Managing the Footprint of Agriculture: Towards a Comparative Assessment of Risks and Benefits for Novel Agricultural Systems

Report of the ACRE Sub-Group on Wider Issues raised by the Farm-Scale Evaluations of Herbicide Tolerant GM Crops

Revised after public consultation

3 May 2007

Summary

This report has been drawn up by a sub-group of the Advisory Committee on Releases to the Environment (ACRE) in response to requests by the Secretary of State and the Agriculture and Environment Biotechnology Commission to assess the wider implications of the Farm-Scale Evaluations (FSEs) of genetically modified herbicide tolerant (GMHT) crops. ACRE's remit is currently limited to GMOs and the release of certain non-GM species of plants and animals that are not native to the UK. However, this report is based on the experience gained by ACRE in reviewing the findings of the FSEs, on the deliberations of the ACRE sub-group established to examine the wider implications of this study, and on evidence submitted by a variety of stakeholders to an open meeting held in October 2004.

A draft version of this report was sent to a wide range of stakeholders for consultation on 17th March 2006, the consultation period ended 9th June 2006. The report has now been revised to take into consideration the evidence submitted in consultation responses. A document published alongside this report[1] details the responses made during the consultation period and the revisions made to the report.

In recent years, it has become apparent that there are inconsistencies in the regulatory assessment of the environmental impact of GM crops in comparison with other agricultural crops and practices. The EU Directive 2001/18, which covers the release of genetically modified organisms, requires an environmental risk assessment of possible immediate and/or delayed, direct and indirect environmental impacts of the specific cultivation, management and harvesting techniques used for the GM plant as part of a rigorous approval process. Non-GM crops and other changes to agricultural management do not require similar risk assessments.

Quantitative field studies have shown that the environmental impact of changes in agricultural management can be at least as significant as those associated with GM crops. Examples include the change from spring to winter sowing in arable crops and the shift from hay cutting to silage production. There is, however, currently no equivalent regulatory requirement for assessment of the positive and negative effects of such changes in agricultural practice on the environment prior to their widespread adoption.

This inconsistency is further illustrated by GM herbicide tolerant crops that require an extensive environmental risk assessment before approval for cultivation and marketing whilst herbicide tolerant crops produced by non-GM breeding methods can be grown without an equivalent assessment. The FSEs showed that differences in the impact on wild flora and fauna can be greater between different conventional crops (e.g. between maize and oilseed rape) than between a GM herbicide tolerant crop and its non-GM herbicide susceptible counterpart. Directive 2001/18, however, requires that the

[1] Overview of Responses available at www.defra.gov.uk/acre/fsewiderissues/

environmental impact of a GM crop is solely judged in comparison with the impact of its non-GM counterpart.

Directive 2001/18 also makes no provision for assessing both potential environmental risks and benefits. For example, the negative effects on weed and invertebrate populations of the herbicide treatment used in the FSEs with GM herbicide tolerant beet was a key factor in the decision not to permit the cultivation of GMHT beet as managed in the FSEs. As the Directive only considers risks, evidence of any potential environmental benefits (such as reduced herbicide use leading to reductions in direct and indirect CO_2 emissions arising from herbicide manufacture, transport and field operations) were not considered.

By contrast, environmental benefits are now a major focus in the introduction of a number of other novel crops (e.g. energy crops) and agricultural management practices in the UK. There is no regulatory requirement to assess potential environmental costs in a fashion similar to GM crops. Environmental benefits (or side-effects) are also the focus of the most recent round of EU and national agricultural policy reforms, which now focus on the multifunctional nature of agricultural systems, and their capacity to contribute to a wide variety of environmental goods and services in addition to food, fibre, oil and other primary products. Under new policies, and some emerging private markets, farmers will increasingly be paid to produce these environmental goods and services (such as flood protection, carbon sequestration, landscape aesthetics, and biodiversity services), as well as to continue to produce food.

It is possible to conceive of transitions towards environmental sustainability as arising partly from systems of management that minimise the negative side-effects of agriculture (environmental costs) whilst maximising positive side-effects (environmental goods). Thus, understanding and balancing the potential risks and benefits of existing and new agricultural technologies (whether GM or non-GM) should be part of the UK's current support for the goal of greater environmental sustainability in all its agricultural and land management systems. The wider challenge is to achieve such changes whilst sustaining the economic viability of farming. It is commonly stated that the farming industry only contributes a relatively small amount to GDP, yet this contribution rises substantially if all environmental goods and services are counted alongside primary food production.

To assess and manage more effectively the environmental footprint of agriculture as a whole, ACRE suggests that a broader and more balanced regulatory approach is required. This approach would deal not only with GM crops but also with other novel crops and agricultural practices. It would allow the assessment of both environmental risks and benefits, and the development of rigorous and balanced decisions.

The purpose of this report is to serve as a catalyst for debate about the future development and regulation of novel agricultural technologies and practices, and it is hoped that a number of agencies would find some utility in adopting the approach described. The report is primarily aimed at Ministers, policy makers and regulators in Defra, in the devolved administrations and across the EU.

ACRE concluded that the following principles should be used to guide future assessment of novel agricultural products and practices. An effective approach should:

1. take account of benefits as well as risks,
2. be evidence based,
3. recognise that an opportunity will often be needed to assess the impact of novel crops and practices on a limited scale, before widespread use,
4. be based on comparative assessment with current crops and practices,
5. protect and nurture opportunities for innovation and therefore choice of comparator should take care to avoid the rejection of novel crops and practices while retaining more damaging established crops and practices,
6. be straightforward to apply,
7. be sensitive to the competitiveness of all sectors of UK agriculture.

ACRE proposes a matrix-based approach in the form of a Comparative Sustainability Assessment (CSA) that could be used to encourage a more objective and comprehensive approach towards agricultural and rural policy. The CSA presented in this report has been revised in response to comments made during the consultation.

The revised CSA contains ten criteria for assessing sustainability, benefits and risks. None of these criteria have precedence, and all factors will be assessed and evaluated in order to come to a judgement.

This report contains seven worked examples to illustrate how the CSA might be used in practice. The examples were chosen to cover a broad range and include GM as well as non-GM examples. Although the focus of this report is on novel crops, animals and practices, examples of past introductions are included here to show their impact. The examples are:

i. Japanese Knotweed as an example of the past introduction of an ornamental plant;

ii. Winter wheat as an example of the past expansion of a crop/practice;

iii. Biocontrol of the European corn borer with *Trichogramma* as an example of the past introduction of a new practice (compared with two alternative control methods, insecticides and Bt maize);

iv. The energy crop Miscanthus as an example of a recently introduced crop;

v. Bt cotton as an example of a novel insect resistant GM crop;

vi. A comparison of herbicide tolerant amenity grasses developed through GM or conventional means – an example of a potential future introduction;

vii. American mink as an example of the past introduction of a non-native mammal.

The worked examples are a synopsis of the evidence that would be considered in a full CSA analysis, and illustrate that there are positive and negative side-effects in each case. These examples show that the introduction of ornamental plants and non-native mammals could have significant negative effects; that changes in agricultural practice can have major environmental impacts and that breeding methods are less important than the nature of the trait expressed by a novel crop. The worked examples highlight some areas of uncertainty and areas of further research, which would be required for the development and use of the CSA.

When defining the scope of ‘novel crop’ and ‘novel practice’, to which a CSA should be applied, regulators will have to take into account not only the change, but also the potential scale of introduction and what it is expected to replace.

The report considered important factors to take into account regarding implementation of the suggested approach but its role was not to provide a detailed guide.

In the short-term ACRE envisages that CSAs and currently available supporting evidence could be used in the development or pre-assessment of government schemes to encourage environmental benefits or the use of novel crops (e.g. mitigation measures used in Environmental Stewardship schemes, incentive schemes for biofuels).

In the long-term ACRE envisages CSAs and the comprehensive evidence supporting them to be used to inform the workings of an advisory committee. CSAs would enable the committee to advise policy makers about the balance between negative and positive impacts of a proposed introduction, allowing policy makers to base their decision on all relevant evidence.

By taking into account the overall benefits associated with a new product or practice in comparison with currently available systems, ACRE’s proposals are designed to encourage innovations that can assist government commitments for sustainable agriculture. ACRE does not envisage the CSA to be used at the level of the individual farm, thus ensuring that the direct regulatory burden on farmers is not increased. The Committee recommends that any decisions based on the CSAs should be reversible in the light of any new evidence.

All EU Directives are subject to revision over time and in the long-term ACRE believes that the CSA method could be accommodated within European legislation concerning the release of genetically modified organisms. At present applicants wishing to release GMOs are not required to submit any information on the benefits associated with the use of the GM products. However this information is important in order to determine whether the overall impact of a GM and its management is worse than that of equivalent products in current use. ACRE stresses that a revision of this nature would not represent a “softening” of the current regulatory regime with respect to GMOs.

ACRE notes that before implementing regulation (either by formal legislation, codes of practice or information campaigns) government departments are required to carry out a regulatory impact assessment[2] (RIA). An RIA is a framework for analysis of the likely impacts of a policy change and the range of options for implementing it. These assessments cover the impact of regulation on social, economic and environmental sustainability. Under the current system environmental considerations are assessed using monetary value based on consumer willingness to pay or willingness to accept compensation for environmental damage. ACRE suggests that the CSA method presented in this report could provide a useful alternative to the approaches currently used in these assessments as a mechanism for achieving environmental policy goals and ensuring more consistent regulation with respect to the environment.

This revised report was approved by ACRE in December 2006.

[2] http://www.cabinetoffice.gov.uk/regulation/ria/ria_guidance/index.asp

Contents

1 Introduction

1.1 ACRE is the statutory scientific advisory committee appointed to provide advice to the UK Government regarding the release and marketing of genetically modified organisms (GMOs). The Committee works within the legislative framework that implements the EU Directive on the deliberate release of genetically modified organisms into the environment (Directive 2001/18/EC). ACRE also advises on the release of certain non-GM species of plants and animals that are not native to Great Britain.

1.2 The Secretary of State for Environment, Food & Rural Affairs, in her statement to Parliament in March 2004, noted that the Farm-Scale Evaluations of GM herbicide tolerant crops (FSEs) (see Box 1) raised far reaching questions about crop management and the environment. [3]

1.3 The Agriculture and Environment Biotechnology Commission (AEBC) also asked ACRE to consider issues highlighted by the FSEs that have implications for both GM and non-GM crops and the management practices associated with them (see AEBC open letter, November 2004, in Annex A).

Box 1. The Farm Scale Evaluations (FSEs)

The FSEs were a four-year programme of research to study the effect that the weed management practices associated with the GMHT crops would have on farmland wildlife, when compared with weed control used with non-GM crops. The FSEs were initiated in response to concerns raised by English Nature and others that the introduction of GMHT crops might further exacerbate declines in farmland wildlife that have been observed since the middle of the 20th century. The FSEs were designed to test the null hypothesis "that, for each crop, the effect on the abundance and diversity of wildlife of the management of the GM crop does not differ from the effect of the management of the conventional equivalent".

ACRE was asked by Government to advise on the implications of the FSEs of GMHT crops and the Committee published their advice in January 2004 (for the spring-sown crops maize, beet and spring oilseed rape) and July 2005 (for winter oilseed rape).

In the advice on the FSEs, ACRE concluded that the management of GMHT maize would not result in adverse effects if managed as in the FSEs. However, ACRE concluded that the management of the other three GMHT crops tested would result in adverse effects on weed populations (particularly broad-leaved weeds) if the crops were to be grown and managed as they were in the FSEs. These negative effects on weeds would be likely to result in adverse effects on other organisms at higher trophic levels, particularly farmland birds.

(http://www.defra.gov.uk/environment/gm/fse/index.htm)

1.4 The regulatory regime of GMOs in the EU has been considerably developed and expanded since GM crops were first produced.[4] The

[3] http://www.defra.gov.uk/corporate/ministers/statements/mb040309.htm
[4] The first EU Directive governing the release of GMOs, Directive 90/220/EEC, stipulated that no product comprising or containing GMOs could be placed on the market until it had been shown that measures have been taken to avoid

current Directive covering the release of GMOs, 2001/18/EC[5], requires that the environmental risk assessment takes into account immediate and/or delayed, direct and indirect environmental impacts of the specific cultivation, management and harvesting techniques used for the GM plant. 2001/18/EC also requires a post-market monitoring plan.[6] The regulatory regime is based on the precautionary principle and applied on a case-by-case basis. However, scientists have recently recommended that for well-known traits (such as herbicide tolerance), there is a need to move away from a model of assessing risk to one of assessing the degree to which the new technology improves or detracts from the delivery of wider social, economic and environmental aspirations.[7]

1.5 Several wider issues were raised by the FSEs:

i. Directive 2001/18/EC provides no means of balancing risks and benefits. ACRE recommended in its advice to ministers that potential environmental benefits of any novel crops or management regimes (e.g. reductions in CO_2 emissions) be taken into account.

ii. A key finding of the FSEs was that the differences between the biodiversity impacts of the management regimes associated with the GMHT and non-GM crops grown were no greater than the impact of growing different species of conventionally managed crops (Fig. 1). However, Directive 2001/18 requires ACRE to compare the environmental impact of a GMO solely with that of the non-modified organism from which it was derived.[8]

iii. The FSE results also highlighted that other major changes in agricultural practice, not just those associated with GM crops, may need to be scrutinized in terms of their environmental impact.

1.6 ACRE established a sub-group to examine these wider issues, as they were beyond the scope of ACRE's advice on specific FSE crops.

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adverse affects on human health and the environment.[4] In the late 1990s, the European Union decided to revise Directive 90/220/EEC to reflect current best practice in Member States and to introduce new measures.

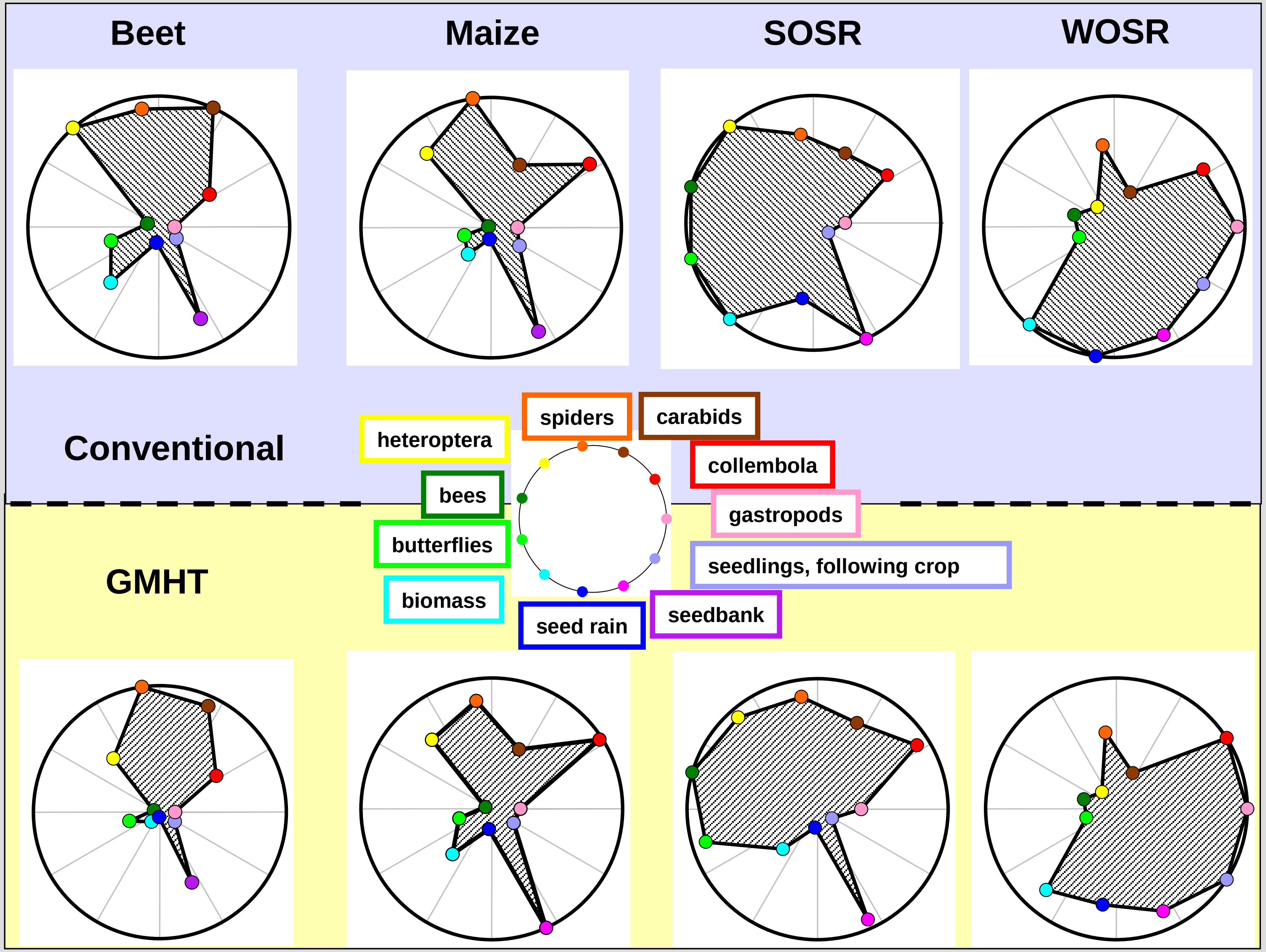
[5] http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_106/l_10620010417en00010038.pdf

[6] The objectives of post-market monitoring are to (a) confirm that the assumptions in of the environmental risk assessment regarding the occurrence and impact of potential adverse effects of the GMO or its use in the environmental risk assessment are correct, and (b) identify the occurrence of adverse effects of the GMO or its use on human health and the environment which were not anticipated in the environmental risk assessment (http://www.defra.gov.uk/environment/acre/postmarket/acre_postmarketmonitor-guidance.pdf)

[7] Firbank, L, M. Lonsdale and G. Poppy. 2005. Reassessing the environmental risks of GM crops. *Nature Biotechnology* **23**, 1475-1476.

[8] There may have been extensive backcrossing of the transgenic line so that it is genetically very different from the original line used for transformation. The European Food Safely Authority's Guidance Document of the Scientific Panel on Genetically Modified Organisms for the Risk Assessment of Genetically Modified Plants and Derived Food and Feed interprets the meaning in terms of "compare with non-GM counterparts" or "requires evaluation with current non-GM equivalents" (http://www.efsa.europa.eu/etc/medialib/efsa/press_room/publications/scientific/1497.Par.0005.File.dat/gmo_guidance%20gm%20plants_en.pdf).

Fig. 1. Star plots comparing mean values of major biodiversity indicators across conventional and GMHT treatments of beet, maize, spring (SOSR) and winter oilseed rape (WOSR) crops in the Farm-Scale Evaluations (FSE) of herbicide tolerant GM crops. For each indicator, the length of the star corresponds to the value relative to the maximum value found in any of the eight combinations of crop and treatment. The diagram in the centre shows which section of the star plots relates to which indicator (provided by J. N. Perry & L. G. Firbank).



1.7 The present report was produced by the ACRE Sub-Group on Wider Issues raised by the FSEs in order to highlight some inconsistencies in the legislation covering the growing of GM crops in comparison with other agricultural crops or practices in the EU, and to suggest a broader framework for assessment that takes into account potential environmental benefits as well as risks. Rather than concentrating solely on biodiversity in our deliberations, the sub-group took a broader approach that aligns more closely with the current EU and national policy reforms relating to energy efficiency, agricultural policy and water usage.

1.8 The report is primarily aimed at Ministers, policy makers and regulators in Defra, the devolved administrations and the EU.

1.9 In terms of agriculture in general, recent policy changes have increasingly taken into account the need to reduce the negative environmental impact of agricultural practices. As a result of the recommendations made by the Policy Commission on the Future of Farming and Food led by Sir Donald Curry, [9] Defra published "The Strategy for Sustainable Farming and Food" in December 2002, which sets out the Government's vision for a more economically, environmentally and socially sustainable approach to farming and the food-chain as a whole. [10]

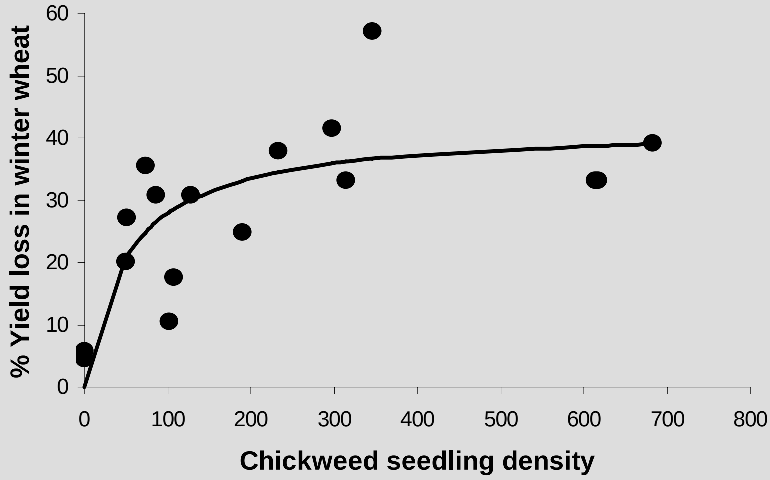
1.10 A set of shared UK principles that provide a basis for sustainable development policy in the UK have been agreed by the UK Government, Scottish Executive, Welsh Assembly Government and the Northern Ireland Administration.[11] The priorities include the area of Sustainable Consumption and Production, whose agenda includes minimising the life cycle impacts of products. A set of high-level indicators (the 'UK Framework Indicators') has also been established to give an overview of sustainable development and the priority areas shared across the UK. [12] The UK Framework Indicators include greenhouse gas emissions, resource use, waste, bird populations, fish stocks, ecological impacts of air pollution, river quality, economic output and active community participation. Farmland bird populations, for example, have been particularly affected by the intensification of agriculture: in 2003 farmland bird populations were 18% lower than in 1990, and 44% per cent lower than in the mid-1970s.

1.11 Many inherent conflicts occur between environmental, economic and social benefits and costs of agriculture. Figure 2 illustrates one example, where increased weed density results in losses of winter wheat yield, but contributes to the density of skylarks. It is not only agricultural intensification that can affect biodiversity. Land abandonment, as observed in some areas of Mediterranean

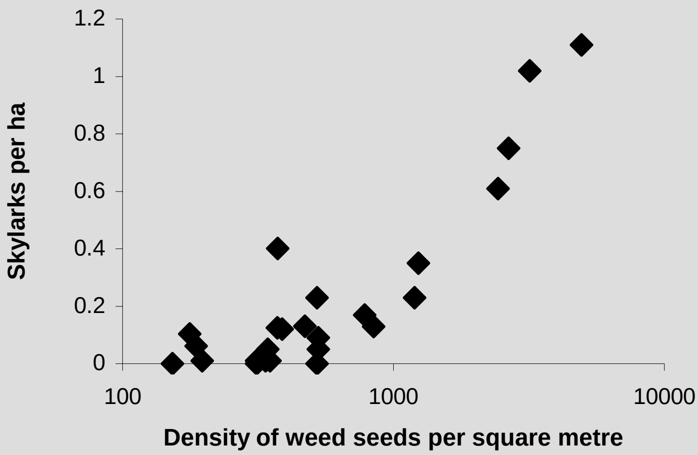
[9] http://archive.cabinetoffice.gov.uk/farming/pdf/PC%20Report2.pdf
[10] http://www.defra.gov.uk/farm/policy/sustain/pdf/sffs.pdf
[11] http://www.sustainable-development.gov.uk/publications/uk-strategy/framework-for-sd.htm
[12] Defra (2006) *Sustainable development indicators in your pocket 2006 (SDIYP)*, http://www.sustainable-development.gov.uk/progress/documents/sdiyp2006_a6.pdf.

