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"Rio+10", sustainability science and Landscape Ecology☆

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Abstract

The 'sustainability debate' has had a profound influence on contemporary Landscape Ecology. This paper explores the implications of the second global summit for the research agendas that developed after the Rio Summit (1992), and argues that although the Declaration from Johannesburg 2002 restates the earlier summit concerns, the messages it sends to the research community are subtly different to those a decade earlier. The growing body of literature, which identifies the need for a new kind of sustainability science, is reviewed, and its relevance to Landscape Ecology is discussed. Although recent commentators have argued for a more transdisciplinary approach to Landscape Ecology that appears to meet the requirements of this new science we still lack ways of taking this forward. The paper concludes by proposing a new paradigm for Landscape Ecology based on the concept of ecosystem goods and services, or natural capital. It is argued that in the decade since the Rio Summit, a key focus of the future research agenda for the discipline should be an exploration of the 'sustainability choice space' defined by the interaction of biophysical limits and social and economic values at the landscape-scale. The paper provides a conceptual model (the tongue model) that describes how biophysical and socio-economic constraints can be combined in sustainability planning.

Keywords: Sustainability science; Landscape Ecology; Rio+10; Transdisciplinarity; Biophysical limits; Social and economic values; Sustainable landscape

1. Introduction

The outcomes of the 1992 Earth Summit in Rio de Janeiro had a profound influence on the development of Landscape Ecology. References to Rio and Agenda 21 are often used as context for research within the discipline. The development of concepts and tools for sustainable landscape planning and the conservation of biodiversity are now important focal points for research activity (Vos and Meekes, 1999; Council of Europe, 2000; Haines-Young, 2000; Tait and Morris, 2000; Wascher, 2000; Saunders and Briggs, 2002; Von Haaren, 2002; Haines-Young and Potschin, 2004; Antrop, 2006; Blaschke, 2006). There is also widespread recognition that approaches in Landscape Ecology must find ways of solving problems that take account of the visions of different stakeholder

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groups (Luz, 2000; Buchecker et al., 2003; Fish et al., 2003).

Given the importance of the Rio meeting and its outcomes, it is therefore likely that the Johannesburg Earth Summit in 2002 should have an equally significant influence on the future development of Landscape Ecology. The aim of this paper is to review the place of Landscape Ecology within the sustainability debate, and to explore the question of whether research agendas need to be revised as a result of the Johannesburg Summit. The paper concludes by suggesting, as a focus for discussion within the discipline, a conceptual model for Landscape Ecology that captures the new scientific, social and economic contexts in which the discipline is, and will increasingly be, practised.

2. Johannesburg 2002: science and the civil society

Part of the difficulty we face in coming to terms with the outcomes from the Johannesburg Summit is that the messages contained in the declaration are apparently all too familiar. One view of the decade after the Rio summit ('Rio+10') is that it simply reaffirmed sustainable development as a central element of the international environmental agenda. A closer reading of the Johannesburg Declaration (see United Nations Department of Economic and Social Affairs, 2002) suggests, however, that the debates surrounding the environment and the sustainability concept are changing and it thus may have a profound influence on disciplines such as Landscape Ecology.

A key focus of the Rio Summit was the protection of the environment and the search for 'appropriate' forms of social and economic development (United Nations, 1992). Social and economic sustainability were seen as the prerequisites for environmental sustainability. By contrast, the Johannesburg Summit sought to broaden and strengthen the concept of 'sustainable development'. Implicit in the Declaration is the proposition that social and economic sustainability are legitimate and essential goals in their own right. The task, according to the Johannesburg Declaration is to deliver a 'civil society'. That is one which promotes human dignity by the elimination of poverty, and which emphasises the importance of 'partnership' and 'solidarity'.

By asserting that "sustainable development requires a long-term perspective, and broad-based participation in policy formulation, decision making and implementation at all levels" (Johannesburg Declaration on Sustainable Development, 2002, p. 3, para 26), the Declaration is, it seems, as much about governance issues as it is about environmental problems. Thus, while the Rio Summit was important for Landscape Ecology because it shaped and legitimised what kinds of science we did after the Summit, the significance of the Johannesburg Summit, is that it challenges us to think through how that science is undertaken in a 'civil society'.

