SIP

SUSTAINABLE INTENSIFICATION
RESEARCH PLATFORM

SIP Project 2: Opportunities and Risks for Farming and
the Environment at Landscape Scales (LM0302)

Defining Sustainable Intensification and Developing Metrics with respect to Ecosystem Services for the SIP Research Platform

Richard Gunton and Les Firbank (University of Leeds)
Alex Inman and Michael Winter (University of Exeter)

September 2015

Background

The Sustainable Intensification Research Platform (SIP) is a multi-partner research programme comprising farmers, industry experts, academia, environmental organisations, policymakers and other stakeholders. The platform has explored the opportunities and risks of Sustainable Intensification (SI) from a range of perspectives and scales across England and Wales, through three linked and transdisciplinary research projects:

SIP Project 1	Integrated Farm Management for improved economic, environmental and social performance
SIP Project 2	Opportunities and risks for farming and the environment at landscape scales
SIP Project 3	A scoping study on the influence of external drivers and actors on the sustainability and productivity of English and Welsh farming

Projects 1 and 2 have investigated ways to increase farm productivity while reducing environmental impacts and enhancing the ecosystem services that agricultural land provides to society.

Project 2 partners are: University of Exeter (lead), ADAS, Bangor University, Biomathematics and Statistics Scotland (BioSS), University of Bristol, University of Cambridge, Centre for Ecology and Hydrology (CEH), Eden Rivers Trust, Fera, Game and Wildlife Conservation Trust (GWCT), James Hutton Institute, University of Kent, Lancaster University, University of Leeds, Linking Environment And Farming (LEAF), Newcastle University, NIAB, University of Nottingham, Rothamsted Research, Westcountry Rivers Trust

Acknowledgements

Funding for the SIP from Defra and The Welsh Government is gratefully acknowledged.

Data

[leave blank]

Citations

This report should be cited as:

Gunton, R., Firbank, L., Inman, A. and Winter, M. (2015). Defining Sustainable Intensification and Developing Metrics with respect to Ecosystem Services for the SIP Research Platform. Report for Defra project LM0302 Sustainable Intensification Research Platform Project 2: Opportunities and Risks for Farming and the Environment at Landscape Scales

Contact

Michael Winter (D.M.Winter@exeter.ac.uk)

Defining Sustainable Intensification and Developing Metrics with respect to Ecosystem Services for the SIP Research Platform

Contents

1. Defining and Conceptualising SI

Introduction

Since the introduction of the term Sustainable Intensification in the mid 1990s (e.g. Pretty 1997, Reardon et al 1997), a review of the literature suggests there has been a slow evolution in the discourse surrounding the use of this now ubiquitous phrase. Definitions of SI appear to have initially revolved around the notion of agronomic *efficiency*; that is the ability to deliver the greatest level of food output for the lowest amount of input (Lang and Barling 2012; Mueller et al. 2012). This view of SI focuses on the ratio of inputs to outputs, which by definition is a discussion about intensity. Thus early on in its evolution, SI appears to have been framed as a vehicle for producing *'more from less'*.

This focus on efficiency, or intensification, to produce more from less, has attracted considerable criticism from many observers who argue that this is a very narrow interpretation of SI which pays little attention to wider sustainability criteria (Loos et al, 2014). Buckwell et al (2014) have suggested that input intensification per se should not be the goal of SI so much as *'a consequence of achieving sustainability'.* However, it is possible to be economically efficient at producing food without being sustainable. Franks (2014) points out that Total Factor Productivity (TFP), a standard measurement used to monitor the increase in output per unit of all inputs, is an indicator favoured by several proponents of SI (Foresight Report 2011). However, whilst TFP includes the measurement of agricultural outputs (provisioning services), it does not take into account negative externalities experienced by non-provisioning services. Therefore, on its own, TFP is insufficient as a metric of SI. An unqualified focus on more agricultural output has also been questioned by some observers such as Garnet (2014) and the BBSRC Working Group on SI, who argue that the debate around SI needs to consider not just how much food is produced but also its type, variety and nutritional content. This is what the BBSRC Working Group means by needing to 'go beyond more for less' (BBSRC, 2014). This sentiment chimes directly with Smith (2013), who defines SI as 'the process of delivering more safe, nutritious food per unit of input resource, whilst allowing the current generation to meet its needs without compromising the ability of future generations to meet their own needs''.

Smith's definition is also interesting because it includes reference to the need for SI to deliver intergenerational equity (Johnston et al. 2007) and a robust natural resource base for future generations. This very much borrows from the definition of sustainability developed by Brundtland (WCED, 1987). So rather than simply producing food that does not produce negative externalities, this definition of SI implies there is a requirement to maintain the long-term capacity of land to produce food and other services (Garnett et al. 2013; Neufeldt et al. 2013). This means protecting fundamental ecological functions which is a very different vision of sustainability than simply reducing agro chemical or faecal pollution or soil erosion through greater efficiency in agricultural production systems.

If the definition of SI is to give adequate weight to the "sustainability" part of the couplet, some observers have highlighted that this necessarily requires inclusion of social and ethical considerations surrounding labour rights, animal welfare and gender equality as well as agro-ecological parameters. As Garnet and Godfray (2012) have argued, *'sustainable intensification, if it is to be a meaningful aspiration, needs to be mindful of the social, economic and ethical context within which food production activities take place'.*

A belief in the need to include long term protection of ecosystem function embedded within a wider social context is clearly demonstrated by the Montpellier Panel. In their 2013 report entitled *Sustainable Intensification, A New Paradigm for African Agriculture* (Montpellier Panel, 2013), SI is defined as a system for ‘producing more outputs with more efficient use of all inputs – on a durable basis – while reducing environmental damage and building resilience, natural capital and the flow of environmental services’. They go on to state SI ‘is also about conserving natural landscapes not only because of the ecosystem services they provide, but also their present and future cultural value’. Here ecosystem services (‘environmental’ or ‘cultural’) are directly cited in the context of SI. In addition, for the Montpellier Panel, a fair income for farmers and the production of nutritious food are just as important as yields of food per unit of input.

Another interesting point to note from the Montpellier Panel is that they see intensification of outputs as a product of both technological intensification (defined as ecological and genetic intensification) and socio-economic intensification (includes social and human capital). This links to the assertion by Buckwell et al (2014) that SI is as much about ‘more knowledge per hectare’ as it is about investments in financial or physical capital.

Finally, in this opening section it is worth pointing out that some researchers are now challenging the utility of SI. For example, in a recent paper Petersen and Snapp (2015) have suggested that the term is not uniformly understood by agricultural experts (30 were interviewed) and the majority do not see it as a significant departure from current agricultural practices. They suggest the need for an alternative approach through exploring ‘ecological intensification’ (Bommarco, Kleijn & Potts 2013). Similarly, Cook et al (2015) consider SI to be a useful guiding framework for raising agricultural productivity on existing arable land in a sustainable manner but not a paradigm for achieving food security over all, being just one element of a sustainable food system situated in a green economy.

Scale as a crucial element within the SI definition debate

The literature reveals that two distinct camps have developed regarding how greater food output can be achieved without adversely impacting non-provisioning ecosystem services. These opposing viewpoints are delineated by very different outlooks regarding the capacity of farming systems to produce non-provisioning services. Firstly, there are the advocates of ‘land sparing’ (Baulcombe et al, 2009), who believe SI can only be achieved by partitioning landscapes into agricultural and non-agricultural units. In this view biodiversity conservation is best served by the land-sparing: maintaining tracts of habitats free from agricultural activities while allowing agriculture to intensify in other parts of the landscape (Balmford et al 2005). This is by no means a new view and in various guises was strongly promoted by some in the 1960s and 1970s (e.g. Fairbrother, 1970, Green 1981), prior to the agri-environment policy turn of the 1980s and 1990s. It is a view predicated on a belief that farming systems cannot adequately deliver biodiversity and other non-provisioning services, which must, therefore, be obtained from ‘non farmed’ protected areas (Phalan et al, 2011). This logic suggests that farmland must not be allowed to encroach on current non-agricultural land areas. Any increase in agricultural output must come from more efficient use of existing farmland, and increases in other services may actually require a reduction in farmed area (Fig. 1). Inherent within the land sparing vision is a need for landscape scale planning, presided over by some form of institutional arrangement capable of deciding an optimal mosaic of land uses that will deliver the best outcomes (Selman 2012). Radical land use change interventions will be required rather than low intensity agri-environmental schemes, which Baulcombe at al (2009) cite as having had little impact (Franks, 2014), although some empirical research suggests a much more significant role (Baker et al 2012, McCracken et al 2015, Pywell et al 2012).

