Chapter 2
Strengthening Landscape Ecology's Contribution to a Sustainable Environment

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Abstract The need to avert unacceptable and irreversible environmental change is one of the most urgent challenges facing society. Landscape ecology has the capacity to help address these challenges by providing spatially-explicit solutions to landscape sustainability problems. However, despite a large body of research, the real impact of landscape ecology on sustainable landscape management and planning is still limited. This essay identifies four key areas where landscape ecology can strengthen its contribution to achieving a sustainable environment. These are: recognising the growing complexity of landscape sustainability problems; adopting a formal problem-solving framework to landscape sustainability problems; helping to bridge the implementation gap between science and practice; and developing stronger links between landscape ecology and restoration ecology.

Keywords Communities · Complexity · Decision analysis · Economic constraints · Landscape sustainability problems · Risk · Uncertainty · Institutional design

2.1 Introduction

One of the most urgent challenges facing society is to avert unacceptable and irreversible environmental change arising from unsustainable land use and climate change (Rockström et al. 2009; Wijkman and Rockstrom 2012; Wiens 2012). Managers of human-modified landscapes face a large number of interrelated environmental problems stemming from a long history of cumulative land use and land cover changes, including land degradation, loss of habitat and biodiversity decline (Lindenmayer et al. 2008). Twenty-five percent of Earth's land resources

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are highly degraded, 8 % are moderately degraded, 36 % are stable or slightly degraded, and only 10 % are ranked as "improving" (Nachtergaele et al. 2011). An increasing proportion of the world's biodiversity is listed as threatened (Pimm et al. 2006; IUCN Red List). Addressing these challenges requires the development of sustainable landscape management and planning strategies that help solve current and anticipated environmental problems in a proactive, comprehensive and cost-effective manner (Wu 2006; McAlpine et al. 2010).

In recent decades, landscape ecology has made considerable progress in understanding the linkages between landscape structure, function and change, particularly for managing and designing landscapes for conservation (Lindenmayer and Hobbs 2007). Landscape sustainability is becoming an increasingly important focus for landscape ecology (Musacchio 2011; Wu 2012). It is a difficult concept to define, but can be considered in terms of a landscape's adaptive capabilities to cope with uncertainties rather than the maintenance of a landscape in a static state (Wu 2012). Ecologically, landscape sustainability requires avoiding irreversible change through careful management and continual ecological improvement (Fischer et al. 2007; Mac Nally 2007). However, ultimately, the sustainability paradigm is a human centred concept about meeting the needs of people, now and in the future (Wiens 2012).

Landscape ecology has the potential to contribute significantly to landscape sustainability and there are some signs of integrated, solution-driven research (Wu 2006), but its real impact on sustainable landscape management and planning is still limited (Naveh 2007). Similar to much environmental research, there is a lack of policy uptake, and a lack of implementation of research outcomes from landscape ecology. This stems partly from the division of knowledge into narrow, specialist fields throughout the 20th century, and partly from the institutional and social constraints to achieving landscape sustainability goals in many regions of the world, especially those where development is poorly planned or unplanned.

There are three ways through which the contribution of landscape ecology to landscape sustainability can be strengthened: (1) by better integrating bio-ecological and humanistic perspectives in landscape ecology; (2) by adopting socio-ecological thinking that focuses on the multiple functions of landscapes and the multiple actors involved in their construction; and (3) by involvement in and adoption of principles of adaptive management to deal with the complex and uncertain responses of landscapes to changing conditions (McAlpine et al. 2010). In essence, landscape ecology needs to increase involvement in and knowledge exchange between the bio-sciences that are the main focus of landscape ecology and the human-oriented decision sciences that are the main focus of land planning (Vos et al. 2007; Termorshuizen and Opdam 2009). An example of this is the pattern-process-design paradigm proposed by Nassauer and Opdam (2008) that actively links landscape science and landscape planning to achieve vitally important environmental and social outcomes. This new paradigm aims to improve the impact of landscape science in society and enhance the saliency and legitimacy of landscape ecological knowledge in addressing landscape sustainability problems (Nassauer and Opdam 2008).