The issue of the relationships between science and society is a significant one, for as Gallopín et al. (2001) note, there is increasing concern that "science is not responding adequately to the challenges of our times, and particularly, those posed by the quest for sustainable development". To overcome this problem these and other commentators have argued for the development of what they called "sustainability science" (for example, see Kates et al., 2000, 2001). Such ideas are likely to become more significant as we work on the post-Johannesburg Summit research agenda. In the remaining parts of this paper we will, therefore, explore some of the implications of this emerging paradigm for the future of Landscape Ecology.

3. Sustainability science and Landscape Ecology

It is important to review the discussions about the character and methods of sustainability science because the ideas can help us to reflect critically both on the different traditions in Landscape Ecology, and the different approaches to environmental problem solving in Geography and Ecology more generally. For quite apart from the debates about sustainability science, a number of other authors have recently challenged the direction and relevance of much current work in the natural sciences, of which Landscape Ecology, Geography and Ecology are part (Kates et al., 2001).

In their discussion of ideas surrounding the concept of sustainability science, Kates et al. (2001) suggest that during the late 1980s and early 1990s, the science and technology communities became "increasingly estranged from the societal and political processes that were shaping the sustainability agenda". Gallopín et al. (2001) argue more forcefully that as a result, a new 'social contract' for science is necessary to deal with the situation we face at the start of the new century. They develop their arguments by reference to the 'analytical' and 'integrative' streams of science within ecology (cf. Holling, 1998).

It is claimed that the narrow focus of the analytic stream, which is represented by the traditional view of Ecology as an experimental science, is one that enables practitioners to "pose hypotheses, collect data and design critical tests to reject invalid hypotheses" (Gallopín et al., 2001, p. 221). Although such traditions have been successful in tackling a particular class of problems that are relatively well defined and stable, it is suggested that they are not really appropriate for dealing with the more 'messy' situations and issues that arise out of problems of organised complexity. When faced with systems that evolve or change as we study them, both as the result of our own management action and the expansion of human impact, Gallopín et al. (2001) argue that more integrative approaches to science are appropriate. It is claimed that within this framework, problem solving is more broad and exploratory, involving the evaluation of multiple, competing hypotheses across different scales. Such a framework, it is argued, is more appropriate when dealing with the type of policy-related research that arises in the context of sustainability. For Gallopín et al. (2001) and Kates et al. (2001) it provides the basis of what is known as sustainability science.

Sustainability science is characterised by a number of important features that marks it out as different from traditional approaches to the natural sciences (see Table 1). On the one hand commentators suggest that it helps to avoid the compartmentalised thinking that they claim characterises the traditional 'analytical' tradition. On the other they argue that it is 'integrative' and able to confront a situation in which knowledge is both incomplete and not exclusive to any one interest group. The juxtaposition of the terms 'analytical' and 'integrative' in Holling's (1998) schema is perhaps unfortunate, because integrative studies can be analytical. However, setting terminology aside, Table 1 is useful in highlighting many of the tensions evident in the contemporary research environment.

The term sustainability science is a relatively new one, but the thinking that lies behind it has been developing for some time. For example, in his *Citizen Science*: *A Study of People, Expertise and Sustainable Development*. Irwin (1995) explored the role of 'public science', that is science conducted outside formal scientific institutions. His analysis focuses on the relationship of this 'formal science', which often claims to be universal, and the less-systematic

Table 1
The two cultures of biological ecology (after Holling, 1998)

Attribute	Analytical	Integrative
Philosophy	Narrow and targeted Disproof by experiment Parsimony the rule	Broad and exploratory Multiple lines of converging evidence Requisite simplicity the goal
Perceived organisation	Biotic interactions Fixed environment Single scale	Biophysical interactions Self-organisation Multiple scales with cross scale interactions
Causation	Single and separable	Multiple and only partially separable
Hypotheses	Single hypotheses and nulls Rejection of false hypotheses	Multiple, competing hypotheses Separation among competing hypotheses
Uncertainty	Eliminate uncertainty	Incorporate uncertainty
Statistics	Standard statistics Experimental Concern with Type I error	Non-standard statistics Concern with type ii error
Evaluation goal	Peer assessment to reach ultimate unanimous agreement	Peer assessment, judgment to reach a partial consensus
The danger	Exactly right answer for the wrong question	Exactly right question but useless answer

and 'local knowledge' possessed and developed by 'citizen groups' (Irwin, 1995, p. xi). He stresses the importance of citizen science in the context of more effectively pursuing the goals of sustainable development. Such an imperative for the 'sustainability transition' has also been stressed by O'Riordan (1998, 2000), in his related account of 'civic science'. The notions of 'citizen' and 'civic' science entail not just the promotion of the better public understanding of science, but rather the involvement of the public in decision-making and legitimisation of lay knowledge alongside that of the expert in decision making processes.