Envisaging a very different path for SI, proponents of ‘land sharing’ take a multifunctional view of agricultural systems where provisioning and non-provisioning services can be delivered simultaneously by the same unit of land. Land sharing is an approach favoured within the Foresight

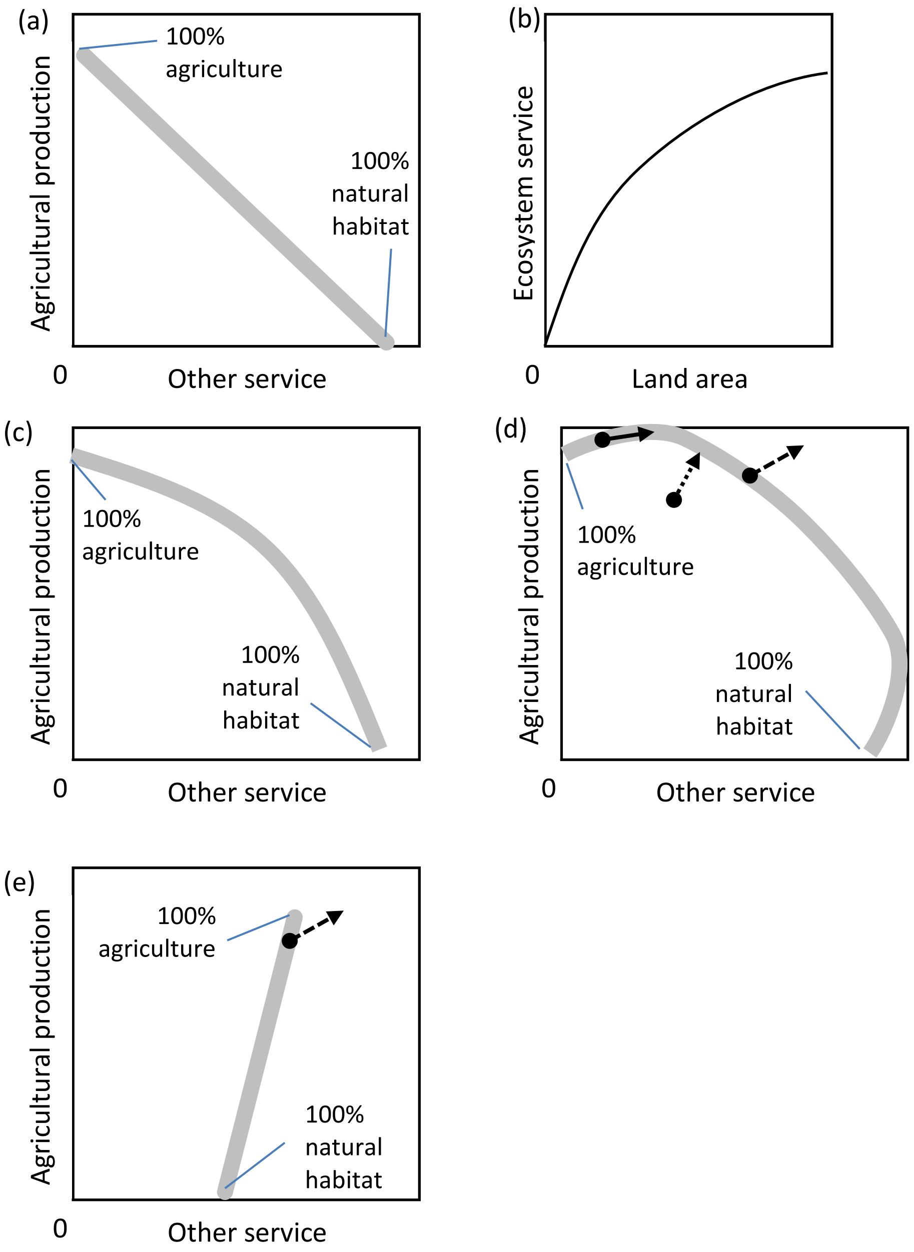
Group report and has been a central tenet in the design of UK agri-environmental schemes since their inception. Advocates of land sharing appear to see a value in protected areas but they do not see dividing landscapes into intensive farmland and non-farmed habitats as an optimal SI model. This stems from a view that provisioning and non-provisioning outputs do not have to be negatively correlated if agro-ecological principles are applied and conventional intensification is likely to undermine the ecological functions upon which those systems ultimately depend to maintain food production (Tscharntke et al 2012). Moreover, in the UK, where anthropogenic factors shape all major habitat-types, few species require very large tracts of undisturbed habitat, and a large proportion of biodiversity depends upon open countryside and its interface with woodland.

Discussion of the pros and cons of land sharing vs. land sparing (Garnett and Godfray, 2012) suggests that SI will probably need to include elements of both approaches, depending on the range and typology of ecosystem services that need protecting. For example, protection of different species of bird will require different habitat types that might be better delivered by land sharing or land sparing depending on the habitat profile required. Protection of drinking water reserves may only be possible through a land sparing approach, for example where groundwater aquifers are covered be free draining shallow soils making them very prone to leached nutrients, irrespective of the farming system being used.

The corollary of all this is that SI may be defined – and success measured – at various spatial scales (Garnett and Godfray, 2012). A given agricultural system considered at a farm scale may well yield significant benefits to soil biology, facilitating the development of mycorrhizal fungi which have been shown to increase the availability of plant nutrients, thereby reducing nutrient leaching to adjacent watercourses (Williams, 2010). However, this same system may do nothing for specific farmland birds or butterfly populations. The BBSRC Working Group argues that for SI to result in sustainable outcomes, the impacts of agriculture on different ecosystem services must be assessed in space and time. This in turn requires multiple metrics applied to multiple scales of measurement.

Much of what is termed 'land-sharing' might actually be described as 'land-sparing on fine scales' (Balmford et al 2012). For example, reducing field sizes, allocating field boundaries and margins to semi-natural vegetation and incorporating fallow periods into rotations (Kremen & Miles 2012) are all means of incorporating spatial and temporal heterogeneity into agricultural landscapes. Such intercalation of agricultural and non-agricultural land functions is generally expected to result in some non-agricultural ES being derived from agricultural land even without any modification to agricultural techniques (Fig. 1d), and field margins are regarded as a key element of farmland conservation policies throughout Europe (Carvell et al 2007). Field et al 2007). Examples of ES that readily benefit would be those associated with farmland bird populations and endangered arable weeds, or the reduction of soil erosion. There may also be marginal benefits for agricultural production, if, for example, the mosaic of land-uses is part of an organic system that results in greater market value, or if the semi-natural vegetation supports pollinating insects that increase crop yields. Thus spatial intercalation can bring about a net increase in either agricultural production or other ecosystem services or both when they are sought from the same landscape in a complementary fashion.

Figure 1. Land-sparing and land-sharing frameworks for sustainable intensification (SI).



With simple land-sparing, agricultural production is segregated from other ecosystem services (ES) so that the two functions compete with each other. If both agricultural productivity and another ES (e.g. carbon sequestration by trees) scale linearly with land area, there may be a zero-sum relationship for these two variables (a). If an ES (e.g. some measure of biodiversity) has a decelerating response to land area (b), there may be a curved relationship, as in (c). With fine-scale land-sparing (typically called 'land-sharing'), the intercalation of agricultural land with non-agricultural land may produce benefits for either or both of the services, breaking the trade-off and producing curved relationships (d) even if the services scale linearly with area. SI implies moving a system upwards, to the right, or both; it may be achieved by (i) optimising the spatial configuration of farmed and unfarmed areas to reach the "production possibility frontier" (Franks 2014) on both axes (dotted arrow), (ii) adjusting the allocation of land between farmed and unfarmed areas (solid arrow), or (iii) innovative management techniques that break the trade-off in other ways, moving a system off the curve (dashed arrow). True land-sharing means that certain ES are unchanged or increase with allocation of a landscape to agricultural land (e). Here SI simply implies innovative management techniques that move a system off the existing line (dashed arrow).

Some definitions of SI stipulate innovation: i.e. that SI actions must represent technical improvement beyond current best practice, so that the grey curves of Fig. 1 represent optimal performance under current techniques, and SI is considered to shift these curves upwards and to the right.

From a practical implementation point of view, SI becomes more challenging where protection and enhancement of given ecosystem services requires co-ordination between multiple actors beyond the individual farm scale i.e at a sub-catchment, catchment, regional, national or international scale. This leads to the conclusion that any definition of SI needs to include reference to suitable governance arrangements capable of delivering macro scale solutions. This may involve potential clashes with local (private) interests and is, therefore, a real challenge to rolling out SI going forward.

Thus a picture emerges from the literature that the path to SI will vary for different farms and agricultural systems. As Buckwell et al (2014) point out, '…the direction of the path and the actions required to meet it will depend partly on the conditions, particularly the current agricultural productivity and environmental performance of that farm or system'. They go on to state that a route to SI may involve a farm increasing output per hectare of environmental services and/or increasing agricultural production per hectare. Similarly, Thomson (2011) demonstrated that within the Scottish Highlands, there are examples where both too much intensification and too little intensification (extensification) have led to the degradation of environmental services. Pretty (2014) is also of the view that SI "does not articulate or privilege any particular vision or method of agricultural production", but "emphasises ends rather than means, and does not predetermine technologies, species mix, or particular design components'.

Competing Visions of SI

Buckwell et al (2014) postulate that it may be impossible to develop scientifically derived sustainability limits or thresholds owing to the technical complexities and uncertainties surrounding measurement of such indices and the ability of humans to adapt to natural systems. A view is therefore expressed that SI targets and parameters may need to be determined through stakeholder dialogue and a question is posed whether in fact SI merely means 'intensification which meets the environmental, economic and social performance standards which society has agreed'. This point is mirrored by Garnett et al (2013) who suggest that, in most cases, a trade off will need to be made regarding the delivery of different ecosystem services, and that this will be a matter decided by societal values and beliefs and not within a technical or science led vacuum.

