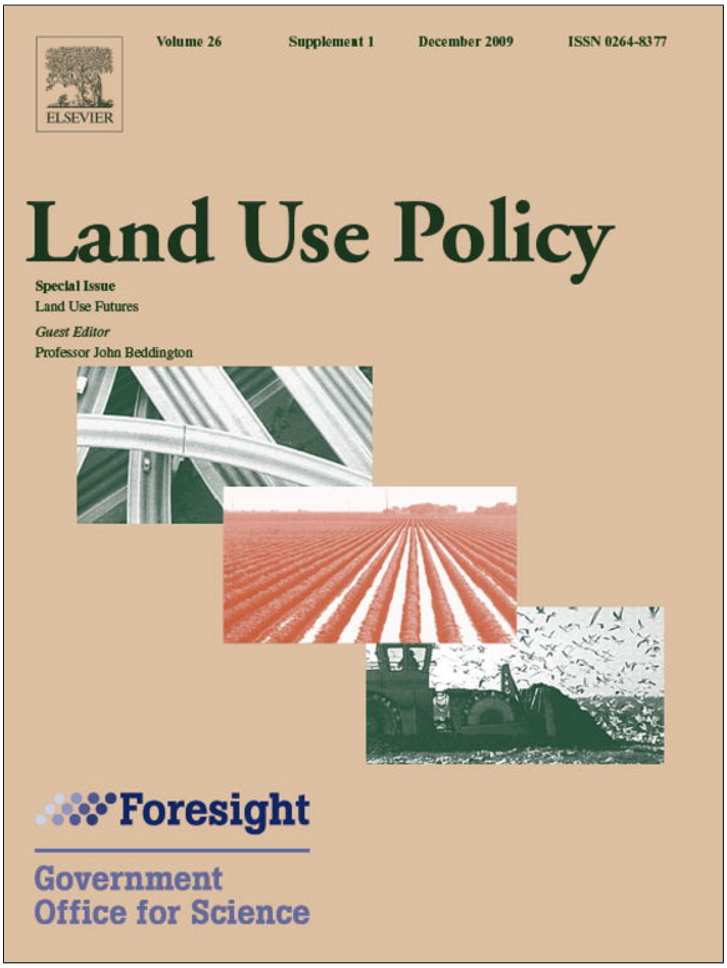
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Land use and the state of the natural environment☆

Marion Potschin

Centre for Environmental Management, School of Geography, University of Nottingham, Nottingham NG7 2RD, United Kingdom

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ABSTRACT

Land use and land cover are important determinants of the state of the natural environment. As a result, measures of land use and land cover change have been widely used as indicators of environmental condition and quality. This review explores the range of measures that have been applied in the UK at national, regional and local scales, and their sensitivity to particular drivers of change. The extent to which these indicators are important properties in themselves or are surrogates for wider environmental qualities is considered.

The discussion focuses on the evolving frameworks used to analyse the relationships between land use and the state of the natural environment. The limitations and strengths of the DPSIR reporting and analytical framework are explored. Recent approaches to the assessment of the impacts of future land use change on the natural environment using model-based scenario methods are examined, and the need to develop new types of aggregate measure of land use function is identified. There is also a pressing need to link assessments of trends to the analysis of sustainability thresholds or limits. It is concluded that the concept of a socio-ecological system offers a more fruitful approach to the analysis of the relationships between land use and the state of the natural environment than the simplistic cause–effect models that have been used in the past.

Introduction

Indicators based on land use have been widely employed as a way of characterising the state of the natural environment. Land use is sometimes used as a measure of the state of the environment in its own right, for example, when tracking the area of farmland of high conservation value. Alternatively, it can also be used as a surrogate for some wider environmental pressure, such as the conversion of land to arable use and the implications this might have for sediment loss, or as a measure of the effectiveness of a particular policy. As a result, land use emerges as one of the core concepts used to represent sustainable development issues and to measure progress towards this important goal.

Numerous studies underpin the assertion that land use is an important determinant of the state of the natural environment. The Millennium Ecosystem Assessment (MA, 2005), for example, has shown that at global scales the conversion of ecosystems through human activities has adversely affected not only biodiversity but a range of ecosystem services. These include the regulation of climate, air and water quality, soil formation, and the regulation of flooding and other natural hazards. At more local scales, land use has been employed to predict the output of ecosystem services and to value different types of land parcel in relation to both its market and its non-market products (Troy and Wilson, 2006). Furthermore, there are a number of reviews that focus specifically on the relationships between particular land cover and land use types, and the way in which their condition and management impact upon different aspects of the natural environment. For example: in the UK Calder et al. (2008) have reviewed the woodland actions for both biodiversity and water management; Petit et al. (2001) and Petit and Elbersen (2006) have reviewed the impact of agricultural intensification on ecologically valuable habitats in Europe through the MIRABEL project, and the EEA has published a range of more empirically based measures describing the impact of agriculture on the environment through the IRENA initiative (EEA, 2005); finally, the impacts of land cover and land use change on carbon storage in soils has been described by Bradley et al. (2005). Thus it is clear that a range of specific indicators describing the impact of land use on the state of the natural environment could be constructed.