For O'Riordan (1998), the idea of civic science involves two interconnected issues. On the one hand, there is the belief that there is no science outside culture. On the other is a need for empowerment "... through direct and constructive involvement" (O'Riordan, 1998). Civic Science, he claims, is 'deliberative', 'inclusive', 'participatory', 'revelatory' (sic) and designed "to minimise losers" (O'Riordan, 2000, p. 9). Like Irwin (1995), O'Riordan (2000) argues that such a movement is necessary, given problems of uncertainty in institutional and public decision making, and the fact that scientists operate within some set of underlying social assumptions and models. Similar arguments have been made by Chambers (1998), in his discussion of a 'new paradigm for professionals in sustainable development'.

At the time of his writing O'Riordan (1998) suggested civic science, as he conceived it, was not well developed, but a review of the literature suggests that these themes are being explored (for example, see Bell and Evans, 1997; Burgess et al., 1998; Irwin, 2001). Despite O'Riordan's claims, it is also clear that there has been a long discussion of the need for public involvement in environmental decision-making (for example, see review by McDaniels et al., 1999), and the theme is now frequently part of corporate policy. In the UK, for example, we see the ideas expressed in policy documents by Central Government (e.g. Department of the Environment, Transport and the Regions, 2000). In Germany, it is incorporated in the law related to Environmental Impact Assessment or in general in the approach to Local Agenda 21. At the global-scale, we also find the ideas embodied in the 1999 UNESCO Declaration on Science and the Use of Scientific Knowledge (UNESCO, 2002).

Although commentators often do not make explicit reference to the debates surrounding the relationships between science, society and sustainability, we can see many of these themes are also being explored in the wider scientific literature. Thus, Ormerod et al. (2002) recently reviewed the uptake of applied Ecology and concluded that while there is evidence that ecological science is aiding environmental management and policy 'across a wide range of regions, ecosystems and types of organisms', there are also barriers to further progress. These include the difficulties of dealing with large-scale perspectives, as well as the perceived importance of issues, and institutional and public receptiveness. They suggest that for the future scientists must pay much closer attention to the views and needs of the user community than they have done in the past.

The call by Ormerod et al. (2002) for better communication between researchers and end-users is hardly revolutionary (for example, see Tress et al., 2002). Other commentators, such as Kinzig (2001) and O'Neill (2001), have gone much further in suggesting new models of Ecology that are more fit for the future. Kinzig (2001) considers the need to bridge disciplinary divides in order to meet current environmental challenges, and argues that science must not only be more 'policy driven' but also engage in 'truly integrated and interdisciplinary research'. She suggests:

> The final hurdle each of us will have to clear... – [in] studying human–environment interaction – is to understand and question where we think "nature" leaves off and society begins (Kinzig, 2001, p.715).

In exploring a similar theme, O'Neill (2001) asks us to question the appropriateness of the ecosystem concept itself, when dealing with highly non-equilibrium situations produced, for example, through human disturbance. Although he concludes that the concept is still valuable and should be retained, he suggests that we need to develop more spatially explicit or landscape orientated approaches for future work.

It is not appropriate here to review the wider debate about the changing relationships between science and society that are implied by the sustainability concept. For the purposes of this paper we must consider the implications for Landscape Ecology in particular and its relationships to disciplines such as Geography and

Ecology. These issues are not, however, of local significance, since geographers for a long time and also landscape ecologists often claim that their field of research is a holistic one, spanning the social and natural divide (Bartels, 1968; Neef, 1969; Leser, 1976; Weichhart, 1975), and that the discipline can help us confront many of the key problems relevant to the sustainability debate (Antrop and van Eetvelde, 2000; Haines-Young, 2000; Moss, 2000; Palang et al., 2000; Bastian, 2001; Tress and Tress, 2002).

