

Changing landscapes to accommodate for climate change impacts: a call for landscape ecology

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Abstract Predictions of climate change suggest major changes in temperature, rainfall as well as in frequency and timing of extreme weather, all in varying degrees and patterns around the world. Although the details of these patterns changes are still uncertain, we can be sure of profound effects on ecological processes in and functioning of landscapes. The impact of climate change will affect all types of land use, ecosystem services, as well as the behavior of humans. The core business of Landscape Ecology is the interaction of landscape patterns and processes. Most of these interactions will be affected by changing climate patterns, so clearly within the focus of our science. Nevertheless, climate change received little attention from landscape ecologists. Are we missing the boat? Why is it that our science

does not contribute to building a knowledge base to help solving this immense problem? Why is there so little attention paid to adaptation of landscape to climate change? With this editorial article IALE would like to receive inputs from the Landscape Ecology scientific community in related research on adaptation of landscapes to climate change, on tools or approaches to help landscape planners and stakeholders to this new challenge where landscape ecology can play a key role.

Keywords Climate change · Research challenges · Landscape patterns · Climate adaptation

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Climate change research calls for landscape ecology

Science has played an important role in putting climate change on the world agenda. Well known is the work by the IPCC, the United Nations' Intergovernmental Panel on Climate Change—a successful science-policy network with a major impact on the political debate (IPCC 2007). Another landmark is the Stern Review (Stern 2007), focusing on the economic aspects of the effects of climate change and the costs and benefits of developing timely solutions. These key publications for a wide audience are supported by numerous studies in many domains of

science, which can be categorized into five focal topics: (1) monitoring climate change patterns, reconstructing historic climate change, including predictions of future climate patterns; (2) computing direct and indirect effects of climate change on the distribution of ecosystems, landscapes, species and their interactions; (3) effects on the socio-economic and political systems; (4) strategies and measures to slow down or stop the increase of greenhouse gasses, including mitigation by land use change; and (5) adaptation of land use patterns to diminish the impacts of climate change and improve opportunities for natural and social-economic systems to respond.

In the ecology domain, an increasing list of documented climate-associated changes in ecosystems and populations is being reported (an early example is Lovejoy and Hannah 2005), showing potentially significant impacts on ecological processes that support basic life support systems. With the growing international awareness of the loss of biodiversity and its importance for maintaining 'healthy' ecosystems to preserve life (see the Millennium Ecosystem Assessment 2005), it is not surprising that such reports have caused a growing international awareness about the potential of ecological systems to respond to climate change. The European Union and IPCC agreed upon a maximum temperature rise by 2°C (3.6 F) above pre-industrial level (European Union 2007). This level is suggested to be the maximum rate of climate change in which humanity can still prevent unmanageable damage and ecological systems can still adapt. However, recent estimations of temperature rise tend to exceed that supposedly critical limit. It is evident that although preventing further growing of the concentration of greenhouse gasses remains of prime importance, this strategy will not prevent climate change and its effects on our landscapes.

Thus, we have to recognize and accept that the world's climate is already changing and will continue to do so for decades. Considering the resulting impacts on land use and biota (Barker et al. 2007; Stern 2007), the option of adapting land use and landscapes to mitigate undesired implications by climate change is now appearing on the political and research agendas. Adapting landscape systems to climate change is an emerging topic in science. A small search in *Google scholar*, including both papers in refereed journals and grey literature, showed a

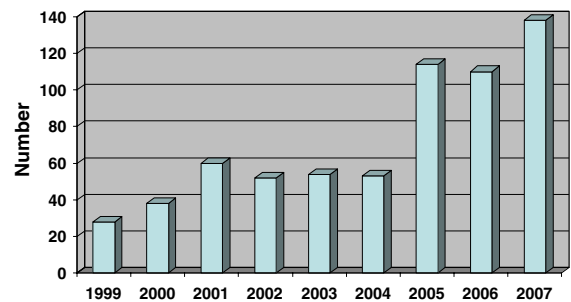


Fig. 1 Number of publications on adaptation to climate change with reference to land use or landscape (Google scholar search 23-08-2008; $N = 771$)

distinct increase in the number of papers addressing adaptation (Fig. 1). In 2007, the European Union (EU) discussed “green” approaches for climate adaptation, considering a wide variety of sectors including agriculture, water management and biodiversity conservation. The EU has now published a “white paper” on how it will focus its climate change adaptation policy (Commission of the European Communities 2009). The emphasis is on mainstreaming adaptation measures into EU policies: agriculture, forestry, health, biodiversity, ecosystems and water, coastal and marine areas and production systems and technical infrastructure. In terms of knowledge building, this calls for integrative approaches, crossing economic, social and environmental borderlines. The EU puts developing the science base as one of four pillars of action of the adaptation policy. It shows that science is called to play a role in identifying solutions and ways to implement these in complex multifunctional landscape change (Rounsevell et al. 2006; Metzger et al. 2008).