If measures based on land use are to be employed as indicators of the state of the natural environment, then it is important that their conceptual basis is sound and that the messages they provide can be communicated easily. There is always a danger that indicators may over-simplify issues. And as some have argued, such indicators may not always be as neutral as they seem (e.g. Svarstad et al., 2008). The selection of indicators to represent a system or issue may

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E-mail address: marion.potschin@nottingham.ac.uk.

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reflect the concerns, assumptions and priorities of those undertaking the analysis. The aim of this review is to examine the different ways in which land use indicators are being used to inform environmental management and policy. It will consider the role of land use indicators in reporting the state of the environment and progress towards the goal of sustainable development, and what part they play in allowing new methods of integrated environmental assessment to be developed. Although biodiversity is clearly an important topic area, this paper seeks to deal with natural resources more generally. Its purpose is therefore to complement and broaden the discussion provided by Haines-Young (this issue) which is focused more specifically on biodiversity issues. 'Land use' is defined here in the same way as in this other study, in terms of the purposes of either active or passive management of land by people and the material and non-material benefits they derive from it. In looking at 'natural resources', we focus only on those benefits that depend on the biophysical characteristics of land.

Tracking land use change and its implications

The problem with tracing the relationships between land use and the state of the natural environment is that while monitoring data exist, surveillance systems rarely link the two components. Issues of 'land use' and 'environmental quality' tend to be owned by different communities, and so integrated understandings are often difficult to make. In Europe, for example, extensive land use and land cover data are available through the CORINE initiative (EEA, 2006). While change in land cover and land use between 1990 and 2000 can now be analysed effectively, the consequences of such change for the wider environment in terms of, say, the impacts on biodiversity or water quality remain a matter of speculation. Thus indicators that can be developed using the land accounts constructed around these monitoring data can only give an approximate picture of what might be happening on the ground at broad spatial scales. This situation arises despite the considerable efforts made by other groups to develop indicators of biodiversity change and to understand the impacts of the different drivers upon ecological systems (Haines-Young, this issue).

Despite these issues, the advantages of developing integrated approaches to monitoring land use change and its consequences for the natural environment are considerable. They can be illustrated by reference to the outputs of Countryside Survey in the UK,[1] which now provides time series data for a range of land-related characteristics extending back to 1978 (Carey et al., 2008; Haines-Young et al., 2000, 2003a,b). The initiative has been based on a stratified random sample of 1 km × 1 km squares distributed across Great Britain. These have been surveyed repeatedly for their land cover, the state and condition of associated landscape features such as hedgerows, their vegetation characteristics, soil conditions, and water quality. As a result it is possible to build up a more complete picture of how changes in land use and land management might be impacting on wider aspects of the natural environment.

For example, a series of policy measures have been used since the late 1990s to encourage farmers in the UK to create arable margins sown with mixtures of grasses and wild flowers species. Countryside Survey 2007 reports that these arable margins have now improved the level of plant diversity in arable landscapes, which were found to have twice as many species as crops and a much higher percentage cover of plants. It was concluded that these changes in vegetation are likely to benefit farmland birds, butterflies and other animal species in these landscapes.

[1] http://www.countrysidesurvey.org.uk/.

The result of policy change in relation to hedgerows is also detectable through successive Countryside Surveys. Since 1997, the Hedgerow Regulations have restricted the removal of hedgerows in England and Wales and this is reflected in the reduced rate of loss of hedge length recorded in the survey squares between 1984 and 1990. The most recent survey suggests that although the stock of hedgerows is now stable, the most serious threat is the neglect and over-management of these features, which are important to the character of the British countryside.

Broad-scale monitoring systems such as Countryside Survey can never eliminate the need for more controlled experimental investigations of the cause–effect relationships between land use and the state of the natural environment. However, more integrated monitoring approaches are possible. They can go some way to tracing the impacts of different pressures on the characteristics of land, and the links between land management actions, policy interventions and environmental outcomes. In the future it is likely that we will see monitoring systems such as Countryside Survey evolving further. We can also foresee attempts to develop a wider range of indicators that will also enable us to track change in the ecosystem services associated with different kinds of landscape. For example, as part of Countryside Survey 2007, an integrated assessment of ecosystem services is now underway,[2] and the UK National Ecosystem Assessment is also considering how spatially explicit approaches can be used to describe change at a range of scales.[3] In addition, Natural England are exploring how methods previously used to assess change in landscape quality can be extended to assess the broader functional integrity of the National Character Areas of England through the CQuEL Project.[4] However, the design of these new indicator frameworks is complex and represents a considerable research challenge.