The relevance of landscape ecological thinking to the concerns of sustainability science are perhaps best explored by reference to the core questions suggested as being at the centre of the new science by Kates et al. (2001, p. 641), namely:

1. How can the dynamic interactions between nature and society – including lags and inertia – be better incorporated into emerging models and conceptualisations that integrate the Earth System, human development, and sustainability?
2. How are long-term trends in environment and development, including consumption and population, reshaping nature–society interactions in ways relevant to sustainability?
3. What determines the vulnerability or resilience of the nature–society system in particular kinds of places and for particular types of ecosystems and human livelihoods?
4. Can scientifically meaningful "limits" or "boundaries" be defined that would provide effective warning of conditions beyond which the nature–society systems incur a significantly increased risk of serious degradation?
5. What systems of incentive structure – including markets, rules, norms and scientific information – can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?
6. How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?
7. How can today's relatively independent activities of research planning, monitoring, assessment and decision support be better integrated into systems for adaptive management and societal learning?'

Each of these questions should have a particular resonance for Landscape Ecology because it is clear that for most of them an understanding of the configuration of landscapes and how landscape patterns and processes interact at local, regional and global-scales is likely to be fundamental in their resolution. Indeed it could be argued that Landscape Ecology is not merely relevant to their solution but fundamental, for as Wascher (2000) has emphasised:

> Like hardly any other discipline, the landscape approach offers holistic assessment and planning tools to define and develop the interface between nature and culture. Hence, landscape, as the place of human interaction with nature appears to be at the heart of sustainability (Wascher, 2000, p. 7).

But is Landscape Ecology presently equipped to meet this challenge? Unfortunately, it is not entirely clear that it is.

Bastian (2001), for example, argues that Landscape Ecology is not a unified discipline, and, following Moss (1999), suggests that it needs both a better focus and a profile. The lack of focus reflects the different traditions in Landscape Ecology and the lack of cooperation between those involved in the pure and applied aspects of research (cf. Ahern, 1999; Potschin, 2002). For the future, Bastian (2001) proposes that we need to transform the natural science concepts, which have been at the heart of much landscape ecological work, to make them relevant in the context of human society. The solution, he argues, lies in the development of more transdisciplinary approaches to the solution of landscape evaluation and the elaboration of different visions of landscape development.

Fry (2001) and Tress and Tress (2002) have considered the issues surrounding the need for a transdisciplinary approach to Landscape Ecology and the latter suggest that it provides a foundation for a post-modern landscape science, in which there is a more fruitful engagement between science and society. Unfortunately, it is not clear from such work how we can operationalise these ideas, given the analytical tools and concepts available to landscape ecologists. Indeed Fry (2001) notes the considerable institutional and conceptual barriers to such a development. One solution is, however, offered by Opdam et al. (2002) who also consider the gap between science and society in terms of

Landscape Ecology on the one hand and spatial planning on the other.

Opdam et al. (2002) agree with Moss (2000) that the justification of Landscape Ecology as a science requires that the gap between process studies and planning must be bridged. They argue that the gap can be filled by developing: (1) empirical case studies of different scale, organisms and processes; (2) modelling studies that extrapolate these empirical studies across space and time; (3) guidelines and standards for landscape conditions; (4) methods for integration at the landscape level, which can be built into multidisciplinary tools for design and evaluation. Elements (1) and (2), they suggest, are already well represented in the ecological literature, and it is in the pursuit of (3) and (4) where the main challenges are to be found.

Opdam et al. (2002) argue that as a consequence of current deficiencies in our knowledge, there is a need to develop alternative solutions in the planning cycle, given the complexity of real landscapes and real world communities, and that overall a new approach to the theory and practice of Landscape Ecology is required. Although Bastian (2001) is sceptical about the possibilities of achieving what is required in planning landscape development, it seems clear that we must endeavour to develop a landscape discipline that is closer to the centre of the triangle used to describe the pillars of sustainability. In this context, recent commentators from the Landscape Ecology research community are in tune with the change in emphasis detectable between the declarations between the Rio and Johannesburg Summits, in which more equal weight is given to environment, social and political sustainability than before. However, it is not clear how this can be achieved or whether it is possible, since it requires a reorientation of the current paradigm, which is strongly focused on the biophysical elements of landscape. It would seem, for example, to involve a move away from the more purely ecological approaches to Landscape Ecology, approaches grounded on the study of cultural landscapes, in which the role of people in shaping and understanding patterns and processes is a more central concern of the discipline. Moreover, it would seem that while the study of natural landscapes can give us many insights, consideration of the 'everyday' human constructed landscapes in which most of us live and work is also an important focus of activity (cf. Council of Europe, 2000). A model outlining how this might be done is described below.