This essay identifies four key areas where landscape ecology can strengthen its contribution to achieving a sustainable environment. These are: recognising the growing complexity of landscape sustainability problems; adopting a formal problem-solving framework to landscape sustainability problems; bridging the implementation gap between science and practice; and developing stronger links between landscape ecology and restoration ecology. We conclude with key principles through which landscape ecologists can contribute towards improved outcomes for landscape sustainability.

2.2 Recognise the Growing Complexity of Landscape Sustainability Problems

Complexity is at the core of landscape sustainability problems for two reasons.

First, incorporating complexity into sustainable landscape management is an essential step in attaining sustainable landscapes that are resistant and robust to future human and environmental disturbances (Parrott and Meyer 2012). There is a growing recognition that landscapes are complex social–ecological systems comprising a dynamic mosaic of land uses, and that the future of a landscape can be conceived in terms of ensembles of likely future system states, given particular management scenarios and external drivers (Parrott and Meyer 2012). The dynamics of landscapes are becoming inherently unpredictable as a result of non-linear relationships, feedbacks between emergent patterns and processes and the components that created them, and in many cases constantly changing external drivers or boundary conditions (Ryan et al. 2007, 2010). The unpredictable impact of climate change is an example of changing boundary conditions (Solomon et al. 2009). However, recognising and managing for the potential of multiple meta-stable states in landscapes presents a major challenge. An important part of this challenge is buffering landscapes against the strong interaction pressures of global environmental change, both land use and climate. Another part lies in what is deemed as 'desirable' in terms of landscape components and what functions we wish to maintain or restore (Ryan et al. 2007, 2010). Much more work is necessary to fully incorporate the science of complexity into sustainable landscape management, planning and policy.

Second, landscape sustainability problems are becoming increasingly complicated, even complex, and difficult to predict (see McAlpine et al. 2010 for a typology of landscape sustainability problems). "Complicated" contexts to landscape sustainability problems have no clear cause-effect relationship and high uncertainty with no single right answer. Here, a problem-solving process requires an evaluation of multiple options, each with recognisable economic and social trade-offs. It requires an inter-disciplinary or trans-disciplinary approach where the input from planners and stakeholders is essential.

"Complex" contexts to landscape sustainability problems are synonymous with systems thinking and trans-disciplinary research, and involve problems that are inherently "wicked" with no clear solution or resolution (Brown et al. 2010). They are unpredictable with emergent behaviour, no clear cause-and-effect relationships, no right answers, high uncertainty, and they are riddled with ambiguity, dilemmas and hard choices (Snowden and Boone 2007). Complex problems often result from over exploitation of natural resources and governance failure (Jentoft and Chuenpagdee 2009), but increasingly include novel drivers arising from climate change, and their cumulative impact on landscape pattern and processes. Inherently, decision-making approaches to resolving complex problems are participatory, trans-disciplinary, based on multiple models and support tools, and focused on the governance system.

2.3 Towards an Improved Problem-Solving Framework

We suggest that landscape ecology will be better able to provide the scientific basis for the design and planning of sustainable landscapes by becoming a more applied problem-solving science (sensu McAlpine et al. 2010), which searches for real, integrated solutions to landscape sustainability problems (c.f. Costanza 2009). The framework we propose explicitly draws on the decision and planning sciences and this allows a formal integration of the different problem-solving components (see Fig. 2.1). Earlier problem solving frameworks have been criticised for being: (a) elitist (highly expert orientated with limited public participation and recognition of non-expert knowledge); (b) overly dependent on the capacity of the steering group/technology/facilitator; and (c) politically simplistic in assuming that it is possible to produce an enduring consensus which will be easy to implement (Staes et al. 2008). We believe that the modification of the problem-solving framework by landscape ecologists and planning scientists will facilitate greater disciplinary integration because it requires explicit acknowledgement of the multiple facets of each problem and the involvement of multiple stakeholders.

The framework has seven stages, which are: (1) identify and contextualise the problem; (2) set agreed objectives and management actions; (3) conduct data analysis and integration; (4) understand risks and uncertainties; (5) conduct objective and participatory decision analysis; (6) apply landscape management and planning actions; and (7) implement monitoring and adaptive management programs. While the stages take place sequentially, the implementation process can be iterative, involving modification of early stages (e.g., management objectives) based on feedback from subsequent stages (e.g., data analysis and integration) of the problem-solving process. Furthermore, stakeholder participation via an independent facilitator occurs throughout the process, for the purposes of both legitimacy (stakeholder buy-in) and efficiency (stakeholder knowledge) (Friedmann 1987).