Indicator frameworks and the place of land use

Although a number of indicator frameworks are available, the OECD 'DPSIR' model is perhaps the most widely used, and it is useful to reflect on its ability to meet future needs. The acronym stands for Driving forces, Pressures, State, Impacts and Responses. They are linked in the conceptual framework as a causal loop running from the pressures and events that trigger environmental change through to the responses and interventions that might be tried in order to mitigate the problem. The model is illustrated in Fig. 1, using examples of different types of measure employed to track land use change, the influences upon it and the way in which specific changes can be used to monitor the effectiveness of different policy interventions.

Segnestam (2002) has given a useful summary of the development of the DPSIR model, which was refined from an earlier framework proposed by the OECD in 1994 that recognised only pressures, states and responses. Many commentators felt that the early 'PSR' idea was limited, in that it only flagged up the immediate factors that led to environmental change and not the wider social, economic and institutional aspects that triggered these pressures. This led to the notion of 'drivers' being introduced. Similarly, many felt that the representing the environment merely in terms of its current state was too limited, because this did not suggest the sorts of issues that may prompt society to act. Thus the idea of 'impacts' was added to better capture these types of concern.

[2] http://www.countrysidesurvey.org.uk/work_packages_6.html.

[3] http://www.unep-wcmc.org/eap/ukNationalEA.aspx.

[4] Character and Quality of England's Landscapes (A. Baker, personal communication).

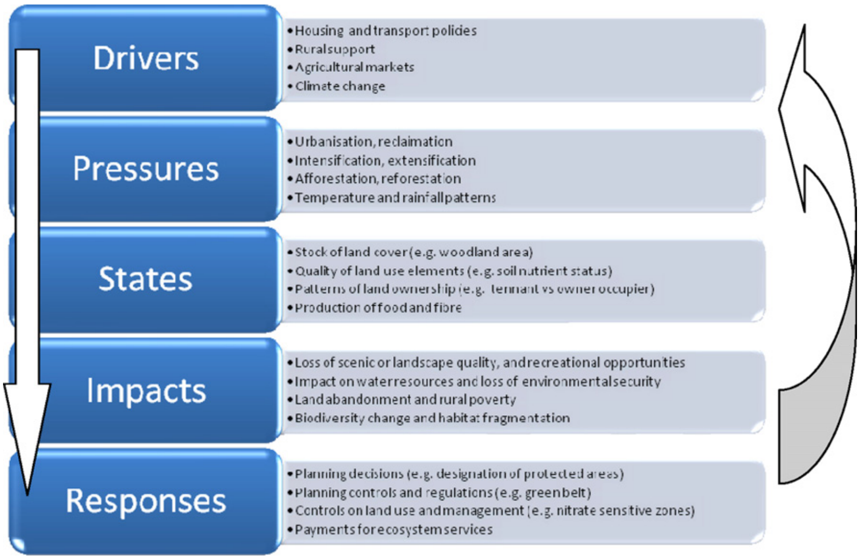

Fig. 1. The DPSIR model with examples of indicators related to land use issues.

The strength of the DPSIR model is that it seems to show in a simple way the important connections between people and the state of the natural environment. By linking issues across the nature-society divide, it also seems to help in communicating ideas between different disciplines and between researchers, policy makers and stakeholders. However, while it is a key concept underpinning much of the recent work aimed at specifically understanding the relationships between land use and the state of the natural environment, it is clear that the paradigm has crucial limitations. This paper focuses on two areas of concern, namely on its use as a reporting framework and its use as an analytical tool.

The evolution of the indicator framework used to report UK progress on sustainable development illustrates many of the problems of using the DPSIR model as a reporting framework. Unfortunately, these have resulted in the importance of land use being under-represented in national debates.

In contrast to the more recent publications that review progress towards sustainable development, which make little mention of the DPSIR framework, the 1999 Quality of Life Counts did attempt to the reference the model. However, it was noted that it did not easily translate from environment to the other dimensions of sustainability. More significantly, while it was thought to be a 'useful analytical tool' it was felt that '. . .. most nontechnical users would find it confusing for the model to be used explicitly in presenting the indicators' (DETR, 2000, chapter 2, p. 8). As a result, the report used the labels drivers, pressures, states, impacts and responses to describe the character of indicators rather than to place them in some wider causal framework (Haines-Young, 2007).

A similar difficulty of applying the DPSIR framework is evident in successive EEA reports on Europe's environment. In the fourth and most recent publication (EEA, 2007) the DPSIR model is used only to sequence the summaries of trends in the different thematic areas rather than to lay out any causal connections between these elements. Part of the difficulty of taking reporting to this kind of level is noted in the third EEA environmental report (EEA, 2003), where it was observed that while 'Information on the interlinkages within the environmental causality chain is indispensable', it is here where 'we lack complete and consistent information'.