4. Landscapes and sustainability: a conceptual model

The case for an alternative paradigm for Landscape Ecology, based on the concept of ecosystem goods and services, or natural capital, has been suggested as one way of meeting the challenges that face the discipline in the context of the sustainability debate (Haines-Young, 2000). The paradigm argues for a shift away from an ecological focus for the discipline to a more anthropocentric one, in which landscapes and the ecosystems associated with them are viewed as a resource that provides a range of goods and services for people (for discussion of the concept of natural capital and ecosystem goods and services see, for example, Costanza and Daly, 1992; De Groot et al., 2002; De Groot, 2006). A sustainable landscape is one in which the output of these goods and services is maintained, and the capacity of those systems to deliver benefits for future generations is not undermined, where benefits are assessed in both monetary and non-monetary terms.

The outlines of the natural capital paradigm can be illustrated by reference to Fig. 1, which seeks to identify how we can take account of the evolutionary nature of multifunctional landscapes and need to keep future options 'open'. The model also seeks to counter claims that Landscape Ecology should seek to identify 'optimal' configurations of landscape that deliver sustainability (cf. Forman, 1995; Wu and Hobbs, 2002). Thus, the model proposes that while landscape structure and function are important in the real world a range of alternative configurations can more or less sustain the range of ecosystem goods and services currently identified and valued by people as essential or desirable. This set of alternative configurations defines the grey "tongue" shape, which gives the model its nickname, the tongue model.

The axes of Fig. 1 are 'time' and some measure of the 'state' of a landscape mosaic. One way of thinking about Fig. 1 is that it is a window in a multidimensional space used to represent the state or structure of a landscape in terms of the proportions of the different cover elements or ecosystems present. However, there is, as we shall see, no reason to confine our attention

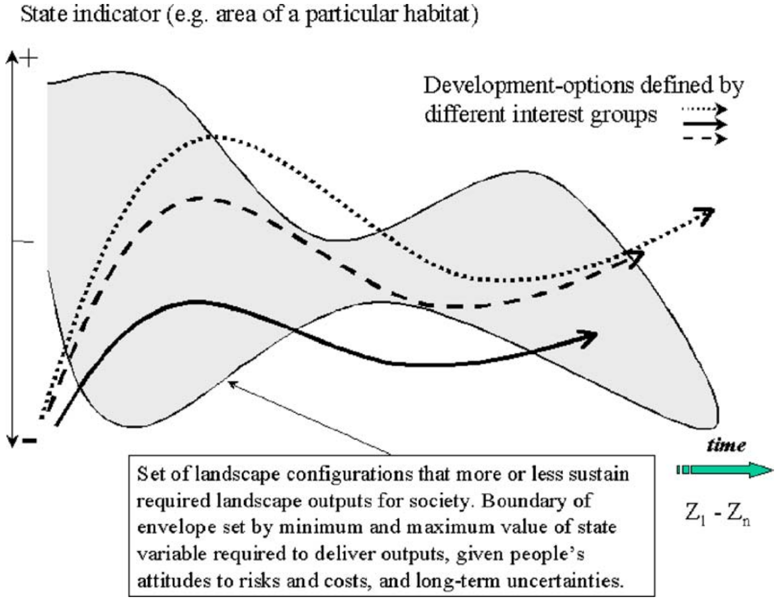

Fig. 1. Conceptualising the sustainability choice space (tongue model).

to cover alone, but for the moment it is useful to see Fig. 1 as mapping the trajectory of a landscape through some state space, and ask questions about the properties or abilities of that mosaic to provide different combinations and levels of ecosystem goods and services. The forces that drive this trajectory need not, for the moment, concern us. But in the real world they are the environmental, economic, cultural and political factors that trigger land cover change.