Fig. 2. An example of the inherent conflict between economic and environmental aspects of agriculture. Weeds in fields need to be controlled to a certain extend as high numbers of weeds reduce crop yields (a) but reducing weed populations also reduces food availability for wildlife such as birds (b).

(a) Effect of weed competition on crop yield (redrawn after Cussans et al. 1996)[13]



(b) Relationship between field use by birds and weed density (redrawn after Watkinson et al. 2000)[14]



[13] Cussans J. W., P. J. W. Lutman, J. Storkey, A. M. Blair, S. J. Corbett, M. Green *et al*. (1996) Inter-site variability in crop-weed interference in winter wheat. Proceedings of the Second International Weed Control Congress, 1996, Copenhagen.
[14] Watkinson AR, Freckleton RP, Robinson RA and Sutherland WJ. 2000. Predictions of biodiversity response to genetically modified herbicide-tolerant crops. *Science* **289**, 1554-1557

countries, often has undesirable effects on a range of environmental parameters (e.g. habitat availability for priority bird species).[15]

1.12 The Curry Commission recommended that subsidy payments under the Common Agricultural Policy (CAP) should be decoupled from production. This establishes the principle that agriculture and land management also have many positive side-effects, contributing to public goods such as biodiversity, landscape aesthetics, water quality, carbon sequestration and so on. Such public goods may attract public financial support (and possibly private markets too) to ensure their continued maintenance and flow (the "provider gets" principle).[16]

1.13 Substantial policy change was negotiated on an EU wide basis at the CAP mid-term review in 2003. Agri-environment schemes in England were reviewed from 2002 with the result that a new scheme 'Environmental Stewardship' (ES) was launched in 2005. This replaces previous schemes and has substantially more funding. It is split into an Entry Level Scheme (ELS) which is available to all farmers and a more demanding, competitive Higher Level Scheme (HLS). It also covers organic farming (Annex B).

1.14 In addition, the UK Government has signed up to other European legislation affecting agriculture. This legislation includes the Water Framework Directive, the Nitrates Directive, the Waste Framework Directive, the Birds Directive and the Habitats Directive (Annex C). The UK is also in the process of developing new Environmental Impact Assessment (Agriculture) Regulations to implement aspects of the EU Environmental Impact Assessment (EIA) Directive (Annex C). The UK is playing a major role in the EU review programme designed to ensure that all active ingredients used in pesticides meet modern standards of human and environmental protection. The Government has also made a pledge to halt the decline in farmland bird populations and a public service agreement to bring 95% of SSSIs into favourable condition by 2010.

1.15 To maintain and improve biodiversity and water quality in line with the Government's commitments and reduce the environmental impact of pesticides, an industry-led scheme (The Voluntary Initiative) also encourages best practice in applying crop protection measures amongst farmers through research, training, stewardship and communication (Annex H).

1.16 Although agriculture's core aim remains the production of food, fibre, oil and other primary products, it also provides other important benefits to society and the environment. These include landscape and aesthetic value, recreation and amenity, water accumulation and supply, nutrient recycling and fixation, wildlife habitats, storm protection and flood control as well as carbon sequestration.[17]

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[15] MacDonald, D., J. R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. G. Lapita and A. Gibon. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* **59**, 47-69. Suarez-Seone, S., P. E. Osborne and J. Baudry. 2002. Responses of birds of different biogeographic origins and habitat requirements to agricultural land abandonment in northern Spain. *Biological Conservation* **105**, 333-344.

[16] Dobbs T and J. N. Pretty. 2004. Agri-environmental stewardship schemes and `multifunctionality. R*eview of Agricultural Economics* **26**, 220-237

[17] Pretty, J. N. *et al.* (2000). An assessment of the total external costs of UK agriculture. *Agric. Systems* **65**, 113-136; Tegtmeier, E. M. and M. D. Duffy. 2004. External costs of agricultural production in the United States. *Int. J. Agric. Sust.*, **2** (1), 1-20;

These services were the focus of the recent Millennium Ecosystem Assessment.[18]

1.17 At the same time, a new integrated agency ‘Natural England’ has been created to take over the functions of English Nature, parts of the Countryside Agency and the Rural Development Service. The general purpose of ‘Natural England’ is described in the Natural Environment and Rural Communities Act 2006[19] as ”to ensure that the natural environment is conserved, enhanced and managed for the benefit of present and future generations, thereby contributing to sustainable development”. The creation of 'Natural England' aims to provide an integrated approach to sustainable land management, enhancement and use of the natural environment. Its mission will be to address the multifunctionality of the land, with a special focus on activities that contribute to environmental services, in particular conservation of biodiversity.

1.18 The Natural Environment and Rural Communities Act also requires public bodies to give regard to the purpose of conserving biodiversity and in particular to the United Nations Environmental Programme Convention on Biological Diversity of 1992.

1.19 Progress towards sustainability can only be obtained if agricultural and land management systems seek to reduce negative side-effects whilst increasing the positive outputs. There remains, however, a need to establish both principles and methods for assessing and choosing the technologies and practices best-suited to contributing to such progress, as well as maintaining farmers’ economic viability.

[18] Millennium Ecosystem Assessment. 2005. http://www.millenniumassessment.org/en/index.aspx.
[19] http://www.opsi.gov.uk/acts/acts2006/60016--f.htm#40

2 The ACRE Sub-Group on Wider Issues raised by the Farm-Scale Evaluations of GMHT Crops

2.1 ACRE established the Sub-group on Wider Issues raised by the FSEs in 2004 after the publication of ACRE's advice on the three spring crops tested in the FSEs. The membership of sub-group included the ACRE members Professor Jules Pretty (chair), Professor Jeff Bale, Dr Phil Hulme, Mr Jim Orson, Professor Chris Pollock and Professor Mark Rees as well as Professor David Macdonald from the Wildlife Conservation Research Unit, University of Oxford, and Professor Phil Dale, Emeritus Fellow of the John Innes Centre. The sub-group had the following terms of reference:

(i) To advise ACRE on the wider implications of the farm-scale evaluation (FSE) results with respect to the deliberate release of genetically modified organisms into the environment.

(ii) To advise on the implications of the FSEs for the scientific assessment of the environmental impact of agriculture generally, including advice on the appropriate objectives for environmental protection in farmland including the baselines against which the risks of the deliberate release of genetically modified should be compared.

(iii) To advise on the assessment of adverse effects with respect to agricultural management (building on the work of previous ACRE sub-groups) in a way that is consistent with Government objectives for enhancing farmland biodiversity.

(iv) To advise on the extent to which the assessment of indirect environmental benefits is relevant in the assessment of GM crops.

(v) To advise on issues arising from the use of comparative risk assessment methods in assessing indirect management effects of GM crops (building on the work of previous ACRE sub-groups).

(vi) To advise ACRE and Ministers of any discrepancies in regulation that hamper the assessment of GM and other crops and management practices.

(vii) To advise ACRE on any new research needs to address the wider implications of the FSEs.

2.2 The sub-group's work built on outputs of the two ACRE sub-groups on Wider Biodiversity Issues and on Harm. The Wider Biodiversity Issues sub-group advised ACRE between 1999 and 2001 on wider impacts of the use of GM crops on farmland wildlife and produced guidance for applicants (Annex D). This sub-group considered jointly with the Environmental Panel of the Advisory Committee on Pesticides (ACP) how the environmental impact of the changed pattern of herbicide use on GMHT and other crops should be assessed. The Harm sub-group advised ACRE on the concept of environmental 'harm' with respect to the deliberate release of GMOs into the environment (Annex E).

2.3 The Agriculture and Environment Biotechnology Commission (AEBC) suggested to ACRE in an open letter (attached in Annex A) that the sub-group on wider issues raised by the FSEs might wish to consider a wider canvas than that used by ACRE to judge the first round of commercialisation applications. The AEBC also suggested that the sub-group investigates other possible comparative assessment systems and their relative merits. The AEBC further raised questions relevant to the Government's considerations of the wider impact of agriculture, including what approaches can be used to assess the environmental impacts of different conventional crops and management systems, and whether there are other ways of regulating GM and new non-GM crops, which would be more consistent than the current regulatory system.

2.4 A draft version of this report was prepared following ACRE's publication of its advice on the fourth and final crop tested in the FSEs, GMHT winter oilseed rape, in July 2005. Following consultation with a wide range of stakeholders the report has now been revised to take into consideration the evidence submitted in consultation responses. The sub-group held one open meeting and met seven times to produce this report. [20] Discussions were also held at full ACRE meetings.

[20] Minutes of sub-group meetings are available on request from ACRE's secretariat (contact; acre.secretariat@defra.gsi.gov.uk).

3 Evidence considered

3.1 A common theme running through the work of the sub-group was how environmental benefits of new agricultural technologies (including, but not limited to, the use of GM) could be taken into account. The subject of currencies or metrics for environmental impact assessment was chosen as a topic for an open meeting involving the whole of ACRE. This open meeting took place on 22 October 2004 in London. Seven written submissions of evidence were received (Annex F).

3.2 Four submissions were invited for presentation at the open meeting in front of an audience of stakeholders and the public[21]. The four cases covered life cycle assessments, environmental economics, and the use of indicators (one developed for use in the private sector; the other a multi-criteria assessment method) (Annex F). These four examples were selected because of their (i) use of a wide variety of multi-criteria approaches to the assessment of agricultural systems; (ii) reliance on evidence and datasets; (iii) potential applications in agricultural settings; (iv) use in comparing whole systems rather than just single technologies. They illustrated several important principles and methodologies as well as their limitations. Important outcomes of the open meeting were the high dependence of methods on the baselines and boundaries chosen, the wide range of different methodologies available, the high data requirements of most approaches, and the importance of modelling.

3.3 Methods for assessing and comparing agricultural practices and systems were found to have a series of problems in common:

- (i) incommensurables (how to compare very different measurements?);
- (ii) user bias (how are methods affected by assumptions?);
- (iii) baselines, boundaries and comparators (against what will sustainability be measured? What are the system boundaries?);
- (iv) data requirements (there will never be enough data to be comprehensive; how reliable are available data?);
- (v) comparisons may need to be over time and across space.

[21]The submissions and video footage of the open meeting are available on request from ACRE's secretariat (contact; acre.secretariat@defra.gsi.gov.uk).

3.4 The sub-group built on the work of the ACRE Sub-Group on Harm, which, in 2001, reviewed a range of approaches for the assessment of potential environmental harm, some of which would allow the weighing of harm against beneficial outcomes (Annex E).

3.5 The sub-group also considered a recently published framework document and report on Assessment of Wider Biodiversity Effects of Pesticides published by the Advisory Committee on Pesticides (ACP). The relevance of some highly specific indicators (such as the chick feed index) for biodiversity impact for the work of this sub-group was noted.

3.6 Examples of other regulatory approaches that are beginning to address the question of what society needs and wants from its agricultural and land management systems were also considered. Canada, for example, focuses on the product characteristics of novel crops, rather than the method of production and thus novel crops developed through biotechnology and conventional breeding methods are covered by the same Canadian regulation (Annex G). In the Canadian regulation, safety is defined as the level of “acceptable risk”, not as the absence of risk. The release of biocontrol agents represents an example where environmental risks and benefits are weighed against one another. The risk assessment of biological control agents is also an example of how risks assessments relating to introductions of organisms into new habitat evolve over time (Annex H). In addition to regulatory approaches, voluntary initiatives are an option to reduce environmental impacts of existing and novel agricultural systems. The Voluntary Initiative to Minimise the Environmental Impacts of Crop Protection Chemicals is one example (Annex I).

3.7 Also relevant is the concept of swapping or offsetting environmental damage (‘biodiversity swaps’, ‘bartering biodiversity’), a concept under development by conservation biologists to prevent further deterioration of the natural environment and to help repair damage already done.[22] While the ultimate goal of impact management is to cause no damage to the environment (and indeed, where possible, to repair damage caused previously), it is clear that the pressure of the increasing human population and a range of commercial activities involve some unavoidable environmental impacts. At the centre of the concept lies the idea that if a business (or nation) intends to cause unavoidable environmental damage this would in certain cases be permitted if the business (or nation) compensates this environmental ‘bad’ by implementing a corresponding environmental ‘good’ (as applied e.g. to carbon offset as a mechanism for ameliorating climate change caused by greenhouse gases). Starting from the position that negative biodiversity impacts should be minimised, the Biodiversity Impacts Compensation Scheme (BICS, Fig.3) was developed to capture the elements of good practice for the work of companies, institutions or individuals that has an impact on biodiversity.

3.8 Government departments are required to carry out a regulatory impact assessment (RIA) before implementing regulation (either in the form of formal legislation, codes of practice or information campaigns)[23]. An RIA is a

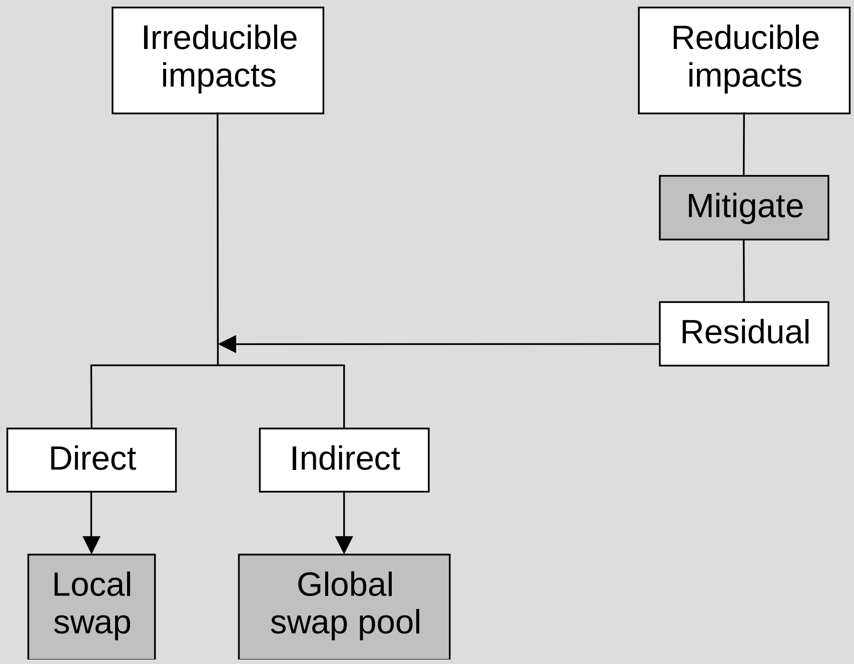
[22] Macdonald, D. W. 2000. Bartering biodiversity: What are the options? In: Environmental Policy. Objectives, Instruments, and Implementation by Helm, D. (ed.). p. 142-171, Oxford University Press.
[23] http://www.cabinetoffice.gov.uk/regulation/ria/ria_guidance/index.asp

framework for analysis of the likely impacts of a policy change and the range of options for implementing it. These assessments cover the impact of regulation on social, economic and environmental sustainability. Under the current system environmental considerations are assessed using monetary value based on consumer willingness to pay or willingness to accept compensation for environmental damage.

3.9 Whilst the sub-group acknowledges the wide range of useful methods and approaches that have already been developed, members felt that the assessment approaches available do not provide the comprehensive yet cost-effective and proportional approach needed for an assessment of novel crops and agricultural practices that would help the UK move towards its environmental targets whilst sustaining a viable farming community.

3.10 An alternative approach was therefore developed by the sub-group. This was presented in the consultation draft of this report. Several comments were received on the original comparative sustainability assessment matrix proposed by the subgroup. The matrix has been refined to take into account suitable approaches highlighted in consultation responses and presentations made to ACRE by research teams working on methods of risk assessment[24]. The revised matrix is introduced in the following chapter.

Fig. 3. Biodiversity impacts compensation scheme (redrawn after Macdonald, 2000).[20] A case study for which this model has been further developed can be found in Macdonald & Sillero-Zubiri (2004).[25]



[24] Presentation to ACRE by Andy Hart from CSL and Defra project team ARO31713 July,*"Rethinking Risk"* (1999), Andy Stirling and Sue Mayer. DLTR guidance on the use of multi-criteria analysis matrices, http://www.communities.gov.uk/pub/252/MulticriteriaanalysismanualPDF1380Kb_id1142252.pdf

[25] Macdonald, D. W. and C. Sillero-Zubiri. 2004. Conservation. From theory to practice, without bluster. *The Biology and Conservation of Wild Canids*, by Macdonald, D. W. and C. Sillero-Zubiri (eds). p. 353-372, Oxford University Press.

4 Comparative Sustainability Assessment (CSA) for novel crops and agricultural practices

4.1 ACRE suggests that it is important to consider impacts of novel agricultural crops and practices within the context of the multifunctionality of agricultural and land management systems. These systems produce primary products (e.g food, fibre, oil, wood), and at the same time shape local to global environments. These external effects can be both positive and negative[26].

4.2 In this chapter, ACRE sets out the principles for a Comparative Sustainability Assessment (CSA) for novel agricultural crops and practices, and presents some worked examples to illustrate how the assessment can be used.

4.3 The Committee does not set out here an absolute definition of agricultural sustainability, noting simply that firm definitions have long been open to dispute and that both definitions and priorities change through time. Our concern is to identify progress towards sustainability through comparisons of technologies, practices and systems. The focus is on major not minor changes. We note that no single method of assessment will be perfect[27] (see evidence considered in Chapter 3 and Annex F) and that any new method that is to be applied widely has to be proportionate in terms of costs and ease of administration.

4.4 The specific aim of this report is to produce a framework that addresses wider aspects of agricultural management and practice. The suggested CSA would form part of a trend towards a new type of objective and evidence-based, transparently evaluated agricultural and rural policy, with policy processes helping to define these objectives, to engage the farming community positively, and to develop novel technical solutions that can deliver more flexible and sustainable systems that maximise the production of environmental goods and services (as well as minimise harm). The core policy questions are:

- What does society want from the countryside?
- How do we achieve both economically viable and environmentally sustainable farming?

4.5 ACRE also recognises the need for a flexible regulatory approach that does not increase the economic burden on farmers and the agricultural support industry.

4.6 For the balancing of risks and benefits, ACRE considers that a multi-criteria matrix approach is superior to a two step approach as suggested, for example, by the UK statutory conservation agencies. The agencies' suggestion is that a novel technology or practice (e. g. a GMO) should first pass an environmental risk assessment (e. g. based on the requirements established by Directive 2001/18/EC) before an assessment of relative sustainability is carried out. This approach is limited by the fact that Directive 2001/18/EC currently does not permit a GMO to progress to a sustainability assessment stage if a single

[26] Millennium Ecosystem Assessment. 2005. http://www.millenniumassessment.org/en/index.aspx
[27] Carey P, Manchester S J and Firbank L G. 2005. Performance of two agri-environment schemes in England: a comparison of ecological and multi-disciplinary evaluations. *Agriculture, Ecosystems & Environment* **108**, 178-188.

biologically significant harmful environmental feature is detected, irrespective of any potential environmental benefits that the novel technology or organism could offer. This approach also fails to take into account the potential for mitigation strategies to reduce or eliminate any harmful effects of a release or use occurring.

4.7 As outlined in Chapter 3, methods to compare agricultural systems have a series of problems in common, including the need to compare very different measurements as well as the difficulty of quantifying and valuing environmental goods and services. It is therefore unavoidable that expert judgement plays an important role in the proposed CSA. Expert systems are widely used in the assessment of environmental risks, including risks relating to GMOs, quarantine plant pests and biocontrol agents.

4.8 For example, the European and Mediterranean Plant Protection Organization (EPPO) utilises qualitative risk assessments to screen the risk of introducing potential invertebrate pests.[28] Risk assessments are based on the International Standard for Phytosanitary Measures (ISPM 11), which provides detailed instructions for risk analysis for quarantine pests: initiation, pest categorization, probability of introduction, economic impact assessment. It provides a simple scheme based on a sequence of questions for deciding whether an organism could present a pest risk. Expert judgement is used in interpreting the replies. A fundamental attribute of expert systems is that it is the process of undertaking the individual steps in the risk assessment rather than any final scoring that determines decision making.

4.9 Eight key principles for the Comparative Sustainability Assessment (CSA) have been identified. The CSA should:

i. Reveal likely order of magnitude of biological effects

ii. Assess trade offs (benefits and costs) in environmental and health terms using a multi-criteria matrix approach;

iii. Compare effects of a new crop, technology or practice against key indicators or targets, using an appropriate and realistic baseline for comparison. Where possible targets should be quantifiable and tied to existing policy aims (e.g. the PSA targets for farmland birds or water quality).

iv. Identify potential mitigation measures, both to reduce the negative impacts of novel systems or technologies, and to increase the positive side-effects.

v. Assess potential compensatory measures so that gains in one part of the system can be offset against losses elsewhere. The calibration of these gains will depend on the values that society places on different parameters. This would be best judged by policy makers, ACRE does not therefore intend to comment on how different elements of the CSA should be weighted.

[28] http://www.ippc.int

vi. Accept that all factors cannot be resolved to a single score (by collapsing multivariate to univariate outcomes), so expert judgement (within a regulatory/policy framework set out by government) will be required for incommensurable criteria;

vii. Be proportionate (i.e. not too expensive) and flexible enough to allow for the different environmental constraints that the technology or product will be used under (soil type, climate);

viii. Be applicable to a wide range of spatial scales, from fields to crop rotations, farms and whole landscapes

4.10 It is not ACRE's aim to produce a detailed prescription. The Committee also emphasises that, despite the revisions made following consultation, the CSA presented here is for the purposes of illustration and would need to be further developed and amended according to its desired function before implementation.

4.11 In the following chapter, several worked examples of CSAs are presented for past introductions as well as for a potential future introduction or practice to illustrate how a CSA could work. These are synoptic, and do not represent the full evidence that would be expected to be presented on a novel practice or technology. Indeed, we would envisage that each cell on the grid would be populated by appropriate supporting scientific evidence.

4.12 ACRE envisages CSAs to be used to inform the workings of an advisory committee. A CSA and its supporting evidence would enable the committee to advise policy makers about the negative and positive impacts of a proposed introduction following a transparent process. Thus policy makers would be able to base their decision on the on all available evidence. ACRE does not envisage the CSA to be used at the level of the individual farm, thus ensuring that the regulatory burden on farmers is not increased.