Difficulties in gathering information and in understanding of how different cause–effect relationships operate, coupled with the need to keep reporting clear and simple, have meant that issues such as land use, which can play many different roles in the context of environmental change, are often glossed over by these reporting systems. Measures of land use do not, for example, figure strongly in the most recent national report of indicators measuring progress towards sustainable development (Defra, 2008) either within the 20 UK framework indicators or the full set of 68 used to measure progress towards sustainable development. Although land use is reported explicitly as a state measure, it is regarded as one of the contextual indicators that provide background information. It is not used formally to review progress in the Strategy. The land use data provided are the proportion of agricultural land under grass and rough grazing, agricultural land under crops and fallow, other agricultural land, forest and woodland, urban land and other developed land, and inland water, and there is little explanation of what a particular configuration of uses means, what change implies or how it relates to other sectors.

In the UK work, further information on the qualitative aspects of land use are covered implicitly through some of the other indicators, such as those dealing with water stress by catchment (indicator 17), priority habitat status (21), emissions from the agricultural sector (22), farmland covered by environmental stewardship (23), land recycling (25), dwelling density (26), number of dwellings at risk of flooding (31), and environmental equality (60). However, our picture of the role of land, and in particular the impact of land use change on the natural environment, is highly fragmented.

At EU level (EEA, 2007) a wider range of land use issues are considered, with indicators such as the organic farming (indicator CSI026), the area of designated sites (CSI008), the proximity of designated sites to transport infrastructure (TERM07), the fragmentation of land and forest (TERM06), land take by expansion of artificial areas (CSI014), and progress in the management of contaminated sites (CSI015). However, there is little systematic treatment of land use trends in relation to sustainable development, or the impact of land use change on the state of the natural environment.

Although land use change as an integrated topic area appears to be under-represented in UK and EU suites of indicators, this does not mean that questions about the implications of land use have not come to the fore as a result of trends identified by other types of measure. The key point is that the importance of land use change is not easily seen at the strategic level.

For example, Gregory et al. (2005) have examined initiatives that were triggered in response to trends in the UK indicators for farmland and woodland birds. They show that the farmland bird indicator stimulated much research and policy interest, much of it related to issues surrounding the management of particular land uses. The trend in the farmland bird indicator led to a Government commitment to reverse long-term decline by 2020. As a result, they suggest the indicator 'played a central role in wholesale change in land use policy in the UK' (Gregory et al., 2005, p. 271). It encouraged a shift to forms of agricultural production that help maintain and restore biodiversity, encouraged by the introduction of various agri-environmental schemes. The most recent data suggest that the rate of decline in the farmland bird indicator has slowed.[5]

The success of the farmland bird indicator in shaping land use policy in the UK was largely based on the fact that there is a good understanding of the cause–effect relationships between particular drivers of change and their impacts in this area (Gregory et al., 2005). Work such as that of Gillings et al. (2005) showed, for example, that at local scales critical limits can be identified for the area of winter stubble needed to ensure the breeding success of skylarks and yellowhammers in arable landscapes. Unfortunately, this level of understanding and success has not always been achieved in relation to the links between land use and other components of the natural environment described in the national indicator sets. As a result, the strategic importance of understanding land use issues has not always been recognised in using the DPSIR model as a reporting framework.

Although the DPSIR model may be questioned as a basis for designing indicator reporting systems, a number of workers have argued that it is still a useful analytical tool. Borja et al. (2006) recommend it as a methodology for assessing the risks of failing to achieve good ecological status in the context of the Water Framework Directive (WFD), while Agyemang et al., 2007 makes a similar argument in the context of environmental degradation in northern Ghana. O'Connell et al. (2007) have recently examined the link between agricultural land use and flooding in the UK. They suggest that while there is substantial evidence that modern land use practices can increase the risks of high run-off at the local scale, it is less certain that these local-scale changes have cumulative effects further downstream. To test the proposition that they do have such effects, these workers call for new approaches to 'multi-scale' catchment experimentation and modelling because the available models and validation procedures are limited. They conclude that a holistic view must be taken of the anthropogenic impacts on catchments and how to manage them, and go on to suggest that the DPSIR framework is an appropriate one to consider.

The extent to which the multifunctional aspects of land systems can be captured by the DPSIR model remains to be seen, however. Certainly the limitations and hidden assumptions of the framework as an analytical tool have been the focus of an ongoing discussion. In contrast to the many studies which have advocated the DPSIR as an analytical tool, others have stressed its limitations.