An important component of an applied problem-solving approach is to bring the social and institutional dimensions of the problem to the fore. This is done by

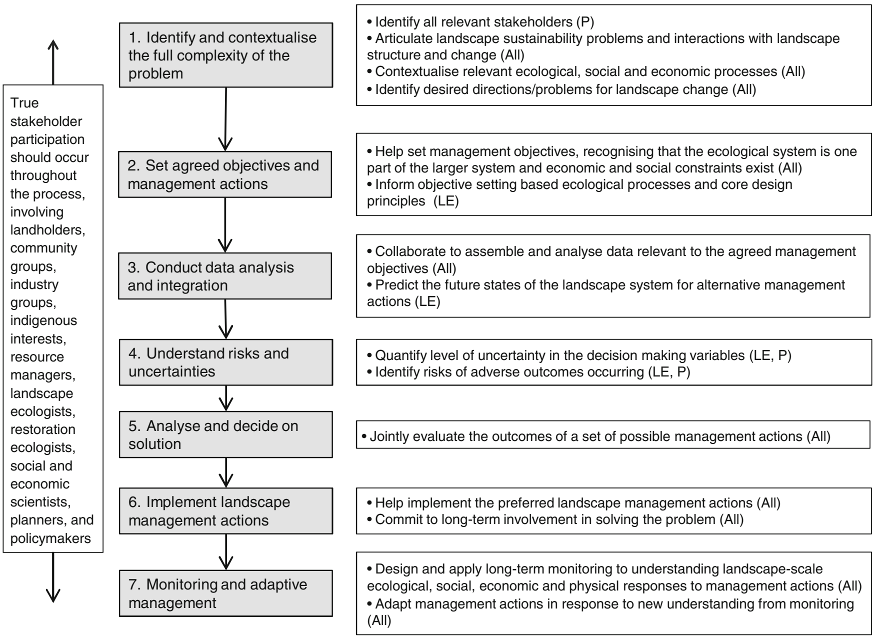

Fig. 2.1 A conceptual framework for strengthening landscape ecology's contribution to a sustainable environment. The framework is divided into seven stages of the problem-solving process. The key contributions of landscape ecologists (*LE*), planners (*P*) and all stakeholders (All) to each stage are highlighted (Modified from McAlpine et al. 2010)

incorporating stakeholder participation and institutional design considerations throughout the analytic process (Morrison 2006). There is evidence that explicitly considering the socio-institutional context compels landscape scientists and managers to think about design and implementation. This evidence comes from collaborative environmental planning and common property resource management, where it has resulted in established principles for considering stakeholder participation and institutional design factors in implementation research (Sabatier 1986; Ostrom 1990; Lane and McDonald 2005; Heikkila et al. 2011; Schmidt and Morrison 2012).

The seven stages of the framework are outlined below.

Stage 1: *Identify and conceptualise the problem*. The first stage is to identify and conceptualise the problem. Precisely defining the problem is often the most difficult but important step in the problem-solving process (Possingham and Nicholson 2007), partly because problem identification is a complex social construct, involving the aspirations of, and constraints on, the various stakeholder groups which, by necessity, brings together the social, economic and ecological sciences (Bartuska 1999). In most cases, the 'problem' will actually comprise a set of related problems, which represent the perspectives and interests of different stakeholders in a given landscape. Stakeholder participation starts at this early stage (Friedmann 1987). The involvement of these different parties during the problem identification process allows recognition of the wider issues (Crosby et al. 2000; Vos et al. 2007). Landscape ecologists can make an important contribution to this stage of the problem-solving process by helping to: (1) articulate landscape sustainability problems and their interactions with landscape structure and change; (2) identify and draft desired directions and visions for landscape change; and (3) anticipate future problems.

