing landscape patterns that were calculated to be immediately recognizable as good conservation, by designing at a scale that was familiar to local stakeholders—watersheds less than 35 square miles in extent, and by representing the designs in digital simulations that looked “real”, like images made with a camera in the field.

Design strategy for the product: making the value of new landscape pattern inventions, based on transdisciplinary knowledge, recognizable by designing new patterns to resemble some aspects of familiar, valued conservation patterns. For example, a new pattern of perennial herbaceous native plants was understood by Iowa farmers to represent stewardship, and they chose this pattern as “best for the future of the people” of the state in 2025 (Nassauer et al. 2007a).

Design scale of the product: designing at a “local” second-order watershed scale at which features and practices in the landscape pattern remain concrete and recognizable to local people who manage the landscape.

Verisimilitude of the method of representation: allowing new patterns to be represented in digital imaging simulations that “look like” a photo image of the landscape as it might be seen in everyday experience.

These three characteristics made the Corn Belt landscape designs highly complementary to the integrated assessment of the MRB. Policy experts believed that the realism of the landscape designs of local scale watersheds enhanced the legitimacy of the integrated assessment of the entire MRB for affecting federal agricultural policy (Doering et al. 2007).

Was the design brought back into science?

In this case, landscape invention occurred within a scientific investigation; it was intentionally and inherently part of science. Science knowledge was not only transferred into new landscape patterns by the transdisciplinary design process, these patterns were brought back into science as the subject of more specific scientific assessments. In addition, the process transferred knowledge among experts as they learned from other disciplines in the intense exchange of ideas throughout the design process. After the completion of this project, variations on the landscape designs were used by some members of the team as well as by other investigators to examine patterns for bringing perennial energy crops into Corn Belt landscapes, and to investigate local peoples' perceptions of other agricultural policy scenarios.

Synthesis: a model for design in landscape ecology

We call for landscape ecology to include design as a method and as a product to increase the saliency and legitimacy of scientific knowledge. We discussed examples of landscape ecological research in which landscape design was essential to science and to knowledge innovation. These examples can be regarded as transdisciplinary research, in the sense that the landscape design was the result of a common activity shared by scientists from many disciplines including designers, as well as practitioners and stakeholders. The design invoked knowledge innovation in the sense that the design concept was incorporated into societal action to improve landscape functioning, and it also initiated questions for further understanding of pattern–process relations. Consequently, we conclude that landscape design created collaboratively by scientists and practitioners has the potential to enhance the saliency and legitimacy of scientific knowledge about pattern–process relations, and to allow science to affect landscape change. Therefore, to increase the societal impact of landscape science, we recommend extending the *pattern–process* paradigm with a third part: *design*. To further realize the intellectual potential of this tripartite paradigm, we also call for a more mature design science that enhances understanding of why and how humans manage and change landscapes in particular patterns and compositions relevant for their anticipated effects on ecosystem services.

We take this conclusion a step further by interpreting our landscape ecology paradigm in Fig. 1 as a model for an approach to landscape science that employs design process as part of research and that employs design pattern as a means of landscape change (Fig. 3). We distinguish three main phases in this approach: a phase of landscape process analysis, a phase of integrating this knowledge into general design pattern rules, and an application of the pattern rules as designs for specific landscapes to solve a problem and/or to increase or protect the value of the landscape for the future. These phases are represented by the three columns in Fig. 3, and they form a logic circuit of knowledge production. In the first phase, research about landscape processes, including design research, is often disciplinary. In itself, research will not result in landscape innovation. In the second phase, research about landscape pattern calls for design process to integrate knowledge among disciplines, practitioners, and stakeholders. In the third phase, place-specific design patterns integrate stakeholder knowledge and scientific knowledge. Our three phases can be distinguished in the hierarchical view of landscape ecology presented by Wu and Hobbs (2007). The first phase in our model is the almost exclusive domain of scientists in many disciplines including the design disciplines (but questions in Phase 1 should be affected by what science learns from the second and third phase of the model). In the second phase, stakeholder knowledge or anticipatory societal knowledge is required, and in the third phase researchers and representatives of societal stakeholders and professionals contribute to design for specific landscape changes. We suggest that these phases are most productive when they are pursued iteratively. If the designed pattern is treated as an hypothesis about the effect of pattern change on process parameters and brought back into the first, analytical phase, it can contribute to inductive theory building.