Fig. 1 provides a way of thinking about the trajectory of particular landscapes in the context of a subset of our 'state space' or tongue, which has particular properties. The boundaries of the tongue are defined by the combination of the biophysical limits of the ecosystems that make up the landscape, between which the outputs of the particular goods and services are possible, and the social and cultural values people attach to them. The latter define both the levels of outputs of the various ecosystem goods and services required and the risks, costs and uncertainties people are prepared to accept in terms of their continued delivery.

Within the tongue shape, the landscape configurations are "more or less sustainable", in that while the proportions of the different outputs may vary due to trade-offs, the total range or level of services current generations require is approximately maintained. Outside the tongue, however, the capacity of the landscape to supply some or all of the range of goods and services is lost. The organic shape of the tongue arises from the fact that not only is the set multidimensional, but that over time constraints and social and economic values may change. The set is also shown as closed at some point in the future, to indicate that while we may continually redraw the boundaries of the set as we move forward, our knowledge of the future is always limited, and there is a point beyond which we cannot see or speculate. Some may prefer, however, to think of the space as extending, more like a corridor, into the future.

The features of the tongue model can be illustrated by means of an example, which concerns the landscapes targeted by the New National Forest Initiative in the English Midlands (Fig. 2a). The initiative, which aims to establish a new, forested landscape over an area of about 500 km^2 is designed to transform the environment and economy of the area. In 1995, when the forest was established, woodland cover was around 6%. The aim is that woodland cover increase to about 33% by 2014; progress can be judged by the fact that already existing woodland cover has more than doubled (Evans,

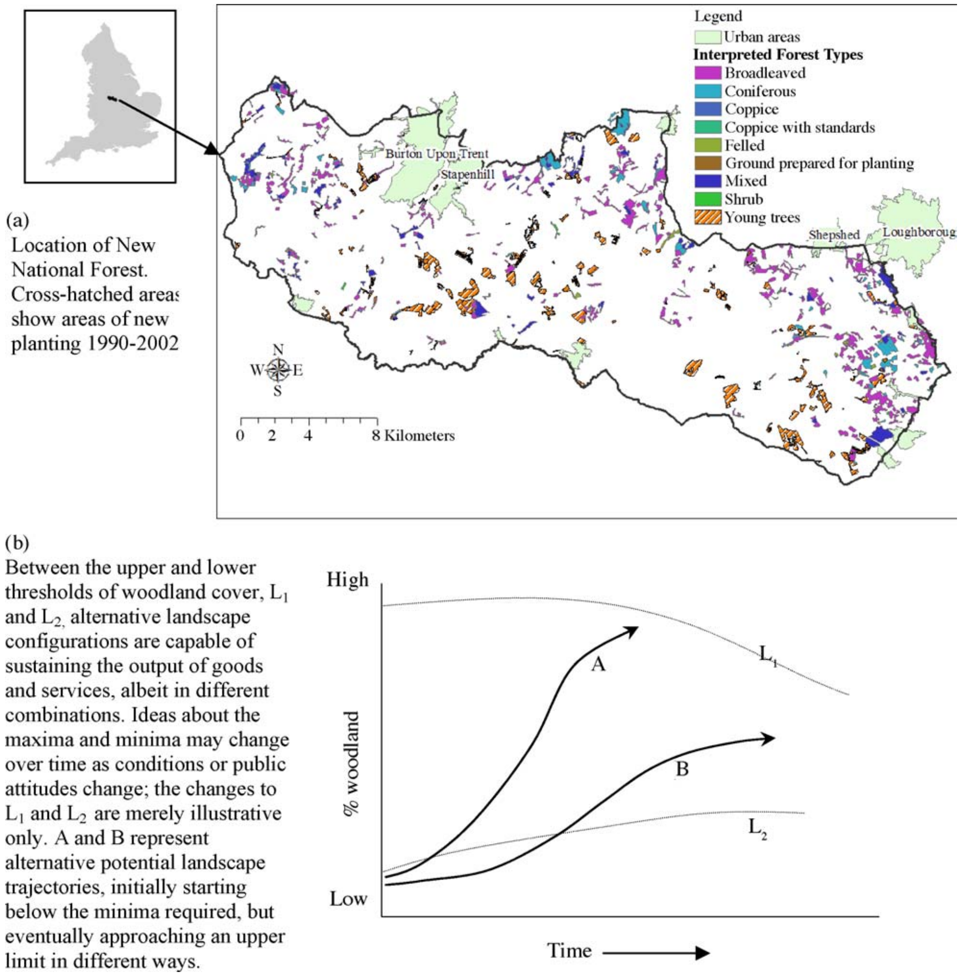

Fig. 2. (a and b) The New National Forest case study (data source for (a): National Forest Company, 2004).