Is science ready for this? Our view is that for science to get itself well-equipped for this major task, it has to evolve its emphasis from a reductionist, analytical approach aimed at identifying impacts, to a synthetic, design oriented approach aimed at generating solutions (Meinke et al. 2006). A recent review by Heller and Zavaleta (2009) showed that ecological studies usually provided general narrowly scoped recommendations, which are difficult to implement into planning and management. To improve this, science faces three major methodological problems. The first one is that the majority of publications considering the interaction between climate change and land use, ecosystems or biodiversity analyse the

impacts of a changing climate rather than adaptation (Heller and Zavaleta 2009). For example, changes in geographical species distributions are correlated with changes in climatic factors (Parmesan and Yohe 2003). This provides important proof for climate change effects, and sometimes evidence for the extent and urgency of the problem (Thomas et al. 2006). But the sort of information is not what science for adaptation demands. Most effect studies aim at finding significant correlations between a cause and an effect, while eliminating as many confounding factors as possible; it is the scientific proof these studies search for. On the other hand, in exploring land use design alternatives that might be acceptable and effective at the local level, the relation between cause and effect should be interpretable in the reversed direction: “what can be done to eliminate the effect?” For this purpose the causal and confounding factors might be equally interesting: if the causal factors related to climate can not be ameliorated, other factors influencing the relationship may be can. For example, temperature rise affects biodiversity, but the effect gets stronger with increasing habitat fragmentation. Thus, while temperature rise can’t be changed within several decades, improving the spatial cohesion of habitat networks offers better opportunities, especially for ecosystems that can develop relatively quickly (Opdam and Wascher 2004).

The second problem is that impact studies often lack an explicit consideration of the role of spatial patterns in the observed process. Some of the most obvious landscape related omissions from the Millennium Assessment scenarios (Millennium Ecosystem Assessment 2005) are pattern-process feedbacks, scale dependencies, and the role of landscape configuration. Other examples can be found in the recent flow of studies based on statistical correlations between species distribution patterns and climate factors (an analytical technique called “climate envelopes”). By this technique it is possible to predict shifting distribution patterns (e.g., Harrison et al. 2006). However, whether or not the potential spatial response of species will take place, very much depends on the interaction between the rate of temperature increase, the life history traits of species (for example growth rate and dispersal capacity) and the spatial cohesion of habitat patterns at the regional and European-wide scale. So the combination of

climate envelope analysis and ecosystem network approaches (Vos et al. 2008) and land use scenarios (Pompe et al. 2008) may reveal where in the European landscape spatial changes in land use or spatial cohesion of habitat networks might provide a solutions to loss of biodiversity due to temperature rise. The challenge is to translate these threats to biodiversity into tangible and quantifiable factors which can be used by policymakers if they want to promote the development of flexible and effective conservation strategies (Harrison 2008). Because adaptation is about changing spatial features of land, only studies incorporating the role of spatial patterns of ecosystems are meaningful for developing adaptation measures.

The third problem is that most effect studies are narrow in scope and dominated by ecological views (Heller and Zavaleta 2009). Ecological and economic studies are often carried out separately (Carpenter et al. 2006). For example, landscape ecological research is mainly concerned with pattern/process relationships and few studies address values, whereas in ecological economics, the relationship between the functions that produce values and the physical world is often neglected (Termorshuizen and Opdam 2009). Thus, landscape ecology and ecological economic studies can not be “summed up” to generate solutions for adapting landscapes in response to evolving human needs. Research integrating ecology and economics to evaluate and design biodiversity management strategies is scarce, but increasing (e.g., Ando et al. 1998; Polasky et al. 2001, 2005; Nalle et al. 2004). Their focus is often rather narrow, for example on maintaining the maximum number of species on a given land area or the minimum land area with a given number of species (Ando et al. 1998; Polasky et al. 2001).