It is not surprising that food production – the delivery of provisioning services – has dominated discussions over SI. After all, the term SI has been born out of a perceived need to increase food production to feed a rapidly growing population over the next 30-40 years. There is an undoubted sense from reading policy documents issued by influential food related institutions – particularly the UN Food and Agriculture Organisation (FAO) – that the way these parties are interpreting SI is very much from what might be described as a 'food centric' or productivist standpoint. Non-provisioning services play second fiddle.

Within the FAO vision for SI, non-provisioning ecosystem services are framed as supporting the long-term viability of provisioning services (i.e. food production). This interpretation of non-provisioning services sees them as ‘intermediate services’ that ultimately deliver ‘final’ services such as food (Fish et al, 2014). It would appear, therefore, that from an FAO perspective, food (provisioning service) and other services (e.g. regulating, cultural services etc) do not carry equal weight. For example a 2010 communication from the FAO Committee on Agriculture (FAO, 2010) sees SI as using an ‘ecosystem approach’ (by that they mean techniques such as Integrated Pest Management, not The Ecosystem Approach as defined by the Parties to The Convention on Biological Diversity) to enhance crop productivity. No mention is given to protecting non-provisioning services in their own right. Similarly, a 2011 SI guidance document from the FAO (FAO, 2011) makes reference to the need to ‘*value ecosystem services’*, thereby providing a mechanism for farmers to derive benefit from their protection. The term Payments for Ecosystem Services (PES) is specifically mentioned. However, within the context of discussing the value of services, the document recommends ‘incorporating the value of natural resources and ecosystem services into agricultural input and output price policies’. In other words, the text implies that payments should be incorporated within prices for agricultural products to protect the services on which these products depend, rather than made to support ecosystem services that do not necessarily have direct linkage with agricultural production. The document makes fleeting reference to existing PES initiatives focussing on ‘land diversion programmes’ but does not go on to expand on this idea and makes no further reference to using financial mechanisms to support non-production-based PES schemes.

It is possible to infer from the above that SI is perceived by some stakeholders to involve the protection of non-provisioning ecosystem services for the sake of agricultural production; but they do not see the protection of non-provisioning services as a stand-alone objective in its own right. This is some way off what might be described as a ‘post-productivist’ vision for SI which places environmental outputs from land management on an equal footing with food and energy outputs. In other words, marketed goods (food) are given the same status as non-marketed goods. This is view demonstrated by Buckwell et al (2014):

‘Under this vision ‘sustainable intensification’ would and should include examples where there is a rise in the non-provisioning services, i.e. the environmental services, produced per hectare…… A correct interpretation of sustainable intensification should embrace examples where the output or production which is intensified per hectare are the conservation outputs, e.g. pollinators or fledged lapwings per hectare……So pursuing intensification of environmental services per unit of land is critical, and sustainable intensification must put the task of producing non-provisioning eco-system services alongside the provisioning services of food and energy’

One may suggest that it is only through giving provisioning and non-provisioning services equal status that the BBSRC Working Group’s vision for SI will be achievable i.e. *‘…balancing food production (and optimising inevitable trade-offs) with maintenance of the natural capital on which it and other ecosystem services depend…’* (BBSRC, 2014). A food-centric vision of SI is unlikely to deliver the balanced outcomes that are required.

2. Ecosystem Services in Agriculture

Introduction

Ecosystem services (ES) may be defined as “the outputs of ecosystems from which people derive benefits” (UK National Ecosystem Assessment 2011) or “the aspects of ecosystems utilized (actively or passively) to produce human well-being” (Fisher, Turner & Morling 2009). Agricultural production is one important ecosystem service, derived from what may be termed “agro-ecosystems”.

In order to integrate all kinds of agricultural outputs with SI, we must consider other ways in which they may be affected by agricultural activities, not just those attributable to farmland as an agro-ecosystem. Thus, for example, farmland may provide an ecosystem service of carbon sequestration, but farm machinery and fertilizer manufacture also release CO2 through fossil fuel combustion. We must therefore take a *life-cycle assessment* approach, including both ecological and non-ecological components, and recognising that both of these components may be either positive or negative. Some authors refer to “ecosystem disservices”, and in many of the cases we will consider, a comparison with the level of some service potentially delivered by a pristine ecosystem would be negative.

The ecosystem services (ES) to be considered here are taken from the UK National Ecosystem Assessment (2011) with some modifications and a purpose-made classification. The next section outlines the ES that we consider, along with the principal ecosystem processes on which they are based, the benefits (or disbenefits) they produce and any directly-associated anthropogenic activities that modify these (dis)benefits (see Figure 1).

Classification of ES

First, **agricultural production** (including food, bioenergy and animal products) is based on a range of processes including the growth and in some cases pollination of field and forage crops. Agricultural production may be considered not only as an ecosystem service but also an output from a wide range of anthropogenic actions: agricultural techniques such as tillage, sowing, planting, weeding, crop protection and harvesting technologies.

The remaining ES are considered in three groups in order to distinguish important spatial, temporal and functional aspects of their delivery. We group ES into (A) agricultural sustainability services that contribute to both agricultural production and other final services and (B and C) ES that do not necessarily have any direct contributions to agricultural production, separating those contributing to “local” (B)and “global” (C) sustainability.

(A) The following services are considered beneficial at least partly because of their contribution to agricultural production itself; thus they are “intermediate services”(UK National Ecosystem Assessment 2011) and a positive relationship with agricultural production may be expected in at least some situations. They may be provided by the cropped area itself and/or by adjoining habitats, such as in field margins. Our general term for this category is *agronomic sustainability*. Importantly, these services tend to function primarily as private goods for the farmer, at least insofar as they increase agricultural production during the farmer’s tenure of the land.

1. **Soil maintenance** (including formation and protection of soil quality and stock)is due to ecosystem functions associated with soil fauna and other plant rhizosphere activities, and also mediated through anthropogenic effects on landscape morphology and shelter and inputs of fertilizers, etc.
2. **Biocontrol**(disease and pest regulation) is related to the trophic balance between herbivores and their natural enemies. The abundances of different invertebrate species are affected by the vegetational composition of both cropped and uncropped areas, and by anthropogenic actions such as insecticide application.
3. **Pollination** of crops is related to the diversity and abundance of pollinating insects, which in turn depends upon the composition of plant communities, including both arable crops and casually-occurring species. Relevant anthropogenic actions here include the siting of beehives in order to increase pollination by feral honeybees, and insecticide application.

"Ecological replacement" has been coined to describe the substitution of an ES in place of an anthropogenic contribution to productivity, while "ecological enhancement" is where the net benefit can be increased while the anthropogenic contribution is reduced – described as "ecological intensification" (Bommarco, Kleijn & Potts 2013) or, in our terms, SI. However, each of the above services also has value beyond agricultural production. Soil protection can be valued beyond any given time-horizon of agricultural production, while the predator and pollinator communities that service a focal agricultural unit may also deliver their services further afield; moreover, they also have cultural value insofar as humans appreciate these insect types in their own right (Schowalter 2013). Thus these ES they are prone to being double-counted (Fisher, Turner & Morling 2009) in assessing the value of farmland to humans, and may be considered as both private (to farmers) and public goods (Robertson *et al.* 2014).

(B) The following ES are typically enjoyed by humans within the vicinity of farmed land but do not necessarily contribute to agricultural production. Our general term for this category is *local sustainability*.

4. **Biodiversity and the abundance of popular taxa may be considered** a cultural service. There is a very large literature on this, so here we consider farmland birds. These are influenced by fruit and seed production by both crop and non-crop plants and by the suitability of vegetation as a habitat for nesting and foraging. Anthropogenic impacts may include the effects of pesticides, as well as the timing of tillage, spraying and harvesting operations.
5. **Recreational activity** (including tourism and other leisure) is a cultural service that may be facilitated by certain types of crop- and non-crop vegetation, although this benefit mostly derives from anthropogenic factors such as access arrangements and field layout. We include **educational** goods in this category, since they are closely related to appropriate forms of farmland recreation. Appropriate anthropogenic contributions such as access arrangements are important for realising most benefits in this category.
6. **Aesthetic landscape quality** is a complex cultural service that arises from a complex interaction of various sensory features of farmland (e.g. crop appearance, geomorphology and spatial and temporal variation in these) with public aspirations and beliefs. We include **human health** goods in this category, since the little literature available refers to psychological wellbeing. The aesthetic value of farmed landscapes depends upon a wide range of anthropogenic impacts that cannot be considered here.

(C) Finally, the following ES can provide benefits to humans more diffusely, potentially at a global scale. We consider these under the heading of *general sustainability.*

7. **Air and water quality impacts** occur via exchange of gases and air-borne particles (e.g. NH3, O3, aerosols, dust and pollen) with plants and soils, constituting both ES and ecosystem disservices.