2004; National Forest Company, 2004). The National Forest is a useful case study to consider because it illustrates some of the issues facing those concerned with planning in a multifunctional landscape (Helming and Wiggering, 2003; Brandt and Vejre, 2004). Such landscapes pose particular challenges for Landscape Ecology, since they confront us with the problem of understanding how planning and management can deliver a range of landscape outputs for society from given area.

The area covered by the New National Forest is mostly a mixed farming landscape in which are set remnants of the former ancient forests of Needlewood and Charnwood. The character of the area has also been shaped by the presence of the former Leicestershire and South Derbyshire Coalfield, and the industrialised corridor of the Trent Valley. By establishing the New National Forest, the goal is not only to develop a high quality timber resource, based on native broadleaved woodlands, but also to create a ‘multipurpose’ that stimulates recreation and tourism, leads to the creation of new wildlife habitats, helps restore damaged landscapes, and also provides alternative uses for productive farmland. Such developments must also be sensitive to the existing historic, ecological and cultural interests of the area.

If we consider the case of the New National Forest, there are likely to be a number of trade-offs to be considered in deciding where and how much planting should take place. In the context of the model shown in Fig. 1, therefore, we can envisage a tongue shape that define the set of alternative landscape configurations for the forest, within which the range of outputs might be maintained, albeit at different levels. The limits (see Fig. 2b, L_1 and L_2) delimit a 'choice' of 'possibility' space, in which decisions about sustainability can be made. Up to present, the main focus for the New National Forest has been the identification of the lower limit, L_2, which depends on consideration of both how much woodland is required to ensure that the wider socio-economic benefits are achieved as well as more biophysical considerations, such as those related to the amount of recreation required. Since socio-economic conditions or public attitudes as to what constitutes a minimum 'return' from the forest, may change, L_1 can vary over time. As the forest develops, however, attention will switch to the upper limit for woodland cover. Questions such as how much woodland cover is required or can be afforded, or how much can be sustained without undermining the output of other landscape goods and services will come into play. At present something around 33% cover is envisaged for this upper limit, but again as public attitudes to costs and risks, and biophysical conditions change over time, L_1 may also change. For those concerned with issues of sustainable landscape planning, analysis of these changing thresholds and information about the possible and actual trajectories of our landscapes through this sustainability choice space are essential.

5. Addressing the sustainability science research agenda

Devices, such as, the tongue model can help us to define a number of key questions for the research and policy communities that are likely to arise in the post-Johannesburg Summit 'sustainability science' era. Not only does the model challenge us to find ways to define the range of landscape configurations that are sustainable, that is to identify the boundaries or thresholds of the sustainability 'choice space' or 'possibility space', but also to describe the relationship of present landscape trajectories to this set and what other pathways are possible or necessary. It also challenges us to find ways of constructing this sustainability choice space as a framework in which our understanding of biophysical limits and stakeholder values are linked in an integrated way through the idea of landscape. The tongue model can be thought of as a device to help us think about the way in which we might 'conduct' Landscape Ecology and to compare that vision with other, more traditional approaches. In particular, the model highlights the need to develop more transdisciplinary approaches to the discipline, in which natural scientists not only engage with different publics to identify landscape issues, but also work alongside economists and other social scientists to develop an integrated understanding of these sustainability limits.

Identification of the boundaries of the sustainability choice space shown in Fig. 1 is, unfortunately, a non-trivial problem. On the one hand, as a science community we have only a rudimentary understanding of how the biophysical limits of ecosystems vary spatially and how different structural–functional arrangements of landscape mosaics potentially may deliver a given set of ecosystem goods and services. Moreover, our ability to identify and represent the divergent values of different groups or stakeholders in a landscape in relation to these biophysical limits, so that we can understand where the different thresholds lie, is also at an early stage of development (Fish et al., 2003). Nevertheless, we would argue that even as a thought model it provides a useful framework in which we can discuss the kinds of research issues that need to be explored in the context of understanding and planning sustainable landscapes. Such thought models, can for example, provide a framework in which the scenario techniques described by Peterson et al. (2003) can be developed.

