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Bridging the gaps between agricultural policy, land-use and biodiversity

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The fate of biodiversity is intimately linked to agricultural development. Policy reform is an important driver of changes in agricultural land-use, but there is considerable spatial variation in response to policy and its potential impact on biodiversity. We review the links between policy, land-use and biodiversity and advocate a more integrated approach. Ecologists need to recognize that wildlife-friendly farming is not the only land-use strategy that can be used to conserve biodiversity and to research alternative options such as land sparing. There is also a need for social scientists and ecologists to bring their approaches together, so that land-use change and its consequences can be investigated in a more holistic way.

Land-use change and biodiversity

The fate of biodiversity is intimately linked to the use of land for agricultural production. Agricultural land-use throughout the world overlaps spatially with areas of high conservation value and is related to the extinction risk of potentially vulnerable species [1–4]. Studies from developed agricultural systems in Europe also reveal links between agricultural intensification and biodiversity loss [5,6]. In response, wildlife-friendly farming approaches have been developed that include the retention of natural habitat patches, extensively farmed semi-natural habitats and farming in a manner that reduces the negative effects of chemical inputs on non-target organisms [7]. Focus on such approaches has resulted in both the EU and US developing a range of wildlife-friendly farming policies (http://www.ers.usda.gov/publications/arei/ah722/) [8,9]. However, wildlife-friendly farming has been criticized for its lack of success in Europe [10,11] and in some regions alternative land management strategies could have more beneficial effects on biodiversity [7].

The challenge for ecological research is to identify the most appropriate land management strategy for an area that delivers effective biodiversity conservation in the face of land-use change driven by agriculture. Such work, however, cannot operate in a vacuum. The political, social, economic, technological and physical environment influences agricultural land-use both internationally and within countries and regions. The appropriate strategies for biodiversity conservation are likely to vary against this dynamic background. We therefore need to understand the links between biodiversity, land-use and the drivers that shape land-use (Figure 1). Ecologists clearly have an important role in this process, so our aim here is to stimulate ecologists to consider agricultural land-use and biodiversity conservation strategies within this wider context. We focus on agricultural policy, a key driver of land-use [12]. We discuss the ways in which policy can shape agriculture in different regions, methods used to link agricultural policy with land-use and approaches used to link land-use to biodiversity. We then highlight the possibilities for more effective interdisciplinary integration.

Agricultural policy as a driver of land-use change

Policies designed to support farming within particular regions have considerable direct and indirect impacts on both farmers and biodiversity (Box 1). The World Trade Organization (WTO) aims to eliminate policy-driven trade distortion by negotiating the discontinuation of such policies (agricultural deregulation) [13–16]. National agricultural policies are formed within the context of existing agreements and long-term WTO targets [17,18]. Response to global agricultural policy is therefore a major driver of land-use change, but this depends on the existing status of agriculture and the opportunities provided by change within different regions. Although it is difficult to

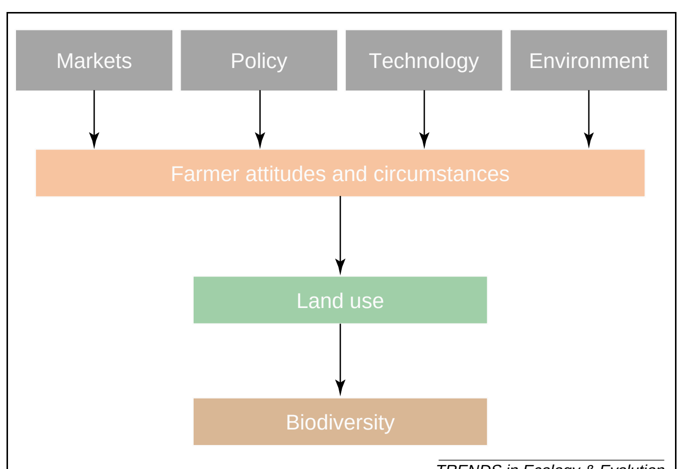

Figure 1. Links between drivers of land-use and land-use change (black boxes) and biodiversity. These drivers interact with the attitudes and circumstances of individual farmers who then determine land-use decisions, which in turn affect biodiversity.

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Box 1. 'Protectionist' agricultural policies

The WTO Agreement on Agriculture [13] defines three 'pillars' of agricultural subsidy: domestic support, export subsidies and import tariffs. Reductions in each pillar were agreed upon following the Uruguay round of trade negotiations and negotiation of further deregulation is planned for late 2005 [15–17].