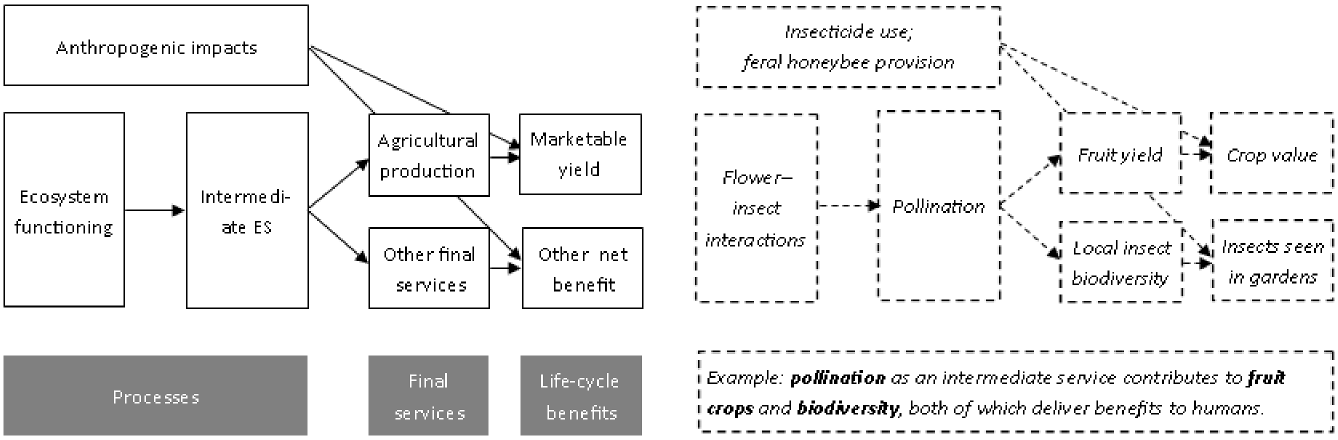
Anthropogenic impacts involve some of the same substances as well as exhaust gases from machinery (both on- and off- farm equipment).

8. **Climate impacts** occur via exchanges of greenhouse gases (GHGs), particularly CO2 uptake by plants, release of methane (CH4) by cattle, and release of nitrous oxide (N2O) and ozone (O3). The anthropogenic actions to offset against these impacts mostly concern fossil-fuel combustion in the manufacture of agrochemicals, particularly nitrogenous fertilizers, as well as in on-farm machinery.
9. **Animal welfare**(in livestock)is taken here as a cultural service, to be distinguished from animal health, which is a factor in agricultural production. It may be provided by the overall agricultural habitat, including crops and other farmland vegetation. Anthropogenic contributions to animal welfare include a wide range of aspects of livestock management, which will not be considered here.

ES in category C, and to a lesser extent category B, tend to function as public goods: they are appreciated mostly by people other than the farmer from whose land they are delivered. As such, increasing their delivery will typically require some kind of financial incentive to the farmer.

Many of these final services will be modified by management practices that affect the net benefits enjoyed. They are therefore affected not only by ecosystem functioning but also by anthropogenic actions, calling for integrated assessments of net benefits for any particular agricultural context and management practice. Figure 2 shows our scheme for relating ecosystem services, anthropogenic impacts and benefits to each other. We use the acronym ES to refer to both intermediate and final ecosystem services, and the term "benefit" to refer to quantifiable outputs where any anthropogenic impacts may also be taken into account. The ideal is a "whole-life-cycle assessment" that takes a critical currency of one or more human benefits, such as carbon sequestration or financial profit, and identifies all relevant contributions to them, positive and negative, through all stages in a process delivering a specified good (Zhang et al 2010, 2010).

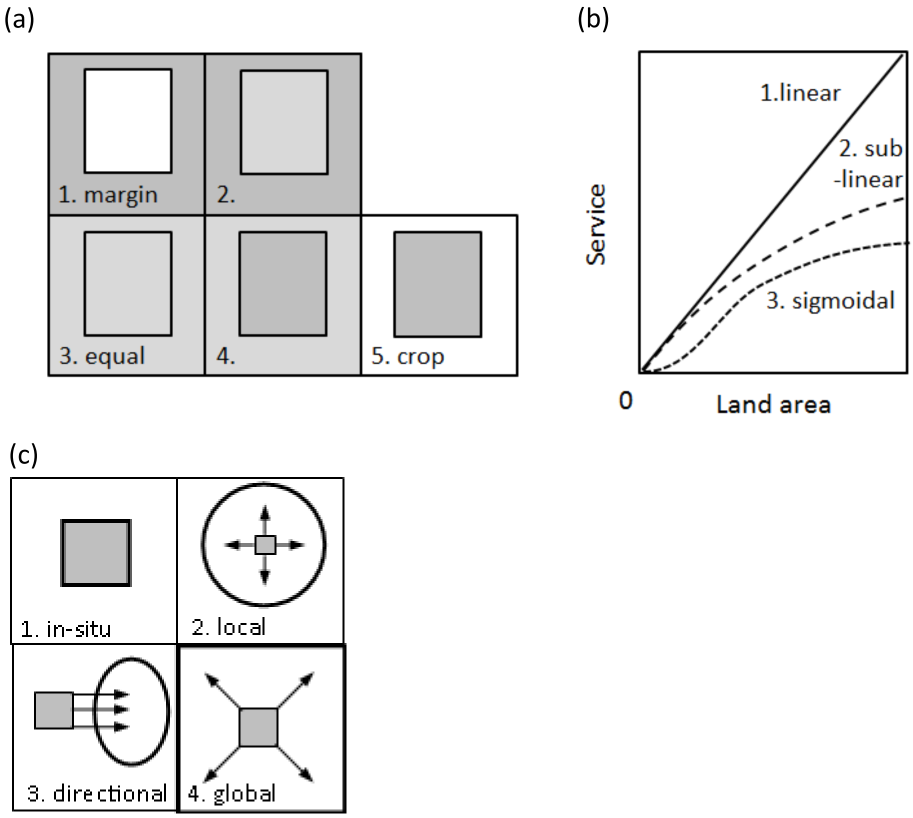
Figure 2. Conceptual scheme relating ecosystem services (separated into intermediate and final services) and anthropogenic impacts to human benefits.



Considering the spatial characteristics of ES can shed light on the potential for their contribution to SI. First, we note that most agro-ecosystem services can be delivered at least partly by the cropped area itself (Fig. 3a). Besides crop and livestock production, these include benefits to climate, air quality, water quality and soil maintenance and quality. Such ES (all but type 1 in Fig. 3a) are of particular interest for SI, since any actions affecting their delivery are likely to have collateral effects on crop yield.

The scaling of ES with land area is also crucial for understanding SI (*cf.*Fig. 1), . Thus it is important to distinguish basic categories such as “linear”, “sublinear” and “sigmoidal” forms of area-dependence (Fig. 3b) for interpreting and predicting the value of particular SI actions. ES based on fluxes between the air and the land or its vegetation are likely to scale linearly with area (type 1); the archetype of these is the exchange of greenhouse gases and other pollutants. Meanwhile. ES based on the viability of biotic communities, such as pollination and biocontrol, are most likely to scale sigmoidally with area (type 3) owing to some kind of Allee effect. Finally, we adapt the spatial categories of (Fisher, Turner & Morling 2009) for the relationship between areas of service delivery and areas of benefit (Fig. 3c). This categorisation maps closely onto our classification of ES: those in our category A tend to be enjoyed within or close to the areas from which they are delivered (type 1); those in category B are enjoyed in the vicinity of their source (types 2 and 3) and those in category C are enjoyed more diffusely, perhaps even globally (type 4).

Fig. 3. Spatial classifications of service delivery in farmland. (a) A 5-point scale for the relative rate of service delivery (darkness of shading) by cropped areas (central squares) and other land (outer regions). Level 3 or above is necessary for true land-sharing (cf Fig. 1). (b) Scaling relationships for services with land area from which they are derived. (c) Spatial relationships between regions where services are produced (shaded) and where benefits are received (bold outlines).



The following ES from the UKNEA are not considered in this review because their delivery by agricultural land in the UK is variable and difficult to predict: Nutrient cycling, Water cycling, Hazard regulation, Noise regulation, Non-agricultural food production (marine, aquaculture, wild game, honey), Forest products, Peat, Ornamental resources, Genetic resources, Water provision, Heritage goods, Religious and spiritual goods.

Also, while our analysis identifies farmland bird diversity and abundance as a cultural service and briefly considers the cultural value of insect diversity under "biocontrol" and "pollination", it does not consider other elements of biodiversity. Most of these services are likely to be better provided by more-natural habitat types, so that the relative level of delivery by agricultural land would normally be negative. While beyond the scope of this review, this is an important consideration in any land-use planning discussions concerning changes in the overall area of land farmed.

We performed a literature review to investigate how agricultural production correlates with other ES in situations where farming systems are modified. The aim was to understand what kinds of system modifications qualify as SI by increasing both marketable agricultural production and other ES, or at least promoting an increase in one without a decrease in the other (Figure 1).

We therefore searched the literature for studies reporting empirical relationships between agricultural yields, or market values of produce, and delivery levels of other ES. We focused on scientific articles published since the start of 2010, since only recently has there been a proliferation of studies on agricultural methods for increasing yields while monitoring a wide range of other functions of the farmed landscape. Indeed, the term "ecosystem services" has become particularly useful as a search term since its widespread adoption within the last few years. We also prioritised studies from the UK and other temperate regions.

We used the online literature search tool Scopus to search for papers containing certain terms in their title, abstract or keywords. First, we searched for "ecosystem service*" and "yield*"; this yielded 645 articles published since the start of 2010. Filtering out marine, wetland and forest-focused studies, plus those with a specific tropical or dryland focus, broad-scale land-use studies and those considering a management action not considered part of UK agriculture left some 200.For better coverage of cultural services, we performed an additional search for "wellbeing" or "cultural service*" or "recreation" alongside "yield*" or "productivity" *and* "farm*" or "agriculture*". This yielded just34 articles published since the start of 2010 and deemed relevant under the criteria mentioned above. We therefore supplemented this search with a targeted search by looking at papers cited by Church *et al.* (2014) and some additional key-word searches.