The tongue model can, for example, suggest ways of approaching the core questions of sustainability science posed by Kates et al. (2001, p. 641) and cited earlier. Specifically, the nature of the 'choice space' envisaged by the model provides both a way of representing the boundaries or limits beyond which degradation of "nature–society system" might occur (Kates et al.'s, 2001, question 4), and shows how we might approach questions of the vulnerability and resilience of such systems in different places (Kates et al.'s, 2001, question 3). Moreover, by emphasising that these boundaries are the result of the relations between biophysical constraints and social and economic values, the model shows how the "dynamic interaction between nature and society" can be addressed (Kates et al.'s, 2001, question 1), and how long-term trends in environment and development may reshape "nature–society interactions in ways that are relevant to sustainability" (Kates et al.'s, 2001, question 2). As a result, we may be better placed to resolve the final two issues identified by Kates et al. (2001) concerning the types of incentive structure that may be needed to promote sustainable trajectories, and the development of appropriate tools for monitoring progress towards such goals.

The tongue model also helps to deal with some of the broader implications of the global Leitbild (mission statement in a very specific way, see Potschin and Haines-Young, 2003) of sustainability highlighted by earlier writers, such as Kläy (1994), who have argued that long-term sustainability cannot be guaranteed because it depends on the current set of anthropocentric values which may change. However, while there are no absolute criteria by which sustainability can be judged, the model shows that a robust and testable body of scientific understanding can be developed that describes the biophysical conditions under which the outputs of particular combinations of ecosystem outputs are possible in particular landscapes at particular times.

6. Conclusions

The aim of this paper was to review the place of Landscape Ecology within the sustainability debate, and in particular to explore the question of whether we need to reposition our research as a result of the decade since the Rio Summit. We have argued that although the outcomes of the Johannesburg Summit partly restate and re-emphasise the concerns of the first global summit, they do not imply that it is 'business as usual'. The more equal emphasis given to the environmental, economic and social 'pillars' of sustainability proposed in the Johannesburg Declaration reflects wider shifts in thinking about the form and content of science in the context of sustainability. If Landscape Ecology is to put itself forward as a discipline that is relevant to the resolution of contemporary issues and problems (cf., Bastian, 2001; Opdam et al., 2002; Wu and Hobbs, 2002) then it must be aware of these changes and possibly respond accordingly.

There seems to be a wide and developing body of literature that identifies the need for a new kind of sustainability science. Through this paper we have sought to bring this body of work to the attention of landscape ecologists so that we may place current debates about the future of the discipline in this wider context. We have argued that the study of landscape, and therefore the discipline of Landscape Ecology, could be close to the core of this new sustainability science, because landscapes provide an arena in which biophysical limits and economic and social values interact. However, for the discipline to play this key role, it must move beyond its traditional ecological focus, and develop a more people centred approach that places the study of everyday, cultural landscapes at the centre of concern (cf. Council of Europe, 2000). Many in the Landscape Ecology community have already picked up some of the key themes that are important in the years since the Rio Summit, and have suggested recasting the discipline as a more transdisciplinary field of study. However, these are early days, and much remains to be done. The task of defining sustainability choice spaces at the landscape-scale is, we suggest, one way in which natural and social scientists can work with stakeholders to develop a broader understanding.

As a discipline we have always been adept at proposing modes that capture the spirit of 'what we do'. Forman's (1995) 'patch-matrix-corridor' concept has, for example, done much to underpin current thinking about the relationships between pattern and process. However, while we accept that the key propositions of Landscape Ecology remain valid, and acknowledge that "spatial patterns have significant influences on the flows of materials, energy and information, while processes create, modify and maintain special patterns" (Wu and Hobbs, 2002), it is clear that such ideas have to be reconsidered and perhaps reengineered in the light of recent developments. A modern and relevant Landscape Ecology needs conceptual models and tools to help us analyse and represent the nature–society interactions that lie at the heart of the sustainability debate. The natural capital paradigm is perhaps one way forward in this respect. We have argued that in the Rio+10 era, a key focus of the research agenda for the discipline should be an exploration of the 'sustainability choice space' defined by the interaction of biophysical limits and social and economic values at the landscape-scale.

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