Domestic support

This financial support to farmers is categorised as amber, blue or green-box subsidy. Amber subsidies are production-linked payments (e.g. guaranteed prices) that encourage increased agricultural output. Blue-box payments are for the reduction, control or cessation of production. Green-box subsidies include government services and non-crop specific payments that are thought not to stimulate production. The 1995–1998 average annual amount of domestic support reported to the WTO was over US$227 billion [81]. Agri-environmental programs based on wildlife-friendly farming are a way of shifting farmers' income support to the green-box. Such policies should benefit biodiversity in developed agricultural regions.

Export subsidies and export-credit agreements

Produce that is not required domestically can be sold internationally. If the domestic price of a product is higher than the world price, export subsidies are used to facilitate sale on the world market. An average of US$18 billion was committed to export subsidies in 1995–1998 [81]. Export-credit agreements occur when a government guarantees repayments to private lenders who finance the export of agricultural products. These subsidies put developed agricultural systems at a trading advantage compared with other areas. Their removal is predicted to cause a rise in global agricultural prices, thereby stimulating agricultural production in developing regions [15]. Export subsidies have contributed to agricultural intensification in developed regions [17] and hence biodiversity loss. However, increased agricultural production because of their abolition might result in conflict between potential economic and social gains and conservation of existing biodiversity in transition and subsistence farming regions.

Import tariffs

These are used by both developed and developing nations to restrict imports of agricultural commodities that are also produced domestically [15]. The average import tariff on agricultural products is 17% of the price although there is huge variation [81]. The removal of import tariffs is predicted to stimulate increased agricultural exports from developing nations to countries such as the US, Canada and the UK. This would also potentially increase biodiversity loss in regions where the agricultural area can expand or be farmed more intensively for exportable products.

generalize, agricultural status, and therefore the associated land-use changes liable to impact biodiversity, can be divided into three broad categories: those associated with developed agricultural systems, transition agricultural systems and mainly subsistence farming.

Existing policy in developed agricultural systems varies, from provision of little subsidy in New Zealand to highly subsidised Japanese agriculture [19]. Support for and interpretation of the WTO drive towards deregulation varies a lot. For example, the Clinton administration introduced a framework for deregulation in the USA [20], whereas expansion of farmers' income support has occurred under George W. Bush [21]. The EU Common Agricultural Policy also evolves continually, with only recent movement towards removal of some agricultural subsidies [22]. An increasingly common policy approach in developed agricultural systems is the provision of agricultural subsidies for goods and services beyond the production of marketable food and fibre. This 'multifunctional' approach aims to improve sustainability (e.g. through wildlife-friendly farming [23,24]).

The impacts of deregulation on biodiversity in developed agricultural systems are uncertain. Farmers could cut costs and manage risk by reducing inputs and diversifying their farming systems, as seen in New Zealand [25,26], with potentially beneficial outcomes for wildlife in existing agricultural landscapes [27,28]. By contrast, research in Canada has shown that farmers could follow market trends and expand production of high-priced commodities, with the resulting reduction of crop diversity at a landscape scale being potentially detrimental to farmland biodiversity [29].

Countries in developmental transition tend to rely heavily on agriculture [15]. For example, economic growth in South America has developed in tandem with more intensive agricultural systems and enlargement of the agricultural area. Drivers of agricultural expansion include the creation of the South American free trade agreement MERCOSUR and national agricultural policy reforms; deregulation of EU and US agricultural markets, driven by the WTO, would provide further stimulus for agricultural development [30]. Land-use changes in transitional agricultural regions are because of agricultural commodity production rather than subsistence farming and often have negative impacts on biodiversity because of the accelerated rates at which natural habitats are converted to agriculture. In South America, examples of this process include the continuing conversion of Amazonian rainforest and Brazilian Cerrado to beef production and soybean cropping [31,32]. In both of these regions, there is the potential for further agricultural expansion.

Much of the agriculture in developing nations is subsistence farming and growing human populations drive conversion of land to agricultural use [12]. There is pressure to intensify agricultural production to cope with demand [33]. Recent studies indicate that global policy and commodity markets increasingly influence land-use change such as deforestation, suggesting that the area covered by subsistence-based farming is declining and the impact of economics and policy is increasing [34–37].

Linking economics and policy to land-use change

Insight into the impacts of agricultural development on biodiversity requires an understanding of the relationships between agricultural policy, economics and land-use. Models that describe changes in the volume of agricultural production, the demand for agricultural inputs and agricultural prices have existed for many years. The various approaches used both to test economic theory and as a guide for agricultural policy makers cover a range of scales and are potentially suitable for integration with ecological approaches that link land-use with biodiversity.