Because SI concerns changes to management practises, we prioritise evidence for causal links in which feasible human actions bringing about changes in land use or management were suggested.

Results from the Review

A wide range of studies suggested actions promoting increases in agricultural production and one or more other ES, or increases in either of these without detriment to the other. We first present studies that report relationships between agricultural yield and one of our categories of ES taken individually, focusing on positive (or neutral) relationships and then mentioning negative ones. We then present studies reporting impacts on multiple categories of ES, and studies that integrate across several categories of ES including agricultural production – e.g. by using monetary valuations. Finally, we present a few studies with an even broader kind of integration: the life-cycle assessment, which typically integrates across a broader range of factors including anthropogenic impacts.

In all cases we emphasise the human action (e.g. agricultural management technique) that appears to be causally responsible for the relationships reported. Findings from studies based on experimental interventions are particularly valuable and highlighted with the annotation (E). Where few studies based on human actions were found, any studies reporting spatial correlations are presented separately. These are important because potential SI actions that involve system-level changes, such as organic conversion or broad-scale landscape modification, are more-easily studied by comparing extant systems than by organising experimental manipulations expressly. A summary of the overall patterns we found is given in Table 1. The results are presented following the numbering of our ES categories, with multi-category reports as a tenth category.

Table 1. Characteristics of agroecosystem services. For each of the ES considered in this review, this table indicates (i) the diversity of options for SI and then, with reference to Fig. 3, (ii) the degree to which cropped land typically provides the service (codes as in Fig. 3a), (iii) the form of its scaling with area (*cf* Fig. 3b) and (iv) the spatial topology of its delivery (*cf* Fig. 3c).

ES	(i) Potential for SI[a]	(ii) Cropped land?	(iii) Scaling	(iv) Topology	Suggested general land-use strategy for SI
(A) *Agronomic sustainability:*					
Soil maintenance	++	3	1	1	General farmland management
Biocontrol	(+)	2	3	2	Well-located margins
Pollination	(+)	2	3	2	Large, well-located margins
(B) *Local sustainability:*					
Farmland birds	(+)	2	3	2	Large, well-located margins
Recreational activity	(+)	2	3	4	Access; Management with respect to location
Landscape aesthetics	(-)	4	3	2	Management with respect to context
(C) *General sustainability:*					
Air and water quality	++	3	1	3	General farmland management
Climate impacts	++	3	1	3	General farmland management
Animal welfare	(+)	4	3	3	General farmland management

[a] ++ Many options for positive associations with agricultural yield; + Several options; (+) Several poorly-attested options; (-) Few or no options

Agronomic sustainability (ES in group A)

Our first three ES (soil maintenance, biocontrol and pollination) may be considered as intermediate services for agricultural production. In principle their contributions may be quantified in terms of final agricultural yield or market value over a period of time. Actions that maintain or increase such outputs may be deemed sustainable in the most basic sense, in that present needs are met without compromising the ability of future generations to meet theirs (Smith 2013). Other intermediate ES that might be considered in this category are mycorrhizal activity (Baar 2012), and also agro-ecological education. The concept of natural capital is fundamental to addressing the temporal sustainability of agriculture (Azqueta and Sotelsek 2007).

The temporal aspect of sustainability can be broken into two distinct issues: long-term and short-term maintenance of yields. The problem of long-term progressive yield declines on a site over time is mostly attributed to soil impoverishment, and proposed remedies include reverting to longer crop rotations or break crops, double-cropping or inter-cropping, tillage and organic amendments (Bennett et al. 2012), as well as improvement of fertiliser regimes.

Short-term maintenance of yields concerns resilience, which is a topic of increasing concern in view of global climate change and instabilities. Some authors see “ecological intensification” as a strategy to increase the resilience of agricultural systems: particularly techniques promoting the substitution of ecological processes for anthropogenic inputs, such as biocontrol and organic soil management (Bommarco, Kleijn & Potts 2013). What may be more useful is a broader strategy aiming to build up all kinds of natural capital so as to buffer against transient environmental threats. Soil improvement and maintenance will remain primary among these, so the following section below is of particular importance for short-term resilience as well as long-term maintenance of yields – i.e. both aspects of agronomic sustainability.

1. Soil maintenance

Maintaining soil quality and depth is generally expected to have positive relationships with agricultural productivity, and is the most direct form of SI. That is, agricultural practices that deplete soil are ultimately unsustainable. SI must be distinguished from any practices that increase yields in the short term while depleting soil stocks or causing soil quality to deteriorate. Squire *et al.* (2015)found that, in a highly-productive region of Scotland, high-intensity cropping was associated with reduced soil organic carbon (SOC), water-holding capacity and bulk density in comparison with low-intensity sequences, suggesting a temporal dynamic that is likely to be unsustainable.

Soil organic matter (SOM) has been proposed as the most important metric of soil quality (Lehman *et al.* 2015), although it is less easy to measure than other metrics such asSOC and soil depth. A number of recent reviews suggest options to improve soil quality, such as:

- Reductions in tillage intensity and implementation of integrated, multifunctional cropping rotations that include forage legumes and/or small grains(Lehman *et al.* 2015);
- Increasing SOC using conservation agriculture (no-till and mulch farming), use of cover crops and green manures, application of manure and biochar and use of perennial cultures, including agroforestry (Lal 2013); and
- Pursuing an integrated soil–crop system management (ISSM) paradigm that (i) considers all possible measures for improving soil quality, (ii) integrates the utilization of diverse nutrient resources and match nutrient supply to crop requirements, and (iii) integrates soil and nutrient management with high-yielding cultivation systems (Zhang *et al.* 2011).

There are also many studies reporting positive empirical associations of soil quality metrics with agricultural production:

- The cost of soil erosion was better offset by rye yield in extensive than in intensive farmland in Germany (Bastian *et al.* 2013).

- (E) A range of soil compaction avoidance technologies was found to increase gross margins, ranging from £26/ha for tracked tractors on sandy soil to £118/ha for controlled-traffic farming on clay soil (Chamen *et al.* 2015).
- Mulching in orchards increased C sequestration (SOM) compared to other ground-cover management systems, while maintaining high yields (Leinfelder, Merwin & Brown 2012).
- SOC was increased under *Miscanthus* bioenergy crops in Ireland (Zimmermann *et al.* 2014).
- A model is offered for managing soil natural capital (particularly SOC) to buffer against energy price shocks and adverse weather events (Cong *et al.* 2014).

Negative associations are, of course, possible:

- (E) Organic cultivation had 20% lower yields but was more effective than diversified rotations (3 or 6 crop spp) for improving soil carbon stocks and nitrogen retention in a study in Michigan(Snapp, Gentry & Harwood 2010).
- There was no apparent trade-off between increasing crop yields and the levels of various soil ES in a comparison of organic with conventional farming in Sweden (Williams & Hedlund 2013).
- Along a landscape spatial-heterogeneity gradient, barley yield was not traded off against a range of soil indicators: stocks of SOC, N, available phosphorous, water-holding capacity; nor net N mineralisation rate, microbial biomass. Heterogeneity was correlated with yield but not with the soil indicators, suggesting these are determined at the field level (Williams & Hedlund 2014).

Some other relevant studies appear under “8: Air and Water Quality” below, since soil, air and water are linked in agroecosystems by flows of substances between them, and nitrogenous compounds in particular connect SOM to nitrogen inputs and leaching.

2. Biocontrol

Biocontrol has the potential to increase crop yields, but only a small proportion of studies of biocontrol report final crop marketable yields and/or profit values (Eubanks & Finke 2014), which are the essential metrics for assessing provisioning benefits. So far as the associated ES benefit of insect biodiversity is concerned, many more studies report the abundances or diversity of relevant species, although there is insufficient consideration of the spatial scales at which insects move (Bommarco, Kleijn & Potts 2013) and how widely the biodiversity benefits may be enjoyed.

Techniques producing positive effects on crop yield are reported in a number of studies and reviews:

- A review suggests that optimising the timing and spatial patterning of weed management can help balance natural pest management services (not necessarily through biocontrol) against yield loss (Gunton 2011).
- (E) Ceasing the use of neonicotenoid seed-coating treatments designed to protect soya beans from slug damage in trials in the eastern USA increased yields by releasing biocontrol by natural predators(Douglas, Rohr & Tooker 2015).
- (E) Ants and termites (which may become more significant in the UK under climate change) can increase wheat yield by 36% from increased soil water infiltration due to their tunnels and improved soil nitrogen, having similar functional roles to earthworms (Evans *et al.* 2011).
- Greater biological control of pests in organic compared to conventional fields in a New Zealand study minimised yield reductions, and the estimated economic value of organic farming was greater when accounting for nitrogen mineralisation and soil formation by earthworms as well as crop market value(Sandhu, Wratten & Cullen 2010).