Stage 2: *Set agreed objectives and management actions.* The second stage in the problem-solving process is to set agreed landscape sustainability objectives and possible management actions. Objective setting is a transdisciplinary activity where landscape ecologists need to work with social and economic researchers, and stakeholders, to ensure the objectives are quantifiable, able to be prioritised and achievable. This is critical as poorly defined objectives are less likely to result in effective or measurable outcomes (Knight et al. 2006). Objectives need to be set within a medium-long time horizon, normally 15–20 years, with endpoints sufficiently ambitious so as to inspire innovative solutions to sustainability problems (Fischer et al. 2007).

Although this is an area where landscape ecologists have not traditionally had a strong involvement, they in fact have an important supportive role in setting objectives for the sustainable functioning of the ecological system. In working to ensure that objectives are achieved in a cost-effective, timely and socially acceptable manner, landscape ecologists need to recognise that the ecological system, while vital for landscape sustainability, is one part of a larger system that includes social, economic and institutional components. By adopting this approach, landscape ecologists will need to engage with other disciplines and a diverse range of stakeholders in transdisciplinary research.

Stage 3: *Re-conceptualize the problem and conduct data analysis and integration*. The aim of this stage is to re-conceptualise the problem and predict the likely outcomes and uncertainties of the set of possible management actions within the specified time frame in terms of the management objectives. Landscape ecologists are well equipped to make an important contribution to this stage of the problem-solving process by conceptualising processes operating at different scales relevant to the problem, providing landscape-scale data, models and analyses relevant to the specified management objectives and actions. Critical considerations include: (1) what are the relevant system components, processes, dynamics and scales/boundaries of the studied system; (2) what is the current level of understanding of these processes and what data (empirical and expert) and models are available to represent and predict these processes; (3) how can process models be better integrated with socio-economic models; and (4) what is the level of uncertainty of these data and model predictions. These analyses need to go beyond ecological assessments and inventories associated with landscape planning (Golley and Bellot 1999; Steinitz et al. 2003) by providing a more detailed understanding and prediction of landscape processes, functions and dynamics, and by including human activities as components of the landscape.

Landscape ecologists need to work with other discipline areas to design the methodology and assemble and analyse data relevant to these processes. This requires teams of researchers from multiple disciplines and relevant members of the community to be involved in the analysis of the possible socio-economic interactions and constraints among the agreed set of objectives and management actions (Tress et al. 2005a, b, 2007; Fry et al. 2007). This necessitates ongoing dialogue amongst the research team, stakeholder groups and the wider community. However, it needs to be acknowledged here that true socio-economic and ecological data integration may not be possible or necessary (Brown and Pullar 2011).

Stage 4: *Understand risks and uncertainties*. Risks and uncertainties are inherent in landscape sustainability problems and need to be acknowledged and incorporated into any decision making framework. Risk is the chance that an adverse outcome occurs (Burgman et al. 1993), while uncertainty arises from an imperfect understanding of a system (Regan et al. 2002). An important role for landscape ecologists is to integrate the quantification of uncertainty into decision making processes, while acknowledging that definitions of risk and uncertainty vary across stakeholders and experts (Stirling 1998; Wynne 1992).

Landscape ecologists have focussed considerable effort on developing methods for understanding and quantifying risk and uncertainty in landscape patterns and processes (See Sheppard Chap. 7, this volume; also Mooij and DeAngelis 2003; Shao and Wu 2008), but specific links to the implications for decision making and landscape planning are often not made. Consequently, landscape ecologists need to more fully integrate methods for quantifying uncertainty into the problem-solving processes. Much of the expertise for quantitatively dealing with uncertainty in decision making lies in fields of mathematics and the decision sciences (e.g., Stewart 2005; Ben-Haim 2006), and for qualitatively dealing with uncertainty lies in the planning and policy sciences (e.g., Renn et al. 1993; Innes 1996; Smith and Wales 1999). Therefore, this will require considerable collaboration among landscape ecologists and researchers in other fields.

Stage 5: *Decision analysis*. Decision analysis is a process by which the outcome of a set of management actions are evaluated in terms of explicit pre-defined management objectives and constraints (Clemen 1996). Its key strength is that it provides a formal process for bringing together the components described above in a coherent fashion. Decision analysis requires the formal linking of specific management objectives, management actions, system understanding and uncertainty within a coherent framework. Importantly, by formally linking these factors, decision analysis promotes the integration of the different components of a decision problem. Therefore, by embracing decision analysis within a formal problem-solving framework, landscape ecologists are better positioned to move towards a much more integrated science. Specific attention to the governance of the decision process also guards against vested interests, enhances ownership of the problem and ensures the incorporation of a broad range of socio-economic and environmental values (Van Driesche and Lane 2002; Rayner and Howlett 2009).