Why is landscape ecology in a strategic position to organize adjacent science domains around a focus on developing cost/effective, integrated adaptation strategies? The core business of Landscape Ecology is to understand the interactions between landscape patterns and processes, and how these relationships are manifested across spatial and temporal scales. Most of these interactions will be affected by changing climate patterns. Landscape ecology offers the potential to study and understand the scaling functions and the importance of pattern in maintaining a wide range of ecosystem services in the face of

climate change. Ecosystem service management, policy and governance involve many different scales, even when we consider a single service. Equally, the different states (habitats, species, human behaviour and their interrelations) also involve a wide range of scales. As landscape ecologists we can actually provide the spatial context to bridge differences between economists and ecologists. Spatial scale is not something that economics deals with particularly well, but actually the spatial representation and modelling based-approach from a landscape ecology perspective may allow a common understanding to achieve applied results in relation to services and conservation costs as an example, bridging different scales and approaches (see e.g., Kallio et al. 2008; Martin-Lopez et al. 2008).

Yet, thus far, climate change has received little attention from landscape ecologists. The 2007 IALE World Congress in Wageningen brought two symposia on stage, one about the effects on wetland systems, the other dealing with effects on species in fragmented ecosystems (which included a few papers on adaptation strategies). Only four papers with climate change in the title were published in *Landscape Ecology* (1991, 1993, 2004, 2007), and only two in *Landscape and Urban Planning* (2007, 2008), suggesting that the recent increase in attention has not touched landscape ecology research.

In the following section, we offer a conceptual basis for developing a research agenda that we believe brings landscape ecology into the heart of climate change research. Our aim is to define the key role of landscape ecology in developing a solid science base for adaptation of landscapes.

A framework for building the landscape ecology science base

At the heart of our task as a science is the understanding of how prediction of climate change impacts on landscape functioning can be linked to design options for climate proof landscapes (Fig. 2). Important differences between the two are that the predictions are done at large scale levels and are mainly a scientific activity, while the design activities are only relevant at the local level and do involve both scientists and local actors (Nassauer and Opdam 2008). The predictions are typically about impacts on

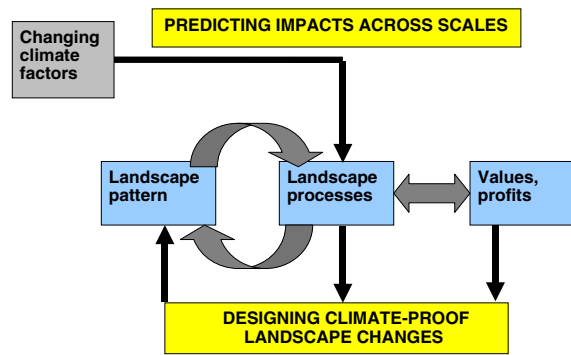


Fig. 2 Conceptual framework showing the relationship between climate change impact assessment on landscapes and design based research generating plans for adapting landscapes. While impact assessment provides insight into impacts on landscape functioning, to get relevant to adaptation change of function need to be translated into change of value. If it is known how the change of functioning can be mitigated by adapting the pattern of ecosystems or land use in the area, an adaptation plan may be designed to find which adaptation option suits best in the local context

landscape processes, for example metapopulation demographics or land use functions. But because adapting landscapes is about changing the physical features of the landscape, for example crop patterns or the pattern of green infrastructure, knowledge about the process pattern relationship is indispensable. Thus, we arrive at the core business of landscape ecology.

Furthermore, climate induced adaptation assumes that something can be changed and that the change is effective. Any opportunity for ameliorating landscape patterns is very much dependent on the perceptions of many human actors and organizations and the availability of enough money. So to get adaptation projects accepted and running requires a feel of urgency among stakeholders. This means that any predicted change of a landscape process due to climate changes need to be transferred into what it means to humans; this is all about values, profits and safety. The predicted loss of value should legitimate the landscape change. Also, it implies that the required change in the process (which caused the loss of value) is mitigated or prevented by reshaping the landscape pattern or the land use. For example, if climate change causes more frequent storm water flooding, and this is perceived as a safety and economic problem, than the physical features of the landscape can be adapted to accommodate the

landscape service “water storage capacity”. We offer Fig. 2 as a framework for developing a research agenda.

From the framework it can be inferred that for predictive impact studies to serve as a basis for landscape adaptation, a relationship to landscape pattern is required. This implies that the usual scientific method of eliminating confounding factors is not the most useful approach. It also means that studies should attempt to link impacts with valuation (Termorshuizen and Opdam 2009). We suggest that to make impact studies relevant, they should meet with at least the following requirements: (1) using politically accepted indicators (to make the analysis relevant and legitimate to decision makers), (2) being explicit in what will happen where, and (3) expressing effects in terms of ecosystem and landscape services (i.e., in terms of loss of economic, ecological or social value).