Negative relationships with crop yield are not uncommon, because of unexpected insect population dynamics and/or yield losses on land given up to vegetation designed to host natural enemies. Successful biocontrol depends upon complex trophic relationships, so inconsistent relationships with crop yields are probably more common than reported in the literature. Some examples were found:

- (E) Diversifying apple orchards in the USA did not consistently reduce pest damage despite increasing natural enemies (Brown 2012).
- In a comparative landscape study in Québec, spatial patterns of arthropod diversity and abundance across varying field sizes were not closely related to those of pest regulation or crop yield (Mitchell, Bennett & Gonzalez 2014).

Biocontrol is likely to be very context-dependent, and there is a need for much further research in the area. For example, interactions among natural enemies may be important(Marquès *et al.* 2013; Martin *et al.* 2013), and an area-wide approach to IPM should be considered(Brévault & Bouyer 2014).There is also some interest in weed seed predation, but little evidence as yet to show that it can increase crop yields.

It is important to recognise that pest attacks may be avoided or minimised by other cultural techniques that target the herbivore rather than higher trophic levels (Gunton 2011). Such techniques qualify as SI without using biocontrol as an ES.

3. Pollination

There is currently a great deal of research on pollinator activity in UK landscapes, and strong indications of the economic importance of wild pollinators (Breeze *et al.* 2011). However, there is a shortage of studies exploring the agronomic outcomes of realistic management options targetting pollination services. A few reports of positive relationships with crop yield were found:

- A review concludes that management of non-cropped areas to encourage wild pollinators may prove to be a cost-effective means of maximizing crop yield (Nicholls & Altieri 2013);
- (E) Growing wildflowers instead of grass in uncropped margins with c.10% of the area of adjacent fields in mid-western USA increased blueberry yields after 3–4 years, producing net financial benefits(Blaauw & Isaacs 2014).
- Organic farms yielded strawberry crops with greater pollination rates and correspondingly-fewer misformed fruits (suggesting an economic benefit of pollination services) than conventional farms in Sweden (Andersson, Rundlöf & Smith 2012).
- An agent-based model illustrates the potential for enhanced pollination-dependent crop yields under scenarios where neighbouring farmers cooperate in optimising the fraction of pollinator habitat on their land – such as might occur with suitable agri-environment schemes (Cong *et al.* 2014).

Other studies simply report correlations:

- Yields of more-pollinator-dependent crops in France did not increase with a regional intensification index, in contrast to non-pollinator-dependent crops (Deguines *et al.* 2014), and a global study found that pollinator-dependent crops have shown lower growth and stability of yields over the last 47 years compared to other crops (Garibaldi *et al.* 2011).
- Cherry yields were correlated with the abundance of wild flowers within a 1-km radius, but not with flower-cover of ground vegetation within German orchards(Holzschuh, Dudenhöffer & Tscharntke 2012).

- The pollination benefit of *Apis* honeybees was enhanced in the presence of non- *Apis* bee communities in Californian almond orchards (Brittain *et al.* 2013).

  Finally, the associated cultural benefit of insect biodiversity should be considered. Within a paucity of relevant research, one study found that elevated abundances and species richnesses of wild Hymenopteran insects have been observed in gardens adjoining oilseed rape fields compared to urban gardens in Germany (Pereira-Peixoto *et al.* 2014).

Local sustainability (ES in group B)

The remaining ES are of relevance to the broader definition of SI: that of using agriculture to increase a diverse range of environmental benefits. A number of the following ES (nos. 4, 5, 6 and 9) provide benefits to humans that are cognitively mediated, often considered under the heading of "cultural services". Methodologies to quantify such complex benefits are often open to criticism and subject to ongoing development (Hernández-Morcillo, Plieninger & Bieling 2013; Scholte, van Teeffelen & Verburg 2015), but the studies cited in the following sections provide a sample of innovative methods in this rapidly-developing field.

1. Farmland Bird Communities

Farmland bird diversity, and by extension the diversity of other taxa, may chiefly be considered to deliver a cultural benefit, and there is also some evidence for public health benefits. For example, psychological wellbeing may be linked to biodiversity of familiar taxonomic groups (Fuller *et al.* 2007), although the link may depend upon perceived rather than actual biodiversity (Dallimer *et al.* 2012). The Farmland Bird Index is already used as a "sustainable development indicator" by the UK Government (ONS 2014).

Some species may benefit from measures that do not decrease agricultural productivity, especially those that forage within cropped fields:

- (E) Cereal-based whole-crop silages based on spring-sown barley supported seed-eating birds both on the crop in summer and on ensuing stubbles in winter, while the crop value compared favourably with alternative forage crops for the English region studied (Peach *et al.* 2011).
- Scenarios of modifying land-use in an area of England in order to meet bioenergy production targets were modelled to have minimal impacts on farmland birds (Rivas Casado *et al.* 2014); similar modelling for the Upper Midwest USA predicted increased local species richness if diverse perennial crops were used or decreased richness under annual crops (Meehana, Hurlbert & Gratton 2010).

However, most farmland bird populations are limited by resources predominantly found outside of crops, such as stubbles, hedges and ditches. As such, their associations with agricultural yield will predominantly be determined by spatial or temporal trade-offs between crop and non-crop land-uses, creating negative associations and limited opportunities for SI:

- (E) Corn buntings in Scotland were shown to benefit from agri-environment schemes that reduce agricultural production, including delayed mowing (Perkins *et al.* 2011; Perkins *et al.* 2013).
- A study modelling skylark nesting behaviour failed to identify any mowing regimes that would allow grass fodder crops to yield acceptable fledgling rates and recommended that alternative

high fecundity breeding and foraging habitats be provided at the landscape scale (Buckingham, Giovannini & Peach 2015).
- Organic systems tend to contain more overwinter stubbles, which benefit seed-eating birds at the cost of lower yields , but a cross-European correlation study found positive effects of organic farming to be limited to simplified landscapes, even while extensive management and pastures were generally beneficial for species abundances and richness (Geiger *et al.* 2010).
- Stubbles from crops untreated with pesticides support more farmland birds (McKenzie *et al.* 2011).
- Ground-nesting waders and other birds benefit from hydrological features such as ponds and flooded washlands, which must reduce agricultural production (Rhymer *et al.* 2010).
- A correlational study across European farmland found that densities of birds including the skylark were higher in landscapes dominated by agriculture, especially those with smaller fields and greater crop diversity, although densities were negatively correlated with crop yields (Guerrero *et al.* 2012).

Birds also affect agricultural production (providing intermediate services and disservices). One review comparing potential benefits, such as biocontrol, with costs, such as crop damage, suggested that management options be designed to optimise the bird community composition according to the behavioural traits of species present (Triplett, Luck & Spooner 2012).

2. Recreation

Leisure activities such as walking, birdwatching, fishing and farm visits are an important public use of farmland throughout much of the UK. Such activities are typically assumed to have both health and educational benefits, among others. The simplest metric for quantifying the overall level of recreational benefit is numbers or density of visits by members of the public (e.g. Bateman *et al.* 2013); other scales on which to assess benefits include wellbeing (e.g. Bieling & Plieninger 2013) and monetarised benefits. The level of recreational ES that a parcel of land can deliver will tend to be constrained by its distance from human settlements and transport hubs.

It is likely that recreational benefits are often traded off against agricultural production, since land given over to paths and other leisure facilities is generally not agriculturally productive – and indeed, trespass of members of the public onto cultivated land tends to reduce its productivity. However, a few cases of positive or neutral relationships with agricultural productivity have been found:

- Modelled future UK land-use scenarios aimed at increasing agricultural market values could also increase nonmarket recreational values (density of visits to open-access countryside), although this was at the expense of greenhouse gas emissions and urban green space (Bateman *et al.* 2013).
- Traditional, productivity-oriented farmers in Denmark tended to oppose the establishment of national parks, holding the view that "sharing" the land with others diminished their competitiveness, but there was also an emerging trend of small-scale food entrepreneurs, who wanted to see joint marketing and labelling of food products in parks (Hjalager & Johansen 2013).
- Community-supported agriculture schemes can serve as highly-valued leisure activities (Farmer *et al.* 2014), and it appears that hands-on participation in the field can increase yields compared to conventional farming, as well as improving economic returns for growers (Saltmarsh, Meldrum & Longhurst 2011).

Direct negative relationships with productivity are likely to arise from trampling; no studies on this specific to crop plants were found, although a small meta-analysis confirmed that annual vegetation is particularly susceptible, while hemicryptophyte perennials (such as grasses) are particularly resilient (Pescott & Stewart 2014). Rather more correlational data were found:

- Spatial correlation data from eastern Germany showed no strong associations between publically-perceived recreational value of landscapes and the presence of cropped land (Plieninger *et al.* 2013).
- In another multifactor correlational study, UK property prices were found to increase with proximity to enclosed farmland, which was interpreted in terms of its amenity value (Gibbons, Mourato & Resende 2014).
- In a spatial correlation study using stated preferences of tourists in north-German landscapes, respondents who valued recreation possibilities considered agricultural landscapes less important in comparison to the other groups in the study (Van Berkel & Verburg 2014).

Farm visits as a component of formal education programmes are widespread (e.g. Kloppenburg, Wubben & Grunes 2008). By investing in the understanding and creativity of future generations of farmers, policy-makers and researchers, farm-based education may serve as the most important sustainability initiative of all (Francis *et al.* 2011). As such an intrinsic condition for the future viability of farming, it might also have been considered in our Group A, along with soil maintenance.