4.13 Additional panels of experts with specific expertise may be necessary, perhaps with specific matrices designed to reflect their areas of expertise, along with a carefully designed system for collating the results, to highlight areas of consensus or disagreement as well as gaps in existing knowledge. Revisions to the proforma (see Chapter 5) may be required to reflect the expertise of the respondents. In this revised version of the report, ACRE has included social and economic considerations in the CSA matrix, although specific criteria for assessing these factors have not been detailed.

4.14 A number of other issues will need to be addressed. The UK framework indicators for sustainable development were developed for a large scale and wider schedule, and further work will be necessary to identify a comprehensive yet cost-effective set of indicators that can be applied to a crop, farm or landscape level.

4.15 Further work may be necessary to develop a framework suitable for consideration of several alternative application scenarios or a range of potential management options, which would require multiple comparisons. It will also be important to consider the scale at which the CSA could be applied (e.g. farm scale applications compared with national implementation of a novel system). The latter two points combine in relation to the assumed ‘baseline’ i.e. the difficulty of making comparisons against a ‘status quo’ which is always shifting. A range of possibilities may be taken into account, including options to remove some land from agricultural production.

4.16 Definitions of what constitutes a ‘novel’ crop, animal or practice will also have to be developed if regulation is to be applied. Difficulties with defining novelty have been tackled in various ways in other legislation, for example the pesticides legislation and the Novel Foods Regulation (258/97)[29] and problems have been experienced with the definitions of novelty given in Canadian legislation[30] (see Annex G for details of the Canadian regulation of novel agricultural products). Although such definitions will be a regulatory decision, ACRE advises, following the principle of evaluating a complete evidence-base, that not only the species and the trait should be taken into account, but also the potential scale of cultivation and what a new crop or practice is expected to replace.

4.17 It is difficult to predict the extent of uptake or how and where a product or practice will be used until farmers have had some experience with the technology. In order to overcome this difficulty small-scale trials, together with monitoring, could provide appropriate data.

4.18 ACRE acknowledges that in some cases the use of certain products or practices may be damaging in some environments (e.g. a particular soil type or at a particular time of year) and not in others. This point is recognised in national legislation for pesticide use and it is important that recommendations for use could be attached to novel products or practices.

4.19 Information from ongoing Defra-funded research, which aims to develop a cost-effective scheme to assess undesirable indirect effects on farmland ecology and wildlife of novel crops or production practices, is due to be completed at the end of 2007 and will contribute to the debate at a later stage.[31]

4.20 Economic sustainability forms part of a CSA but will not dominate the assessment. In the CSA, none of the criteria are paramount, and all factors need to be assessed together. An example of where both economic and environmental costs and benefits are considered jointly is planning gain in the Town and Country Planning Act.

4.21 The Committee recognises that a change in regulation would be required to implement CSAs for novel crops and agricultural practices. ACRE’s remit is currently limited to GMOs and the release of certain non-GM species of plants and animals that are not native to the UK. Current EU regulation covering the release of GM crops does not permit ACRE to take into account the possible benefits of GM crops (including to biodiversity conservation) in its assessment

[29] http://eur-lex.europa.eu/LexUriServ/site/en/consleg/1997/R/01997R0258-20040418-en.pdf
[30] http://www.nationalforumonseed.com/documents/PNTWGI.pdf
[31] Defra project AR0317 (http://www2.defra.gov.uk/research/project_data/More.asp?I=AR0317&SCOPE=0&M=CFO&V=IACR). Case studies considered in the project include the move from spring to autumn sowing, introduction of a new pesticide, introduction of a novel flowering crop, and introduction of a herbicide-tolerant management system in cereals.

of GM crop dossiers. Novel crops other than GMOs are not required by law to be assessed for their environmental impact prior to introduction into the UK.

4.22 Although the purpose of this report is to serve as a catalyst for debate rather than a detailed guide on how a CSA could be implemented, ACRE advises against regulatory constraints and instead argues for a system that allows for innovation and adaptation based on transparent evaluation of a comprehensive evidence-base.

5 The CSA Matrix and Worked Examples

5.1 Matrices are used as a way of presenting multiple risks and benefits, and as such can provide a useful summary or abstracting device for a larger body of evidence (such as a dossier).

5.2 Ten criteria have been selected for the revised CSA matrix. The sample proforma with the criteria is shown in Table 1. The criteria chosen will need further refinement fully to fulfil the CSA principles (Chapter 4), to fill in any gaps and avoid duplication, as well as to allow better comparison and evaluation within and between matrices. The criteria would also be expected to evolve with experience in the use of CSA and in each assessment only relevant technical and scientific details would be required in the CSA. The criteria are as follows (their order does not imply precedence of one criterion over any other):

i. Management system and inputs required – ease of management plays an important role in adoption of a new agricultural crop or practice. Inputs such as nitrogen, phosphate, water and pesticides applied to crops can have considerable direct and indirect impacts on the environment.

ii. Persistence and invasiveness - key biological characteristics that should be assessed for a novel organism prior to introduction into a new habitat. They are influenced by environmental conditions (e.g. winter temperatures).

Direct and indirect effects on environmental goods and services – direct effects refer to the potential consequences of a release on agricultural and natural systems. Indirect effects include impacts of changes in agricultural practice arising from the adoption of a new crop (or practice) (attributes of harm, Annex E). Environmental goods and services to be considered;

iii. Biodiversity – the effect of the product or practice and its management on non-target plants and animals, particularly those with conservation status.

iv. Water - the effect of the product or practice and its management on quality and flood protection and the amount of fresh water required to produce a given yield of the product.

v. Soils - the effect of the product or practice and its management on soil biodiversity, carbon sequestration, other soil nutrients and erosion,

vi. Energy balance – the amount of (non-renewable) energy used in the production of the crop produced compared with the energy output of the crop over the same area.

vii. Latency/cumulative effects – latency represents the delay between cause and effect and cumulative effects are those that accumulate steadily over time until a critical threshold is passed, whereupon effects manifest themselves (an attribute of harm, Annex E).

viii. Reversibility of effects - addresses the inherent properties of a novel organism or practice that would increase the chance of its persistence or the persistence of its side effects; also addresses the management techniques that can help to reverse the effects (an attribute of harm, Annex E).

ix. Economic sustainability - this would be concerned primarily with the economic costs to society (for example the costs of cleaning up diffuse pollution from water courses) and benefits of the use of this product or practice and its associated mitigation strategies in comparison to current technologies. ACRE believes that it would be unrealistic to try and divorce an assessment of environmental sustainability entirely from any consideration of economic sustainability. All factors will need to be assessed and then evaluated within the framework dictated by regulation.

x. Social sustainability - this would include the considerations of factors such as whether the technology is suited to small or large farming enterprises, effects on employment, food security, landscape aesthetics, human and animal health and welfare and a consideration of who would benefit from the technology.

Each criterion is assessed in terms of the benefits and negative impacts caused and the potential for mitigation of the impacts identified. Evaluation of the overall impact is more straightforward to evaluate in the case of like-for-like swaps. Trading off incommensurables is (logically and practically) a much harder task, and will hinge on society's values as embodied in legislation (for example, some losses of biodiversity may be beyond compensation and might be ruled out because they are not compatible with government policy or EU Directives).

5.3 Clear guidance will need to be developed regarding information requirements (e.g. use of indicators, quantitative data on magnitude of effects, inherent assumptions, tradeoffs, perception of risks, and potential 'unknowns'). It would be expected that there would be a considerable body of evidence presented to support the summaries in each of the cells in the matrix.

5.4 This chapter includes seven worked examples to illustrate how the CSA can be used in practice. The examples were chosen to cover a broad range and include GM as well as non-GM examples. Although the focus of this report is on novel crops and practices, examples of past introductions are included here to show the impact some non-GM introductions had in the past. The examples are (in approximate order of time of introduction into Europe):

i. Japanese Knotweed as an example of the past introduction of an ornamental plant;

ii. Winter wheat as an example of the past expansion of a crop/practice;

iii. Biocontrol of the European corn borer with *Trichogramma* as an example of a practice already in use (compared with two alternative control methods);

iv. The energy crop Miscanthus as an example of a recently introduced crop;

v. Bt cotton as an example of a potential novel insect resistant GM crop;

vi. A comparison of herbicide tolerant amenity grasses developed through GM or conventional means – an example of a potential future introduction.

vii. American mink as an example of the past introduction of a non-native mammal.

5.5 These are worked examples from a range of possible applications to demonstrate the value of the method. They were developed for illustration only and if the CSA is implemented, the matrices would have to contain more detailed and extensively refereed information. The examples given here have been developed from freely available information and do not necessarily reflect the full range of views within the scientific community.

5.6 Impacts are currently judged as high, medium, low or none. The same rule is applied to both benefits and negative impacts. The aim is to compare for each row the benefits and negative impacts rather than adding up a total score for the system or technology. At the stage of evidence gathering and synthesis, no weighting system is adopted for ten criteria. Considerations for weighting are discussed in paragraph 4.9v. The text in the boxes is seen to be more important than the scores.

5.7 There is also the potential for these impacts to be judged quantitatively as to their contribution to government (e.g. PSA) targets, such as farmland bird populations or water quality.

5.8 The matrix approach is flexible in terms of the choice of comparators. In many cases one or more appropriate comparators will be easily identified (e.g. winter wheat replacing spring wheat), while in other cases it will be more difficult to identify which crop a novel crop replaces. Thus no comparator was available for Japanese Knotweed and Miscanthus. The worked examples show that there are positives and negatives in each case, that the introduction of ornamental plants can have significant negative impacts, that changes in agricultural practice can have major environmental impacts, and that breeding methods are less important that the trait expressed by a novel crop.

5.9 The matrix approach works well in cases where the background scientific research has been conducted. In cases where no scoring is possible due to lack of data the matrix would help assessors to highlight important gaps where further scientific research is required and thus will aid in focussing resources. By exposing lack of data (especially on environmental impacts) the CSA approach would foster transparency in a regulatory process.

5.10 In cases where the benefits substantially outweigh the costs, where there are no critical problems or losses, and where any potentially adverse effects can be reversed, ACRE would suggest that the novel system or technology be approved provided that adequate post-release monitoring is conducted.

Table 1. Comparative sustainability assessment sample proforma

	Benefits	**Magnitude of effect/difference**[a)]	**Negative Impacts**	**Magnitude of effect/difference**	**Potential for Mitigation**
1. **Management system and inputs required**					
2. **Persistence/invasiveness**					
3. **Environmental goods and services** - Biodiversity					
4. **Environmental goods and services** - Water					
5. **Environmental goods and services** - Soils					
6. **Environmental goods and services** - Energy balance					
7. **Latency/cumulative effects**					
8. **Reversibility of effects**					
9. **Social factors** [b)]					
10. **Economic factors** [b)]					
Overall Assessment of sustainability					

[a)] 'Magnitude of effect' applies when no comparator is used in the CSA. 'Magnitude of difference' applies when the novel crop or practice is compared with another crop or practice.

[b)] The Committee does not intend to list factors that would be taken into consideration in the assessment of social and economic benefits and negative impacts and these have not been explored in the case studies.

Illustrative Example 1: Japanese Knotweed

Japanese Knotweed (*Fallopia japonica*), a native of Japan, Taiwan and Korea, was introduced into the UK as an ornamental garden plant. It has been grown in British gardens since 1825, was first recorded in the wild in 1886 and became well-established between 1920-1940. It is now widespread in the UK and an invasive weed. This assessment uses the matrix approach for a species already known to be a problem in the UK and for which substantial data exist. The plant is a vigorous growing herbaceous perennial with annual stems. Stems arise from strong rhizomes to form a dense thicket. Rhizomes are thick and woody when old, and have been recorded as spreading 5-7 m laterally. They act as a carbohydrate store in the winter months. Male fertile plants are not known from the introduced range.

Hybridization is relatively common. The hybrid between *F. japonica* var. *compacta* and *F. japonica* var. *japonica* can produce plants with 2n=44 chromosomes. These tetraploid plants are very rare although they are able to interbreed with either of their parents. The most commonly observed hybrid is between *F. japonica* var. *japonica* and *F. baldshuanica*, a commonly planted and invasive climber called Russian vine. Fortunately the seed from this hybrid very rarely survives in the wild and possesses none of the aggressive attributes of either of its parents. The cross between *F. japonica* var. *japonica* and *F*. *sachalinensis* is known as *F* x *bohemica* and has 2n=66. These hexaploid plants are reasonably common but only partly fertile, and any pollen produced usually contains between 30 and 66 chromosomes. If a pollen grain with 66 chromosomes were to pollinate a *F. sachalinensis* flower in Europe, a fertile octoploid *F*. x *bohemica* would be produced. Such plants would be able to cross-pollinate the all-female *F. japonica* and potentially be a replacement for the absent male *F. japonica*, allowing *F. japonica* to reproduce by seed again.

Table 2. Comparative sustainability assessment of the benefits and negative impacts of Japanese Knotweed (no comparator available)

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for Mitigation
1. Management system and inputs required	Able to survive on a wide range of managed and unmanaged habitats, soil types and water availabilities. *F. japonica* can survive very harsh conditions as it tolerates a pH range of 3.0-8.5, extreme heavy metal and salt pollution as well as low available nitrogen.	Low	Non-native weed able to colonise semi-natural habitats and in sufficient local abundance to influence species richness. It can spread solely by vegetative means. Thus much of the invasive *F. japonica* in the world may be clonal as is the case in the UK, thus it has managed on a very small gene pool.	High	
2. Persistence/ invasiveness			A persistent rhizomatous perennial forming dense thickets on waste ground, rubbish tips, roadsides, railway banks, along canal, stream	High	Low – but physical clearance and herbicides can help to mitigate

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for Mitigation
			and river banks, as well as on sea-loch shores. Rhizome fragments are dispersed in garden and other rubbish as well as by river floods.		
3. **Environmental goods and services** – Biodiversity	Late nectar source, although this benefit has not been evaluated.	Low	Invasion by *F. japonica* can impact on species richness but biodiversity value of invaded sites is often low. However effective control measures may have serious impacts on other flora and fauna. *F. japonica* can hybridise with some closely related species.	Medium	None
4. **Environmental goods and services** – Water	None	Low	*F. japonica* damages the environment through an increased risk of flooding and its impact.	Medium	Limit invasiveness with physical clearance (no herbicides near water courses) and replacement with other vegetation
5. **Environmental goods and services** – Soils	None	Low	The lack of any understorey species beneath an established population can result in soil erosion following winter die-back of established plants.	Medium	None
6. **Environmental goods and services** – Energy balance	The considerable and rapid biomass accumulation of this species resulted in it being considered as a potential biomass crop.	Medium	These attributes also make the species a successful colonist and competitor of native vegetation.	Medium	None
7. Latency/cumulative effects			*F. japonica* has been grown in British gardens since 1825, was first recorded in the wild in 1886 and became well-established between 1920-1940. There is a clear lag between initial introduction and subsequent spread reflecting the latency that occurs in many invasive species expansions.	Medium	
8. Reversibility of	Mechanical control is difficult but	Low	The estimated annual control costs	High	

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for Mitigation
effects	continual mowing will reduce the resources of the extensive rhizome system if carried out throughout the growing season. Pulling up plants complete with root systems can eliminate small stands. Digging up roots, is more challenging since they can extend to a depth of 2 m, and 7 m away from the crown. Several herbicides are available for *F. japonica* control but restrictions may apply near water. Repeated applications may be required.		for one county council in Wales in 1994 was £300,000. To control *F. japonica* on a national scale in the UK would cost c. £1.56 billion. The presence of *F. japonica* can add around 10% to the costs of a development project, especially if soil is considered contaminated and subject to additional removal fees.		
9.Social	*F. Japonica* was introduced as an ornamental plant. It has medicinal properties and has been considered as a source of biofuel.	Low			
10. Economic			*F. Japonica* is not economically viable as a source of biofuel.	Medium	

Conclusions

The initial perception of benefits accruing from this species with regard to horticultural value or as a biomass crop are significantly outweighed by the environmental and economic costs resulting from invasion in semi-natural as well as urban habitats. This example highlights the unpredictable nature of species introductions and the risks they pose that may only become evident several decades after initial introduction.

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Illustrative Example 2: Winter Wheat as a Replacement for Spring Wheat

During the early 1970s, the introduction of effective herbicides for the control of annual grass weeds in winter wheat (i.e. autumn-sown wheat) enabled this crop to be grown more often in rotations. At some locations, it became possible to grow winter wheat every year. The 1970s also witnessed the introduction of new winter wheat types and cereal fungicides that enabled higher doses of applied nitrogen to be used economically. The resulting high yields increased the popularity of winter wheat, particularly on clay soils that are suited to its production but often lack the flexibility for the profitable exploitation of spring-sown crops. The other major crops on heavy soils are autumn-sown oilseed rape and autumn-sown field beans. The dominance of relatively weed free winter wheat grown in conjunction with other autumn-sown crops in arable areas with clay soils has been associated with reductions in biodiversity, particularly farmland birds such as the skylark.

Table 3. Comparative sustainability assessment of the benefits and negative impacts of winter wheat in comparison to spring wheat

	Benefits	**Magnitude of difference**	**Negative Impacts**	**Magnitude of difference**	**Potential for Mitigation**
1. Management system and inputs required	Winter wheat provides farmers with a larger and more reliable time window for sowing.	High	It is more difficult to manage weeds for the benefit of wider biodiversity in winter wheat (see indirect effects and cumulative effects). More nitrogen and pesticide inputs are applied to a hectare of winter wheat than to spring-sown wheat (but not necessarily per tonne of production)	Medium	
2. Persistence/ invasiveness	Both winter and spring wheats are annual plants, which have no long-lived seed bank. No survival outside agricultural system.	None	Volunteers of both autumn and spring-sown wheat only occur in a crop sown in the autumn of the year of harvest when the shed seed is not buried by the plough	None	
3. **Environmental goods and services** – Biodiversity			Winter wheat does not offer the possibility of over-wintered stubbles Thicker canopy than spring-sown wheat, which is less beneficial to some farmland birds than spring-sown wheat	High	The current agricultural support system may result in more uncropped land that, if managed in a targeted way (eg conservation headlands, beetle

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for Mitigation
			Weed species that contribute most to wider biodiversity occur more frequently in spring-sown wheat		banks), may compensate for the loss of biodiversity in winter wheat. Small unsown areas in autumn-sown wheat can increase numbers of skylarks through better survival of second and subsequent clutches.
4. **Environmental goods and services** – Water	Less nitrate leaching into water courses than when the land is bare of vegetation over winter prior to sowing spring wheat	Medium	More pesticide pollution and silting of water courses than spring-sown wheat, due to both time of application and herbicides used.	High	Improved tramline management and buffer strips will reduce erosion and diffuse pollution of phosphate and pesticides.
5. **Environmental goods and services** – Soils	Less damage to soil structure than spring-sown wheat due to cultivations being carried out when the soil is more likely to be dry	Medium	There may be more erosion than with spring-sown wheat when the autumn-sown crop is slow to develop in a fine seedbed	High	As described above
6. **Environmental goods and services** – Energy balance					
7. Latency/cumulative effects			Grass weeds associated with autumn-sown crops (including wheat) can be difficult to manage in subsequent autumn-sown crops and their control with herbicides can result in it being almost impossible to manage those weed species that contribute most to farmland biodiversity	Medium	Mixed rotations (reduces autumn sown crops)

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for Mitigation
9. Social	None		None		
10. Economic	Winter wheat outyields spring wheat (in HGCA variety trials over recent years, winter wheat yielded 10.2 t/ha and spring-sown wheat yielded 7.5 t/ha) More consistent yield from year to year than spring-sown wheat	High			

Conclusions

Winter wheat is the economic backbone of arable farming, particularly on clay soils (which represent approximately 40% of the arable area of England) and the increased environmental impacts should be balanced against the reduced output from spring-sown crops. Many of the negative impacts on biodiversity and the quality of water of winter-sown wheat can be mitigated by targeted management of uncropped land and specific measures. However, some pesticides used in the crop and other autumn sown crops for the control of annual grass weeds are appearing at levels above those specified in EU directives and continue to be a problem. A rotational approach, i.e. the frequent adoption of spring-sown crops, can be used to control annual grass weeds but may result in uneconomic cropping patterns, particularly on heavy soils.

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Illustrative Example 3: Biological Control of the European Corn Borer in Maize

In this worked example, the benefits and negative impacts of an insect biocontrol agent used to control a major insect pest (the European corn borer, *Ostrinia nubilalis*, in maize) are compared with the benefits and negative impacts of two other control methods for the same pest: (a) synthetic insecticides, and (b) transgenic Bt maize. Synthetic insecticides have been used in maize for decades while transgenic Bt maize has only recently been introduced into Europe. Biocontrol is commercially available for control of the European corn borer in form of egg parasitoids of the species *Trichogramma brassicae.* This small parasitic wasp which deposits its eggs in the eggs of moths and butterflies. The parasitoid larva feeds on the host egg thus preventing further host development. *Trichogramma bassicae* was introduced from Moldavia to western Europe some 30 years ago and since then has been inundatively released to control the European corn borer in maize in several countries. In 2004, *T. brassicae* was used on approximately 100,000 ha of maize in Western and Central Europe (biocontrol of the European corn borer is not required in the UK as the pest does not normally reach economic pest status in this country)). *Trichogramma brassicae* attacks the eggs of a wide range of moth and butterfly species and concerns have been raised about potential risks this parasitoid poses for non-target butterflies. Risks to non-target butterflies and moths differ between regions as they are influenced by the presence or absence of native hosts of the parasitoid as well as the presence or absence of competitive native egg parasitoids. Recent Swiss studies found that *T. brassicae* can attack eggs of several endangered Swiss species. They also found that *T. brassicae* disperses from maize fields following mass release for European corn borer control and is able to overwinter in Switzerland. However, the risk *T. brassicae* poses to butterfly populations is nevertheless considered low for Switzerland as further studies showed that *T. brassicae* does not outcompete native *Trichogramma* species. Only a few *T. brassicae* persisted in non-target habitats into the following year and were by far outnumbered by indigenous *Trichogramma* species.

a) Control with *Trichogramma brassicae* compared with synthetic insecticides

Conventional control of the European corn borer involves deep ploughing and pesticides. Insecticides are more likely to be used in areas where more than one generation of the pest occurs. Windows for effective insecticide application are narrow due to the need to catch larvae before they tunnel into the stem. In the USA only a small proportion maize was sprayed as farmers accepted yield losses as unavoidable before Bt maize became available.