Sector models describe changes in the consumption of agricultural inputs and products, production of agricultural commodities and prices across whole economic units such as the US or EU agricultural sector [38]. Modern sector models can predict changes in the volume of production of crops and livestock at a regional scale based on available land, expected prices and expected yields. For example, the Policy Analysis System (POLYSYS) simulates the US agriculture sector and predicts output volumes from 305 regions of crop production [39,40]. The results from this type of model do not provide explicit descriptions of land-use; rather, they highlight potential changes in the regional or national distribution and intensity of agricultural production.

Econometric estimation of site-specific production costs and output prices in combination with site-specific yield predictions can be used to predict which cropping system farmers choose in particular locations. For example, the use of continuous corn versus corn-soybean rotations and conventional versus minimum tillage in the upper-Mississippi river basin was predicted; changes in tillage decisions were modelled following the introduction of payments for the use of minimum tillage [41].

Individual farm models can be used to find the optimum farm plan in a given situation [38]. Production technology, finance, price, policy, rotation and labour can all be described explicitly and integration with biophysical models of production is possible, resulting in explicit land-use predictions [42]. Representative farm models can cover a large area, producing predictions of typical land-use at a specified scale. For example, the integration of a linear programming model with a soil and input-dependent crop-growth model has produced representative farm models across the UK at a resolution of 5 km×5 km [43]. Linear programming using an individual farm model to represent a typical farm has also been used to investigate socio-economic changes in part of Costa Rica [44]. If such farm models are based on a statistically representative sample of farms in the region of interest, generalizations based on their output are possible [42].

At very fine scales, agricultural land-use change can be predicted by modelling every individual farm within the study area. Current research focuses on the integration of individual farm models with GIS technology to provide a visualization of potential changes and an assessment of different policy scenarios [45,46]. This has the added advantage that model predictions can be tested directly against observed land-use change.

Socio-psychological approaches are also used to study the impact of policy change because farmers' decision-making processes can be an important source of variation in local response to policy and could explain apparent deviations from profit-maximizing behaviour by farmers [47]. First, actor network theory [48,49] aids understanding of the diversity of both human and non-human actors and their interactions during the uptake (and the processes following uptake) of new policies. This is important because the reasons behind attainment or non-attainment of both social and biodiversity targets can be identified [50]. Second, the decision-making process behind farm-management change can be modelled using the Theory of Reasoned Action and its extension the Theory of Planned Behaviour [51]. If applied rigorously, these models link farmers' attitudes with their behaviour [52] and have been used to describe farmers' environmentally oriented decision-making [53,54].

Ecological approaches linking land-use and biodiversity

The most direct approach is to manipulate land-use experimentally and to monitor the response of biodiversity. The majority of such experiments are conducted at the plot or field scale and are necessarily limited in terms of spatial and temporal scale compared with the scales typical of agricultural landscapes. Nevertheless, some experimental studies have partly addressed these issues of scale. Examples include the recent farm-scale evaluations of genetically modified crops in the UK [55] and the Biological Dynamics of Forest Fragmentation Project established in Brazil in the mid-1980s that examined the impact of forest clearance on biodiversity in isolated forest fragments of varying size [56]. Although experiments play an important role, there is an inherent difficulty in replicating the spatial and temporal scales relevant to agricultural landscapes experimentally.

Perhaps the simplest observational approach is to link spatio-temporal patterns in biodiversity to spatio-temporal patterns in land-use using statistical models. Examples span a range of taxa from different agricultural landscapes [57–59]. The approach is popular, at least in part, because of the relative ease with which data can be obtained, its intuitive appeal to decision-makers and it having provided valuable practical insights [60,61]. Some drawbacks exist, which means the approach should be applied with caution. First, the approach assumes that land-use associated with high population densities of biodiversity represents high-quality habitat, which might not be the case [62,63]. Second, studies to date are equivocal on the spatial generality of models generated using this approach [64–66]. Third, the application of this approach often ignores issues of scale, whereas recent examples of population restoration show that population responses to land-use change are likely to be scale-dependent [67]. Furthermore, large-scale datasets illustrate the importance of considering landscape context when relating biodiversity to land-use, particularly for wide ranging taxa such as birds [68].

Demographic modelling has assumed a potent role in conservation biology [69]. This approach can be used to explore population responses in specific components of biodiversity to land-use change if estimates of vital rates associated with the change (births, deaths and dispersal) can be estimated [70,71]. However, the issue of model reliability is intensely debated [72,73] and the critical evaluation of model outputs is problematic. Theory can be used to develop a mechanistic model of the links between land-use and demography [74,75]. This has the advantage that assumptions concerning the ecological mechanisms are amenable to evaluation, and the approach permits populations to respond adaptively to land-use change.

Recent work has highlighted the importance of yield–density relationships in considering land management strategies for biodiversity within agricultural landscapes [7] (Figure 2). Conservationists frequently consider wildlife-friendly farming options to be the most appropriate way of resolving the potentially damaging impacts of agriculture on biodiversity. However, when important biodiversity is unable to persist even in low-intensity agricultural habitats [76], then the best strategy is to

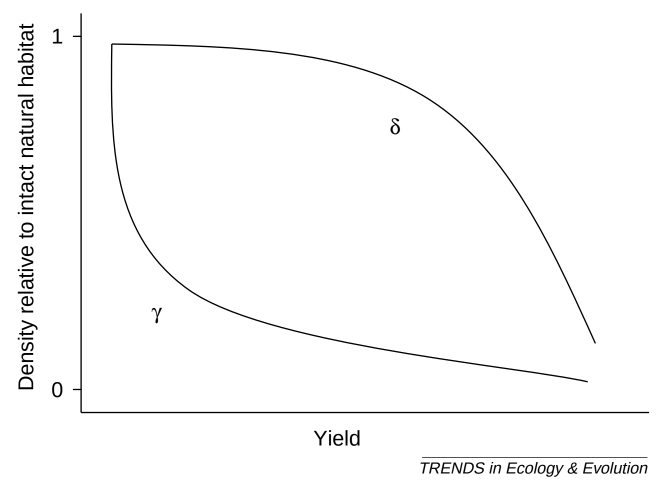

Figure 2. Yield–density relationships. These relationships describe how the population density of particular species varies along an agricultural yield gradient. The shape of the yield–density relationship dictates the best conservation strategy for biodiversity – land sparing or wildlife-friendly farming [7]. Land sparing is the best strategy for γ populations because population density declines rapidly as soon as intact natural habitat is converted into low-intensity agricultural production. Wildlife-friendly farming is the best strategy for δ populations because population densities in intact natural habitat and habitat converted to relatively low-intensity (low-yield) agriculture are relatively similar.

spare natural habitats by intensively farming land converted to agriculture (so called 'land sparing').

Towards a more integrated research agenda

We raise two key questions. First, how should ecologists approach the task of linking land-use with biodiversity in a way that aids biodiversity conservation in agricultural landscapes practically? Second, how should ecological approaches be integrated with socio-economic techniques linking land-use to the main drivers of land-use change such as policy reform? Box 2 illustrates the potential for integrated land-use research and policy formation.

In developing countries and those in which there is potential for future agricultural development (e.g. those in South America), there is considerable scope for collecting and applying yield–density data that could be used to identify the appropriate land-use strategy for conserving biodiversity (i.e. land sparing or wildlife-friendly farming) [7]. Although this approach could be criticized because of its simplicity, it has the substantial merit that it challenges us to identify the most ecologically appropriate strategy for biodiversity conservation. It also provides a clear framework for identifying further information needs. For example, when important biodiversity is unable to persist even in low-intensity agricultural habitats, we must be able to determine how much land containing intact natural habitats should be spared from conversion to agriculture. There is a need for further generic ecological research on this issue and its application in specific cases. The ecological approaches described above then function as a toolkit that can be deployed as necessary. For example, spatial patterns in biodiversity in relation to the spatial loss of natural habitats might provide 'broad-brush' insights into the possible consequences of sparing different areas of land, whereas more detailed statistical or demographic modelling might be required on individual species of high conservation value or concern. Finally, such studies need to be integrated in a more holistic framework that also considers the implications for agricultural production and the wider environment [77].

Box 2. An opportunity to develop integrated land-use and biodiversity conservation policies

The woodlands, savannah and grasslands of the Brazilian Cerrado support diverse flora and fauna with many endemic species (Figure I). More than 50% has been cleared, mainly for pasture and the cultivation of cash crops. Biodiversity is threatened by habitat loss, soil degradation, the spread of exotic species, pollution caused by agricultural chemicals and fire damage [34]. Drivers of agricultural expansion in the region include the MERCOSUR trade agreement, increased international demand for soya products and agricultural policy reform in Brazil [32]. Conversion of the Cerrado to crop production is expected to continue, promoted by international agricultural deregulation [32] and the Brazilian congress' approval of low-cost genetically modified strains of soya and cotton [34].

To aid the creation of integrated land-use policies and biodiversity conservation in the Cerrado, we suggest that several techniques described in this review could be put into practice.

- Yield–density relationships of key species across the range of existing land-use in the Cerrado and monitoring of important taxa before, during and after agricultural conversion would increase understanding of the response of biodiversity to agricultural land-use. Data could be used to inform decisions on the use of land sparing and wildlife-friendly farming to conserve biodiversity and improve sustainability.
- Sector modelling would provide predictions of the rate and type of agricultural expansion across the Cerrado, while econometric estimation of site-specific agricultural profitability would identify places most likely to be affected by expansion and highlight areas of high priority for policy makers.
- A combination of individual farm modelling and socio-psychological approaches would enable predictions of the economic consequences of different land-use policy scenarios and provide a social context for those predictions.
- Actor network theory could aid identification and monitoring of all actors affected by policy implementation and act as a framework for monitoring the success of integrated policies.

Figure I. The Brazilian Cerrado. Pristine woodland is shown in the foreground, behind an area that has been cleared for grazing. Reproduced with permission from Thais Martins.

In some developed countries in which biodiversity of high conservation value is often closely associated with agricultural habitats (e.g. the EU), wildlife-friendly farming has been adopted as the primary biodiversity conservation strategy [8,9]. In these cases, the ecological toolkit described above is being used to identify management measures that can be adopted by farmers. However, in the EU, calls have been made to consider agricultural land in a broader context [78], which would require consideration of alternative conservation strategies within a more holistic framework. This has many parallels with the framework and information needs pertinent to countries undergoing agricultural development outlined above. Ecologists have an important role in informing such a debate.

More generally, there is a need for ecologists to work more closely with social scientists who are attempting to link policy reform and other drivers with land-use and land-use change to integrate the different ecological approaches with socio-economic modelling. This would enable researchers, for example, to assess how biodiversity is likely to respond to policy reform and to identify how policy might need to be reformed to generate land-use that is compatible with biodiversity conservation. Effective integration would provide a framework for exploring the links between land-use drivers, resultant land-use and biodiversity (Figure 1).

The type of ecological integration will depend broadly on the spatial scale over which socio-economic models operate and the need for spatially explicit predictions of land-use. For example, sector modelling provides coarse-grained insights into land-use change at various scales (e.g. economic areas, countries or regions). Some ecological studies have linked data that are typical outputs of sector models with trends in biodiversity [5]. However, sector models do not make spatially explicit predictions about land-use change, and can only be linked with large-scale datasets that are limited in availability.

Farm models can provide explicit predictions about land-use change, including the conversion of natural habitats to agricultural production [48]. They vary in the spatial resolution of the resultant land-use, from 'representative farms' that provide a relatively coarse-grained description of land-use to 'individual farms' that provide field-scale resolution. Potentially, farm models can be integrated with the range of ecological approaches described above, the most appropriate type of farm model being dictated largely by the spatial resolution in land-use predictions required for a specific ecological application. Farm models also provide a framework for moving between ecological scales. For example, field-scale experimental data on land-use and biodiversity could be combined with farm models, and potentially other ecological approaches, to explore patterns in biodiversity at larger spatial scales.

Predicted land-use derived from farm models is based on economic decisions rather than taking account of the broader socio-economic environment within which farmers make land-use decisions. Approaches that consider this broader context, such as the Theory of Planned Behaviour, could be used to predict possible land-use changes in response to policy reform, among other factors, that could then be linked with ecological approaches to understand how biodiversity might respond. However, there is a real practical need for more generic, predictive tools that permit a scenario-based approach to exploring the links between policy, land-use and biodiversity. Although social scientists are resistant to a 'reductionist' approach to human decision-making, recent work has shown that such ideas, which are used widely in ecology, can provide insights [79,80]. In our view, there is merit in bringing social science and ecological approaches together to identify if/when general rules might provide valuable insights into land-use decisions by farmers and when a more case-specific approach is needed.

Conclusions

There has been considerable recent ecological research aimed at exploring the links between land-use and biodiversity, and applying this research to benefit biodiversity conservation. We now need a more integrated approach in two main areas that recognizes the broader context within which changes in agricultural land-use occur. First, ecologists need to recognize that wildlife-friendly farming is not the only land-use strategy that can be used to conserve biodiversity, and to devote research resources to identifying the most ecologically appropriate strategy in a particular set of circumstances. Second, there is an urgent need for social scientists and ecologists to bring their approaches together, so that land-use change and its consequences can be investigated in a more holistic way. Although this integration is challenging, its achievement is, in our view, the only effective way to address the multiple facets that constitute sustainable land-use.

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References

1 Scharlemann, J.P.W. *et al*. (2004) Land-use trends in Endemic Bird Areas: global expansion of agriculture in areas of high conservation value. *Glob. Change Biol.* 10, 2046–2051
2 Scharlemann, J.P.W. *et al*. (2005) The level of threat to restricted-range bird species can be predicted from mapped data on land use and human population. *Biol. Conserv.* 123, 317–326
3 Ricketts, T. and Imhoff, M. (2003) Biodiversity, urban areas, and agriculture: locating priority ecoregions for conservation. *Conserv. Ecol.* 8, 1 (http://www.consecol.org/vol8/iss2/art1/)
4 Wessels, K.J. *et al*. (2003) Identification of potential conflict areas between land transformation and biodiversity conservation in north-eastern South Africa. *Agricult. Ecosyst. Environ.* 95, 157–178
5 Donald, P.F. *et al*. (2001) Agricultural intensification and the collapse of Europe's farmland bird populations. *Proc. R. Soc. London B. Biol. Sci.* 268, 25–29
6 Wilson, J.D. *et al*. (1999) A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. *Agricult., Ecosyst. Environ.* 75, 13–30
7 Green, R.E. *et al*. (2005) Farming and the fate of wild nature. *Science* 307, 550–555
8 Buller, H. *et al*. (2000) *Agric.-environmental Policy in the European Union*, Ashgate
9 Vickery, J.A. *et al*. (2004) The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. *Biol. Conserv.* 119, 19–39

10 Kleijn, D. *et al*. (2001) Agric.-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. *Nature* 413, 723–725
11 Kleijn, D. and Sutherland, W.J. (2003) How effective are European agri-environment schemes in conserving and promoting biodiversity? *J. Appl. Ecol.* 40, 947–969
12 Mannion, A.M. (2002) *Dynamic World: Land-Cover and Land-Use Change*, Arnold
13 World Trade Organisation (1994) *Agreement on Agriculture. Commitments on Tariffs, Tariff Quotas, Domestic Supports, Export Subsidies: in Schedules Annexed to the Marrakesh Protocol to the General Agreement on Tariffs and Trade 1994*, WTO (http://www.wto.org/english/docs_e/legal_e/14-ag.pdf)
14 Grossman, M.R. (2003) The Uruguay round agreement on agriculture and domestic support. In *Agriculture and International Trade: Law, Policy and the WTO* (Cardwell, M.N. *et al*., eds), pp. 27–47, CABI Publishing
15 World Trade Organisation (2003) *Understanding the WTO*, 3rd edn, WTO Information and Media Relations Division
16 World Trade Organisation (2004) *Dohar Work Programme: Decision Adopted by the General Council on 1 August 2004*, WTO. Document no. WT/L/579 (http://www.wto.org/english/tratop_e/dda_e/dda-draft_31jul04_e.pdf)
17 Anania, G. *et al*. (2004) *Agricultural Policy Reform and the WTO: Where are We Heading?*, Edward Elgar
18 Adhikari, R. and Athukorala, P. (2002) *Developing Countries in the World Trading System: the Uruguay Round and Beyond*, Edward Elgar
19 Organisation for Economic Co-operation and Development (2004) *Agricultural Policies in OECD Countries at a Glance: 2004 Edition*, OECD Publishing
20 Guyomard, H. *et al*. (2000) Impact of the 1996 US FAIR Act on the Common Agricultural Policy in the World Trade Organisation context: the decoupling issue. *Food Policy* 25, 17–34
21 Sumner, D.A. (2003) Farm subsidies and agricultural trade policy: the case of US support programmes. In *Agriculture and International Trade: Law, Policy and the WTO* (Cardwell, M.N. *et al*., eds), pp. 69–84, CABI Publishing
22 Rodgers, C.P. and Cardwell, M.N. (2003) The WTO, international trade and agriculture policy reform. In *Agriculture and International Trade: Law, Policy and the WTO* (Cardwell, M.N. *et al*., eds), pp. 1–25, CABI Publishing
23 Grossman, M.R. (2003) Multifunctionality and non-trade concerns. In *Agriculture and International Trade: Law, Policy and the WTO* (Cardwell, M.N. *et al*., eds), pp. 85–129, CABI Publishing
24 Cardwell, M. (2003) Multifunctionality of agriculture: a European Community perspective. In *Agriculture and International Trade: Law, Policy and the WTO* (Cardwell, M.N. *et al*., eds), pp. 131–164, CABI Publishing
25 Cloke, P. and Le Heron, R. (1994) Agricultural deregulation: the case of New Zealand. In *Regulating Agriculture* (Lowe, P., *et al*., eds), pp. 104–126, David Fulton
26 Anderson, K. (1992) Agricultural trade liberalisation and the environment: a global perspective. *World Econ.* 15, 153–171
27 Bradshaw, B. and Smit, B. (1997) Subsidy removal and agroecosystem health. *Agricult. Ecosyst. Environ.* 64, 245–260
28 Potter, C. and Goodwin, P. (1998) Agricultural liberalization in the European Union: an analysis of the implications for nature conservation. *J. Rural Stud.* 14, 287–298
29 Bradshaw, B. (2004) Plus c'est la même chose? Questioning crop diversification as a response to agricultural deregulation in Saskatchewan, Canada. *J. Rural Stud.* 20, 35–48
30 Schnepf, R.D. *et al.* (2001) Agriculture in Brazil and Argentina: developments and prospects for major field crops. *Agriculture and Trade Report WRS-01-3*. Market and Trade Economics Division, Economic Research Service, US Department of Agriculture http://www.ers.usda.gov/publications/wrs013/
31 Fearnside, P.M. (2005) Deforestation in Brazilian Amazonia: history, rates, and consequences. *Conserv. Biol.* 19, 680–688
32 Klink, C.A. and Machado, R.B. (2005) Conservation of the Brazilian Cerrado. *Conserv. Biol.* 19, 707–713
33 Breth, S.A. (2004) *From Subsistence to Sustainable Agriculture in Africa*, Sasakawa African Association
34 Madhusudan, M.D. (2005) The global village: linkages between international coffee markets and grazing by livestock in a south Indian wildlife reserve. *Conserv. Biol.* 19, 411–420
35 Angelsen, A. and Kaimowitz, D. (1999) Rethinking the causes of deforestation: lessons from economic models. *World Bank Res. Obs.* 14, 73–98
36 Barbier, E.B. (2004) Explaining agricultural land expansion and deforestation in developing countries. *Am. J. Agricult. Econ.* 86, 1347–1353
37 Coxhead, I. and Demeke, B. (2004) Panel data evidence on upland agricultural land use in the Philippines: can economic policy reforms reduce environmental damages? *Am. J. Agricult. Econ.* 86, 1354–1360
38 Hazell, P.B.R. and Norton, R. (1986) *Mathematical Programming for Economic Analysis in Agriculture*, MacMillan
39 Ugarte, D.G.D. and Ray, D.E. (2000) Biomass and bioenergy applications of the POLYSYS modeling framework. *Biomass Bioenergy* 18, 291–308
40 Walsh, M.E. *et al*. (2003) Bioenergy crop production in the United States - potential quantities, land use changes, and economic impacts on the agricultural sector. *Environ. Resour. Econ.* 24, 313–333
41 Wu, J. *et al*. (2004) From micro-level decisions to landscape changes: an assessment of agricultural conservation policies. *Am. J. Agricult. Econ.* 86, 26–41
42 Antle, J.M. and Capalbo, S.M. (2001) Econometric-process models for integrated assessment of agricultural production systems. *Am. J. Agricult. Econ.* 83, 389–401
43 Roundsevell, M.D.A. *et al*. (2003) Modelling the spatial distribution of agricultural land use at the regional scale. *Agricult. Ecosyst. Environ.* 95, 465–479
44 Kruseman, G. *et al*. (1995) Farm household modelling for estimating the effectiveness of price instruments in land use policy. *Neth. J. Agricult. Sci.* 43, 111–123
45 Lauber, S. *et al*. (2004) Combining farm models and GIS to examine farm structures, land use and effects on landscape. *Grassland Sci. Eur.* 9, 100–102
46 Jansen, H.G.P. *et al*. (2005) An interdisciplinary approach to regional land use analysis using GIS with applications to the Atlantic Zone of Costa Rica. *Agricult. Econ.* 32, 87–104
47 Edward-Jones, G. *et al*. (1998) Incorporating psychological variables in models of farmer behaviour: does it make for better predictions? *Etudes Res. Syst. Agraires Dev.* 31, 153–173
48 Lowe, P. *et al*. (1997) *Moralizing the Environment: Countryside Change, Farming and Pollution*, UCL Press
49 Burgess, J. *et al*. (2000) Knowledges in action: an actor network analysis of a wetland agri-environment scheme. *Ecol. Econ.* 35, 119–132
50 Morris, C. (2004) Networks of agri-environmental policy implementation: a case study of England's Countryside Stewardship Scheme. *Land Use Policy* 21, 177–191
51 Ajzen, I. (1991) The theory of planned behaviour. *Org. Behav. Human Dec. Proc.* 20, 179–211
52 Burton, R.J.F. (2004) Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective. *J. Rural Stud.* 20, 359–371
53 Beedell, J. and Rehman, T. (2000) Using socio-psychology models to understand farmers' conservation behaviour. *J. Rural Stud.* 16, 117–127
54 Carr, S. and Tait, J. (1990) Farmers' attitudes to conservation. *Built Environ.* 16, 218–231
55 Zeki, S. (ed) (2003) The farm-scale evaluations of spring-sown genetically modified crops. *Philos. Trans. R. Soc. London B* 358, 1775–1890
56 Laurance, W.F. *et al*. (2002) Ecosystem decay of Amazonian rainforest fragments: a 22-year investigation. *Conserv. Biol.* 16, 605–618
57 Smith, R.K. *et al*. (2004) Conservation of European hares *Lepus europaeus* in Britain: is increasing habitat heterogeneity the answer? *J. Appl. Ecol.* 41, 1092–1102
58 Poyry, J. *et al*. (2005) Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. *Biol. Conserv.* 122, 465–478
59 Norris, K. (2004) Managing threatened species: the ecological toolbox, evolutionary theory and declining population paradigm. *J. Appl. Ecol.* 41, 413–426

60 Green, R.E. (1996) Factors affecting the population density of corncrakes *Crex crex* in Britain and Ireland. *J. Appl. Ecol.* 33, 237–248
61 Green, R.E. *et al*. (1997) A simulation model of the effect of mowing of agricultural grassland on the breeding success of the corncrake (*Crex crex*). *J. Zool.* 243, 81–115
62 Van Horne, B. (1983) Density as a misleading indicator of habitat quality. *J. Wildl. Manage.* 47, 893–901
63 Kokko, H. and Sutherland, W.J. (2001) Ecological traps in changing environments: ecological and evolutionary consequences of a behaviourally mediated Allee effect. *Evol. Ecol. Res.* 3, 537–551
64 Petit, S. *et al*. (2003) Knowledge based models for predicting species occurrence in arable conditions. *Ecography* 26, 626–640
65 Whittingham, M.J. *et al*. (2003) Do habitat association models have any generality? Predicting skylark *Alauda arvensis* abundance in different regions in southern England. *Ecography* 26, 521–531
66 Chamberlain, D.E. *et al*. (2004) Rule-based predictive models are not cost-effective alternatives to bird monitoring on farmland. *Agricult. Ecosyst. Environ.* 101, 1–8
67 Peach, W.J. *et al*. (2001) Countryside stewardship delivers cirl buntings (*Emberiza cirlus*) in Devon, UK. *Biol. Conserv.* 101, 361–373
68 Robinson, R.A. *et al*. (2001) The importance of arable habitats for farmland birds in grassland landscapes. *J. Appl. Ecol.* 38, 1059–1069
69 Reed, J.M. *et al*. (2002) Emerging issues in population viability analysis. *Conserv. Biol.* 16, 7–19
70 Aebischer, N.J. and Ewald, J.A. (2004) Managing the UK grey partridge *Perdix perdix* recovery: population change, reproduction, habitat and shooting. *Ibis* 146, 181–191
71 Topping, C.J. and Odderskaer, P. (2004) Modelling the impact of temporal and spatial factors on the assessment of impact of pesticides on skylarks. *Environ. Toxicol. Chem.* 23, 509–520
72 Coulson, T. *et al*. (2001) The use and abuse of population viability analysis. *Trends Ecol. Evol.* 16, 219–221
73 Brook, B.W. *et al*. (2002) Critiques of PVA ask the wrong questions: throwing the heuristic baby out with the numerical bathwater. *Conserv. Biol.* 16, 262–263
74 Stephens, P.A. *et al*. (2003) Predicting the response of farmland bird populations to changing food supplies. *J. Appl. Ecol.* 40, 970–983
75 Sutherland, W.J. and Norris, K. (2002) Behavioural models of population growth rates: implications for conservation and prediction. *Philos. Trans. R. Soc. London B* 357, 1273–1284
76 Tejeda-Cruz, C. and Sutherland, W.J. (2004) Bird responses to shade coffee production. *Anim. Conserv.* 7, 169–179
77 Mooney, H. *et al*. (2005) How can ecosystems provide sustainable services to benefit society? *Nature* 434, 561–562
78 Sutherland, W.J. (2002) Restoring a sustainable countryside. *Trends Ecol. Evol.* 17, 148–150
79 Bowles, S. and Posel, D. (2005) Genetic relatedness predicts South African migrant workers' remittances to their families. *Nature* 434, 380–383
80 Mace, R. (1993) Nomadic pastoralists adopt subsistence strategies that maximize long-term household survival. *Behav. Ecol. Sociobiol.* 33, 329–334
81 Hoekman, B. *et al*. (2004) Agricultural tariffs or subsidies: which are more important for developing economies? *World Bank Econ. Rev.* 18, 175–204