Stage 6: *Implementing landscape management and planning actions*. This stage of the framework involves implementing the preferred landscape management actions identified and evaluated in the above stages. Traditionally, landscape ecologists have had little involvement with this stage of the problem-solving process. Once the understanding of the information gleaned from the previous stages has been communicated to the stakeholders, the implementation process normally becomes the realm of the non-scientific participants. However, landscape ecologists should contribute to the design of the final plan where parts of the landscape could be viewed as long-term landscape experiments. By engaging in this stage of the problem-solving process, landscape ecologists continue to interact with policy makers, resource managers and the public, thereby helping to ensure the relevance and results of the work (Spies et al. 2002). The longer landscape ecologists can stay involved in the plans during and after their implementation, the more likely it is that the plans will take on a more adaptive form and evolve toward practices that can approach long-term sustainability (McAlpine et al. 2007).

Stage 7: *Monitoring and adaptive management*. This final stage involves the design and implementation of an adaptive management and monitoring protocol (Holling 1978; Walters 1986). Linking monitoring and adaptive management allows plans to be adjusted over time.

The aim of monitoring and adaptive management is to learn about landscape processes by monitoring the consequences of management actions. This then feeds back into future decision-making processes. Long-term and adaptive monitoring is required to understand adequately landscape-scale ecological, social and physical systems and their responses to management actions. Its specific application is context-dependent and will vary with the problem to be resolved (Lindenmayer and Likens 2009). Monitoring programs developed through placed-based collaborative partnerships between scientists, landscape managers and policy makers can help lead to the resolution of important environmental problems, the identification of new problems (Lindenmayer and Likens 2009) and acceptance of inevitable change (e.g., climate change, Spies et al. 2010). Monitoring of management actions must include impacts on social, physical and ecological systems and not just one of these components (Redman et al. 2004).

2.4 Address the Implementation Gap

Despite some successes in areas concerned with sustainability issues, there is a growing appreciation of our inability to tackle major sustainability issues such as biodiversity loss and climate change. The gap between research and implementation is a fundamental problem in all ecological and environmental sciences, and calls for improved integration and implementation are widespread and diverse (e.g., Bammer 2005; Knight et al. 2008). Bammer (2005) identifies three pillars for an evidence-based approach to improving integration and implementation: (a) systems thinking and complexity science, which orient us to looking at the whole and its relationship to the parts of an issue; (b) participatory methods, which recognize that all the stakeholders have a contribution to make in understanding and, often, decision making about an issue; and (c) knowledge management, exchange, and implementation, which includes a better understanding of how decisions are made, and how actions are and can be influenced by scientific evidence.

We argue that landscape ecology also suffers from a lack of effective implementation (see Naveh 2007; Wu 2012). We agree with Nassauer and Opdam (2008) that landscape design can create collaboration between scientists and practitioners and improve the impact of landscape science, and that landscape planning is the appropriate process for implementation. However, while the principles of landscape design are mostly well established (see Lindenmayer and Hobbs 2007), the enactment these principles remain a major challenge (Haila 2007). Hard choices and decisions need to be confronted, as making do with impoverished, low-productivity parts of landscapes will probably doom many landscape designs to failure (Mac Nally 2007). These choices are as much a political and social challenge as they are a scientific challenge. Most dysfunctional landscapes have resulted from poor institutional arrangements and landscape governance, and unsustainable societal values. Ultimately, solutions require reforming governance arrangements at all levels and transforming societal values (Fischer et al. 2012; Swaffield 2012).

There are several core practical approaches where landscape ecology and landscape ecologists can help bridge the implementation gap (see Bammer (2005) for a detailed discussion). One essential approach is through engagement and direct interaction among researchers and stakeholders, including policy makers (van Kerkhoff and Lebel 2006; Gibbons et al. 2008). Knowledge exchange between different research disciplines, planners, land managers and other stakeholders builds trust, establishes lines of communication, and allows the identification of common goals. Clear communication of the beneficial outcomes of landscape sustainability is essential, as the costs of implementing actions are often high and may take many decades before the benefits are realised. For instance, a meta-analysis of restoration projects found that only those which are seen to be of direct benefit to people are likely to be funded and supported in the long run (Aronson et al. 2010). However, active participation in implementation requires the involvement of all stakeholders, including landscape ecologists, which can be difficult and time consuming (Lang et al. 2012).