Table 4. Comparative sustainability assessment of the benefits and negative impacts of Trichogramma brassicae in comparison with synthetic insecticides

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for Mitigation
1. Management system and inputs required	No perceived need for implementation of resistance management strategies and none carried out In practice. Fewer or no insecticide applications	High	Efforts of parasitoid release and insecticide spray similar. Both should be timed based on monitoring of the pest as timing crucial to efficacy of	Low	

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for Mitigation
	required. Less exposure of farm workers to insecticides		both control methods. Large numbers of wasps need to be released every season (120,000 or more females per ha). In most cases costs of *T. brassicae* higher for farmers. It is not known how energy costs for parasitoid rearing compare to manufacturing of a pesticides. Costs involved in transport/storage are higher than for insecticides.		
2. Persistence/ invasiveness	*T. brassicae* is able to survive cold winters but is only effective in controlling the corn borer when large numbers of parasitoids are inundatively released every year.	Low	Adult *T. brassica* may disperse from fields where they are released. *T. brassicae* can develop in native hosts and overwinter in cool climates.	High	Target use of *T. brassicae* to certain areas only
3. **Environmental goods and services** – Biodiversity	Fewer non-target species impacted than with insecticides. No negative impact on soil, water or air quality known. Less insecticide enters soil and water.	High	*T. brassicae* can pose a risk to native non-target moths and butterflies as it can attack eggs of a wide range of species and is known to disperse from fields where it is released. This risk has been shown to be low under central European conditions but it may vary between geographic regions due differences in native fauna and climate.	Medium to High	None
4. **Environmental goods and services** – Water	Less insecticide water courses.	High			
5. **Environmental goods and services** – Soils	Less insecticide enters soil	High			
6. **Environmental goods and services** – Energy balance		Unknown	It is not known how energy costs for parasitoid rearing compare with manufacturing and application of		

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for Mitigation
			pesticides.		
7. Latency/cumulative effects			Covered above. The repeated release of large number of parasitoids may over time lead to negative impact on non-target butterfly and moth populations. *T. brassicae* has been used since the 1930s and so far no major negative impacts have been reported.	Low	Reduce use of *T. brassicae* if off-site effects discovered
8. Reversibility of effects			Covered above. No negative effects reported despite frequent releases. May not be 'directly reversible', but long term fate of released populations unknown if releases were suspended.	Low	
9. Social	Less exposure of farm workers to insecticides. Spray drift problems reduced.	Medium	None		
10. Economic	None		In most cases costs of *T. brassicae* higher for farmers. Costs involved in transport/storage are higher than for insecticides.	Low	Encourage use of a variety of IPM options

Conclusions
Biocontrol with *Trichogramma brassicae* has major environmental benefits compared to the use of synthetic insecticides. The use of this introduced biocontrol agent is, however, not without risks to non-target native moths and butterflies. Scientific studies in Switzerland have shown that the latter risk is small although likely to differ geographically depending on the local fauna. Decades of use are not known to have resulted in significant negative impacts of *Trichogramma brassicae* on any native fauna.

b) Control with *Trichogramma brassicae* compared with Bt maize

Although only recently introduced into Europe, transgenic Bt maize provides an interesting second comparator to biocontrol with *T. brassicae.* Like biocontrol with *T. brassicae* Bt maize is also specifically targeted at controlling corn borers. This GM crop was first released for commercial planting in 1995 in the US and by 2004 was grown in nine countries (representing 14% of the global biotech crop area). Bt maize is more effective in controlling the European corn borer than biocontrol or insecticides. Concerns that this high selection pressure may lead to rapid selection of Bt resistant corn borer larvae have led to the implementation of resistance management strategies and so far no resistance to Bt maize has been found in this pest. The use of Bt maize has provided farmers with more security and higher yields (5%-25%). A large body of research on the effects of Bt maize on non-target arthropods has not shown any ecologically significant negative impacts in the field. Bt toxins enter soil through post-harvest incorporation of Bt maize crop residues and through root exudates and can persist. No significant effects of Cry1Ab in from Bt maize biomass or root exudates were found on earthworms, nematodes, numbers of culturable protozoa, fungi and bacteria and the toxin was also not taken up from soil by other plant species. Monitoring of commercial Bt maize crops in Spain has not shown any negative side effects on soils so far. Outcrossing of maize to wild relatives does not occur in Europe.

Table 5. Comparative sustainability assessment of the benefits and negative impacts of Trichogramma brassicae in comparison with Bt maize

	Benefits	**Magnitude of difference**	**Negative Impacts**	**Magnitude of difference**	**Potential for mitigation**
1. Management system and inputs required	Co-existence regimes in Europe likely to require Bt maize farmers to coordinate their plantings with neighbouring farmers while no such requirements are in place for biocontrol agents. No implementation of resistance management strategies necessary for biocontrol agents. In contrast Bt maize farmers need to plant areas with non-Bt maize as a refuge (required in several countries as a resistance management strategy)	Medium	Biocontrol with *T. brassicae* requires monitoring of pest development and careful timing of parasitoid releases. No such monitoring is required for Bt maize. Biocontrol with *T. brassicae* requires mass releases of parasitoids while with Bt maize farmers have only to buy the appropriate seeds. Cost of Bt maize seed usually higher than that of non-GM seed.	Medium	
2. Persistence/ invasiveness			Unlike *T. brassicae* maize has no wild relatives with which it can hybridize in Europe. *T. brassicae* does survive cold winters in Europe unlike maize. *T. brassicae* is known to persist in e.g. Switzerland, but no significant biological impact on the native fauna has been found.	Medium	None required
3. **Environmental goods and services**	Both control measures have very little effect on wider biodiversity, apart from	Low	Biocontrol with parasitoids does not affect soils but Bt toxin enters soil with	Medium	None required

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
– Biodiversity	other moth and butterflies and their specialist natural enemies.		decaying plant material (although no negative effect on soil organisms have been found so far). Bt maize pollen can kill some non-target moth or butterfly larvae, where it falls in significant quantities on weeds in and near maize fields. The only Bt maize event with high levels of Bt toxin in pollen has been taken off the market. *T. brassicae* parasitises and kills the eggs of a range of non-target moth and butterfly species. One *T. brassicae* female can parasitise a large number of host eggs, and *T. brassicae* has a higher capability of dispersal than Bt maize pollen. Risk of Cry protein moving through trophic levels higher than with parasitoids (but high specificity of Cry toxin for narrow group of insects means that impact low).		None required
4. **Environmental goods and services** – Water	Both control measures have no negative effects on water quality.	Low		Low	
5. **Environmental goods and services** – Soils			Potential for Cry protein to build up in soils (but not shown in experiments to date)	Low	
6. **Environmental goods and services** – Energy balance					
7.			Unlike Bt maize, *T. brassicae* can	Medium	

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
Latency/cumulative effects			reproduce and multiply in Europe and can survive cold winters (see above). *T. brassicae* has no effects on soils while Bt toxins have been detected in some soil three years after incorporation of Bt plant biomass, although no significant effects on soil organisms of Bt toxins released into soil have been found.		
8. Reversibility of effects			Release of *T. brassicae* is not reversible while the release of Bt maize is reversible. However, there are no reported negative effects despite frequent releases over many years.	Medium	
9. Social	None		None		
10. Economic	Bt maize more effective than *T. brassicae* in controlling the corn borer. More yield security for farmers.	Medium	*T. brassicae* places less selection pressure on the target pest than Bt maize, which is less likely to lead to development of Bt resistance in the European corn borer. However, after nine years of use of Bt maize no corn borer resistance to Bt maize has been detected. Monitoring is required to ensure efficacy of *T. brassicae* release, this will add to farmers costs. Contribution to co-existence/liability fund likely for GM products in some European countries.		Resistance management plans may be required

Conclusions

Biocontrol with *Trichogramma brassicae* and Bt maize are both low in environmental impact. *T. brassicae* is less efficient in controlling the corn borer than Bt maize and more labour intensive to use. However, farmers using biocontrol agents do not have to comply with any co-existence or resistance management requirements.

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Illustrative Example 4: Miscanthus Cultivated in the UK as a Biomass Crop

Miscanthus is a non-native C4 grass which has been widely studied as a source of biomass for combustion[32]. The crop is perennial and grows quickly after initial establishment. Establishment grants are available in the UK for Miscanthus under the Energy Crops Scheme.[33] When a farmer applies for such a grant, the Forestry Commission or other parties can request from Defra an environmental impact assessment but this usually only applies to environmentally sensitive areas, uncultivated and semi natural land. Miscanthus is an efficient way of harvesting solar energy into a combustible product and has the added advantage that the current season's growth "dries off" naturally at the end of the season, with most of the nutrients being recycled into the overwintering crown. It is a relatively novel cultivation system, and could substitute for a wide range of arable and pasture crops. The matrix evaluation does not compare Miscanthus with any other crop, but attempts to predict the balance of benefits and negative impacts.

Table 6. Comparative sustainability assessment of the benefits and negative impacts of Miscanthus (no comparator available)

	Benefits	**Magnitude of effect**	**Negative Impacts**	**Magnitude of effect**	**Potential for mitigation**
1. Management system and inputs required	Within-year management minimum. Self-drying. Harvest using relatively simple machinery. Easy to kill (two application of glyphosate herbicide). Low fertiliser requirement (K only). Water use efficiency is high (8g biomass/kg water).	Medium	Establishment of clonal material high cost. Use of seed could encourage invasion although there is no evidence of the seed produced in the UK being invasive. There may be a need every other year for weed control pre-emergence (can use broad spectrum herbicides). Deep rooting *gigantea* hybrids have no stomatal control so in dry conditions can dry out fields to depth (*sinensis* hybrids are better in this respect).	Low/ Medium	Not applicable
2. **Persistence/ invasiveness**	Perennial, lasts for up to 10 years, reduced cost of management.	Medium	Sterile hybrids do not invade. Fertile hybrids will proliferate but rate of invasion is low and cultivated headlands/margins provide an	Low	Field monitoring to check for increased invasiveness. Breeding Programmes to use

[32] http://www.iger.bbsrc.ac.uk/Miscanthus/ ; http://www.defra.gov.uk/erdp/pdfs/ecs/miscanthus-guide.pdf
[33] http://www.defra.gov.uk/erdp/schemes /energy/establishment.htm

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
			effective barrier. There are some concerns about the potential sensitivity of particular systems to invasion.		only non-invasive parents
3. **Environmental goods and services** – Biodiversity	Supports better biodiversity in small plots than do cereals, and good habitat for pheasants. No specific insect pests, so risk of associated introductions seems low. No major studies on broad impacts on biodiversity yet completed under UK conditions. Late sprouting suits some weeds, which can be abundant early this may have some benefit to biodiversity but do not reduce off-take because they are usually dwarfed in time.	Medium	Weed and arthropod biodiversity may be indirectly affected if Miscanthus replaces a crop such as oilseed rape. Landscape value may be reduced if grown on a wide scale	Low	Mitigate by improving biodiversity elsewhere with conservation headlands, beetle banks, and diverse rotations
4. **Environmental goods and services** – Water	Water use efficiency is high (8g biomass/kg water).		Winter harvest can impact on water quality through silting or increasing flooding risk as a result of compaction. Deep rooting *gigantea* hybrids have no stomatal control so in dry conditions can dry out fields to depth (*sinensis* hybrids are better in this respect).		Limit Miscanthus growth to where there is abundant water.
5. **Environmental goods and services** – Soils	17% of total biomass enters soil, so good way of enhancing soil C.	Medium	Winter harvest can impact on soils. Biomass offtake contains: - 40 kg/ha N (replenished by natural N deposition), - 10 Kg/Ha P (low, and most soils contain excess P), and - 40-60 Kg Ha K (this will deplete soil over time and ends up in fly ash).		K supplementation may be required occasionally

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
6. Environmental goods and services – Energy balance	Combustible biomass at 12 tonnes per ha per year (equivalent to 13 tonnes CO_2 emissions saved per yr per ha cultivated)	High		None	Not applicable
7. Latency/cumulative effects	Mainly covered above. No evidence of long-term effects following cultivation.	Medium		None	Not applicable
8. Reversibility of effects	Mainly covered above.	None		None	Not applicable
9. Social	None		None		Not applicable
10. Economic	Annual farm income based on current energy costs	High	Only those farmers within fixed distances of energy generation plants will be able to grow Miscanthus.	Medium	Possible advantages of small-scale on-farm combined heat and power production

Conclusions

Strong, well characterized benefits, with small negative impacts that are generally not unique to Miscanthus. A few areas where knowledge is incomplete.

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Illustrative Example 5: Bt Cotton vs Conventionally Managed Non-GM Cotton

This matrix compares Bt cotton with conventionally managed non-GM cotton. This worked example was included to show the benefits and negative impacts associated with the replacement of a heavily sprayed conventional crop with a Bt crop. Bt cotton was developed as an alternative to synthetic insecticides for the control of cotton bollworms. The commercial introduction of Bt cotton in 1996 led to large reductions in numbers of insecticide applications in the USA (e.g in Alabama insecticide sprays were reduced from 10 to 0-1 spray per season) and in Australia (where sprays where reduced from 10 to c. 4 per season). Yield increases of up to 63% have been reported for Bt cotton in developing countries (Brookes and Barfoot, 2005). A reduction in cases of pesticide poisoning amongst farm workers has been documented following the introduction of Bt cotton into China (Pray *et al*., 2002). Bt cotton allows cotton farmers to implement integrated pest management strategies aimed at other pests, which were previously prevented by the frequent broad-spectrum insecticide sprays required for bollworm control. Field studies with Bt cotton indicate that the effects of Bt cotton on non-target arthropods are minor in comparison compared to the use of broad-spectrum insecticides (Head *et al.* 2005, Naranjo 2005a,b). The colonising ability of upland cotton is poor. Cotton has the potential to hybridise with feral cotton and some wild cotton relatives in limited geographic locations. For example, no cropping of Bt cotton is permitted in Hawai by the US authorities because a wild native species in Hawaii is capable of forming fertile hybrids with cultivated cotton (Wozniak, 2002). Bt toxins enter soil through post-harvest incorporation of Bt crop residues. They can persist and retain their insecticidal activity in some soils (Flores *et al.* 2005). Bt toxins do not appear to be taken up from soil by other plant species. No significant effects of Bt toxin from plant biomass on earthworms, nematodes, numbers of culturable protozoa, fungi and bacteria in soil have been found. Nor was any decrease in the activities of representative enzymes involved in degradation of plant biomass observed. C evolved as CO_2 during decomposition of cotton residues has been reported to be lower from soil amended with biomass of Bt cotton than from soil amended with non-Bt cotton but the ecological and environmental relevance of this finding is not yet understood (Flores *et al.* 2005).

Table 7. Comparative sustainability assessment of the benefits and negative impacts of Bt cotton compared to conventionally managed non-GM cotton

	Benefits	**Magnitude of difference**	**Negative Impacts**	**Magnitude of difference**	**Potential for mitigation**
1. Management system and inputs required	Bt cotton is easier to manage for farmers as few or no insecticide sprays are required and farm workers are less likely to be exposed to toxic insecticides. Bt cotton gives farmers the opportunity to develop integrated pest management systems to keep other pests below economically damaging levels. Fewer insecticide	High	Bt cotton provides a continuous high level of plant resistance, which exerts a higher selection pressure than sprayed insecticides (resistance management regimes were therefore implemented in several countries for Bt cotton at the time of commercialization, see below). Bt cotton seeds are more expensive.	Low	The risk of selecting for Bt resistant pests can be reduced by implementation of resistance management strategies. For example, in the USA cotton bollworms have not developed Bt resistance

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
	applications required than in non-GM cotton.		Use of water and fertiliser the same in both conventional and Bt cotton. Some insecticide applications to Bt cotton can still be required in areas where pests other than bollworms cause economic damage.		in the field after nine years of Bt cotton cultivation, an indication that the high dose/refuge resistance management strategy used in the USA is effective. Populations of non-target insects are likely to also benefit from unsprayed non-Bt cotton refuges.
2. **Persistence/ invasiveness**			Cotton does have the potential to hybridise with feral *Gossypium hirsutum* populations and some wild *Gossypium* relatives in limited geographic locations. Upland cotton is a poor coloniser.	Low	None required
3. **Environmental goods and services** – Biodiversity	More non-target arthropods survive in Bt cotton. No chronic long-term effects of Bt cotton were observed.	High	Bt cotton likely to reduce food supply for some specialist natural enemies that feed on the target pest more than insecticides do.	Low	Maintain below economic threshold levels of pests
4. **Environmental goods and services** – Water	The growing of Bt cotton results in less synthetic insecticide entering water courses.	High			None
5. **Environmental goods and services** – Soils	The growing of Bt cotton results in less synthetic insecticide entering soils.	High	Bt toxin enters soil with decaying plant material but no negative effect on soil organisms known. See latency and cumulative effects	Low	None required
6. Environmental goods and services – Energy balance					
7.			Incorporation of plant residues after	Low	None required

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
Latency/cumulative effects			harvest introduces Bt toxins into soil. Cry toxins can adsorb and bind to clays and humic substances in soil and have been detected in some soils three years after incorporation of plant biomass. Evolution of C into CO_2 during decomposition has been reported to be reduced during decomposition of Bt cotton compared to non-Bt cotton. No significant effects on soil organisms of Cry toxins released into soil have been found.		
8. Reversibility of effects			Reversible as long as cropping not permitted in regions where introgression into populations of wild species and feral populations is possible.	Low	
9. Social	Bt cotton is easier to manage for farmers as few or no insecticide sprays are required and farm workers are less likely to be exposed to toxic insecticides.	High	None		None required
10.Economic	Yield gains and an increase in yield security have been reported for Bt cotton, particularly from developing countries.	High	Decision about the use of Bt cotton has to be made before the pest pressure is known for a season. As bollworms reach economic threshold levels in most seasons this is a minor issue (unless pest pressure changes in the future). The performance of GM crops depends heavily on the suitability of the local varieties into which genes are inserted. GM Bt seeds are more expensive for farmers than non-GM seeds. These factors combined mean that the benefits of	Low	None

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
			this crop may be dependent on region. Yield and profit reductions relative to non-Bt hybrids have been reported in some areas.		

Conclusions

Compared to cotton sprayed with insecticides, Bt cotton has major benefits in terms of the environment, yield security and human health. The environmental disbenefits appear marginal in comparison.

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Illustrative Example 6: Glyphosate Tolerant Ryegrass

As it is feasible to obtain glyphosate tolerant ryegrass (*Lolium perenne*) by both GM and non-GM plant breeding methods, this example provides a comparison of two similar products achieved by different breeding methods.

The production of GM glyphosate tolerant ryegrass is technically feasible and certain other GM glyphosate tolerant grass species have been produced in North America, mainly in amenity grasses for golf courses. As an alternative approach, selection for glyphosate tolerant ryegrass by non-GM methods is also possible, and agronomic concentrations of glyphosate can apparently be used on the tolerant ryegrass for weed control.[34] As glyphosate tolerant ryegrasses obtained from both GM and non-GM methods are expected to have comparable phenotypes, their benefits and negative impacts will be considered together and assessed against a non-glyphosate tolerant ryegrass control. Possible differences between the GM and non-GM glyphosate tolerant ryegrass will be discussed in the conclusion.

Table 8. Comparative sustainability assessment of the benefits and negative impacts of herbicide tolerant GM ryegrass compared to ryegrass produced by non-GM breeding methods

	Benefits	**Magnitude of difference**	**Negative Impacts**	**Magnitude of difference**	**Potential for mitigation**
1. Management system and inputs required	Easier to maintain highly productive grass varieties in pastures. Easier to eliminate grass and broadleaf weeds in amenity grass areas. Reseeding would be needed less often. Easier to maintain productive grass species, therefore reseeding required less frequently.	Medium	Would need a spraying regime that minimizes the likelihood of selecting glyphosate tolerant wild grasses. Would need to adopt management practices to minimize gene flow to sexually compatible feral species. The widespread use of glyphosate as a selective weedkiller increases the likelihood of selecting other glyphosate tolerant grasses. Grasses have a high capacity to adapt to a	High	Risk of selection for glyphosate tolerance in other grasses and weed species could be reduced by careful management of spraying treatment.

[34] This issue was discussed during the GM Science Review: "There are developments in the production of herbicide tolerance by non-GM breeding, in some instances conferring tolerance to broad spectrum herbicides (e.g. glyphosate). Agronomic changes associated with the commercialisation of these could have parallel impacts on the environment. The issue is therefore not specific to GM crops although, in the UK, GM HT crops represent the first .potential major deployment of HT crops and this will remain the case for several years" (GM Science Review, Vol. 1 page 149, http://www.gmsciencedebate.org.uk/report/pdf/gmsci-report1-full.pdf).

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
	Heavy doses of sprays (eg. to control dicotyledonous weeds) are often used for amenity purposes, especially on golf courses. Glyphosate has a more acceptable environmental toxicity profile than most other herbicides (including impact on groundwater).		range of stresses, including herbicide application. Public authorities sometimes stipulate that glyphosate is used to control weeds in public areas (e.g rail tracks, pavements) because of its low environmental toxicity. If glyphosate tolerant ryegrass became a common weed species in these areas, it would be necessary to use an alternative herbicide which may have a less acceptable environmental profile than glyphosate.		
2. **Persistence/ invasiveness**	No difference in invasiveness in absence of herbicide	None	Feral ryegrass is widespread and would be sexually compatible with cultivated glyphosate tolerant ryegrass. Gene flow to feral ryegrass populations would be expected. In the absence of glyphosate application, HT ryegrass would not have any greater persistence or invasiveness than glyphosate susceptible ryegrass. In semi-natural areas (rail tracks, pavements, recreational hard surfaces) where glyphosate is often used for weed control, the presence of glyphosate tolerant grasses may make it necessary to use alternative herbicides.	Medium	Risk of gene flow could be reduced by appropriate management of grassland or amenity area (e.g. cut before pollen dehiscence). The dissemination of glyphosate tolerant ryegrass into natural or semi-natural habitats (by seed or pollen) would be difficult, if not impossible, to control. In natural areas where glyphosate is not used, the tolerant phenotype would not be selected for. In semi-natural habitats where glyphosate is

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
					used for weed control, another (possibly environmentally less acceptable) herbicide would need to be used. If glyphosate tolerance became widespread, glyphosate would have a more limited application as a herbicide.
3. **Environmental goods and services** – Biodiversity	None		There is likely to be less plant biodiversity in pastures and amenity areas.	Medium	Limit extent of adoption
4. **Environmental goods and services** – Water	None	None	Herbicide sprays would be used on pastures (currently few sprays are used for this purpose) with possible risks to groundwater and from spray drift.	Medium	Limit spraying to land not near water courses
5. **Environmental goods and services** – Soils	None		None		
6. Environmental goods and services – Energy balance	None		Increasing use of herbicides would mean increased use of direct and indirect energy		None
7. Latency/cumulative effects	Reduction in weeds and weed seeds in pastures and amenity areas could reduce the need to spray in the future.	Low	Reduction over time in diversity within soil seed-bank grassland and amenity areas with possible adverse effects on grassland/farmland biodiversity.	Medium	
8. Reversibility of effects	Many effects could be reversed in agriculture and in amenity areas by stopping glyphosate application and	Low	If glyphosate tolerant ryegrass became common in natural habitats where glyphosate is not applied, the	High	

	Benefits	Magnitude of difference	Negative Impacts	Magnitude of difference	Potential for mitigation
	reverting to conventional management practices.		biological effect on those populations is likely to be minimal. If glyphosate tolerant ryegrass became common in semi-natural areas (rail tracks, pavements etc) where glyphosate is used for weed control, another herbicide would need to be used for weed control. The widespread presence of glyphosate tolerance in natural and semi-natural populations would be irreversible, in the sense of eliminating glyphosate tolerant genotypes in favour of glyphosate susceptible genotypes. But this is a feature of all examples of the selection for herbicide tolerance in agricultural weeds to date.		
9. Social	Possibly easier elimination of poisonous weed species (e.g. ragwort)	Medium	Sprays would be used on pastures with human exposure to spray drift.	Medium	
10. Economic	Both sources of herbicide tolerance would be expected to provide selection against weeds, including weed grasses; therefore, providing easier management and maintenance of desirable grass genotypes. Lower labour and inputs required (e.g. for reseeding)	Medium	None		

Conclusions

A glyphosate tolerant phenotype, obtained from both GM and non-GM plant breeding methods, have been considered together and their impact compared with normal glyphosate sensitive ryegrass. In the analysis, an assumption has been made that both sources of glyphosate tolerance will have closely comparable genetic control and phenotype. In practice, however, there are likely to be differences between any two sources of glyphosate tolerance that would need to be considered in any case by case assessment. For example the mechanism of glyphosate tolerance and the nature of the genetic control may be different.