It has been argued, for example, that the DPSIR model not only leads to the creation of rather static sets of indicators that cannot easily take account of system dynamics, but that it also tends to over-simplify matters by suggesting simple, unidirectional causal chains (e.g. Rapport et al., 1998; Rekolainen et al., 2003). Svarstad et al. (2008) also suggest that the framework is limited because it ignores important non-human drivers of change. These workers note the earlier critique of Berger and Hodge (1998), which emphasised that ecosystems integrate the effects of many 'simultaneously induced' stresses, and that assessments of cumulative effects can only be made in relation to the system as a whole. Not only may some stresses be beneficial or indeed essential for the functioning of a system, but systems may also adapt to pressures. The DPSIR framework promotes reactive rather than anticipatory thinking (Berger and Hodge, 1998). According to Svarstad et al. (2008), the nature of the perspective promoted by the DPSIR model is particularly problematic. They suggest that the 'strong realist view on knowledge behind DPSIR' has been overlooked. As a result, those using the framework tend to present analyses of cause and effect as 'scientific facts' and ignore more discursive analytical approaches to problem solving. For them the model actually hampers communication between researchers, stakeholders and policy makers and tends to favour 'conservationist positions' at the expense of others. The argument that application of the DPSIR framework reproduces or perpetuates existing knowledge has also been made by Carr et al. (2007) in the wider context of sustainable development.

Emerging issues and new challenges

Although the DPSIR model is not used exclusively by those concerned with land use issues, it is clear that many of the limitations associated with it do carry over into this topic area. And so, while it is likely to continue to be employed for both reporting and analytical purposes, it should not be used uncritically. As we look to the future, other approaches to understanding the relationships between land use and environment are likely to emerge. For the land use science community, the challenge is to evolve more sophisticated tools to help explore the complexities arising out of the positive and negative feedbacks between different activities, economic and social mechanisms, and the fact that policy responses may have multiple effects (Verburg, 2006; Dawson and Rounsevell, 2008; Kluvanková-Oravská and Chobotová, 2007). Because feedbacks often make it hard to separate impacts from drivers, Kluvánková-Oravská and Chobotova suggest that the DPSIR model needs to be viewed through the lens of a socio-ecological system (SES), so that indicators can be identified at appropriate spatial and temporal scales, and system dynamics and societal responses properly captured and represented more fully.

A SES is one in which there is a close coupling between social and ecological processes (Folke, 2006, 2007). It has been used to emphasise the fact that ecological and social systems co-evolve at a range of spatial and temporal scales, and to suggest that their structure is best understood in terms of the relationships between resources, resource users and governance systems (Anderies et al., 2004). The value of the SES concept is that it counters the reductionist tendency of the DPSIR model by asserting that these coupled social–ecological systems are 'non-decomposable'—they cannot be separated into their social and ecological components. Thus land use must be seen as being embedded in other processes and not simply represented as driver of change or a measure of the state of a system.

Recent work undertaken through the Rural Economy and Land Use Programme[6] in the UK illustrates the how central the role of land use is in the investigation of the relationships between people and the natural environment. Thus the Sustainable Uplands Project aimed to combine knowledge from local stakeholders, policy makers and social and natural scientists to anticipate, monitor and manage rural change in UK uplands (e.g. Dougill et al., 2006; Holden et al., 2007; Hubacek et al., 2006). The contribution of Prell et al. (2007) to this work is particularly interesting in the context of the present discussion because it illustrates just how complex

[5] http://www.defra.gov.uk/Environment/statistics/wildlife/kf/wdkf03.htm (accessed 14/12/08).

[6] http://www.relu.ac.uk/.