The second message is that, for adaptation to be relevant and legitimate, the design approach need to be based on the relationship between value, function and physical pattern of the landscape. It means for example that the design is effective if it results in repairing or preventing loss of value. Also, the landscape change should be acceptable to local stakeholders and politicians. It contributes to acceptance if the solution was collaboratively chosen from a range of alternatives in search for maximum synergy between landscape functions and for balanced consequences for social, ecological and economic values.

A suit of research priorities follow from this. Firstly, it is urgent to increase the knowledge and awareness of the goods and services provided by landscapes, and the importance of conserving them for maintaining our own quality of life. The central knowledge chain depicted in Fig. 2, which encompasses the relationship between the physical landscape and the landscape services it sustains, needs quantification in a collaborative attempt in which landscape ecologists merge their knowledge with environmental economics (Dale and Polasky 2007; Termorshuizen and Opdam 2009). It will always be a combination of land-use and land cover changes that will facilitate adaptation of species and important ecosystem functions to climate change. Modifications of ecosystems to enhance one service may come at a cost to other services due to trade-offs, but synergy

between landscape services can also be achieved. Relationships between different services, at all parts of the chain, should be addressed. This requires a collaborative effort of social, economic and environmental sciences. The core competence of landscape ecology is at the heart of this collaboration.

Secondly, there is the issue of scale (Adger et al. 2005). While predictions are often expressed at large spatial scales, scaling down to the local level might be necessary to give the impact urgency and significance to local level actors. Reversely, adapting the landscape at the local level is only a small contribution to solving the large-scaled problem; its efficiency depends on what is done elsewhere. For example, adapting the European landscape for improving the spatial coherence of ecosystem networks (Vos et al. 2008) requires a European wide coordination and calls for a top-down spatial planning policy. However, the European Union has no spatial planning policy, and in fact the countries of the European Union differ considerably in the development of their spatial planning policy. Where it exists, it may be organized either at the national level or at the regional level. Hence, the challenge to science is to find a variety of strategies and incentives to account for the variation in planning policies. This requires not only technical landscape ecology knowledge, but also knowledge from social and economic disciplines. Landscape ecology can offer its competence to integrate such knowledge and express its implications in a spatially explicit way across spatial scales.

Thirdly, there is a demand for integrated impact predictions which includes human activities and is built on the relationships between landscape patterns and landscape services. Since changes in the quantity or quality of various types of natural resources and ecosystem services have large impact on human welfare and competitiveness of an economy, comprehensive methods to measure and value biodiversity and ecosystem services are needed to mitigate global change. There is also a need to incorporate temporal dynamics, particularly in relation to responses which often bring in time lags. The time scale of relevance to policy-makers tends to be short whilst ecosystem responses are much longer. It is difficult then to generalise which scale is the most important and this needs to be defined for each situation. While the MA has set a new standard for biodiversity scenarios, future exercises would benefit

from a more multi-scale and more mechanistic framework. An integrative landscape driven research should be envisioned to relate ecosystem processes, global changes including climate changes and socio-economic processes across different governance levels. In the same way, different levels in terms of governance and conflict resolution needs to be considered to adapt to increasing drivers of change within a global perspective.

Finally, adaptation requires far better competencies of transferring science knowledge to landscape planning and design than landscape ecologists have developed thus far. Most of the adaptation will be the domain of local land owners and managers, who eventually will have to implement the adaptation measures on the ground. If the loss of value is in the interest of the public rather than in the interest of their own property, they will not be inclined to take action as long as there is no direct or indirect financial incentive. Landscape ecology could work together with social sciences and economics to provide adaptive management strategies based on shared responsibilities of and owners and users of landscape services. Land managers could be provided with information tools showing what investments could provide which landscape services. Collaborative design tools are required to design landscape patterns that mitigate climate change impacts, while maintaining economically profitable land use opportunities. Such tools also should inform on what level of spatial scale this adaptation measure can be effective: can they just do it by managing the land within their jurisdiction, or are they dependent on changes at broader scales and do they need to collaborate with other land managers around?

In conclusion, adapting landscapes to climate change is organized around the process-pattern relationship across a range of spatial scales. This is the core competence of landscape ecology. However, to make this competence relevant for landscape adaptation, climate change impacts studies need the contribution of landscape ecologists in bringing in the role of landscape pattern. For effective design of climate proof landscapes, landscape ecology needs to develop its expertise and tools as a science base for collaborative design. One of the most important challenges for future research will be to integrate research across different scales, including spatio-temporal scales within an interdisciplinary and

multidisciplinary framework. If we manage to follow this route, science will be able to move from analytical to actionable climate knowledge (quoting Meinke et al. 2006).

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