However, the similarity in the comparison does illustrate the importance, in impact analysis, of placing special emphasis on the characteristics of the particular plant variety, rather than on the plant breeding method from which it was obtained.

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Illustrative Example 7: American Mink

A native of North America, the American mink (*Mustela vison*), has been introduced to the UK (and throughout mainland Europe) by the fur trade. Brought to the UK in 1929 for farming, they were first discovered breeding in the wild in the 1956 (Linn and Stevenson, 1980). Mink are now widespread throughout the country with an established reputation as a successful and invasive alien species (Crawford, 2003), although the number of sites at which mink are recorded has apparently been declining in the past 20 years (Bonesi et al., 2006).
The American mink is a small (0.5 – 1.5 kg), semi-aquatic carnivore of the weasel family, Mustelidae. It inhabits freshwater (rivers, lakes, wetlands, swamps, marshes) as well as coastal habitats. Habitat preferences of mink are linked to food availability, the presence of resting sites and breeding dens, and to a lesser extent to the distribution of competitors (e.g. Melquist et al., 1981; Ben-David et al., 1995; Haliwell and Macdonald, 1996; Bonesi et al., 2000; Yamaguchi et al., 2003). The mating system is such that males occupy ranges that overlap those of several females and some males may range over as much as 12 km of river (Yamaguchi and Macdonald, 2003; Yamaguchi et al., 2004).

Questions about the impact of mink not only on game and fish industries but also on British native wildlife were paramount when the mink began to emerge as a successful colonist in the 1950s. Because of their commercial value, attractiveness and potential vulnerability to the mink, public focus has mainly centred upon the impact of mink predation on game and poultry, fish stocks (including farmed fish), water birds (including coot and moorhen), water voles and the fauna of offshore islands (including ground-nesting sea birds) (Macdonald *et al*., 1999). The overall commercial impact on British fish-farming and game-poultry industries seems to be negligible (Macdonald *et al*., 1999). However, mink appear to have substantial negative impacts on some ground-nesting sea birds colonies and the British water vole population. Mink have seriously affected the nesting success of several ground nesting bird species, including blackheaded gulls, common gulls, common terns, eider, red breasted merganser and oystercatchers (Craik, 1993; 1997). Many tern and gull colonies in the Oban area have been deserted or wiped out (Craik, 1993). Like many carnivores, mink will kill surplus birds (Kruuk, 1964), storing the food to eat later. Up to a hundred birds may be killed in one night. In the Hebrides mink are currently spreading to the more southern islands, home to 25% of the UK breeding populations of ringed plover and dunlin,, two species that are believed to have declined through the 1990s (Fuller and Jackson, 1999). Burrow-nesting shelduck are vulnerable to the arrival of mink on islands in Loch Lomond (Bignal, 1978) and puffins and shearwaters are likely to be similarly at risk. The decline of white-clawed crayfish may also be exacerbated by mink predation (Smal, 1991).

Water voles are a conservation concern in the UK, listed as a UK BAP species and protected under Schedule 5 of the Wildlife and Countryside Act, 1981 (WCA 1998 as amended), subsequently revised under the CRoW 200, and under the Nature Conservation (Scotland) Act, 2004. Water voles are going extinct due to a combination of habitat loss and fragmentation and predation from American mink. Even substantial colonies of water voles are vulnerable to mink predation and, if isolated, the unoccupied habitat is unlikely to be recolonised by dispersal from existing populations (Strachan & Moorhouse, 2006). There is some evidence that where riparian habitat provides dense cover for water voles (such as expansive wetlands comprising inter-connecting waterways, or large reedbeds) the effects of mink predation may be lessened (Carter and Bright 2003).

Table 9. Comparative sustainability assessment of the benefits and negative impacts of American mink (no comparator available)

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
1. Management system and inputs required	No management is necessary to encourage the establishment of this species.	None	Mink have negative impacts on biodiversity in their associated habitats and management to control their populations is time consuming and costly.	High	Effects of mink are locally mitigable, but probably logistically and financially impossible on a national scale.
2. **Persistence/ Invasiveness**	No plausible benefits.	None	Mink are very persistent and invasive because they can survive and establish on almost any waterbody (inc. rivers, streams, lakes, marshes, coast and smaller ditches). It is suggested that males usually disperse further than females and that they can disperse up to 50 km from their natal home range (Mitchell, 1961; Gerell, 1971). Average number of kits born = 5.8; higher than many other similar-sized Mustelids. Reproductive output may increase in response to removal trapping. Mink are therefore highly likely to persist where established, and to invade currently unoccupied, suitable habitat.	Medium	
3. **Environmental goods and services** – Biodiversity	Mink may contribute to controlling rabbit populations living along water sources, but evidence for a substantial role in rabbit control is scarce.	Low	Through predation, mink have serious effects on water voles (a single mink is capable of causing local extinction of even relatively large water vole populations), ground-nesting seabird colonies and possibly on waterfowl in lowland rivers. Biodiversity effects are typically clearly visible (through the absence of formerly common species) although the presence of mink may not be.	High	For many prey species direct mink control may be the only mitigation option. For water voles habitat management may also be possible to encourage re-establishment of natural vegetation in riparian ecosystems, e.g. large reedbeds and isolated ponds may provide

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
					refuges and benefit other species (Macdonald et al., 2002; Carter and Bright, 2003). Targeted removal in areas of national importance for conservation (e.g. water vole strongholds) may be a feasible solution. Effective water vole conservation will require large-scale mink control coupled with proactive habitat restoration and management (e.g. catchment-wide mink control and selected site management).
4. **Environmental goods and services** – Water	No plausible benefits		No plausible impacts		
5. **Environmental goods and services** – Soils	No plausible benefits		No plausible impacts		
6. Environmental goods and services – Energy balance	No plausible benefits		No plausible impacts		
7. Latency/cumulative effects	No plausible benefits		In general, there is little evidence for cumulative effects of mink presence over and above those caused by the action of the observed direct effects over a number of years.	Low	
8. Reversibility of	Reversing the current situation to the	High	There are few probable negative	Low	

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
effects	"pre-mink" one is desirable in principle, and would almost certainly contribute to the conservation of water voles, and some local populations of ground-nesting sea birds. It has been shown that mink can be removed effectively from islands and native species can recover (Nordstrom et al., 2003) and that local mink control, coupled with habitat restoration, can allow water voles to expand their distributions.		impacts on native British fauna associated with the absence of American mink. The removal process, however, may have welfare and by-catch issues.		
9. Social	Mink control is typically conducted either by dedicated staff, or commonly with landowner participation co-ordinated by local organisations. Research is currently being carried out to investigate effectiveness and best strategies for control trapping. These activities contribute to building a functional mink control network, and can become a model system to tackle similar cases of vertebrate pest management. Habitat reconstruction for conservation of mink prey species may provide social benefits by enhancing public recreation.		The farming of mink led to animal welfare concerns. Control of naturalised mink populations through trapping may also constitute an animal welfare issue.		
10. Economic	Mink were farmed in captivity for the fur trade in the UK commencing in 1929. The population that subsequently established all over the country by the 1990s was the result of escapes from this farming practice. It is arguable, but unproven, that mink may contribute to controlling rabbit populations along riversides. This could be beneficial in agricultural	Low	Mink cause negligible financial losses to the game and fish industries (Macdonald et al., 1999). However damage to wild bird and water vole populations encourages control of mink. Mink control in mainland UK is possible but is likely to prove prohibitively expensive and logistically extremely difficult (given the species' capacity for breeding and dispersal).	High	

	Benefits	Magnitude of effect	Negative Impacts	Magnitude of effect	Potential for mitigation
	areas where rabbit damage causes financial losses.		Targeted removal maybe less economically damaging.		

Conclusions

This species was introduced to the UK in order to gain economic benefits through the fur trade. The market for fur products declined and thus the economic benefits were short lived and have been significantly outweighed by the environmental and economic costs resulting from the escape and subsequent invasion of riparian ecosystems by American mink.

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6 Research Priorities

6.1 There are areas of uncertainty that would need to be addressed before this matrix-based approach could be introduced as a novel regulatory step. We suggest several key research priorities, completion of which would provide valuable information to support the development and use of the CSA: [35]

- Standardisation of a small tractable set of core indicators for agricultural sustainability at the crop/agricultural practice level.
- Development of current and appropriate inventories for life-cycle analysis e.g. quantifying inputs and outputs of relevant processes - energy, materials, emissions to (and extractions from) air, water, soil and solid wastes.
- Comparative analyses of agricultural systems using a range of different methodologies e.g. life-cycle analysis, cost-benefit analysis, ecological footprint, energy analysis, assessment of biotic integrity, positional analysis etc.
- Development of appropriate impact classes, including environmental and economic impacts that can be quantified in measurable units (e.g. global warming potential in kg CO_2 equivalent).
- Optimum cost effective experimental designs for the rapid assessment of the positive and negative impacts of agriculture on biodiversity and ecosystem services.

[35] ACRE notes that Defra has already commissioned projects addressing some of these priorities. Details of some of these projects may be found at http://www.defra.gov.uk/wildlife-countryside/natres/research.htm.

7 Recommendations

7.1 To manage more effectively the environmental footprint of agriculture as a whole, ACRE suggests that a broader and more consistent regulatory approach is needed which deals not only with potential negative environmental impacts of GM crops, but also with that of other novel crops and agricultural practices.

7.2 ACRE recommends that understanding and balancing the potential risks and benefits of existing and new agricultural technologies (whether GM or non-GM) should be part of the UK's current support for the goal of greater sustainability in all its agricultural and land management systems.

7.3 For the assessment of the potential risks and benefits of new agricultural crops and practices the Committee has developed a matrix-based approach in the form of a Comparative Sustainability Assessment (CSA) that could be used to encourage a more objective and comprehensive approach towards agricultural and rural policy

7.4 In the short-term ACRE envisages that CSAs and currently available supporting evidence could be used in the pre-assessment of government schemes to encourage environmental benefits or the use of novel crops (e.g. mitigation measures used in environmental stewardship schemes, incentive schemes for biofuels).

7.5 ACRE suggests that the CSA method presented in this report could provide a useful alternative to the approaches currently used by the government in Regulatory Impact Assessment. Changes in the way the RIAs are carried out with respect to environmental benefits and negative impacts could be a mechanism for achieving environmental policy goals and ensuring more consistent regulation with respect to the environment. However attention is drawn to the research priorities that need to be addressed, listed in Section 6.

7.6 In the long-term ACRE envisages CSAs to be used to inform the workings of an advisory committee. A CSA would enable the committee to advise policy makers about the negative and positive impacts of a proposed introduction, thus allowing policy makers to base their decision on the full picture of the best cross-cutting evidence available. The emphasis is on major not minor changes. ACRE does not envisage the CSA to be used at the level of the individual farm, thus ensuring that the regulatory burden on farmers is not increased.

7.7 ACRE believes that the CSA method could be accommodated within European legislation concerning the release of genetically modified organisms. At present applicants wishing to release GMOs are not required to submit any information on the benefits associated with the use of the GM products. However this information is important in order to determine whether the overall impact of a GM and its management is worse than that of equivalent products in current use. ACRE stresses that a revision of this nature would not represent a "softening" of the current regulatory regime with respect to GMOs.

7.8 When defining the scope of 'novel crop' and 'novel practice' regulators should take into account not only the species and the trait, or practice, but also the potential scale of cultivation and what the new crop or practice is expected to replace.

7.9 The Committee advises that any decisions based on CSAs should be reversible in the light of new evidence.

7.10 The report highlights some areas of further research, which would be required for the development and use of the CSA.

Annex A. Open Letter from the Agriculture and Environment Biotechnology Commission

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OPEN LETTER TO GOVERNMENT AND ACRE ON THE WIDER ISSUES RAISED BY THE FARM SCALE EVALUATIONS

The Agriculture and Environment Biotechnology Commission's (AEBC's) first report[1] evaluated the role of the Farm Scale Evaluations (FSEs) in the regulatory process. In its advice to Government on the FSE results[2], the Advisory Committee on Releases to the Environment (ACRE) noted that "the FSEs also have implications for agriculture in general, and may feed into a wider discussion concerning environmental impacts of agricultural practices". ACRE has established a subgroup to examine these wider implications.

This open letter sets out some questions raised by the AEBC in its recent deliberations that we feel might be useful for ACRE, as part of the work of their subgroup, and for Government, in their consideration of the wider agricultural issues raised by the FSEs.

EC Directive 2001/18 obliges Member States to avoid "adverse effects" arising from the release of GM organisms into the environment. As part of the risk assessment for new GMO events in crops, the Directive requires the identification and evaluation of possible adverse effects of "the specific cultivation, management and harvesting techniques" associated with the particular GM crop. The assessment is made by comparison with an equivalent non-GM crop variety, used in a corresponding agricultural context, on a case-by-case basis for each GM variety.

Using this comparative approach, the results of the FSEs highlighted issues that have implications for both GM and non-GM crops and the management practices associated with them. For example:

- It is the individual crop/trait combination that is being judged, not the whole system, and yet it is hard to isolate the environmental impact of a crop from the system in which it is grown. For example, it may be that we need to consider environmental impact throughout the whole rotation.
- The analysis of environmental impacts in the FSEs was limited by the parameters measured and what could be directly inferred from them. ACRE acknowledged this in their advice.
- There seems to be a tacit assumption in the Directive and the guidance that the status quo represented by the non-modified crop is the baseline against which impact should be evaluated. While data is readily available to allow evaluation on this basis, it is a somewhat arbitrary baseline to use, and also one that may change with time (indeed it is known that the biodiversity associated with many conventional crops is declining year-on-year). There is nothing to guarantee that this is the most appropriate baseline to meet policy goals for farming systems that are less damaging

to farmland wildlife; for example, the FSEs showed that the differences between crops were greater than the differences between a GM and non-GM version of the same crop.

- Environmental impact does not necessarily translate into adverse effects, because of the possibility of trading risks against benefits. For example, higher yields due to efficient weed control within the crop could be traded against wider, managed non-crop margins. How such trade-offs could be made is a difficult question, but one that needs to be explored, including whether possible approaches are practicable and whether compliance can be assured.
- Different crop management strategies could give different results for the same crop. Recent research suggests that the flexibility that GM herbicide tolerant systems may offer could be exploited to refine management strategies that favour biodiversity without sacrificing yield [3].
- There is at present no requirement to assess non-GM crops for their 'adverse effects' or environmental impacts.
- These issues suggest a number of questions that the ACRE subgroup might want to consider:
- Does the statistical significance demonstrated in the FSEs translate into ecological significance and ultimately 'harm' in a robust way? How far is the latter a value judgement as much as a scientific, consideration? What is the basis of any value judgement?
- Could this work be done in ways other than through FSE-type experiments? With hindsight, did the FSEs ask the right questions? Would the results have been replicated without the constraints of the "Part B" licence[4]? If the primary focus were on potential indirect effects, then alternative experimental designs might have asked, "Which management system would maximize yield and meet certain biodiversity targets (while remaining easy to administer for farmers)?"
- How widely drawn should be the considerations for assessing 'harm'? Is a wider canvas than that used by ACRE to judge the first round of the commercialisation applications possible under the terms of the Directive? For instance:

    - How far is it possible to rethink the standards for environmental risk assessment using whole farm systems?
    - Could other, non-conventional farming systems, such as organic or precision agriculture, be a more appropriate yardstick for environmental harm?
    - As well as effects on biodiversity, should indirect environmental effects such as fuel and agrochemical savings from new crop systems be brought into the frame, and benefits weighed against risks?
    - Are other possible comparative assessment systems available and what are their relative merits? Who would undertake them, and who should determine the criteria to use?

They also raise questions relevant to the Government's considerations of the wider environmental impacts of agriculture:

- What systems can be used to consider the varying environmental impacts of different conventional crops and different management systems for the same crop?

- What objectives should be set for biodiversity, and the environmental impact of farming overall? How should other, socio-economic dimensions of sustainability be considered alongside these objectives? Is it practical to set targets for biodiversity, considering its complexity, or should future improvements in agricultural biodiversity be driven principally by the pragmatic introduction of practices known to be more favourable to wildlife?

- What stakeholder input would be needed to set these objectives in a robust way? Does the public debate on GM offer any lessons, positive or negative, for how this might be done?

- What new structures within Government will be needed to help meet these objectives?

- What further research might be needed to inform decisions? Should all crops and/or crop systems, past and future, be subject to assessment along the lines of the FSEs?

- Although this would require revision of the EU regulations, should other ways of regulating GM and new non-GM crops, which would avoid or minimise some of the anomalies of the current system, at least be considered (eg. the Canadian model[5])?

This letter also goes to the Ministers to whom we report: Margaret Beckett, Secretary of State for Environment, Food and Rural Affairs); Patricia Hewitt, Secretary of State for Trade and Industry; Allan Wilson (Scottish Executive); Carwyn Jones (Welsh Assembly Government) and Angela Smith (Northern Ireland Office).

We hope that these points prove constructive and useful both for ACRE and for Government in their future consideration of the wider implications of the FSEs, and would be very happy to contribute further to ACRE's work in this area.

Yours sincerely

Professor Malcolm Grant
AEBC Chairman

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[1] Crops on Trial (September 2001). See http://www.aebc.gov.uk/aebc/reports/reports.shtml

[2] See http://www.defra.gov.uk/environment/gm/fse/index.htm

[3] Freckleton et al (2004). Amelioration of biodiversity impacts of genetically modified crops: predicting transient versus long term effects. Proceedings of the Royal Society of London series B - Biological Sciences. **271**(1536) pp 325-331. This is a paper that includes some modelling, using FSE type data, to illustrate that biodiversity benefits may be obtained by early spraying (rather than delaying spraying as in the FSEs).

[4] License conditions for Part B (non-commercial) releases of GMOs under Directive 2001/18, designed for small-scale plot work, may not necessarily reflect normal commercial practice.

[5] The Canadian regulatory system emphasises risk assessment on the basis of novel traits regardless of the technique or process used to generate the trait. "Plants which possess characteristics or traits sufficiently different from the same or similar species" require an assessment of risk. See http://www.inspection.gc.ca/english/sci/biotech/reg/bare.shtml.

Annex B. Cross-Compliance and Agri-Environment Schemes in the UK

A Single Payment Scheme (SPS) has been introduced, which will simplify the application arrangements for subsidy payments by replacing ten major CAP payment schemes with one new single payment. Farmers will have greater freedom to farm to the demands of the market as subsidies are decoupled from production. At the same time, environmentally friendly farming practices will be better acknowledged and rewarded. The Rural Payments Agency, an Executive Agency of Defra, is the single paying agency responsible for CAP schemes in England and certain schemes throughout the UK.[36]

In the UK farmers have to comply with the Cross-Compliance Regulations 2005 to be eligible for the Single Farm Payment.[37] There are two main elements to these regulations: (i) Statutory Management Requirements (SMR) and (ii) maintenance of land in Good Agricultural and Environmental Condition (GAEC). GAEC requires farmers to meet standards which protect soils, habitats and landscape features – some of these are new but many are based on existing legislation. In 2005 GAEC was extended to include a Soil Protection Review.

In response to recommendations by the Curry Commission, Defra increased funds available to agri-environment schemes and launched a new scheme to replace existing schemes. The new Environmental Stewardship Scheme (ES) has now been introduced.[38] The principle objectives of the ES scheme include (a) wildlife conservation, (b) maintenance and enhancement of landscape quality and character, (c) natural resource protection, and (d) protection of the historic environment. Secondary aims are flood management and conservation of genetic resources. The Entry Level Stewardship element (ELS) of the scheme is designed to be applicable to most agricultural land and should increase awareness of environmental issues amongst farmers in addition to the environmental benefits. ELS gives farmers the option to prepare a soil management plan, which should help prevent pollution of water courses. In addition to the soil management plan, farmers may choose from a 'menu' of different environmental management options, to suit the farm business. ELS agreements run for five years. In recognition of the environmental benefits that organic farming can provide, a version of ELS is also available to organic farmers (Organic Entry Level Stewardship, OELS).[39] OELS follows the same principles as ELS for land managed conventionally. Higher Level Stewardship (HLS) will also be available for land of significant environmental interest.[40] Under HLS landowners are required to complete a Farm Environment Plan, which identifies features of environmental importance on their land. As in the former Environmentally Sensitive Areas (ESA) and Countryside Stewardship (CSS) schemes, farmers enter into 10 year agreements. HLS agreements will normally have to be accompanied by an ELS agreement on the remaining area of land on the holding.

[36] http:/www.defra.gov.uk/farm/capreform/index.htm
[37] http://www.crosscompliance.org.uk/
[38] http://www.defra.gov.uk/erdp/schemes/els/default.htm
[39] http://www.defra.gov.uk/erdp/schemes/oels/default.htm
[40] http://www.defra.gov.uk/erdp/schemes/hls/default.htm

Annex C. Recent Changes to Environmental Regulations Covering Agricultural Practices in the UK

The Water Framework Directive

The Water Framework Directive (WFD) is the most substantial piece of EC water legislation to date.[41] It requires all inland and coastal waters to reach "good status" by 2015. The Directive came into force on 22 December 2000. Action to achieve the targets must be taken by 2012.

The recent WFD river basin characterisation exercise revealed a significant number of water bodies were at risk of not achieving WFD objectives because of diffuse water pollution:

- nitrate is a risk for drinking water supplies in 49% of rivers, particularly in England.
- phosphate is a risk for 38 per cent of rivers and 23% of lakes (by area).
- sediment (from eroded soil) is a risk for 21% of rivers.

Agriculture as a whole contributes an estimated 60% of water pollution by nitrates and 43% of phosphate pollution from diffuse sources, much of it through run off of nutrients and soil from farmland. In addition, diffuse water pollution from agriculture also contributes to non-compliance with the Bathing Water Directive (, the Freshwater Fish Directive, the Shellfish Water Directive and the Drinking Water Directive.

Although "good status" of waters has not yet been defined, evidence to date indicates that current regulatory controls, including the Nitrates Directive as well as voluntary and supportive approaches (such as funding through agri-environment schemes and the CSF Delivery Initiative (see below)), will not be sufficient on their own to allow the UK to meet WFD targets and objectives. Stronger measures will be needed to encourage farmers to take up activities which have financial implications for their business.