3. Aesthetic landscape quality

The aesthetic appreciation of landscapes is one of the most complex phenomena to integrate into public policy, and methodology is in development. In some cases it may be possible to use simple proxies such as boundary geometry (Frank *et al.* 2013) or popularity with artistic communities (Casalegno *et al.* 2013), or more subjective assessments concerning, for example, the consistency of a focal area with the character of the surrounding landscape. However, one study reported that the spatial location of cultural services as perceived by the public was poorly correlated with biophysically-modelled locations (Bagstad et al. 2015), illustrating the difficulties of any indirect approach.

Positive relationships between the aesthetic appreciation of a landscape and its productivity have been reported for livestock systems:

- Grazed grasslands have higher species diversity and were found to have higher public “environmental appreciation” (Ford *et al.* 2012).
- European landscapes containing livestock win greater preference by members of the public (Van Zanten *et al.* 2014).

Negative relationships with productivity were suggested by a Swiss survey in which around half the respondents indicated an aesthetic preference for more-complex landscapes (Home *et al.* 2014), which may be assumed typically to have lower agricultural productivity. This degree of preference was little affected by providing respondents with additional information on the ecological benefits of connectivity.

Negative relationships are also found in some correlational studies:

- Spatial correlational data from a study in Cornwall showed that the aesthetic value of landscapes, as measured by density of photographs uploaded on Google Earth, was negatively correlated with agricultural productivity (Casalegno *et al.* 2013).

- Another spatial correlation study using stated preferences of tourists in north-German landscapes found that areas dominated by open agricultural land and large-scale farming were least appreciated (Van Berkel & Verburg 2014).

General sustainability (ES in group C)

1. Air and water quality

These environmental impacts are grouped because air and water pollution from agriculture are largely related to the dynamics of nitrogenous compounds in the agro-ecosystem and are often difficult to separate in practice. The main ES being considered here is efficient uptake of such compounds; there are also ecosystem disservices insofar as some agro-ecosystem components, particularly livestock, release N in forms with increased volatility or solubility. There are, however, some links with soil quality. A key metric for air quality is ammonia emissions, while metrics for water quality include nitrate runoff, sediment and phosphorus runoff and FAOs. In 2006 it was suggested that agriculture would bear a major share of EU Water Framework Directive implementation costs, being compelled to reduce the emission of diffuse water pollutants (Bateman *et al.* 2006).

A number of recent studies suggest potential positive associations of air and water quality with agricultural yields:

- Optimising N application on corn in midwestern USA was modelled to increase yields with respect to water quality(Ewing & Runck 2015).
- Diversified rotations in Iowa (maize–soybean–small grain–forage) with reduced agrichemical inputs achieved similar or greater yields while freshwater toxicity was two orders of magnitude lower (Davis *et al.* 2012).
- New cultivars of annual legume crops have greater N uptake (Duc *et al.* 2015).
- Modifying crop cultivars for better use of mycorrhizas may reduce fertilizer requirements(Courty *et al.* 2015).
- Soil compaction avoidance technologies increased gross margins in a UK study, decreasing leaching and emissions of nitrogen and requiring less fuel (Chamen *et al.* 2015).
- (E) A tractor-drawn implement for subsurface application of dry poultry litter in perennial pasture and conservation tillage systems in the USA reduced losses of ammonium(Pote & Meisinger 2014).
- (E) Augmented earthworm densities increased yield without affecting nitrate leaching (Wu *et al.* 2015)
- Phosphorus losses from potato crops may be minimised by choosing sites where P fertilization is not needed and where slopes are shallow (Ruark, Kelling & Good 2014).
- The nematicide 1,3-dichloropropene (1,3-D) increased the profitability of tomato-growing in Italy with minimal negative effects on soil function and water and air pollution(Alix *et al.* 2014).

Negative relationships with crop yield (i.e. increased pollution)easily occur if the costs of fertilizer application rates do not account for pollution, as suggested by the following correlational studies from Norway:

- Nitrogen losses to the environment were correlated with crop yields (Øgaard 2014).
- Phosphorus losses to the environment were correlated with crop yields (Bechmann 2014).

2. Climate impact

Agricultural activities make significant contributions to carbon cycling and can also release other greenhouse gases (GHGs). A number of studies suggest that carbon storage can be increased, or GHG emissions reduced, without loss to agricultural productivity:

- A meta-analysis for cereal crops found that the lowest yield-scaled global warming potential values were achieved at 92% of maximal yield (Linquist *et al.* 2012).
- Increased use of legumes can reduce CO2 and N2O emissions in fertilizer manufacture (Jensen *et al.* 2012).
- Grassland biodiversity restoration practices increased soil C and N storage especially when combined with promotion of the legume *Trifolium pratense*. These high rates of C and N accumulation were associated with reduced ecosystem respiration, increased SOM content and improved soil structure, although cessation of fertilizer use reduced the amounts of C and N contained in vegetation (De Deyn *et al.* 2011).
- Optimising stocking densities and fertilizer inputs can maximise carbon storage times in pasture (Soussana & Lemaire 2014).
- Results from long-term studies suggest that organic grain systems with animal manures and cover crops can have lower global warming potential than conventional no-till systems, although soil erosion appeared to be greater(Cavigelli *et al.* 2013).
- (E) Low-input and no-till systems at the Kellogg Biological Research Station in Michigan had comparable wheat and maize yields but no negative climate impact, as well as increased SOM and reduced nitrate losses, compared to conventional. An organic system performed even better (with positive climate impact) but had 20–40% reduced yields (Robertson *et al.* 2014).
- Various technological measures can improve the overall climate footprint of a farm enterprise without adverse effects on yield – such as installation of wind turbines and adoption of more-efficient machinery (Firbank *et al.* 2013).

Negative relationships with productivity are, of course, also possible:

- Increased N2O release was found in crop treatments with addition of organic matter and of earthworms (Wu *et al.* 2015)

3. Animal welfare

Animal welfare is considered here as a cultural service of broad human benefit, since ethical concerns for animals are widely distributed among human populations. Whereas animal health is acknowledged to make a positive contribution to economic productivity, animal welfare by definition excludes factors that produce basic symptoms of poor health and associated mortality and so is not linked to survival and growth in easily-observable ways. Its assessment therefore relies on experts, although standardised farmer-assessment schemes are being developed (Edgar *et al.* 2013). While data from such "output" schemes are not yet available, a few studies suggest that productivity can be positively associated with actions ("inputs") designed to promote welfare:

- Keeping reproductively-active pigs in larger heated pens rather than farrowing crates could increase net profit margins as well as welfare, according to modelling of UK systems(Vosough Ahmadi *et al.* 2011).
- Breeding poultry for improved behavioural traits under intensive rearing would increase productivity (Muir, Cheng & Croney 2014).
- Some features intended to increase the welfare of laying hens, such as increased movement space, may actually have detrimental welfare effects as well as reducing productivity per unit space, according to a wide-ranging review (Rodenburg *et al.* 2005).

A correlational study found that Finnish farmers with more positive perceptions of attitudes to animal welfare and productivity saw slightly lower piglet mortality rates and lower stillbirth rates on their farms than those holding less positive views(Jääskeläinen *et al.* 2014).

There are also, unsurprisingly, studies suggesting negative relationships:

- (E) Modern rearing systems for broiler chickens, including high population densities, improve poultry quality and economic yield but appeared to decrease wellbeing (Jorge Servín *et al.* 2013).
- Optimising sheep stocking densities, human labour input and feed-resource management for financial benefit tends to have minimal or negative effects on welfare, in extensive UK sheep farms(Stott *et al.* 2012).
- Most alternatives to caged accommodation are expected to provide "satisfactory" welfare for laying hens (Blokhuis *et al.* 2007). A statutory change from to barn accommodation for laying hens in California has been predicted to increase production costs by 40% (Sumner *et al.* 2011).

Multi-category studies

Table 1 provided an overview of our findings for each category of ES in turn. However, SI will not be achieved if increases in certain ES benefits are accompanied by critical reductions in others. Many useful studies therefore consider relationships among a broad range of ES – in some cases with helpful unified graphics or tables:.

- An analysis of allocating 26 modelled rotations of food, fodder and biofuel crops across a number of hydrological response units in Germany identified a set of alternative Pareto-optimal solutions that maximised combinations of four outputs (agricultural and biofuel productivity and nitrate pollution and critical water flow rates in catchments). The optimality of solutions appeared to depend on the allocation of rotations to catchments much more than on the nature of the rotations themselves (Lautenbach *et al.* 2013).
- A wide range of ES benefits were displayed using 13-spoke radar diagrams, showing the advantages of using cover crops in a wheat–corn–soybean system and facilitating an assessment of the slight reduction in profitability (Schipanski *et al.* 2014).
- Similarly, a range of ES benefits displayed using 8-spoke radar diagrams for annual grain crops at the Kellogg Biological Research Station in Michigan suggested advantages of no-till and reduced-input production systems(Syswerda & Robertson 2014).
- Integrated animal-rearing systems can increase efficiency and reduce pollution and climate impacts by moving towards a closed system: e.g. a French pig farm used its manure to produce biogas for heating the pig housing and also to fertilize arable crops, which in turn were used to produce feeds and, in the case of rapeseed, oil for the biogass digester motor(Dumont *et al.* 2013).
- Harvested perennial grasslands in Kansas yielded more N than annual crops with only 8% of the energy inputs, while increasing soil C and N, reducing nitrates in nearby watercourses and increasing diversity and/or abundance of pollinators and above- and below- ground invertebrates (Glover *et al.* 2010).
- Comparison of alternative farm management practices in the wheat belt of Western Australia on the joint production of ES on mixed crop–livestock farms showed potential for win–win solutions by increasing crop residue retention and avoiding perennial pastures (Kragt & Robertson 2014).
- Installing shelterbelts in fields in Shangdong Province, China, had benefits for soil conservation > crop yield increment > biodiversity protection > CO2 fixation > air purification (Chen *et al.* 2012).