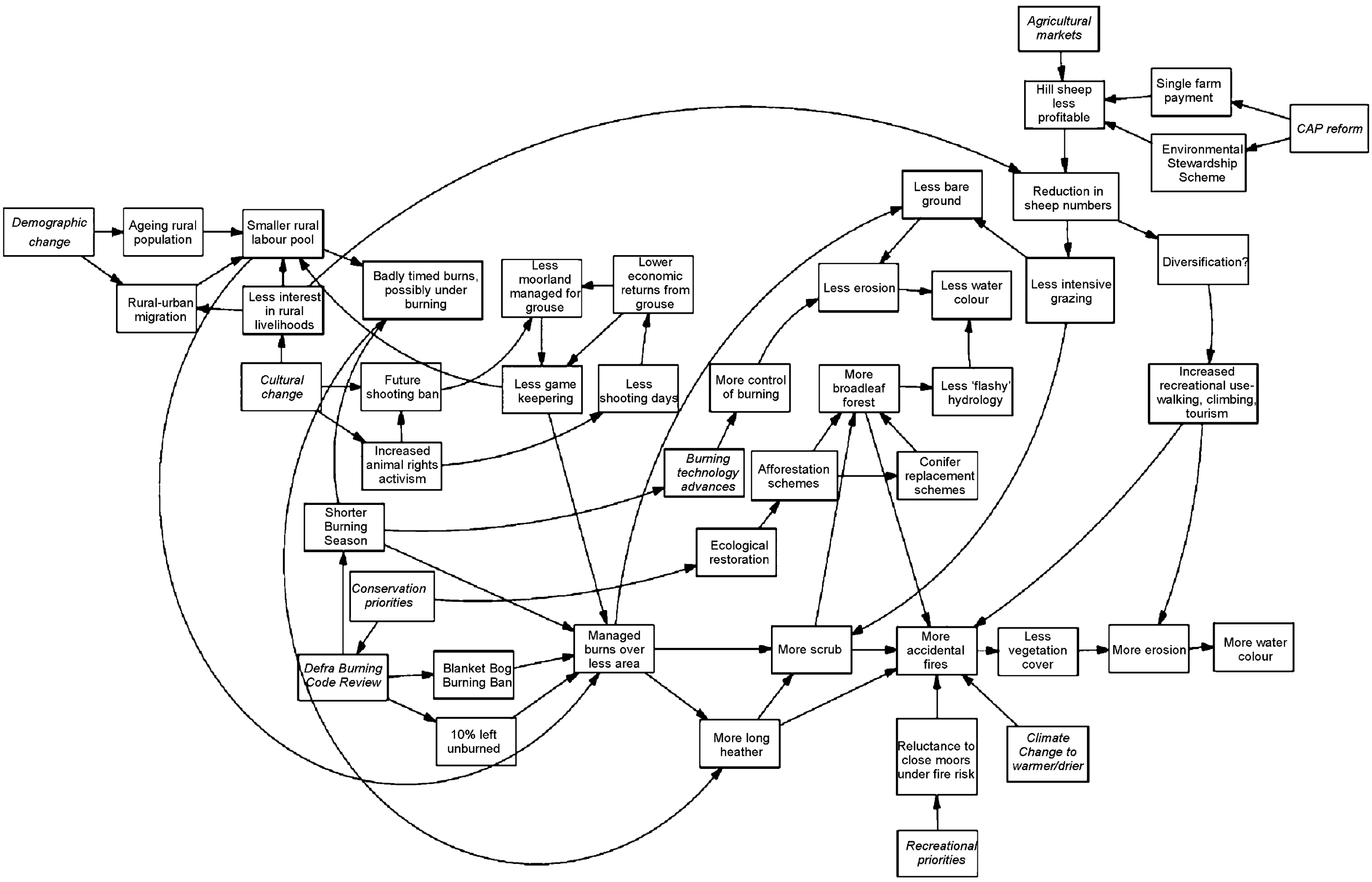

Fig. 2. Conceptual model of socioeconomic and biophysical processes related to burning management (after Prell et al., 2008).

the inter-relationships between land use practices and wider socio-economic and biophysical processes are. This study shows that if we are to understand even a single issue such as burning management in upland catchments, analytical approaches have be grounded in an understanding of stakeholder perspectives (Fig. 2). The importance of collaborative approaches has also been explored in relation to deer management through another project undertaken[7] within the RELU Programme.

Through initiatives such as RELU, and other studies that consider the relationships between land use and ecosystem services, we are seeing the emergence of a much richer conceptualisation of what land use implies. In addition to material, market-based outputs, the importance of non-market environmental benefits is being emphasised as part of the move towards a more holistic analytical and assessment framework than is possible using the DPSIR model. Thus Morris et al. (2008) have shown how the economic valuation of different land use options can be used to examine the costs and benefits of washland creation for flood storage in SW England. This work found that there was both synergy and conflict of interest in management options between flood storage, environment and farming objectives, and that different sites are likely to have different priorities and management systems. The need to address such contextual issues, and weigh up the advantages and disadvantages of different strategies, clearly takes the analysis far beyond simplistic cause–effect frameworks such as DPSIR.

The view that problems of poor water quality can only be overcome by adopting a 'whole system' or 'ecosystem' approach to land management is also evident in the catchment sensitive farming initiative being promoted in the UK.[8] Interestingly, the land management strategies being explored in these river basins not only attempt to deal with nutrient run-off, but also seek to promote good soil structure to maximise infiltration of rainfall and minimise run-off and erosion, and so deliver a range of benefits from the natural environment.

If the principles that lie behind the ecosystem approach are to become embedded in decision making (cf. Defra, 2007) then the more open, discursive frameworks that are developing around the concepts of socio-ecological systems and ecosystem services seem to offer a more fruitful way forward than the paradigm that surrounds the DPSIR model. It could be argued that the relationships between land use and the states of the natural environment that are important to people can only be examined through a process that is built on dialogues between researchers, decision makers and publics. The challenge that now confronts us involves understanding how such dialogues can best be achieved and how such methods can be made part of contemporary governance processes. In the remaining parts of this paper we consider the relevance for land use studies of new techniques for integrated assessment and tools for scenario building.