Estimates suggest that improvements and alterations in farm practices costing in the region of £80-200m will be required to attain the target. The economic benefits of these improvements have been estimated in the region of £250m per year. Other benefits such as benefits to biodiversity have not been costed-in to this analysis and the estimate of benefits is therefore likely to be conservative. The WFD RIA report estimates that 10-15% of farmland might require changes in land use if the 2015 target is to be achieved.

Defra consulted stakeholders in 2004 on the approach and possible measures that should be developed to improve water quality through the catchment-sensitive farming (CSF) programme. Four broad approaches were put forward: existing policies and late regulation; early regulation; the supportive approach and economic instruments. The results of this consultation[42] demonstrated that supportive

[41] http://www.defra.gov.uk/environment/water/wfd/
[42] http://www.defra.gov.uk/farm/environment/water/csf/pdf/Defra-HM-Treasury-consultation.pdf

measures such as the introduction of catchment officers are preferred to regulatory instruments or economic instruments. Changes in land use were considered by many as the last resort. The document also examines possible co-operative approaches between land managers and water companies or supermarkets. These approaches have the capacity to fund more costly solutions since supermarkets may be able to recoup outlay by charging a premium for goods produced in an environmentally friendly way and water companies direct resources saved on water treatment into abatement schemes. Following the consultation, Defra is continuing to develop the evidence base and to identify the most cost-effective policy options required to meet WFD requirements. A CSF Initiative was also launched in December 2005 and will be operational from April 2006 and see £25 M invested in Catchment-Sensitive Farming Officers in 40 priority catchments over the next two years. These officers will raise farmer awareness of diffuse water pollution from agriculture (DWPA) and encourage the voluntary action that will help towards meeting WFD targets.

The Nitrates Directive

In 1991 Europe adopted the Nitrates Directive (91/676/EEC). It is an environmental measure designed to reduce water pollution by nitrate from agricultural sources and to prevent such pollution occurring in the future.[43] Following a range of detailed consultations, 66 Nitrate Vulnerable Zones (NVZs), covering some 600,000 hectares (8%) of England, were designated in 1996 to protect drinking waters from nitrate pollution. However, a judgment by the European Court of Justice in December 2000 ruled that the UK had failed to designate sufficient areas to protect all surface and groundwaters, not just drinking water sources, against diffuse nitrate pollution from agriculture. Subsequently a number of additional nitrate vulnerable zones were identified. As a result of this ruling new nitrate vulnerable zones were designated, bringing the total designated area to 55% of England.

Farmers with land located in Nitrate Vulnerable Zones are required to comply with the Action Programme of measures to control nitrate pollution from agricultural sources. The Action Programme measures are based on best practice in the application, storage and use of fertilisers and manures. The Programme sets limits for the level of organic and inorganic fertiliser that can be applied to nitrate vulnerable zones and also makes certain provisions of the code for good agricultural practice for the protection of water mandatory in NVZs. Landowners in NVZs could apply for up to 40% of costs for improvement to manure and slurry storage facilities under the Farm Waste Grant Scheme until the scheme closed on 31st October 2005.

The Nitrates Directive requires that the Action Programme is reviewed every four years and that nitrate control measures are tightened if the water quality objectives of the directive are not being achieved. The government is currently considering the effectiveness of measures for the Action Programme and aims to consult formally on proposals for revised measures in spring 2006.

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43 http://www.defra.gov.uk/environment/water/quality/nitrate/directive.htm

The Waste Framework Directive

The Waste Framework Directive[44] ("the Directive") was originally adopted in 1975 and was subject to a substantial amendment in 1991. Member States were required to transpose and implement the amended Directive by April 1993. The amendments necessary to comply with the Directive were made in the Waste Management Licensing Regulations 1994 (SI1994 No.1056 as amended). These controls have applied to all sectors of industry and types of waste since 1 May 1994. The only exception has been wastes from mines and quarries and agricultural waste which, have been excluded under section 75(7)(c) of the Environmental Protection Act 1990.

On 9 December 2004 the Department issued a consultation paper on the draft Waste Management (England and Wales) Regulations which propose to repeal this exclusion, the consultation closed for comment on 18 March 2005. The Regulations will come into force in early 2006. On the introduction of the Waste Management (England and Wales) Regulations the basic options available to farmer and growers – and which may be used in combination – will be to:-

- Option 1 – Store their waste, pending collection, on the site where it is produced for up to 12 months;
- Option 2 – Take the waste themselves for recovery or disposal off-farm at an appropriately licensed site;
- Option 3 – Transfer their waste to someone else for recovery or disposal off-farm at an appropriately licensed site;
- Option 4 – Register a licence exemption with the Environment Agency to recover or dispose of their waste on-farm; or
- Option 5 – Apply to the Environment Agency for a waste management licence or a landfill permit to recover or dispose of their waste on-farm.

The Regulations require that agricultural waste has to be disposed of or recovered in ways that protect the environment and human health.[45] Farmers and growers must stop using farm dumps and tips before the Regulations come in to force, they will no longer be able to bury their waste or burn their waste except for the open burning of small quantities of untreated wood and plant matter, which will continue to be allowed under a licensing exemption. The Environment Agency have been working with the Department in developing a waste module as part of the Governments Whole Farm Appraisal.[46] The compliance monitoring of agricultural waste will be included as part of the Integrated Regulation of Agriculture Programme (IRAP). The Hazardous Waste (England and Wales) Regulations 2005 will apply 12 months after the Waste Management (England and Wales) Regulations come into force.

[44] 75/442/EEC, as amended http://europa.eu.int/comm/environment/waste/legislation/a.htm
[45] http://www.defra.gov.uk/environment/waste/topics/agwaste.htm
[46] http://www.defra.gov.uk/farm/wholefarm/benefits.htm

The Birds and Habitats Directives

The two most influential pieces of European legislation relating to nature conservation are the Birds[47] (79/409/EEC) and Habitats[48] (92/43/EEC) Directives. The Habitats Directive complements and amends the Birds Directive. These Directives were transposed into UK law by the Conservation (Natural Habitats &c.) Regulations 1994[49], which came into force on 30 October 1994. The Birds Directive protects wild birds and their habitats within the European Community. It also requires EU Member States to classify Special Protection Areas (SPAs) to protect rare and vulnerable birds. The Birds Directive also makes certain provisions for the protection of wild birds in the wider countryside outside protected areas. The Habitats Directive builds on the Birds Directive by protecting natural habitats and other species of wild plants and animals. The Habitats Directive requires the designation and protection of internationally recognised Special Areas of Conservation (SACs). SACs support rare, endangered or vulnerable natural habitats and species of plants or animals (other than birds). The Special Protection and Conservation Areas protected by these Directives form a European network of protected areas known as Natura 2000.

The Environmental Impact Assessment (EIA) Directive

The UK is currently in the process of developing new Environmental Impact Assessment (EIA) (Agriculture) Regulations to implement two aspects of the EU Environmental Impact Assessment (EIA) Directive (Directive 85/337/EEC as amended by Directive 97/11/EC and Directive 2003/35/EC).[50]

The purpose of the Regulations would be to protect the environment by applying an EIA process to relevant projects which are likely to have significant effects on the environment. A person wishing to undertake a relevant project would be required to make an application to the new Natural England agency to see whether EIA is required. If it is not required, the project would be allowed to proceed. If EIA is required, the assessment would inform a decision by Natural England on whether the work should be allowed to proceed.

The new EIA (Agriculture) Regulations will implement two aspects of the EU EIA Directive. First, they will apply new rules under which certain projects for the restructuring of rural land holdings will have to be made subject to the EIA process. Second, they will replace existing Regulations that apply EIA procedures to projects for the use of uncultivated land and semi-natural areas for intensive agricultural purposes.

The EIA Directive was introduced in 1985. It aims to reduce the environmental effects of a broad range of development projects. Under the Directive, EU countries must make laws which require various types of projects to go through an EIA process before they may proceed.

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[47] http://europa.eu.int/eur-lex/en/consleg/pdf/1979/en_1979L0409_do_001.pdf
[48] http://europa.eu.int/eur-lex/en/consleg/pdf/1992/en_1992L0043_do_001.pdf
[49] Statutory Instrument 1994 No. 2716 http://www.opsi.gov.uk/si/si1994/Uksi_19942716_en_1.htm
[50] http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/consleg/1985/L/01985L0337-20030625-en.pdf; http://www.defra.gov.uk/corporate/consult/eia2005/index.htm;http://www.scotland.gov.uk/Publications/2005/09/09103400/34024

The Directive applies to a very wide range of projects, split into two categories. Annex I of the Directive lists about 70 types of large, high-impact projects which always need an EIA. This includes the construction of motorways, airports, power stations, oil/gas pipelines etc. Annex II lists over 100 types of projects which are considered less likely to have significant effects on the environment. Member states must decide which of these projects might have significant effects, and thus whether they need an EIA. The latter category contains the two types of projects for which the UK is currently developing new regulation.

Annex D. The ACRE Sub-Group on Wider Biodiversity Issues

1. The ACRE Sub-group on Wider Biodiversity Issues[51], active between 1999 and 2001, advised ACRE on wider biodiversity issues with respect to the deliberate release of GMOs, on the necessary information requirements in consent or licence applications, on the baselines against which the risks of the deliberate release of GMOs should be compared so that the release of these organisms is compatible with the maintenance and restoration of biodiversity, in particular in relation to the objectives and targets of the UK Biodiversity Action Plan (BAP). The basis for the Sub-group on Wider Biodiversity Issues deliberations was the ACRE paper on “The commercial use of genetically modified crops in the United Kingdom: The potential wider impact on farmland wildlife”.[52]

2. The Sub-group on Wider Biodiversity Issues produced guidance for applicants with respect to the likely immediate or delayed impact on the abundance and diversity of wildlife arising directly or indirectly from the management associated with the growing of a GM crop.[53] The guidance document identified five key arable farmland habitat types (crop, within-crop flora and fauna, headland flora and fauna, soil beneath the crop, field margin and hedgerow) and nine key arable farmland BAP species (Brown Hare, Pipistrelle Bat, Skylark, Corn Bunting, Linnet, Grey Partridge, Song Thrush, Tower Mustard (*Arabis glabra*) and Cornflower (*Centaurea cyanus*). These species are associated with farmland and have a wide distribution in the UK.

3. In 2001 the ACRE Sub-group on Wider Biodiversity Issues and the Environment Panel (EP) of the Advisory Committee on Pesticides (ACP) have jointly considered how the environmental impact of the changed pattern of use of herbicides on GMHT and other crops should be assessed using the powers in both the GMO and pesticides legislation.[54] The ACP EP recognised the need for a broader approach to pesticide risk assessment involving more organisms and assessment of indirect as well as direct effects. In theory existing legislation would allow for a broadening of risk assessment. However, this would need to be tested and adjustment to Annexes would be needed. Within the pesticide approval’s process, new issues relating to a plant protection product can lead to review of an existing pesticide approval. However, a broader approach to risk assessment could not take place in isolation from a broader approach to crop management and a broader forum would probably be required to address this issue, an approach suggested in a joint letter to the Secretary of State by the ACRE and ACP chairmen.

[51] http://www.defra.gov.uk/environment/acre/biodiversity/index.htm
[52] http://www.defra.gov.uk/environment/gm/wildlife/index.htm
[53] http:// www.defra.gov.uk/environment/acre/biodiversity/guidance/index.htm
[54] http:// www.defra.gov.uk/environment/acre/biodiversity/011005m.htm

Annex E. The ACRE Sub-Group on Harm

1. The report of the ACRE Sub-group on Harm, published in 2002, set out how ACRE considers the concept of environmental 'harm' with respect to the deliberate release of genetically modified organisms into the environment.[55] As none of the existing methods for assessing harm were ideally suited to the assessment of risk from GMOs, the Sub-group on Harm proposed a system based on identifying the context of each release and then assessing the impact of seven attributes of harm on the receiving system, non-target environments and human health. The attributes of harm are (a) direct effects, (b) indirect effects, (c) spatial properties of the release, (d) temporal extent of the release, (e) severity of effects, (f) latency and cumulative effects and (g) reversibility of effects.

2. This approach considers harm as a relative measure rather than against an arbitrary baseline. In line with the relevant legislation the assessment is strictly one of 'harm' rather than a cost/benefit type analysis. The Sub-group on Harm emphasised that it is important to draw a distinction between harm and change. If a release brings about changes to the *status quo* it does not necessarily follow that these changes are harmful. Social responses to harm were beyond the remit of the assessment.

3. The Sub-group on Harm further emphasized that there is no simple single metric that can be used to measure environmental harm. Causes and effects are too differentiated to resolve to a single measure (such as monetary value), and so the critical question involves balancing of often incommensurable information on risk. This implies the need for expert judgement and the development of flexible procedures, which take into account the levels of uncertainty.

4. The Sub-group on Harm recognized that the scientific assessment of harm is accompanied by an important set of attributes that relate to the social responses to harm. Whilst these social responses to harm do not form a part of the scientific assessment procedures, they are clearly important in explaining and understanding public responses to environmental challenges. This has important implications for the effectiveness and legitimacy of public decision-making about risk and the effects on democratic values[56]. The five attributes of social responses to harm are dread, distrust, equity, control and familiarity.

5. The Sub-group on Harm briefly reviewed existing approaches for assessing potential environmental harm. A wide range of traditions and approaches have been developed for the assessment of environmental risk, many of which weigh potential harm with beneficial outcomes. These include (but are not limited to):

i. quantified risk assessments and environmental management systems[57];

ii. dose-response thresholds, for assessing specific chemical compounds

[55] http://www.defra.gov.uk/environment/acre/harm/pdf/acre_harm_report.pdf
[56] Weale (ed). 2002. *Risk, Democratic Citizenship and Public Policy*. British Academy, London
[57] Pollard S *et al*. 2002. *Environ. Sci. Tech.* 36, 530-8; Lewis K A & Bardon. 1998. Environ. Modelling & Software 13, 123-137; Lewis K A *et al*. *J. agric. Engng. Res.* 68, 271-279

using comparisons of toxicity with predicted environmental concentrations, giving a toxicity:exposure ratio;

iii. environmental harm indices and multi-criteria mapping[58];

iv. environmental economics that seeks to put a monetary cost on positive and negative impacts on natural and social resources that have no market prices[59];

v. energy accounting that compare inputs and outputs according to energy content[60];

vi. carbon accounting that measures the sinks and sources of greenhouse gases in systems[61];

vii. environmental audits for the development of management systems (such as BS14001);

viii. key species approaches[62];

ix. sustainability indicators as developed by DEFRA and the OECD[63];

x. standards-based approaches.[64]

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[58] DETR. 1998. Management of Harm to the Environment (London); AEA. Environmental Risk Assessment Methodology (Environment Agency, Peterborough); Stirling A and Mayer S. 2000. *Rethinking Risk* (SPRU, Sussex)

[59] Daily G. 1997. Nature's Services (Island Press, Wash.); *Ecological Economics.* 1999. Volume 25, issue 1; Pretty J *et al.* 2000. *Agric. Syst.* 65 (2), 113-136

[60] Leach G. 1976. Energy and Food Production (IPC Press, Guildford); Pimentel, D. 1980. *Handbook of Energy Utilization in Agriculture.* (CRC Press, Boca Raton); Cormack B and Metcalfe P. 2000. *Energy Use in Organic Farming Systems* (ADAS, Terrington)

[61] Smith P *et al.* 2000. *Global Change Biol.* 6, 525-539; Royal Society. 2001. The role of land carbon sinks in mitigating global carbon change (London); Pretty *et al.* 2002. *Trans. Roy. Soc. Lond A* (in press)

[62] Grieg-Smith P. 1992. *Aspects appl. Biol.* 31, 121-132; Cooke A. 1990. *In Pesticide Effects on Terrestrial Wildlife*.

[63] MAFF. 2000. Towards Sustainable Agriculture: A pilot Set of Indicators. MAFF, London . OECD. 1998. COM/AGR/CA/ENV/EPOC (98) 136, Paris;

[64] Royal Commission on Environmental Pollution. 1998. Setting Environmental Standards. Cmnd 4053. 21st Report. HMSO

Annex F. Summary of submissions to ACRE Open Meeting on 22 October 2004

Life-cycle assessments

Dr Richard Phipps from the University of Reading introduced the background to life-cycle assessment by emphasising that agricultural production systems generally consist of a number of complex and often closely interrelated components, and that research programmes such as the FSEs generally focus on specific areas or components and therefore cannot provide a full picture of the effect of changes in crop management on the environment and human health. Such effects may occur at a considerable distance from the agricultural production system. Further complex analyses are therefore needed to obtain the full impact of a change in production system on environmental and human health. Account should be taken of the different energy input costs for pesticide production, and that if less pesticide is used this will result in reductions in raw materials, manufacturing equipment, diesel in the manufacturing process, fuel for shipment, distribution and storage, water and fuel using in spraying, and packaging for the pesticide required. The decrease in diesel use associated with reduced spraying frequency and/or a change from conventional cultivation practices to minimal tillage would result in decreased production of greenhouse gasses. All of these factors have potential environmental and human health impacts and need to be considered when exploring methodologies that evaluate the whole system as well as its component parts. Life-cycle assessment is one such technique.

Life-cycle assessment (LCA) is a recognized (ISO 14040 series) methodology defined as “objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements”. It can also be described as “the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product or system throughout its life cycle”.[65] LCA focuses on environmental and human health aspects but does not address economic, social or other impacts.

Although LCA has frequently been applied to industrial processes and products, it has rarely been applied in agriculture. An exception is the LCA comparing conventional and GM sugar beet varieties.[66] Dr Phipps suggested that the use of methodologies such as LCA, which apply a systematic approach to identify and analyse environmental burdens and their impacts in terms of the environment and human health, will provide a realistic approach to assessing the impact of complex agricultural production systems.

An LCA involves four main stages, (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. Stage 1 identifies the characteristics of the LCA and its boundaries, the ‘functional unit’ and the policy objective for the assessment. For example, the LCA of GM sugar beet considered only those parts of the system that differed between conventional and GM with the boundary of the analysis stretching from herbicide production to output of the raw sugar beet. The inventory analysis involves defining the system(s), collecting and collating data on processes and quantifying inputs and outputs for each process –

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[65] SETAC. 1991. A Technical Framework for Life-Cycle Assessments. Society of Environmental Toxicology and Chemistry. Washington D.C.

[66] Bennett, R. M., R. H. Phipps, A. Strange and P. Grey. 2004. Environmental and human health impacts of growing genetically modified herbicide-tolerant sugar beet: a life-cycle assessment. *Plant Biotechnology* **2**, 273-278.

energy, materials, emissions to air, water, and soil and solid wastes. The impact assessment involves selecting impact categories (e.g. global warming), characterisation of the impacts in measurable units (e.g. global warming potential in kg of CO_2 equivalents) and their valuation (e.g. weighting the different emissions; methane has a global warming potential weighting of 11 compared to 1 for carbon dioxide). Next the results are evaluated in terms of their robustness and validity. LCA allows 'what if' questions to be addressed in a scientifically defensible manner. It should be noted that existing inventories are often limited and may only relate to circumstances in particular parts of the world, and that the results may be critically dependent on the boundaries used to define the system.

Life cycle assessments show the value of multi-criteria approaches in comparing and judging agricultural systems.

Environmental economics applications to UK agriculture

Professor Joe Morris from Cranfield University, Silsoe, presented evidence on the applications of environmental economics to UK agriculture. After outlining the wider context, Professor Morris emphasised the role or environmental economics in identifying and where possible valuing the complex linkages between agriculture and the environment. This allows a more economically efficient use of resources, guides the development of policy, and provides an assessment of the real contribution of the agricultural sector to societal welfare.

Professor Morris outlined the economic characteristics of environmental goods and services. Environmental economics attempts to value changes in environmental qualities, goods and services, which although not usually traded nor included in business decision-making, nevertheless involve real resource costs and welfare benefits. Many changes in environmental quality are associated with 'externalities'. These are impacts borne by third parties as a consequence of decisions by individuals or organisations for which no compensation is paid. An example of a negative external impact is the cost borne by water companies for the removal of pesticides or nitrate from water draining from farmland. An example of external benefits includes the welfare gain associated with the presence of farmland birds. Externalities cause economic inefficiency because the perpetrator has little incentive to minimize these costs (or maximize these benefits). Externalities are indicative of a failure of market systems and property rights. The principle of polluter pays represents an attempt to correct for this by internalizing the negative externality, and this is now matched by the idea of payment for environmental goods: the provider gets principle[67].

Many environmental goods and services are not traded and so difficult to value in the conventional market sense, and yet they are obviously of value to society. Environmental qualities are often freely available public goods. There is also uncertainty about the impact of human activity on the integrity and resilience of the environment, and of the possible consequences for human society. The adoption of the precautionary principle attempts to address this issue. These characteristics of the environmental qualities, goods and services mean that they are often ignored by individuals, organizations and Governments unless explicit steps are taken to include them.

[67] Dobbs T and Pretty J N. 2004. Agri-environmental stewardship schemes and `multifunctionality'. R*eview of Agricultural Economics* **26**, 220-237.

Recent developments in environmental economics have focused on the links between ecosystem functions, uses and values. Ecosystem functions include production, regulation, carrier and information. Uses include agriculture, industry, tourism and others. Some function-use-value chains are easier to identify than others, e.g. those were the outputs are traded in the market place and well-defined by property rights (e.g. the production function associated with land use for forage maize and the resultant value to diary farmers). But pursuit of optimal or maximal production functions and uses may compromise other eco-system functions. A further complication is that some environmental functions are associated with 'non-use': for example, the existence of bequest value of rare natural species, which are supported by carrier and regulatory functions.

The methods for valuing environmental goods and services can be grouped into two main types: cost-based and demand-based methods[68]. Cost-based methods estimate the impact of environmental change on incomes or expenditures of individuals, households or businesses. They include assessments of dose response (e.g. impact on air quality on public health), change in productivity (e.g. loss of value of crop production due to soil erosion), loss of earnings, defensive expenditure (e.g. measures to reduce erosion), substitute goods or replacement costs. Demand-based methods estimate willingness to pay (or willingness to be compensated) for a given change in an environmental characteristic based on observations of actual user behaviour (revealed preference) or on predictions by respondents of their likely behaviour (expressed preference). These methods can theoretically provide more comprehensive estimates of the impact of environmental change on welfare than cost-based methods. Revealed preference methods include the Travel Cost method, which seeks to determine the value of an environmental good (e.g. a visit to a rural beauty spot) by using the costs incurred by users of the environmental good as a proxy for the price of the good itself. The Hedonic Pricing method seeks to determine the extent to which a particular environmental attribute (e.g. flood risk) is responsible for variations in the price of a marketed good (e.g. a house). Expressed preference methods present users and non-users with hypothetical situations to derive estimates of value. Contingent Valuation creates a hypothetical market for an environmental quality (e.g. hedgerows or whole landscapes). Respondents are asked to express willingness to pay for an increment in a given environmental quality (or willingness to accept compensation in the event of a decline in this environmental quality). Such demand estimation methods are data intensive and have been criticized for potential lack of reliability and/or vulnerability to respondent bias. Other methods, such as multi-criteria analysis and choice modeling, can help determine relative preferences and values for environmental quality such as landscape, but they place less emphasis on monetary valuation.