Full implementation of this model requires that scientific methods make connections between the phases, and also that these methods adapt to collaborative research. For example, in the connection between the first and second phases, scenarios are a way to articulate and, sometimes, anticipate societal values, and landscape designs developed from those

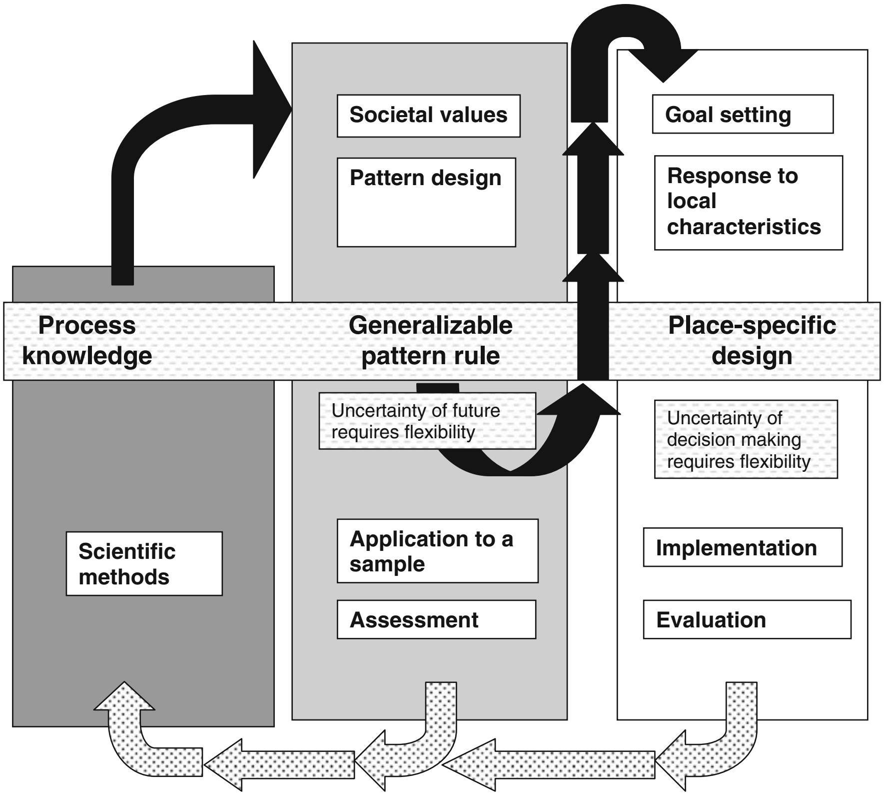


Fig. 3 A landscape science model that employs design process as part of research and design pattern as a means of landscape change

scenarios can help society anticipate surprising futures. These futures are not designs for implementation in particular areas, but serve as samples to explore questions about broader policy scenarios and to gauge societal preferences about the future. Another example of the role of a generalizable pattern in both knowledge integration and communication is the spatial concept, for example the greenway concept (Fábos and Ryan 2004) and the ecosystem network concept (Opdam et al. 2006) discussed in this paper. Spatial concepts in planning guide, inspire and communicate the essence of a plan or planning strategy (Ahern 2006), and are often articulated as metaphors that facilitate communication to the wider public. We argue that the same spatial concepts used as the third part of the process–pattern–design paradigm will invoke interdisciplinary research and facilitate communication and co-operation between science and practice. Such concepts will guide the interpretation of inductive empirical work towards generalized patterns that can be understood by actors in landscape decision making.

Our call for extending landscape ecological research methods beyond the safe boundaries of soley analytical process–pattern research addresses a growing urgency to develop strategies that link ecological science to public involvement and understanding. Johnson and Campbell (1999), Theobald et al. (2000), Palmer et al. (2004a, b), and Liu et al. (2007) have contributed to a research agenda underlying science-based participatory landscape planning. With Palmer and her colleagues in the Ecological Society of America, we advocate that design be adopted as a boundary concept between science and practice, and further, we assert that landscape ecology should be at the active edge of this boundary. The development of design in science invokes new methodologies and a new generation of interactive landscape ecological models suitable for design rather than only for analysis or evaluation of fixed landscape patterns. There is a great need for spatial concepts based on an integration of the pattern–process relationship, especially anticipatory concepts that imagine changing future patterns and their implications for society. If scientists intend to improve the impact of science on human volition, methods to measure this impact are demanded. For example, can we identify characteristics of scientific information that determine their effect upon complex negotiations about landscape change? What is the impact of different forms of scientific knowledge on the planning process and communication among actors?

Cash et al. (2003) emphasized the tension between credibility of scientific inputs and their saliency and legitimacy. Scientists who participate in solving problems of landscape change may perceive this tension as challenges to their own scientific credibility. We assert that scientific methods that incorporate design into science can contribute to relieving this tension. Using design as a method, scientists may act as providers of objective information, warn of societal problems, act as mediators in conflicts, or carry out an independent assessment of the effectiveness of a policy. In fact, the larger societal credibility of science may depend in part on scientific competence in playing these roles and being part of the societal discussion.

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