2.5 Strengthen Links Between Landscape Ecology and Restoration Ecology

The ultimate issue in managing landscape sustainability is to protect what works since it is difficult and expensive to replace or repair (Ehrlich 2007). However, given the current degraded state of many of the world's landscapes, ecosystem restoration is one of the most proactive approaches for reversing degradation and biodiversity loss (Hobbs et al. 2006; Tongway and Ludwig 2010). Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, and is emerging as an important environmental discipline because it can provide potential solutions to real-world landscape sustainability problems. As a discipline, restoration ecology has experienced rapid growth in recent years. It assumes that many degrading stressors are temporary and that it is possible to change a damaged ecosystem to a state that is within an acceptable limit relative to a less-disturbed ecosystem (Young 2000; Palmer et al. 2006; Hobbs et al. 2009). Restoration activities include reinstating historical assemblages of plants and animals, and enhancing ecosystem functions/services such as retaining water, energy, or nutrients (Falk et al. 2006; Tongway and Ludwig 2010).

According to Bell et al. (1997), restoration and landscape ecology have an "unexplored mutualistic relationship that could enhance research and application of both disciplines". A landscape approach recognises that the whole is more than the sum of the parts, and may assist in addressing spatial and temporal prioritisation issues related to practical constraints in restoration actions (Possingham and Nicholson 2007). Restoration can also benefit landscape ecology by providing information derived from restoration ecology projects to test basic questions, especially those linked to landscape structure and function (Bell et al. 1997).

Systematic landscape restoration or landscape reconstruction is designed to reverse the adverse effects of habitat loss, fragmentation and degradation. It is critical for achieving cost-effective environmental outcomes, which balance the many conflicts of interest and competing demands for land with the need to restore landscapes for the protection of biodiversity (Crossman et al. 2007). Landscape reconstruction involves integrating a portfolio of passive and active restoration actions within a spatial framework to achieve landscape synergies between patches often with differing restoration objectives, with the ultimate ecological goal being to restore the structure, function and native biodiversity (both plant and animals) of degraded landscapes (Vesk and Mac Nally 2006). Similar to the problem-solving framework outlined above, systematic landscape restoration involves clearly defining the problem, recognising the complex makeup of landscapes and the socio-economic interests of the inhabitants, and establishing a multi-disciplinary team to work together with stakeholders to find solutions to restoration problems (Crossman et al. 2010). Ultimately, landscape reconstruction is dependent on successful restoration actions at the site-scale. The reconstruction of whole landscapes is a prerequisite for recovering threatened or declining animal populations, but the design may be species-dependent. This requires consideration of context attributes such as remnant landscape patches and riparian areas when deciding where to restore vegetation because proximity to these elements can affect restoration outcomes at the site-scale (Grimbacher and Catterall 2007).

2.6 Key Principles

In summary, if landscape ecology is to strengthen its contribution to the urgent problems hindering landscape sustainability, there are certain key principles that researchers should consider.

1. Recognise that the cause of most sustainability problems are global and national, but the solutions are regional and local.
2. Recognise the complexity of landscapes and landscape sustainability problems, arising as they do from ecological, social, economic, and institutional drivers, and incorporate complexity into the design and restoration process so that landscapes are resistant and robust to future human and environmental disturbances.
3. Protect what currently works since it is difficult and expensive to replace or repair.
4. Set goals that are sufficiently ambitious so as to inspire innovative solutions to sustainability problems.
5. Stay involved in the management plans during and after their implementation, as this increases the likelihood that the plans will take on a more adaptive form and evolve toward practices that can approach long-term sustainability.
6. Recognize and encourage the active participation of all the stakeholders in understanding and decision making to develop solutions to landscape sustainability problems.
7. Actively engage in systematic landscape restoration/reconstruction to reverse the adverse effects of habitat loss, fragmentation and degradation.

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