Three recent studies have produced cautious estimates of the damage costs associated with agriculture in the UK. They vary in their coverage of geographical area and type of environmental impact as well as in the use of valuation techniques. Hartridge and Pearce (2001)[69] estimated an annual environmental cost of £1.1 bn for the UK using predominantly demand-based methods. Pretty *et al.* (2000, 2001)[70]

[68] Bockstael N E, Freeman A M, Kopp R J, Portney P R and Smith V K. 2000. On measuring economic values for nature. *Environ. Sci. Technol.* **34**, 1384-1389.
[69] Hartridge, O. and D. Pearce. 2001. Is UK agriculture sustainable? Environmentally adjusted accounts for UK agriculture. CSERGE Economics Paper. UCL/UEA.
[70] Pretty, J. N., C. Brett, D. Gee, R. E. Hine, C. F. Mason, J. I. L. Morison, H. Raven, M. D. Rayment and G. van der Bijl. 2000. An assessment of the total external costs of UK agriculture. *Agricultural Systems* **65**, 113-136; Pretty J, Brett C, Gee D, Hine R

estimated the annual damage costs to be about £1.5 bn (excluding BSE and food safety impacts), using mainly cost-based methods. Both assessments identified that the greatest costs were associated with emissions to air and water. The Environment Agency[71], giving relatively greater emphasis to soil impacts but excluding biodiversity and public health, estimated annual costs of £1.2 bn for England and Wales. Hartridge and Pearce estimated environmental benefits at about £0.6 bn per year associated with landscapes and biodiversity, whereas the Environment Agency, including the value of carbon sequestration, estimated environmental benefits of agriculture as £0.9 bn per year.

A recent assessment of the transport costs (or food miles) in the UK has confirmed that costs to the farm gate are £1.5 bn per year, but that these are greatly exceeded by the environmental costs of transport of food to the retail outlet and then to the point of consumption[72]. Food mile costs comprise some £3.5 bn per year.

Professor Morris concluded that although there are many uncertainties regarding the completeness and reliability of the estimates outlined above, it is clear that the environmental economic impacts of agriculture and food systems are substantial. He suggested that environmental costs account for probably around 30% of the £5 bn annual value added from the UK agricultural sector (and a significantly greater proportion once the value of production subsidies to agriculture are excluded). The benefits of environmental services provided by agriculture are also currently inadequately accounted for. These observations have important implications for agricultural policies. Through application of the principles of ‘polluter pay’ and ‘provider (of environmental services) gets’ agricultural policy can help deliver a sustainable future for UK agriculture.

Environmental economics seeks to resolve the environmental side-effects of agricultural systems to monetary values where possible, thus permitting easy comparisons. However, there are many different methodologies for valuation, and many important environmental goods and services cannot be easily resolved to monetary values.

Use of indicators in a sustainable agriculture initiative from the private sector

Professor Steve Parry of Unilever R&D, Sharnbrook, introduced Unilever’s sustainable agriculture initiative, which was started in the late-1990s.[73] Unilever is a food company, and its aim was to ensure their continued access to key agricultural raw materials and to develop market mechanisms that allow consumers to influence the sourcing of raw materials through their buying habits.

The question they sought to address was how farming can remain competitive, protect the environment, and contribute to rural communities, while using fewer agrochemical and other inputs and yet produce the quality and quantity of raw materials required. This poses a huge challenge to those involved in agriculture: farmers, scientists, experts, governments and businesses.

E, Mason C F, Morison J I L, Rayment M, van der Bijl G and Dobbs T. 2001. Policy challenges and priorities for internalising the externalities of agriculture. *J. Environ. Planning and Manage.* **44**, 263-283.
[71] Environment Agency. 2002. Agriculture and Natural Resources: Benefits, Costs and Potential Solutions. Bristol.
[72] Pretty J, Lang T, Ball A and Morison J. 2005. Farm costs and food miles: an assessment of the full cost of the weekly food basket. *Food Policy* 30, 1-20.
[73] https://www.livegroup.co.uk/acre/meeting_presentations/Presentation%20to%20ACRE%20-%20Steve%20Parry.pdf

Unilever started by looking at how to improve the sustainability of current farming methods in locations where they sourced key products. Working with a range of stakeholders, NGO's and experts Unilever developed four principles for sustainable agriculture, and ten broad indicators for assessing sustainability in agriculture.

The four principles are to (a) maintain high yield and nutritional quality while keeping resource inputs low, (b) minimise adverse environmental effects; make a positive contribution where possible, (c) optimise the use of renewable resources; minimise the use of non-renewables, and (d) enable local communities to protect and improve their well-being and environments.

The ten indicators are soil fertility/health, soil loss, nutrients, pest management, biodiversity, product value, energy, water, social/human capital and local economy. For each indicator four to five parameters have been defined as a basis for assessment and measurement (e.g. earthworms per square metre, soil cover index, amount of inorganic nitrogen and pesticide applied, ratio of renewable over non-renewable energy inputs)[74]. Seventy-five percent of the parameters are generic to all cropping systems, while the remaining ones are more crop and/or region specific. The process involved collection of baseline data and ongoing monitoring of changing practices. The information and improvements have been incorporated into best practice guidelines. The approach can be applied to a wide range of farming systems.

This indicator system can be used to understand the impact of changing management systems and the trade-offs that might have to be made due to the interactive nature of various processes.

Unilever's experience highlighted some difficulties. For example costly or non-value adding activities were often not implemented and so were difficult to evaluate. However, by working in partnership with growers it was possible to examine all practices with regard to farm economics. In general it was found there was a general resistance to change unless it can provide some private benefits. The Forum for Sustainable Farming, established by Unilever, provided a means by which growers took ownership and sold the benefits to other growers. Finally there was a lack of precedents. Leading experts in sustainability were invited to help Unilever to develop a practical system of measurement, targeting improvements and ways to deliver improvement.

In Unilever's experience the journey towards sustainability requires long term commitment with continuous improvements of agricultural practices based on indicator assessment, expert inputs, farmer participation and best practice guidelines. Stakeholder consultation and external review are critical to ensure transparency and credibility while food industry co-operation is essential to develop future sustainable standards and a move towards market mechanisms for sustainable raw materials.[75]

The Unilever approach shows the value in using simple sustainability indicators when developing potential management options. The aim is to make aggregate progress towards sustainability, and this may mean different farmers seek to innovate in different ways according to their particular circumstances.

[74] http://www.unilever.com/ourvalues/environmentandsociety/sustainability/agriculture/indicators.asp
[75] http://www.unilever.com/ourvalues/environmentandsociety/sustainability/agriculture/

Further approaches for the measurement and assessment of the environmental impacts of agriculture

Dr John Tzilivakis focused on approaches to measure and assess the environmental impacts of agriculture, which are under development at the Agriculture and Environment Research Unit at the University of Hertfordshire.

The aim of the research is to improve understanding and to develop sustainable solutions, from the policy level to the farm level. Examples of studies include the use of indicators to assess pesticide use, energy efficacy and nitrate leaching. The individual studies and techniques quoted fed into a more a holistic environmental assessment framework. All studies involve collecting data on environmental effects. These data can be quantitative and derived either from actual measurements or models. In many instances, expert judgment has to be used to obtain 'soft' qualitative data in the absence of 'hard' quantified information. The data are then analysed and assessed in terms of impact significance or to answer specific questions.

Dr Tzilivakis described environmental indicators as typically simple measures that are understood to be representative of the wider picture. The UK Government launched a national set of indicators for sustainable agriculture[76]. However, as policy tools, many of these indicators are highly technical in nature and often appear relevant only at national level. Consequently, the key messages underpinning the indicators are not easily identifiable at farm level. A Defra-funded project was commissioned to make these indicators more applicable to the farm level[77], which involved breaking down the national data by geographical location and farm type. It was felt that in order to drive progress towards sustainability, it was important to define indicators at a level meaningful to the target audience and that account for the spatial and temporal diversity of farm environments.

A finding of the Defra-funded project was that at the farm level the most important aspect of the indicators was the key messages behind them, in terms of good agricultural practice, rather than the indicator values and trends. One of the more problematic indicators is pesticide use and its impact on the environment. Although it is highly monitored in terms of use, area sprayed, levels in rivers and groundwater, none of these convey the actual impact of the active substances. So although there have been decreases in use this does not necessarily indicate a decrease in impact.

Many techniques have been developed to measure impact of pesticides[78], e.g. the p-EMA software, a risk assessment technique that utilises a toxicity-exposure framework based on the regulatory risk assessment process for pesticide approvals in the UK[79]. p-EMA was applied retrospectively to the LINK Integrated Farming Systems (IFS) project[80]. The results showed that using the quantity of pesticide applied as a surrogate indicator of risk was unsound, and that when a site had few

[76] http://www.sustainable-development.gov.uk/performance/performance.htm

[77] Tzilivakis, J. and Lewis K.A. 2004. The development and use of farm level indicators in England. *Sustainable Development* **12**, 107-120

[78] Reus, J., Leendertse, P., Bockstaller, C., Fomsgaard, I., Gutsche, V., Lewis, K., Nilsson, C., Pussemier, L., Trevisan, M., Van der Werf, H., Alfarroba, F., Blümel, S., Isart, J., McGrath, D., Seppälä, T. 1999. *Comparing environmental risk indicators for pesticides - Results of the European CAPER project*. Centre for Agriculture & Environment, Utrecht. July 1999. CLM 426-1999. See also Pretty J (ed). 2005. *The Pesticide Detox*. Earthscan, London.

[79] Brown, C. D., Hart, A., Lewis, K. A. and Dubus, I. G. 2003. p-EMA (I): simulating the environmental fate of pesticides for a farm-level risk assessment system. *Agronomie* **23**, 67-74; Hart A, Lewis, K. A. and Brown, C. D. 2003. p-EMA (II): evaluating ecological risks of pesticides for a farm-level risk assessment system. *Agronomie* **23**, 75-84; Lewis, K. A., Brown, C. D., Hart, A. and Tzilivakis, J. 2003. p-EMA (III): overview and application of a software system designed to assess the environmental risk of agricultural pesticides. *Agronomie* **23**, 85-96.

[80] Tzilivakis, J., Turley, D. B., Ogilvy, S. E., Lewis, K. A. and Lawson, K. 2004c. Assessing the environmental impact of crop protection strategies for integrated farming systems. *Agronomie* **24**, 67-76.

sensitive habitats there was little difference in the predicted environmental impact of different crop protection strategies. However, when a site was habitat-rich, integrated farming system strategies could lower the predicted risk. The results also demonstrated the need for substantial site and pesticide information to improve integrated strategies. Another important element to this study was that the assessment covered the whole rotation and so took into account how the crop sequences in the rotation can increase or decrease the pest pressure in subsequent crops and thus the need for chemical intervention that could have a negative impact.

Another study carried out by the Agriculture and Environment Research Unit assessed the environmental impact of different sugar beet production scenarios in the UK.[81] Of the nine measures made for each scenario, net margin, global warming potential, energy efficiency, nitrate leaching, denitrification and pesticide ecotoxicity were chosen as key performance measures. A net margin was calculated for each scenario to add an economic element to the analysis. To provide an easy means of comparing the production scenarios, each of the measures was performance indexed thus generating a normalised set of performance scores that can be viewed graphically as a 'sustainability' profile for the thirteen production scenarios studied. This comparison showed that the most economically profitable scenario also had the best overall environmental performance. This scenario represented 18% of UK sugar beet area. Three other scenarios that represented 57% of the total area closely followed this performance. This illustrates that a significant proportion of the UK crop is being grown in an economically efficient way whilst minimising environmental damage.

Determining the significance of effects and impacts in terms of environmental damage is one of the most difficult tasks in environmental assessments. In the studies above, most of the effects and impacts are presented in ways designed to answer specific questions, usually of a comparative nature, i.e. which system or practice has a less or more damaging effect? It is generally not difficult to characterise effects as negative or positive (e.g. we know it is desirable to reduce nitrate losses). In the last example, different sugar beet production systems were compared and those with the best and worst performance in relation to each other identified. The same techniques can also be used to compare sugar beet with other crops. For example, a study[82] of the varietal characteristics required for sustainability in wheat, barley, potatoes, oilseed rape and peas showed that pesticide ecotoxicity and nitrate leaching for sugar beet were typically low compared to the other crops.

Although the above studies provide a broader picture in terms of the environment performance of a crop they do not necessarily indicate the severity of the actual environmental damage. A number of techniques have attempted to address this issue. For example, economic valuation techniques aim to internalise the external environmental costs by attaching monetary values to them. This can be a valid approach and can help identify policy priorities, for example, the cost of removing nitrates and pesticides from drinking water supplies.[83] However, in other instances it

[81] Jaggard, K., Tzilivakis, J., Warner, D. J. & Lewis, K. A. 2004. Beet and the environment. *British Sugar Beet Review* 72, 34-37; Tzilivakis, J., Jaggard, K., Lewis, K. A., May, M. and Warner, D. J. 2005. Environment impact and economic assessment for UK sugar beet production systems. *Agriculture, Ecosystems and Environment* **107,** 341-358; Tzilivakis, J., Jaggard, K., Lewis, K. A., May, M. and Warner, D. J. 2005. An assessment of the energy inputs and greenhouse gas emission in sugar beet (*Beta vulgaris*) production in the UK. *Agricultural Systems* **85**, 101-119.

[82] Defra. 2003. *Investigation of Varietal Characteristics Required for Sustainable Agriculture*. Final Report for project VS0128 undertaken by NIAB and the University of Hertfordshire for the Department for Environment, Food and Rural Affairs.

[83] Pretty, J. N., Brett, C., Gee, D., Hine, R. E., Mason, C. F., Morison, J. I. L., Raven, H., Rayment, M. D. and van der Bijl, G. 2000. An assessment of the total external costs of UK agriculture, *Agricultural Systems* **65**, 113-136.

is a more controversial technique, especially for items that tend to transcend conventional economic frameworks and monetary valuation, such as biodiversity and human health.[84] Economic techniques also do not necessarily characterise actual impacts or damage.

One approach that tries to do this is the distance to target method. This has been developed and used by a number of organizations[85], particularly for Life Cycle Assessment (LCA). The method ranks impacts as being more important the further away an activity is from achieving desired targets. A change in an effect is converted to an index of damage based on an effect-damage relationship (or damage function). NOH (1995) use multiples of the target level to set the index and a standard sigmoid curve as a model in toxicology for the effect-damage relationship. This is an interesting approach, but is hampered by the lack of established effect-damage relationships and targets. Tzilivakis *et al.* (1999)[86] attempted to adapt the distance to target approach as a means of assessing impact significance in relation to the implementation of agricultural policies. The level of uncertainty in the effect-damage relationships and targets were a significant issue that prevented the technique being developed into a practical tool for policy impact assessment.

Dr Tzilivakis concluded that considerable progress has been made in the last decade and that a range of different tools are now available to help construct a better and more holistic picture of the environmental impact of agriculture. However, major gaps in knowledge still exist, such as on the impacts on biodiversity and human health. One solution may be where the more complex tools and techniques (used locally at the farm level) feed data to the tools, techniques and indicators at the policy level. Such an integrated approach could be feasible with the use of information technology.

The approaches described here show the benefits of multi-criteria approaches in the assessment of comprehensive costs and benefits of various agricultural systems and practices. Like the life cycle assessments described earlier, they tend to require large amounts of data, though some farmer-friendly interactive methods have been developed.

Evidence submitted by the British statutory conservation agencies

The British statutory conservation agencies (JNCC, Countryside Council for Wales, English Nature and Scottish Natural Heritage) submitted evidence in writing. After outlining the environmental risk assessment required from applicants wanting to market GMOs in the EU, the statutory conservation agencies reminded ACRE that Directive 2001/18/EC currently makes no provision to take into account benefits of GM crops and other organisms to the environment. They further pointed out that the Seeds Directive requires assessment of agronomic parameters of new crop varieties but not risks to the environment. Some moves have been made towards developing

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[84] Gregory, R. and Slovic, P. 1997. A constructive approach to environmental valuation *Ecological Economics* **21**:175-181

[85] ENDS. 1994. The elusive consensus on life-cycle assessment. ENDS Report **231**, 20-22; NOH (The Dutch National Reuse of Waste Research Programme). 1995. *The Eco-indicator 95. Final Report.* Report produced under the responsibility of the Netherlands agency for energy and the environment (Novem), and, the National Institute of Public Health and Environmental Protection (RIVM); Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D. & Woodward, R.. 1995. *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development.* World Resources Institute; Seppälä, J. and Hämäläinen, R. P. 2001. On the Meaning of the Distance-to-Target Weighting Method and Normalisation in Life Cycle Impact Assessment. *International Journal of Life Cycle Assessment* **6**, 211-218

[86] Tzilivakis, J., Broom, C., Lewis, K. A., Tucker, P., Drummond, C. & Cook, R. 1999. A Strategic Environmental Assessment Method for Agricultural Policy in the UK. *Land Use Policy* 16,223-234

guidelines in England for a ‘sustainability assessment’ of new varieties but this was at an early stage.

The statutory conservation agencies suggested that one option would be for ACRE to advise Government to lobby for amendments to 2001/18 to include benefits. However, the view of the statutory conservation agencies is that risk assessment is concerned primarily with safety, whereas assessment of benefits is part of a wider sustainability assessment that could follow risk assessment if the product is found to be safe as defined by the Directive. They suggest that ‘harm’ is essentially a political concept, because a precise definition depends on the value that society (and its politicians) gives to different environmental parameters.

It is the view of the statutory conservation agencies that risk assessment is designed to set out the environmental ‘bottom line’ for GM crops (and other organisms). They support the idea that all novel crops should be covered by a common regulatory system. Benefits could be defined as changes that move in the direction of one or more national or international environmental targets. A GM crop which was demonstrated to provide a better habitat for biodiversity than its conventional equivalent could, for example, be deemed beneficial.

The statutory conservation agencies commented on AEBC’s suggestion to ACRE that environmental effects other than biodiversity (such as fuel and agrochemical savings) could be brought into a framework to help weigh benefits against risks. The agencies considered the measurement of these parameters useful but they would not consider them to represent the ‘environmental bottom line’ in the same way as biodiversity. Instead, the suggestion was that these are ‘strategic’ issues that should not form part of an environmental risk assessment but should be examined separately through a ‘sustainability assessment’.

The statutory conservation agencies proposed a two-step model for approval of novel crops:

> “*1. Biosafety: Environmental risk assessment to check for any potential adverse effects on human health, food and feed safety and the environment, using the protocols already set out in Directive 2001/18. This could be expanded if necessary to include non-GM crops exhibiting novel traits. New GM traits and crop varieties must pass this assessment if they are to be cultivated commercially in Europe. If a crop failed the biosafety assessment due to adverse impacts of crop management practices, further research could be carried out under a Part B licence to develop mitigatory management practices.*
>
> *2. Relative Sustainability**:** Providing the crop and its management system pass the biosafety hurdle (i.e. receive a “Part C” consent), a “life cycle” assessment should be used to compare performance with existing farming practices. This should include agrochemical inputs, use of farm machinery, greenhouse gas emissions etc, as well as upstream and downstream environmental impacts where relevant. Relative sustainability assessment should be undertaken at the level of the farming system, and could also examine the potential for changes in management practice to enhance biodiversity and other environmental parameters.”*

The principles outlined above could also apply to organisms other than novel crops (e.g. trees, livestock, fish, biocontrol agents, etc) or any situation where the introduction of a novel variety could alter the sustainability of human activities.

Further submissions

Dr Brian John from Newport, Pembrokeshire, expressed support in his submission for ACRE's consideration of the wider issues raised by the FSEs and advised a balanced approach. He suggested that GM and other new technologies developed by large companies may be inherently harmful to the environment. Dr John also criticized the FSE results for GM maize, which he considered to be flawed.

Professor Joe Perry from Rothamsted Research, Harpenden, responded in his submission to Dr John's criticism of the FSE maize results (see above). Professor Perry explained in detail why neither the experiments nor the analysis of the data were flawed, with particular emphasis on the herbicide triazine. He emphasised that the research consortium had explained this issue repeatedly at open meetings and also referred to the analysis, published by the consortium, on those FSE maize sites that did not use triazine[87], which broadly supported the main FSE findings for maize.

Professor Perry also provided evidence for the urgent need for new research on experimental design, analysis and statistical power to develop the means for reducing the cost of future studies of the impact of agriculture on biodiversity, whilst retaining relevance to policy and rigor of the science.[88] It is becoming increasingly evident that studies of the effects of agriculture on biodiversity need to be carried out at a large scale (field or farm) rather than in small-plots. Such a large scale poses new challenges for statisticians regarding the generation of efficient experimental designs, difficulties that are compounded when composites of several practices are studied in evaluations of integrated farming systems. Existing studies of the power required to detect reasonable sized effects at the field scale[89] showed that considerable replication was necessary (in excess of 60 fields). The FSEs used such level of replication and is seen as a benchmark for the evaluation of farming practices. It provided data of high quality but was very expensive. Professor Perry identified several issues relating to biometrical issues (concerned with design, analysis and statistical power) as well as biological issues (relating to the selection of suitable indicator species). (1) Identification of the relevant spatial scale for choice of experimental unit, (2) Identification of the appropriate temporal scale for the experiment as influenced by generation time of taxa studied, (3) Upscaling from plots through fields to landscapes and regions and from seasons through years to agricultural rotations, (4) The ecological evaluation of effect sizes for power analysis, (5) The development of realistic statistical models for statistical power analysis, (6) Development of models for analysis of count data with complex structure, and (7) The elaboration of univariate analyses for autoecological studies to multivariate methods for studies of communities and multi-trophic interactions.

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[87] Perry, J.N., Firbank, L.G, Champion, G.T., Clark, S.J., Heard, M.S., May, M.J., Hawes, C., Squire, G.R., Rothery, P., Woiwod, I.P. & Pidgeon, J.D. (2004) Ban on triazine herbicides likely to reduce but not negate relative benefits of GMHT maize cropping. *Nature* **428**, 313 – 316.

[88] Based on : Perry *et al.* 2004. Research needs on the design, analysis and statistical power of studies of the effects of agricultural practices on biodiversity. Invited contribution to the E-conference in support of the EU Irish Presidency meeting on "Sustaining livelidhoods and Biodiversity – Attaining the 2010 target in the European Biodiversity Strategy."

[89] Perry, J. N., P. Rothery, S. J. Clark, M. S. Heard and C. Hawes. 2003. Design, analysis and power of the farm-scale evaluations of genetically-modified herbicide-tolerant crops. *Journal of Applied Ecology* **40**, 17-31.

Annex G. The Canadian Approach to Regulating Novel Agricultural Products as an Example of an Alternative Approach to the Regulation of GM Crops

The Canadian Food Inspection Agency assesses the safety and efficacy of the various novel agricultural products, including those produced by biotechnology.[90] The purpose of regulation is to set standards for the safety and efficacy of new products for the protection of human, animal and environmental health. While the Canadian Food Inspection Agency is the lead agency responsible for the regulation of agricultural products, it is not the only agency with this responsibility. Health Canada reviews novel products for food safety and sets data requirements for the assessment of the safety of all foods. It also identifies hazards, and specifies the standards that food inspectors observe. The Pest Management Regulatory Agency, Health Canada (PMRA), assumed responsibility for registration and regulation of all pest control products in April, 1995. It evaluates any product having pesticidal properties. Environment Canada works with regulatory agencies to help develop standards required for products that may affect the environment. A wide range of products is regulated under the authority of the Canadian Food Inspection Agency. These include agri-food products, veterinary vaccines and biologics, plants and animals, fertilizers, livestock feeds and seeds. The regulatory authorities for these products are contained in Acts and Regulations. Whether the product has been produced by conventional methods or by advanced biotechnology, the general information requirements are the same. Product evaluators at the Canadian Food Inspection Agency have developed regulatory directives that are consistent with those used by international authorities. Some of the principles that are followed in Canada are:

i. To build on current legislation where possible, rather than creating new legislation to govern new products which are developed.

ii. To focus on product characteristics, rather than the method of production. At the present time, all products developed through genetic engineering (recombinant products) are assessed for unintended effects that may result from the introduction of foreign genes or DNA sequences.

iii. To conduct evaluations for each product on the basis of its unique characteristics and to establish appropriate safety levels based on the best scientific information. Safety is defined, not as the complete absence of risk, but rather as the level of “acceptable risk”. If the risk is not acceptable, the application will be refused by the Canadian authorities.

A wide range of agricultural products are being developed or imported into Canada. Depending on the type of product, where it comes from and the intended use, different control measures are used by the Canadian authorities. All potentially hazardous imported commodities are controlled to reduce the possibility of the introduction of agricultural pests and diseases. Examples of such controls include the use of permits, testing, quarantine or inspection. Products which may pose a hazard to the environment are subjected to an environmental safety assessment. All

[90] http://www.inspection.gc.ca/english/sci/biotech/reg/bare.shtml

new products, whether produced by traditional means or derived through genetic engineering would be included in this category.

Canadian Government evaluators, in collaboration with experts and the Canadian public, have developed guidelines for each class of domestically-produced product, which assist in the development of new products still in the research stage. These regulatory directives facilitate the presentation of adequate and appropriate information by the product developer, so that potential hazards can be identified early in the process. Canadian regulators use this information to determine whether new products meet acceptable safety standards. Based on the product definition, specified protocols are applied which govern the conditions of release into the environment. Frequently, field testing is performed on a confined basis. In certain cases, such as for contract growing, certain confinement conditions may be either imposed or relaxed depending on the characteristics of a novel product. Scientific information is gathered during the development phase, and provided to evaluators as required. Information is produced during research trials conducted under laboratory conditions and field testing of new plants, or, in the case of veterinary biologics and livestock feeds, animal testing. Depending on the product, prior to commercial production, approval, registration or licensing might be required. This is done in the case of biofertilizers, certain plant species, livestock feeds and veterinary biologics. Once the product has been approved, quality assurance monitoring of the products, as in the case of veterinary biologics, or food safety inspection, will be performed. All of these regulatory control measures are taken to assess the quality, safety and efficacy of the product. Labeling is an important means to inform the consumer about product facts. Discussions are underway concerning the various ways to communicate information on products that are derived through genetic engineering.

The existing Canadian legislation for specific product groups is outlined in the Table 1. This table gives examples of products derived from biotechnology for each of the main product groups and some of the key control procedures that apply. The way the Canadian Food Inspection Agency evaluates the safety of the following classes of agricultural products derived from biotechnology is outlined below:[91]

- Plants with novel traits is one of the more active areas of research using both traditional and genetic engineering (recombinant) methods. Crop and horticultural plants are included in this group and are regulated under the *Seeds Act* and the *Plant Protection Act*. Risk assessments are conducted on plants with novel traits, and consider plant biology, the new characteristics, the potential environmental impact and how the plant might affect human or animal safety. In evaluating the application, regulators may request data generated from controlled field trials.
- Biofertilizers include rhizobia, other types of free-living nitrogen-fixing bacteria and some fungi. Recombinant products are not yet commercialized in Canada, and the research focus is on genetically improved rhizobia. The *Fertilizers Act* requires that products must be registered and specifies standards and labelling requirements.
- Feeds are defined as any substance or mixture of substances, manufactured, sold, or represented for use for consumption by livestock, for providing the nutritional requirements of livestock, or for the purpose of preventing or

[91] Further information is available from the Canadian Office of Biotechnology.

correcting nutritional disorders of livestock. Novel feeds include microbial products (both viable and non-viable), plants with novel traits and fermentation products such as enzymes, biomass proteins, amino acids, vitamins and flavouring ingredients.

- Veterinary Biologics include animal vaccines, toxins, antisera and diagnostic kits. Currently there are two classes of recombinant products: those inactivated products prepared from genetically engineered organisms; and those products containing live recombinant organisms. The *Health of Animals Act* requires extensive testing, limited field trials with target species, and ongoing quality assurance monitoring of the manufacturer. Licensing is also required. Some categories of veterinary biologics are regulated by Health Canada under the *Food and Drugs Act*, because these are prescribed substances, such as hormones like rbST.
- Food inspection is a broad area which covers meat, dairy products, eggs and egg products, fruits, vegetables, honey and maple products. The Canadian Food Inspection Agency provides inspection programs that enforce safety standards, review labelling, and monitor the product quality and marketing. Genetically engineered foods require a full risk assessment and Health Canada establishes safety standards and specifies labelling requirements for safety under the Food and Drugs Act.

Table 1. Canadian legislation and regulatory controls of agricultural products, with particular emphasis on products derived from biotechnology[92]

Product	**Act**	**Biotech Products**
Livestock feeds, additives	Feeds Act	novel feeds
Fertilizers, supplements	Fertilizers Act	biofertilizers
Plants	Seeds Act Plant Protection Act	plants with novel traits plants with novel traits and genetically engineered micro-organisms
Animals, veterinary biologics	Health of Animals Act	vaccines produced by or containing genetically engineered organisms

[92] Source: http://www.inspection.gc.ca/english/sci/biotech/reg/bare.shtml

Annex H. Evaluation of Risks Associated with the Release of Biological Control Agents of Arthropod Pests – an Example of an Alternative Approach to Risk Assessment

Risk assessments of natural enemies of pest insects has been divided into a three phase process, which involves (1) risk identification and evaluation, (2) risk management plan (includes risk mitigation and risk reduction), and (3) risk/benefit analysis of the proposed release. It is recommended that a risk analysis for a new biological control agent should involve risk/benefit analyses of other methods used for controlling the targeted pest for comparison.

A framework has been developed for Phase 1, which identified five risk factors (host range, establishment, dispersal, direct and indirect nontarget effects). The risk factors consider different aspects of natural enemy biology and the environment of the system into which the natural enemy will be introduced. Two methods of risk evaluation have been suggested.

One method first identifies the hazards, i.e. any imaginable adverse effects of a biological control agent that can be named and measured. The risk of adverse effects actually arising from the release is then the product of likelihood (probability) and magnitude (consequence). A numerical value is assigned to each risk factor ranging from unlikely (1) to very likely (5) for likelihood and from minimal (1) to massive (5) for magnitude. The overall risk index for each natural enemy is then obtained by multiplying the values for likelihood and magnitude for each risk factor and then calculating the sum for the five risk factors. This methodology shows that different values can be obtained for the same organism for different release areas. However, flaws of the method include a lack of early distinction between high risk and low risk cases (thus increasing costs unnecessarily for applicants), no unequivocal separation between risk categories and the fact that risk categories are not independent and are rated equally.

To overcome these flaws, a new method has been developed, which consists of a stepwise procedure where only high risk cases need to be assessed at each level.

Step 1 – exotic and native natural enemies are distinguished (the latter do not have to undergo steps 2-5)

Step 2 – cases where establishment of the organisms is not intended are separated from cases where establishment of the organism is required

Step 3 – further assessment of cases where establishment of the organisms is not intended to check that no establishment does indeed occur (if establishment does not occur steps 4 and 5 can be skipped)

Step 4 - the host range of a natural enemy is assessed. If a natural enemy only attacks the target pest or attacks only related and no valued non-target organisms, it should be considered for release. If a natural enemy attacks a wider range of related and unrelated non-target and/or valued non-target organisms, the natural control agent should not be considered for release.

Step 5 - dispersal of natural enemies is assessed, whether limited to target area or not

Step 6 – issues related to direct and indirect non-target effects are considered and the recommendation depends on whether effects are transient and limited or not. To calculate risk levels of establishment, dispersal and direct/indirect non-target effects, the same criteria as the earlier method are applied but weighting factors are added.

A basic approach to balancing environmental risks and benefits of biocontrol agents is under development and it is suggested that expected risks, costs and benefits of economic values, human and animal health as well as the environment should be taken into account.

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Annex I. Outline of the Voluntary Initiative to Minimise the Environmental Impacts of Crop Protection Chemicals

Pesticides have a number of adverse impacts on human health and the environment, imposing substantial costs on society. These include direct financial costs (such as treatment of water) and wider environmental costs, such as loss of biodiversity, which are much harder to value. Pesticides can affect wildlife both directly, through deliberate or accidental poisoning, and indirectly, by disrupting food webs. Pesticides have removed vital plants and invertebrates from farmed habitats, research has shown them to have been a major factor in the decline of farmland birds such as the grey partridge.

Since 1997, the UK Government has stated an objective to reduce the environmental impacts of pesticide use. The Government proposed the use of a Pesticide Tax to halt the inappropriate use of pesticides, as part of the "Polluter Pays principle". Following the Parliamentary Environmental Audit Committee finding in favour of a tax on pesticides in February 2000, the Government was poised to introduce such a tax in the 2000 Budget. However, owing to the ongoing crisis in UK farming, the Government decided to move forward by means of a voluntary partnership approach with farmers and the UK's agrochemical trade body, the Crop Protection Association (CPA). This initiative focuses on maintaining and improving biodiversity and water quality in line with the Government's commitments.[93] The initiative has three main activities: research, training and stewardship & communication. To become a supporter of the Voluntary initiative a farmer must join the National Register of Sprayer Operators (NRoSO), have his sprayers tested under the National Sprayer Testing Scheme (NSTS) and complete a Crop Protection Management Plan (CPMP). He also must follow best practice relating to the selection and use of insecticides, water protection and application.

In order to determine the effectiveness of the voluntary initiative the following three specific biodiversity indicators have been chosen: cereal field margins, grey partridge, and corn bunting, relating to relevant farmland species and habitat recovery in line with the UK Government's overall Biodiversity Action Plan (BAP) process.

CPA provides advice in line with the advice issued by the RSPB, Game Conservancy Trust, English Nature, Linking Environment And Farming and the Farming Wildlife Advisory Group in order to achieve biodiversity targets.

The aim is to support through targeted training, the successful adoption of crop protection management plans, communication of relevant research and advisory activities the Government's target of maintaining, improving and restoring through management the biodiversity of 15,000 ha of cereal field margins on appropriate soil types in the UK by 2010.

1. Area of cereal field margins (of value to biodiversity)
Cereal field margins provide an important habitat for UK native arable flora and fauna. Both the grey partridge and corn bunting will benefit from an increase in availability of this habitat. As part of the Voluntary Initiative, the CPA's 'Biodiversity Strategy and Action Plan' has a specific action plan setting out the management aspects needed to enhance and protect this habitat.

[93] http://www.voluntaryinitiative.org.uk/Content/About.asp

2. Terrestrial wildlife population trends for grey partridge
Grey partridges have declined by >50% since the early 1990's (from 145,000 breeding pairs) and therefore are a Red Listed species in terms of conservation concern. Agricultural intensification (shift to winter sowing, use of herbicides and insecticides), loss of habitat such as hedgerows and the employment of fewer gamekeepers have resulted in this decline. The grey partridge is considered to be a good indicator species of habitat quality, i.e. if their numbers increase many other farmland species should also benefit.

3. Terrestrial wildlife population trends for corn bunting
Corn buntings have declined by >50% in the last 25 years and this species is now a Red Listed Species and of high conservation concern. Agricultural intensification and loss of habitat are the major causes of this decline and recent scientific evidence suggests that the use of crop protection products may have reduced the availability of food for rearing of the young. This species is an arable farmland specialist largely dependent upon cropped land and will benefit from measures that enhance available field margin habitats and summer feed availability. A range of policy measures including the careful use of crop protection products, stewardship measures advice and training are being implemented as part of the UK BAP to reverse the decline in populations. The aim is to support the promotion of new habitat management techniques, successful adoption of crop protection management plans, advisor training, communication or relevant research and advisory activities in order to help the Government's long term targets: to increase numbers of corn bunting to at least 50% of 1996 levels and expand the bird's range by 2008.
Water quality

Water quality is also an indicator for the success of the voluntary initiative. The VI Steering Group has agreed that Environment Agency (EA) datasets are currently the best measure for showing long term trends in pesticide contamination of water. Current data show that 3 - 4% of samples exceed the 0.1ppb drinking water standard. The VI target is to maintain and increase the downward trend with the objective of achieving a 30% reduction in detection levels above 0.1ppb by 2006. The same target also applies to the nine pesticides most commonly found in untreated water. The data collected by EA are not sufficiently sensitive to show all the changes achieved by the VI and an additional target of achieving at least an average 50% reduction in pesticides in three specific river catchments has therefore been set.

Additional VI Targets
In addition to targets for biodiversity and water quality, targets have been set for;

1) The number of agronomists who have undertaken a recognised additional environmental training/qualification: at least 750 by 2006.

2) Number and land area of farmers who have obtained the new Farm Environmental Management - Crop Protection Certificate: at least 50% of all eligible "farmer decision makers" trained and registered by 2006

3) Number of products with environmental information sheets published: all professional products marketed by CPA members by 1 April 2006

The steering committee for the initiative includes a range of representatives from industry, farmers groups, NGOs and conservation agencies. If targets set out for the initiative are not met the Government will reassess its position.

Glossary of Terms and Abbreviations

ACP	Advisory Committee on Pesticides
ACRE	Advisory Committee on Releases to the Environment
AEBC	Agriculture and Environment Biotechnology Commission
Alien Species	Species introduced intentionally or unintentionally to locations beyond the native range of the species (usually taken as post-1500). Also known as non-indigenous, non-native, exotic or introduced species. See also invasiveness
Allergenic/allergens	Substances that cause an allergic reaction
BAP	Biodiversity Action Plan
Biodiversity	The diversity of life on Earth. Biodiversity has many components, including the diversity of all organisms (plants, animals and microorganisms), the diversity within and among species and populations, and the diversity of ecosystems. It can be considered at any geographic scale (local, regional or global).
Break crop	A crop grown to benefit the soil and reduce pests and pathogens
Bt	*Bacillus thuringeniensis*, a common bacterium which produces a range of insecticidal proteins. Bt has been used since the 1950s as a microbial insecticides. Some insecticidal proteins from Bt have been expressed in transgenic crops (e.g. Bt maize, Bt cotton and Bt potato)
C4 plants	Plants which use C_4 carbon fixation. The name is derived from the product of the pathway, oxaloacetate, which contains four carbon atoms. This metabolic pathway gives C_4 plants a competitive advantage over plants possessing the more common C_3 carbon fixation pathway under conditions of drought, high temperatures and nitrogen limitation.
CAP	EU Common Agricultural Policy
Co-existence	In this Review, co-existence refers to the simultaneous but separate cultivation of crops by different agricultural methods (eg. conventional non-GM, GM, organic, non-food industrial and certified seed crops)
Conservation headlands	Crops at the edges of fields that are not treated with agrochemicals
Conventional Breeding	Term used in the context of this report to mean non-GM breeding methods
Crop rotation	Crops on a specific area of land are changed year by year in a planned sequence
CSF	Catchment-sensitive farming
Diffuse pollution	Pollution of land, air and water with by-products. In the case of farming systems by-products causing diffuse pollution include silage, liquor, ammonia, nitrate, phosphate, pesticides and silt.
DNA	Deoxyribonucleic acid. The molecule that encodes genetic information. DNA is a double-stranded module held together by weak bonds between

	base pairs of nucleotides. The four nucleotides in DNA contain the bases adenine (A), guanine (G), cytosine (C), and Thymine (T). In nature, base pairs from only between A and T and between G and C; thus the base sequence of each single strand can be deduced from that of its partner. The structure of DNA (double helix) was published in 1953 by Crick and Watson
DWPA	Diffuse water pollution from agriculture
EA	Environment Agency
Energy crops	Crops and/or by-products (e.g. Miscanthus, oilseeds, short-rotation coppice, straw, manure, forestry waste) used to provide a feedstock for biofuels or to generate heat and/or power.
Ecosystem	The complex of a living community and its physical environment, functioning as an ecological unit in nature
Ecosystem services	The benefits people obtain from ecosystems. These include provisioning services (such as food, water, timber and fiber), regulating services (such as the regulation of climate, floods, disease, wastes and water quality), cultural services (such as recreation, aesthetic enjoyment and spiritual fulfillment) and supporting services (such as soil formation, photosynthesis and nutrient cycling).
EFSA	European Food Safety Authority
ELS	Entry Level Scheme, one of several Environmental Stewardship schemes. The ELS's aim is to encourage a large number of farmers across a wide area of farmland to deliver simple yet effective environmental management.
EPPO	European and Mediterranean Plant Protection Organization
ESA	Environmentally sensitive area, a defined geographical area within which farmers are offered incentives to protect, maintain or enhance the landscape.
Externality	An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation. An externality may be positive or negative.
FAO	Food and Agriculture Organisation
FSA	Foods Standards Agency (of the UK)
FSEs	Farm-Scale Evaluations of herbicide tolerant genetically modified crops, a major UK field study. The crops tested were maize, beet, spring and winter oilseed rape.
Gene	The unit of heredity transmitted from generation to generation during sexual or asexual reproduction. The simplest gene consists of a segment of nucleic acid that encodes an individual protein or a length of RNA
Gene construct	The DNA unit, usually including transgenes, promoters and selectable markers, which is used to make a GM plant
Gene flow	The transfer of genes between different individuals eg. pollen-mediated gene transfer between sexually compatible plants. Also refers to the

	transfer of genes from one plant population to another through seed dispersal or the movement of regenerative plants parts, (eg. tubers), or whole plants. This Review also considers the possibility of plant genes being transferred and stably integrated into the genomes of soil and gut microbes and into viruses that infect plants (see horizontal gene flow)
Gene product	RNA and proteins
Gene stacking	Accumulation of genes conferring different traits in one plant resulting from cross-fertilisation or transformation with several gene constructs. Also, see transgene stacking
Genotype	The genetic constitution of an organism, as distinguished from its physical characteristics (its phenotype)
Glufosinate ammonium	Used to provide post-emergence, broad spectrum control of annual grasses and broad-leaved weeds. Glufosinate ammonium can be sprayed after emergence if the crop is tolerant to it. This herbicide acts by inhibiting an enzyme that is responsible for ammonia detoxification ultimately leading to the cessation of photosynthesis. The trade names of herbicides containing glufosinate ammonium include: Basta, Liberty, Ignite, and HOE 39866
Glyphosate	Systemic herbicide that is used for post-emergence, broad spectrum control of annual and perennial broad-leaved and grass weeds. Can be sprayed after emergence if the crop is glyphosate tolerant. Acts by inhibiting an amino acid metabolism pathway that exists in higher plants and micro-organisms, but not in animals. Inactivated on contact with clay particles in soil, and requires no hazard warning symbols on packaging. The trade names of some herbicides in which glyphosate is the active ingredient are: Roundup, Rodeo, Touchdown, and Mon-0573
GM	Genetically modified/Genetic modification. Altering the genetic material of an organism in a way that does not occur naturally by mating and/or natural recombination
GM derived	Products that are derived from genetically modified organisms, including products (eg. some vegetable oils or enzymes used for making cheese) in which it is not possible to detect any DNA or protein.
GMHT	Genetically modified herbicide tolerance
GMO	Genetically modified organisms. An organism in which the genetic material has been altered in a way that does not occur naturally by making and/or natural recombination
HLS	Higher level scheme, one of several Environmental Stewardship schemes. The aim of the HLS is to deliver significant environmental benefits in high priority situations and areas.
ICM	Integrated crop management
Introgression	Introduction of new allele(s) or gene(s) into a population from an exotic source, usually another species. This is achieved by repeated backcrossing of the initial hybrid in order to eliminate all genetic changes except for the desired new gene(s)
Invasiveness (or invasive species)	Ability of an organism, particularly an alien species, to spread beyond its presently established site, and become established in new locations

LSA	Life-cycle assessment, a recognized (ISO 14040 series) methodology defined as “objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements”.
OELS	Organic entry level scheme, one of several Environmental Stewardship schemes. The OELS’s aim is to encourage a large number of organic farmers across a wide area of farmland to deliver simple yet effective environmental management.
Pathogen	Disease-causing organism (generally microbial: bacterial, fungal or viral; but can extend to other organisms, eg. nematodes)
Pest	An organism that reduces the productivity of a crop eg. certain insects, birds and nematodes
Post-marketing monitoring	The hypothesis-driven, routine collection of information after a product is on the market (ie. widely available). For example, epidemiological monitoring involves looking for a disease condition, characteristic or state in a population
Post-marketing surveillance	Surveillance takes a general look at trends eg. epidemiological surveillance is the systematic collection, collation, analysis and interpretation of health-related events occurring in populations
Promoter	A DNA sequence at the start of a gene to which RNA polymerase (an enzyme) will bind and initiates transcription/expression of a gene into messenger (or other) RNA. Genomic and subgenomic promoters also exist in RNA viruses where they initiate copying of RNA into RNA
Recombinant DNA technology	Set of techniques for manipulating DNA, including: the identification, modification and cloning of genes; the study of the expression of cloned genes; and the production of large quantities of gene products
Refuge	Area of non-GM host plants adjacent to a GM crop. Refugia form a component of resistance management strategies employed with Bt crops to reduce the selection pressure on the target insect pest species and thus delay the development of Bt-resistant pest populations.
RSPB	Royal Society for the Protection of Birds
SSSI	Site of special scientific interest
Tillage	Ploughing or harrowing. Zero-tillage or low-till agricultural practices may be implemented
Trait	One of the many characteristics that define an organism. The phenotype is a description of one or more traits.
Transgene stacking	Accumulation of transgenes conferring different traits in one plant. This can arise intentionally or unintentionally through cross-fertilisation or by the introduction of different traits into a GM plant variety through one or a number of successive transformation events
Transgenic DNA/transgene	Isolated sequence of DNA stably inserted into the genome of a recipient organism
Vector	Small DNA molecule (plasmid, virus, bacteriophage, artificial or cut DNA

	molecule) that can be used to deliver DNA into a cell. Vectors must be capable of being replicated and contain cloning sites for the introduction of foreign DNA. Vector can also refer to an organism, usually an insect, which carries and transmits pathogens Also refers to an organism, usually an insect that carries and transmits pathogens/disease
VI	Voluntary initiative to minimise the environmental impacts of crop protection chemicals
Volunteer	Crop plant self-propagated from a previous year's crop (eg. from seed or tubers)
WFD	Water Framework Directive
Wild type	The most frequent allele or genotype found in nature
Wildlife strips	Edges of fields that are not plant or treated with agrochemicals (part of the Countryside stewardship scheme)