Making assessments and building scenarios

In recent years, the term-integrated assessment (IA) has been used to refer to a range of methods designed to bring together

[7] http://www.relu.ac.uk/research/projects/SecondCall/Irvine.htm.

[8] http://www.defra.gov.uk/farm/environment/water/csf/index.htm.

evidence from a range of disciplines to support decision making (Harremoës and Turner, 2001). Within this broad set of methodologies, techniques such as 'Integrated Environmental Assessment' and 'Sustainability Impact Assessment' have drawn upon land use as a focus of the investigation. Thus Rounsevell et al. (2006) have looked at the impact of land use change on ecosystem vulnerability across Europe in the context of the ATEAM Project. The work attempted to make spatially explicit predictions for the ways land use would change, and what the impacts might be, under the assumptions of the global storylines developed as part of the IPCC work on emissions scenarios. The storylines were used to link the major drivers of land use change (e.g. population, GDP and global trade) to quantitative estimates of changes in the area of the major land use types that characterise European landscapes. Spatial allocation rules were then used to distribute these quantities across Europe, so that a geographical picture of their impacts could be built up. All of the scenarios predicted declines in the area of agriculture within Europe, increases in the extent of bioenergy crops, and the expansion of urban centres, although the suggested spatial patterns were different for the different scenarios.

In a review of the uncertainties associated with their assessment, Rounsevell et al. (2006) identify a number of factors that have to be considered. These include problems arising out of the subjective nature of qualitative interpretations made in setting up the scenarios; the assumptions underpinning the land use change models employed; the problem of testing the robustness of future predictions; the quality of the baseline data used to calibrate the models; and the errors involved in downscaling from global to local levels. More recently de Chazal and Rounsevell (2009) have also emphasised the need for integrated perspectives. In the context of exploring the relationships between land use, climate change and biodiversity, they suggest that our understanding of projected changes in biodiversity remains poor if land use and climate effects are examined separately. These kinds of issue are common to all such work and usefully summarise the key challenges that arise in taking the modelling of land use change forward in the context of assessment studies and scenario building.

In terms of the controlling the subjective aspects of scenario development, broadly based consultative or participatory approaches are generally recommended as a way of framing the assumptions on which assessments are based (Eckley, 2001). To improve the robustness of the assumptions made in land use models, Verburg et al. (2008) suggest that an improved characterisation of land use functions may be one way in which the various social and economic drivers can be linked to specific types of land use change. They argue that the more direct causes of land cover change are related to demands for certain functions, such as for agricultural commodities or recreational areas. They suggest that a better understanding of the relationships between such demands and the capacity of land to support them will lead to more reliable predictions about patterns of change. It might also produce a broader understanding of the wider impacts of these transformations on the other benefits or services which these units of land produce. An improved characterisation of land functions will, however, require more integrated, multi-scale data collection. While land cover may be mapped at very broad scales using remote-sensed or census data, the investigation of functional relationships is probably best made at local scales. Such a requirement has strong resonances with calls by Ohl et al. (2007) and others (e.g. Yoccoz et al., 2001; Mirtl and Krauze, 2007) to merge socio-economic and environmental research criteria when selecting sites for long-term environmental monitoring.

An example of work linking models of land use change to impacts on the natural environment is the SENSOR project[9] funded by FP6, the EU 6th Framework Programme for Research. This project aimed to build tools for the ex ante assessment of European land use and environmental policies (Tscherning et al., 2008). Like other projects funded under FP6, it was designed to provide 'quick scan tools' to decision makers which might enable them to rapidly draw upon the results of sophisticated model outputs without the need for researchers to act as intermediaries.

The modelling approach used in SENSOR involves identifying a set of economic, social and environmental indicators that are linked to land use, and which allow the consequences of different policy options to be traced through to their impacts on the different dimensions of sustainability. The fundamental assumption is that land use change is the key driver, and that a set of functional relationships can be built that links these changes to their wider effects (Helming et al., 2008; Petit et al., 2008). SENSOR looks at possible trajectories up to 2025 and the influence that different policy assumptions might have in the context of a set of specific policy cases, for example CAP reform.

The SENSOR Sustainability Impact Assessment Tool (SIAT) has been built by refining and linking several existing models. The major economic processes leading to land use change within individual countries are initially captured by the NEMESIS, and the resulting implications for changes in land use are expressed spatially using CLUES at a 1 km^2 grid resolution (Verburg et al., 2008). Two additional models, CAPRI and EFISCEN, are also used to refine predictions, the first in relation to the outputs from the agricultural sector, and the second to determine the effects of policy interventions on forestry. Finally, the transformations in land use, and particularly the marginal differences between different policy scenarios and the baseline or reference trajectory, are used to estimate environmental impacts via a set of expert-based rules (Petit et al., 2008).