- Various actions reported from a set of innovative UK farms were associated with improved yields, climate impacts and nitrogen retention in arable but not in livestock-based enterprises (Firbank *et al.* 2013).

Integration

There is no unique way to combine benefits on disparate scales such as yield, biodiversity, pollution and aesthetic or recreational value onto a single scale of net value. However, some multi-ES studies choose some procedure for converting such disparate values into a common currency such as monetary values.

Monetary conversion:

- Benefits were calculated for a combined food and energy production system over wheat in Denmark, for multiple ES (Ghaley, Vesterdal & Porter 2014).
- A GIS-based model assessment of land in Virginia, USA, calculated how net economic outcomes integrating production and ES delivery could be increased by optimal allocations of land to biofuel and food crop production (Kokkinidis & Hodges 2013).
- A wide-ranging valuation of the costs of nitrogen application to arable land in US landscapes revealed large externalised costs (Compton *et al.* 2011).

Integration by farmers' preference:

- A survey of US mid western farmers ranked ES in decreasing order of farmers' concern: SOM> soil conservation > N pollution > P pollution > pesticide risks > global warming. It showed preferences for reduced or no-tillage, the addition of a small grain, such as wheat, to corn–soybean rotations, and incorporating rather than spreading manure (Swinton *et al.* 2015).

Another important kind of integration attempts to trace all the contributions to a certain human good or service that may be attributed to a particular product. A few studies provided such"life-cycle assessments" (LCAs) of environmental footprints:

- Maximising the efficiency of milk production with respect to greenhouse gas emissions in Germany favours extensive systems once the production factor is extended by monetarising a range of ES(Robert Kiefer, Menzel & Bahrs 2015).
- A review illustrates how the ecological footprint of European dairy farming must account for the impacts of overseas systems providing animal feed (Taube *et al.* 2014).
- Biophysical, economic, environmental and information costs in conventional crop-breeding compared favourably with those in GM crop development and testing(Rótolo *et al.* 2014).
- An important spatial analogueof the LCA approach is demonstrated by a study that monetarises landscape-wide environmental costs and benefits of nitrogen use in winter wheat production in the UK. The review by Whitmore *et al.* (2012) argues that, for a given rate of overall yield, the cost–benefit balance across the whole landscape will be optimised by any measures that reduce the area of land farmed.
- Finally, since organic systems are widely advocated for their ecological benefits, it is invaluable to have a meta-analysis quantifying the deficits in their typical yields compared to conventional systems. Organic yield deficits ranged from 5% in the best cases (rain-fed legumes and perennials on neutral soils), through 13% when best organic practices are used, to 34% when conventional and organic systems are most comparable (Seufert, Ramankutty & Foley 2012). Meanwhile, a review of crop-breeding technologies and agendas discusses the potential for producing more "ecological" varieties with improved contribution to various ES as well as yield (Charles Brummer et al. 2011).

Our review has focused on describing actions that qualify as "sustainable intensification" according to the broad definition offered above. This definition potentially encompasses positive and negative impacts of agricultural activities in every area of human life, including biotic, psychological, social, economic, aesthetic and broader cultural aspects. Sustainable intensification thus includes a very wide range of actions, such as suggested by the studies cited above.

No doubt many actions have been devised that are not elicited by the studies reported here, while others are yet to be proposed. Our review, therefore, does not lend itself to any general assessment of the feasibility of SI. In particular, the studies reporting negative associations should not be weighed against the positive ones numerically, since our methodology, and indeed the literature itself, is biased towards reporting positive associations.

There appears to be a need for more studies in many of the areas examined here. Experimental studies are particularly needed, measuring the effects of potential SI actions on as broad a range of ES benefits as possible, and including some economic valuation of effects on agricultural yield. Specific ES where more work is needed include biocontrol and pollination. At the landscape-scale, work is needed to show how recreational use, health benefits and other aesthetic services are related to agricultural production.

We conclude with a summary of SI actions to consider. The list below provides a classification of the potential SI actions reported above. The first four classes cover basic changes to farmed (A) and unfarmed (B) land and the spatial (C) and temporal (D) relationships between them. The next three (E–G) are field- or enterprise- based while the remaining five (H–L) are farm-based. SI actions suggested by multiple studies are highlighted in **bold**.

A. *Changes to crop choice*: Crops vs. Livestock; Bioenergy crops; Pathogen-resistant cultivars; Cultivar mixes; GMOs, etc
    - agroforestry
    - diverse perennial crops
    - grassland biodiversity restoration
    - **livestock systems** (2)
    - cereal-based wholecrop silages
    - harvested perennial grasslands
    - avoiding perennial pastures on mixed crop–livestock farms

    Cultivars and breeding:
    - annual legumes for greater nitrogen-use efficiency
    - crops for better use of mycorrhizas
    - poultry for improved behavioural traits under intensive rearing
    - conventional crop-breeding rather than GM

B. *Management of uncropped land*: Sowing trap-crops; Sowing wildflowers; Creation of hedges, etc
    - management to encourage wild pollinators
    - sown wildflowers instead of grass
    - farmers cooperate in optimising the amount and distribution of pollinator habitat

C. *Changing configuration of cropped land*: Dividing large fields into smaller ones; Rearranging field margins, beetle banks, conservation headlands, etc; Creating wildlife corridors; Landscape-level rearrangement of farmland according to potential agricultural vs. conservation value
    - optimal allocations of land to biofuel vs. food crop production
    - **optimal allocation of rotations to hydrological catchments** (2)

  - shelterbelts

D. *Changes to rotations*: Spring vs winter crops; Perennial crops; Fallow periods; Longer rotations, etc
  - diversified rotations with reduced agrichemical inputs
  - **cover crops and green manures** (3)
  - **increased use of legumes** (2)
  - **inclusion of a small grain, such as wheat** (2)

E. *Changes to tillage regimes*: Less-frequent tillage; Shallow tillage; No-till systems
  - **conservation tillage systems** (6)
  - **mulching** (2)
  - **soil-compaction avoidance technologies**: tracked tractors, controlled-traffic farming (2)
  - **incorporating rather than spreading manure** (2)
  - optimising the timing and spatial patterning of weed management
  - increasing crop residue retention

F. *Application of field inputs*: Precision fertilization, pesticide application, irrigation; Organic pest control
  - low-input systems
  - optimising N application on corn
  - **animal manures** (2) and biochar
  - promoting earthworms
  - nematicide
  - ceasing the use of molluscicidal neonicotenoid seed-coating treatments

G. *Livestock management*: More-detailed stock data; Controlled nutrition
  - keeping reproductively-active pigs in larger heated pens rather than farrowing crates

H. *Controlling energy use*: Controlled-traffic systems, Energy monitoring, Renewable energy sources
  - installation of wind turbines and adoption of more-efficient machinery

I. *Staff training* (relevant to various items above):
  - improving attitudes to animal welfare and productivity

J. *Public access management*:
  - farm visits as a component of formal education programmes; farm-based education

K. *Social and certification packages*: organic, processors' schemes, supermarkets' schemes
  - **organic farming** (5)
  - community-supported agriculture (CSA) with hands-on participation
  - small-scale food entrepreneurs

L. *System design*
  - integrated animal-rearing systems
  - combined food and energy production systems

3. Potential Options for Metrics, Indicators and/or Proxies related to Integrating SI and ES Approaches.

Joint scope for ES and SI Indicators

The concepts of Sustainable Intensification (SI) and Ecosystem Services (ES) are very recent, and have developed rapidly to address the issue that the environment provides flows of goods and services not readily captured in conventional markets (Costanza *et al.* 1997; Society 2009) that need to be accounted for should agriculture develop along sustainable lines. The other important concept is that of 'natural capital' (NC), that recognises that the ongoing production of food and other ES replies upon the maintenance of stocks of certain aspects of the environment, living and non-living notably of soil function, that therefore has an analogous to financial capital for the ongoing delivery of business services .

ES considers the range of services that are provided by ecosystems, categorised within the UK National Ecosystem Assessment Phase 1 (UKNEA 2011) as Provisioning, Regulating and Cultural. SI is a pathway of development of a single type of ecosystem (the agro-ecosystem) such that any increase in food production (a provisioning service) is not at the expense of other ecosystem services (Foresight 2011), including non-food provisioning services, e.g. the provision of clean water. Both address flows of goods and services. Fundamentally, therefore, SI should embrace the full range of ES that are relevant to agri-ecosystems. Of the list of ES used by the UKNEA, only the cultural service of 'noise' and the provisioning service of 'fish' are not readily applicable to agro-ecosystems, while the provisioning services of 'water supply' and 'trees, standing vegetation and peat' are best regarded as non-production services within the SI paradigm (Table 1), although the latter would count as an agricultural production service under biomass production. In principle, SI requires no metrics outwith the ES framework. