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A novel, integrated approach to assessing social, economic and environmental implications of changing rural land-use: a case study of perennial biomass crops

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Summary

1. Concern about climate change and energy security is stimulating land-use change, which in turn precipitates social, economic and environmental responses. It is predicted that within 20 years in the UK, bioenergy crops could occupy significant areas of rural land. Among these, dedicated biomass crops, such as Miscanthus (*Miscanthus* spp.) grass and short rotation willow (*Salix* spp.) coppice, differ significantly from arable crops in their growth characteristics and management. It is important that the potential impacts of these differences are assessed before large-scale, long-term planting occurs.

2. We used a Sustainability Appraisal Framework (SAF) approach to landscape planning in the UK to identify stakeholder aspirations (objectives) and associated criteria (indicators) for the planting of dedicated biomass crops.

3. The use of environmental and physical constraints mapping allowed the SAF to focus only on environmentally-acceptable locations, thereby avoiding unsustainable trade-offs. The mapping identified 3·1 million ha of land in England as suitable for planting, suggesting the UK government target of 1·1 million ha by 2020 is feasible.

4. Evaluation of the SAF identified that while biodiversity was of concern to stakeholders, some current indicators of biodiversity are not appropriate. Butterfly abundance proved the most appropriate indicator, and it was found that total abundance was greater in field margins of both willow and Miscanthus biomass crops than in arable field margins.

5. *Synthesis and applications.* The potential conflicts of assuring food security, water availability, energy security and biodiversity conservation are recognized as a key challenge by governments worldwide. Methods with which decision-makers can compare the performance of different land-use scenarios against sustainability objectives will be crucial for achieving optimized and sustainable use of land-based resources to meet all four challenges. Using biomass crops planting as an example, this work illustrates the potential of a Sustainability Appraisal Framework, subject to identification and agreement of appropriate indicators, in securing a holistic understanding of the wide-ranging implications of large-scale, long-term changes to rural land-use in the wider context of sustainable land-use planning *per se*.

Key-words: biodiversity, butterflies, constraints mapping, bioenergy crops, farmland, Lepidoptera, Miscanthus, short-rotation coppice willow, sustainability appraisal

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Introduction

Landscapes that are dominated by arable agriculture are continuously subject to changes resulting from the choice of crops and adoption of different cropping land-use patterns and crop rotations. Market forces and policy can influence the expansion of crops that were previously only grown over limited areas and the introduction of entirely novel crops into the landscape. Although such changes have always occurred, increasing concerns over energy security and climate change are precipitating major land-use changes which could take place over relatively short time-scales and affect significantly large areas of land. Given that crop-use changes, such as the expansion of perennial biomass crops, could have environmental impacts, it is perhaps surprising that the majority of agricultural or forestry activities, even on such large scales, are not considered to be 'development' as recognized in land-use planning. Effectively, this means that, even on a policy-led predicted large-scale basis, crop planting is currently done without appraisal.

The Kyoto Protocol of the United Nations Framework Convention on Climate Change set targets for industrialized nations to reduce greenhouse gases (GHG) emissions (UN 1998). The European Union (EU) ratified the Kyoto Protocol in 2002 (EU 2008) and, in 2007, set a target to achieve at least a 20% reduction by 2020, compared with 1990 (Anonymous 2007). The key aspirations of the UK government set out in the Energy White Paper are to reduce CO_2 emissions to 26–32% of 1990 concentrations by 2020, and increase the proportion of electricity generated from renewable sources to 20% by 2020 (DTI 2007). Steep rises in fossil-fuel energy prices (see DBRR 2008) are also likely to encourage domestically produced sources of alternative fuels. A portfolio of renewable energy sources will be required to meet all these demands and bioenergy crops are expected to make a potentially large contribution (Sims *et al.* 2006).

Perennial biomass crops, such as grasses and fast-growing trees, have particular advantages as bioenergy sources: they are not food crops; there is no annual cultivation cycle; they achieve rapid growth with the potential to produce large yields with low fertilizer and pesticide requirements; and life-cycle analyses of heat, electricity and liquid biofuel production indicate both high energy savings and substantial reductions in GHG emissions (Cocco 2007; Karp & Shield 2008). These advantages have been recognized by both the EU and the UK government, leading to incentives such as the Energy Crops Scheme (Natural England 2008), and a large expansion of land under such crops is thus anticipated. In the UK, the two most developed and widely grown biomass crops are Miscanthus grass (*Miscanthus* × *giganteus*) and short-rotation coppice (SRC) willow (*Salix* spp.). In 2003, these crops occupied less than 2000 ha but now cover *c.* 15 000 ha in England (National Non-Food Crops Centre 2008). The UK government's Biomass Strategy (Defra 2007a) suggests that bioenergy crops, including dedicated biomass crops, grown for generating heat and power could occupy some 1·1 million ha by 2020.

Miscanthus is a rhizomatous grass that originates from Asia (Lewandowski *et al.* 2003; Clifton-Brown *et al.* 2004). Commercially grown Miscanthus is a naturally-occurring sterile hybrid (Clifton-Brown *et al.* 2000). It undergoes C_4 photosynthesis, but is able to produce commercially sufficient biomass yield in the temperate climate of the mid-southern UK as it is more cold-tolerant than, for example, maize (*Zea mays* L.). It is planted as rhizomes in early spring and shoots emerge once mean daytime temperatures exceed *c.* 9 °C (Farrell *et al.* 2006). Miscanthus reaches heights of *c.* 3 m in the UK, before senescing over the winter months. It is harvested annually in late winter/early spring for up to 20 years (Defra 2007b).

Willows are C_3 shrubs and trees that are widely distributed in temperate climates with many species native to the UK and Europe. SRC willows are established by planting 18–20-cm stem cuttings in spring (Defra 2004). Growth occurs largely as single stems in the 'establishment' year, achieving heights of up to 2·5 m by September. The stems are cut back in December–March, after leaf drop. During the following spring, the cut stumps re-sprout to provide multiple 'coppice' shoots which are harvested after 3 years, by which time they may be *c.* 5 m in height. SRC is typically continued on a 3-year cycle for up to 25 years (Defra 2004; Karp & Shield 2008).

The growth attributes and perenniality of Miscanthus and SRC willow present important differences to most current rural land-uses: Unlike arable crops, biomass crops remain *in situ* for 7–25 years; harvest is carried out in winter/early spring (over *c.* 3-year cycles for SRC); the crops are very tall (3–5 m) and dense; and, there are very few agrochemical inputs (see Tubby & Armstrong 2002; Defra 2004, 2007b). These factors modify the appearance of the rural landscape and have potential implications for tourist income, farm income, hydrology and biodiversity.

A number of small-scale studies have investigated the potential impacts on biodiversity (e.g. Sage 1995; Cunningham *et al.* 2004; Semere & Slater 2005; Sage *et al.* 2006) and water use (Howes *et al.* 2002; Finch *et al.* 2004) of biomass crops, in particular SRC willow. Best-practice guidelines and plantation management protocols designed to address, for example, visual impact, biodiversity or hydrological considerations, are also available (Tubby & Armstrong 2002; Defra 2004, 2007b). Impacts of these crops may be varied. For example, mixtures of willow SRC comprise parental stock of species native to the UK and may therefore support a species-rich insect community and wider-associated biodiversity. Miscanthus, however, is non-native and as such may support low biodiversity. Thus, there are many challenges to be faced in meeting the requirements for sustainable production of sufficient feedstock from these crops from large-scale land conversion, while avoiding conflicts with other land-uses or ecosystem functions (e.g. JNCC 2007; UN 2007; Firbank 2008; Rowe *et al.* 2008; The Royal Society 2008).

Despite the lack of land-use planning control in the agricultural sector, some useful tools for informing decision- and policy-makers of the implications of their actions do exist in other sectors which can be usefully applied to agricultural policy. Some form of environmental assessment has been required in the EU since 1988 when the Environmental Assessment Directive (Council of the European Communities 1985) required the assessment of the implications on the environment of new projects. The Strategic Environmental Assessment Directive (European Parliament and the Council of the European Union 2001) extended this requirement to plans and programmes in 2004 and the Planning and Compulsory Purchase Act (UK Parliament 2004) expanded the scope, for local authorities in England only, to include social and economic factors in a Sustainability Appraisal (SA) of their plans.

SA is an objectives-driven approach, which relies on the derivation of aspirational sustainability objectives, against which different plan performances can be compared. By engaging stakeholders (see European Parliament and the Council of the European Union 2003) with ecologists and other relevant scientists, empirical objectives that can be measured are identified. Targets and indicators of these empirical objectives are used to assess the performance of alternatives. Essentially, SA can be seen as an analytic–deliberative process which fuses quantitative, expert-derived data with stakeholder concerns and values (see Petts 2003; Wiklund 2005; Chilvers 2007). For biodiversity, a typical objective is '*to maintain and enhance biodiversity, flora and fauna*' (Office of the Deputy Prime Minister 2005, p. 112). With no agreed definition of biodiversity (Slootweg 2005; Wegner *et al.* 2005), this raises the question as to whether the complexity of biodiversity can be represented in just a few indicators and, given that their selection is value-based, how can objectivity be maintained (see Cloquell-Ballester *et al.* 2006)? Thus, the analytic scope of the process can be seen as encompassing evaluation of the suitability of indicators, and the collection and interpretation of data while the deliberative scope encompasses selection and agreement of the objectives and indicators along with interpretation of data.

Ecological indicators are used to assess the condition of the environment or to monitor trends in condition over time; they can provide an early warning signal and help diagnose the cause of an environmental problem (Cairns *et al.* 1993). The characteristics of indicator species are used as an index of attributes that are too difficult, inconvenient or expensive to measure for other species or environmental conditions of interest (Landres *et al.* 1988). For example, changes in abundance and diversity of taxa can easily be measured at detailed spatial and temporal scales, but they can only reasonably be used as indicators for higher trophic levels, (e.g. seeds as a food resource for birds; Gibbons *et al.* 2006). Arthropods have long been advocated as potential ecological indicators (Kremen *et al.* 1993). Butterfly Lepidoptera have been proposed specifically since, amongst the selection criteria for effective indicators proposed by Dale & Beyeler (2001), they are easily measurable, sensitive to and responsive to environmental stresses, predictors of change, representative of other taxa (Wilson *et al.* 2004; Thomas 2005; Nelson 2007), occur in most terrestrial habitats (e.g. Asher *et al.* 2001) and, in the UK and Europe, monitoring schemes plot the distributions of species at scales of 1–100 km^2 (Asher *et al.* 2001; van Swaay 2003). Thus, measures of butterfly abundance are currently being developed as headline UK farmland biodiversity indicators (UKBMS 2008).

In this study, we outline how, as part of the RELU-Biomass project (www.relu-biomass.org.uk), we are addressing these sustainable land-use planning and biodiversity assessment challenges for the large-scale, long-term introduction of Miscanthus and SRC willow in two regions of England. The East Midlands and South- west Regions (Government Offices 2008) were selected as they contrast greatly in their geographic, farming (Government Offices 2008) and Environmental Zone (Haines-Young 2000) and yet have already witnessed significant plantings of biomass crops (Natural England 2008). Here, we introduce a biomass-planting-specific Sustainability Appraisal Framework (SAF) to demonstrate how it can be used in combination with constraints mapping to protect sensitive habitats against the inevitable trade-offs inherent in decision- making. We demonstrate an appropriate biodiversity indicator from a suite of tools being tested in the RELU-Biomass project that can be used in a range of crops and landscapes under varying management, and we provide some preliminary results from its applications.

Methods

CONSTRAINTS MAPPING

A GIS-based constraints mapping exercise, using data from a review of relevant literature, was conducted to identify areas where Miscanthus and SRC willow planting should not (e.g. for environmental reasons, such as the area is a protected habitat) or could not (e.g. for feasibility reasons, such as the slope is too steep) take place (Table 1). Agricultural land is officially classified from Grades 1 (best) to 5 (worst) (MAFF 1988) and it was assumed that perennial energy crops will not be grown on the best quality land as just over 80% of approved agreements under the Energy Crops Scheme from 2001 to 2007 were on land in Grades 3 or 4 (Natural England 2008). These criteria were combined to identify areas of land that were best suited to energy crop planting for use in the SAF.

SUSTAINABILITY APPRAISAL

Stakeholders were identified through existing contacts known to the project team, assisted by a project Advisory Group (details are available on the RELU-Biomass website, www.relu-biomass.org.uk). An initial workshop was held in each region in 2006 in which stakeholders (13 in the South-west and 14 in the East Midlands) were asked to brainstorm objectives and indicators which would form the basis for the SAF in line with practice suggested by Donnelly *et al.* (2006). In an attempt to avoid unbalanced focus on any particular pillar of sustainability, the meetings were structured so that participants were given equal time to suggest social, environmental and economic indicators. Each participant had access, for guidance, to objectives and indicators suggested by the Government for land-use planning (Office of the Deputy Prime Minister 2005); there was no instruction to 'choose' from those listed. The project team subsequently reworded the SAF to ensure clarity of terminology and undertook additional workshops in each region in 2007 (eight attendees in the South-west

Table 1. Table of criteria and their sources used to create constraints for planting energy crops

Constraints criteria	Source
Unsuitable soil types (e.g. peat)	NSRI NATMAP 1000 data
Slope steepness ≥ 15%	Ordnance Survey Panorama DEM
Areas of improved grassland	CEH Land Cover Map 2000
Existing woodland	Forestry Commission National Inventory of Woodland and Trees, Ancient Woodland areas from MAGIC (http://www.magic.ac.uk)
Urban areas	Ordnance Survey Meridian data
Major rivers	Ordnance Survey Meridian data
Lakes	Ordnance Survey Meridian data
BAP priority and semi-natural habitats	Natural England
Designated nature conservation areas	Natural England or MAGIC website
Designated or registered cultural heritage sites	English Heritage or MAGIC website
Designated areas of landscape sensitivity	MAGIC website

and 10 in the East Midlands) to review objectives and indicators and to suggest changes where appropriate. Subsequent changes were then circulated by e-mail to all identified stakeholders and agreement obtained.

The indicators were then evaluated against the criteria outlined by Donnelly *et al.* (2007). The evaluation identified those indicators which were considered to be unsuitable and afforded opportunities for the project team to subsequently suggest more appropriate indicators based on expert knowledge.

BIODIVERSITY

Local, native populations of characteristic plant and invertebrate species and/or groups was identified as the most suitable indicator selected by stakeholders, (see Results section and Table 4), and butterflies were selected as a test indicator group from a diverse range of plants and invertebrates being assessed as part of the RELU-Biomass project. The abundance counts of families of butterfly in the field margins surrounding Miscanthus and SRC willow were recorded and compared with counts of butterfly species in field margins of arable break crops. Data for the arable crops came from 255 fields, made up of 65 fields of spring-sown beet (*Beta vulgaris* L.), 58 fields of spring-sown maize (*Zea mays* L.), 67 fields of spring-sown oilseed rape (*Brassica napus* L.) and 65 fields of winter-sown oilseed rape (*B. napus* L.), sampled as part of the Farm Scale Evaluations (FSEs) from 2000 to 2003 (Firbank *et al.* 2003; Roy *et al.* 2003; Bohan *et al.* 2005). The distribution of these fields followed the national distribution of arable crops across Great Britain (Champion *et al.* 2003; Bohan *et al.* 2005). The FSEs used a split-field design, where the current 'conventional' arable practice was compared to a modified herbicide management regime associated with genetically modified, herbicide-tolerant crops. Here, only data from the conventional half of the split field are used. Three 100-m-long transects, one in each of the margins of the conventional half, were walked on a number of occasions, depending on the weather, in May, June, July and August.

Butterflies were sampled on transects in the margins of 16 Miscanthus and 16 willow SRC fields in 2006 and 2007, following the methods used in the FSEs (Firbank *et al.* 2003; Haughton *et al.* 2003; Bohan *et al.* 2005). In the biomass crops, one transect was located at each of the four sides of the fields. All the fields were in commercial production of biomass for energy or, in the case of some Miscanthus fields, the production of rhizomes for future planting. The fields were planted between 1999 and 2003, were due to be harvested during the winter following data collection and represent mature biomass crops. The distribution of the fields reflected the current national picture of planting in Great Britain, covering the East Midlands, South-west and Southern regions of England (Natural England 2008).

Table 2. Constraint mapping results for the East Midlands and South-west study regions. Areas are in thousands hectare

	East Midlands	South-west	England
Total land area	1563	2383	13 039
Area meeting constraints	613	410	3120

For butterfly family groups and total butterflies, mean year totals per kilometre of transect walked were calculated for each FSE site (0·3 km per visit, and between 1 and 7 sampling visits) or Miscanthus or SRC willow fields (each 0·4 km per visit, and between 2–5 visits). Following $\log_{10}$ transformation, after adding an offset of one to allow for zeros, the mean logged count and variance was computed over all sites. For each group, the difference between the Miscanthus or willow SRC and FSE mean logged counts was then computed along with a 95% confidence interval. The mean and confidence limits were then back-transformed to the ratio scale.

Results

CONSTRAINTS MAPPING

In the East Midlands, the combination of criteria listed in Table 1 and a restriction to Grade 3 or 4 land excluded 61% of the region (leaving 613 000 ha), while for the South-west this was larger, at 83% of the land area (leaving 410 000 ha). For England as a whole, the area identified as suitable for planting energy crops was 3·1 million ha (Table 2).

SUSTAINABILITY APPRAISAL

The objectives identified by the stakeholders in the East Midlands and South-west region are listed in Table 3 and did not differ significantly.

Indicators suggested by stakeholders for measuring progress towards protecting and enhancing biodiversity reflect those for which data are currently collected and included numbers

Table 3. Sustainability appraisal objectives identified by stakeholders at regional meetings and organized into social, economic or environmental categories. Biodiversity objectives are italicized

Category	East Midlands objectives	South-west objectives
Social	Minimize transport movements	Minimize additional vehicle movements
	Enhance rural quality of life	Enhance rural quality of life
	Increase water availability	Maintain water availability
	Improve public enjoyment of the countryside	Improve public connection with the countryside
	Safeguard the historic environment	Safeguard the historic environment
Economic	Reduce energy costs to the consumer	Reduce energy costs
	Increase amount of energy produced locally	Increase amount of energy produced and used locally
	Increase the viability of local economies	Increase the viability of local economies
	Enhance tourism potential	Maintain tourism resource
	Enhance viability of farming	Enhance viability of farming
	Maximize waste management opportunities	Maximize waste management opportunities
	Enhance employment	Enhance rural employment
	Enhance local landscape character	Enhance local landscape character
	Improve water quality	Improve water quality
	Protect soil resources	Protect and improve soil resources
	Improve air quality	Improve air quality
	Maintain food security	
Environmental	*Protect and enhance biodiversity*	*Protect and enhance biodiversity*
	Reduce greenhouse gas emissions	Reduce greenhouse gas emissions

Table 4. Suitability of indicators (against Donnelly *et al.* 2007 criteria) selected by stakeholders in the East Midlands (EM) and South-west (SW) to test the 'protect and enhance biodiversity' sustainability objective

Suitability criteria	Farmland bird species (EM; SW)	Local (native) populations of characteristic plant and invertebrate species/groups (EM; SW)	Biodiversity action plan priority species and habitat status (EM; SW)
Policy relevant	✓	✓	✓
Cover a range of environmental receptors	✓	✓	✓
Relevant to the plan in question	✓	✓	✗
Show trends	✓	✓	✓
Be easily understandable to the public and decision-makers	✓	✓	✗
Be well-founded technically and scientifically	✓	✓	✓
Prioritize key issues and provide early warning	✗	✓	✗/✓
Adaptable to reflect differing circumstances	✗	✓	✗

of farmland bird species, and Biodiversity Action Plan (BAP) priority species and habitat status (both taken from HM Government 2005). A comparison of these indicators with criteria derived by Donnelly *et al.* (2007) revealed that some are unsuitable. For example, BAP priority habitats status is made redundant by the constraints mapping exercise. The general indicator, suggested by the authors and approved by the stakeholders, of abundance of plant and invertebrate species/groups, satisfied all criteria; thus, butterflies were selected as a representative group of this indicator (Table 4).

BIODIVERSITY

The abundance of total butterflies was significantly greater in field margins surrounding both Miscanthus and SRC willow (60% and 132% more butterflies, respectively) than in field margins of arable crops. The abundance of families of butterflies varied between field margins of biomass crops and the arable break crops, where the abundance of the Pieridae in Miscanthus and SRC willow field margins was lower than in arable field margins at 56% and 64%, respectively. Except for Lycaenidae in Miscanthus field margins, all other families of butterfly were significantly more abundant in field margins of biomass crops than in arable field margins. The Satyrinae showed the largest differences of 370% and 620% in Miscanthus and SRC willow, respectively (Figs 1 & 2).

Discussion

Constraints mapping, which eliminated land classed as inappropriate or unsuitable for planting Miscanthus or SRC willow, suggested that 39% of the land area of the East Midlands and 17% of the South-west regions could be suitable for energy crop planting. The higher area of land excluded from the South-west was due to physical factors such as slope steepness, the extent of permanent pasture and substantial

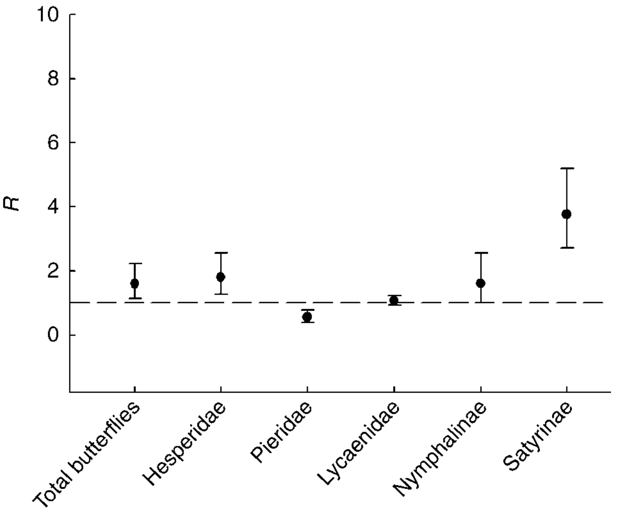

Fig. 1. Ratio (R) of families of butterfly in field margins around *Miscanthus* crops to arable crops. R is computed as 10^d, where d is the difference between the means (over sites) of the logarithmically transformed year totals per kilometre transect walked for each crop. Dashed line is line of unity ($d = 0$). Error bars are 95% confidence limits for R, also back-transformed to the ratio scale (hence asymmetry).

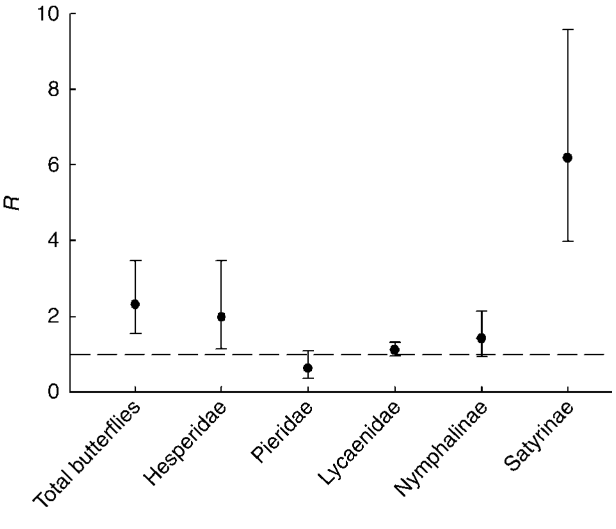

Fig. 2. Ratio (R) of families of butterfly in field margins around willow short-rotation coppice crops to arable crops. R and error bars computed as in Fig. 1. Dashed line is line of unity.

areas classed as sensitive landscapes. Using these approaches, the area identified as suitable for planting the two energy crops in England amounted to 3·1 million ha, which is considerably greater than the Biomass Strategy target of 1·1 million ha for bioenergy crops by 2020 (Defra 2007a) and implies that at least identifying potentially suitable land should not be a constraint on achieving this objective. Concerns have been raised that SA undermines environmental policy by allowing trade-offs of environmental resources against socio-economic gains (Pope *et al.* 2004; Morrison-Saunders & Fischer 2006) and, in this context, the value of using constraints mapping to protect ecologically sensitive areas before trade-offs can occur is clear. It should be noted, however, that much of the land identified as being suitable for growing biomass crops is currently used for growing arable crops, and therefore, there is a potential conflict between land-use for food and land-use for energy production (Lovett *et al.* 2009).

Small-scale biodiversity studies of early, non-commercial SRC willow fields suggested that the proportions of pre-existing and colonizing plant species changed to more slow-growing perennials as the crops matured (Sage 1995; Cunningham *et al.* 2004) and that compared with annual crops, invertebrates were recorded in relatively high densities (Sage & Tucker 1997; Cunningham *et al.* 2004). In a review, Sage *et al.* (2006) suggested a list of 28 breeding and/or wintering bird species that appeared to prefer SRC willow to cereal crops, including many on the UK Government's Woodland or Farmland Bird Index (Anonymous 1999). In contrast, very little research has been undertaken on biodiversity associated with Miscanthus. Benefits to biodiversity might be anticipated because the crops are harvested in late winter and the ground is not cultivated each year (Semere & Slater 2005). In this study, we indeed found that biodiversity, represented by the butterflies as indicators, was more abundant in biomass crop field margins than in arable crop field margins, supporting the indications of earlier work done in both biomass crops. There was also a greater abundance of families containing generalist species of intrinsic conservation interest (Asher *et al.* 2001) in the field margins of energy crops than in those of arable crops, while the abundance of the Pieridae, which comprises crop pest species such as *Pieris brassicae* (L.), was lower than in field margins of arable crops. One concern with comparing data collected at different times is that populations of butterflies in farmland, *per se*, may have changed, making such a comparison problematic. Although there have been annual fluctuations in generalist farmland butterfly populations, the trend from 2000 to 2006 has been stable (Defra 2006). Break crops of a typical arable rotation, such as those assessed in the FSEs, are often viewed as being richer in non-weed plant and non-pest invertebrate species than cereal crops because broad-leaved weeds are less well-controlled (Champion *et al.* 2003; Heard *et al.* 2005), and as such, these comparisons suggest the best-case scenario for butterfly abundance in arable crop field margins. Given that the majority of planting grants have been awarded to growers in arable growing areas (Natural England, personal communication), our data suggest that dedicated biomass crops placed in arable farmland could be used to provide habitat for intrinsically interesting butterflies, while not acting as a source of economically harmful pest species.

While the constraints mapping identified areas where it would be both appropriate and suitable to grow biomass crops, the butterfly biodiversity indicator selected to measure whether biomass crops would 'protect and enhance biodiversity' identified that, compared with contemporary arable cropping, Miscanthus and SRC willows could indeed be beneficial to biodiversity. The objectives selected by the stakeholders showed a tendency to be based on national guidance (Office of the Deputy Prime Minister 2005). Further, a comparison of the indicators selected by the stakeholders with criteria derived by Donnelly *et al.* (2006) revealed that despite being based on national guidance, some were unsuitable. This may call into question the suitability of existing indicators in common use. It is important to recognize that, while stakeholders identified objectives that were important to them, they required the 'expert knowledge' of the ecologists in the project team to identify an appropriate indicator to measure the effects of growing biomass crops. Given the role of the SAF as an analytic–deliberative tool for informing policy regarding biomass planting, it is clear that decisions are subject both to the value placed on ecological issues in comparison to other sustainability issues, that is, the objectives in the SAF, and also on the objectivity and suitability of the analytic data embedded in the method, (i.e. the indicators in the SAF; Table 4).

The goal of the RELU-Biomass project is to demonstrate the application of SAF to better understand the implications of alternative biomass planting scenarios. However, it became clear from the consideration of existing methods that more development is needed of, in particular, the appropriate ecological indicators which can be used in the SAF. A specific challenge is to identify more appropriate measures to examine, *inter alia*, the biodiversity implications of changing land-use from arable to biomass crops, in order that more appropriate data sets can be collected in the future to both assess and monitor potential impacts in robust and practical ways. This recognizes that existing applications of SA rely on indicators drawn from existing data sets rather than from those that are the most appropriate. Here, we have demonstrated both the generic role of ecological understanding and the specific utility of butterfly abundance as an appropriate ecological indicator. Ultimately, use of more appropriate indicators to assess all stakeholder-identified objectives (social, economic and environmental) will enhance the analytic component of SA. This could have far-reaching implications for the level of understanding of not only the ecological, but also the wider-ranging consequences of future decision-making in a diversity of sectors. A critical issue that remains, however, is the identification and application of a mechanism to implement the findings of SA such that benefits are maximized and impacts minimized.

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