Although SIAT has yet to be tested operationally, the work illustrates a number of emerging science issues that need to be addressed if the implications of land use change are to be understood in relation to the goals of sustainable development. Three issues stand out that are of general relevance to the construction of the next generation of assessment and scenario tools.

The first is that to capture the multifunctional character of land over such a large and diverse an area as Europe, new types of aggregated indicators are necessary if the complexity of issues is to be handled by non-experts. Thus, while the SIAT tool will provide decision makers with access to detailed data about particular indicators, it is expected that the major part of the assessment will be based on a set of nine more general land use functions that map onto the economic, social and environmental pillars of sustainability (Pérez-Soba et al., 2008). These land use functions cover the provision of work, human health and recreation, cultural issues, residential and land-independent production, land-based production, transport, the provision of abiotic resources, the support and provision of biotic resources, and the maintenance of ecosystem processes. If these types of land use function are to be used to assess the implications of land use change for both the environment and society, questions about how to handle conceptual overlaps between them, and whether and how they should be weighed against each other in specific decision making contexts, have to be resolved. The potential role of participatory processes and valuation techniques in assigning such weights is yet to be explored. However, the evident need to combine formal modelling approaches with con-

[9] www.sensor-ip.eu.

sultative processes to make effective assessments emphasises the transdisciplinary context in which such work on the consequences of land use change for the environment now has to be set.

The second issue illustrated by projects such as SENSOR is that to understand the implications of change in relation to both the individual and aggregated indicators, a consideration of sustainability thresholds and limits is probably necessary if the significance of change is to be fully assessed (Bertrand et al., 2008; Potschin and Haines-Young, 2008).

Although the terms 'limit' and 'threshold' tend to be used interchangeably, it is useful to distinguish between them because they highlight important features of system behaviour. If external pressures on a natural resource system progressively undermine its integrity, then society may judge that a 'critical point' has been reached, beyond which further change is unacceptable. This critical point is what most commentators call a 'limit' and is defined largely by the value society places upon the output of a particular resource system, or the risks it associates with further damage. By contrast, a threshold or tipping point is said to exist when a system exhibits a rapid regime shift, that is, when it reaches the transition to some alternative and possibly impoverished stable state from which it might be very difficult or impossible to recover. Such thresholds have been observed widely in aquatic ecosystems, and it has been argued that socio-ecological systems may well exhibit similar types of behaviour (Walker and Meyers, 2004; Carpenter et al., 2006).

Progress has been made in a number of areas in relation to identifying thresholds and limits. Examples are the identification of critical loads for atmospheric pollution and their impacts on soils and habitats, the nutrient loading of water bodies, and the possible effects of changes in habitat patch size and isolation. Walker and Pearson (2007) have also described the existence of a significant threshold effect in relation to changes in water table depth and soil salinisation in agricultural areas in Western Australia. But many knowledge gaps remain (see Haines-Young et al., 2006). The current challenge facing the research community is to identify whether such threshold-type behaviour exists more generally in relation to the ways land use change can impact upon different aspects of the natural environment. If so, what are the limits of acceptable change to ensure that the chance of crossing such a threshold is minimised? In any case, decisions about such limits are not solely based on an understanding of the biophysical behaviour of land-based natural resource systems. They also require an understanding of the views people have about the value of the benefits that such systems provide, and their perceptions of the risk to which those benefits are exposed (Potschin and Haines-Young, 2008).

The final issue that arises out of the SENSOR initiative is that the underlying models of land use change are largely deterministic. The uncertainties associated with particular scenario outcomes are difficult to visualise or to compare. Since judgements about different outcomes are mainly dependent upon the marginal differences between them, it is essential to know whether they are derived from the same set of plausible outcomes or not. If assessments are based on understanding the changes in the overall outputs from natural resource systems brought about by transformations in land use, then many different land use configurations might well deliver the same level of benefit. By knowing something about the likelihood of a particular scenario outcome under an alternative set of assumptions, decision makers might be much better placed to evaluate the significance of differences between them (cf. Bevan, 2006).

Conclusions

That change in land use can affect the state of the natural environment is beyond dispute. Land use has been, and remains, one of the major drivers impacting on natural resource systems at all scales. Although its role can usefully be accommodated by the DPSIR framework, there are strong arguments to suggest that as both a reporting and analytical framework, this commonly used model is too simplistic to capture the multiple relationships that exist within a land system.

To take account of the different types of feedback that may exist between the different environmental, social and economic components, and the fact that policy interventions may have multiple and sometimes unpredictable results, it has been argued that land systems have to be viewed as coupled, multi-scale socio-ecological systems. While we may focus on the relationships between land use and the natural environment, these understandings have to be developed and set in their wider social and ecological contexts. Although increasingly complex land change models are becoming available, it is clear that judgements made using them have to be based on deliberative processes, involving both different disciplines and different publics.

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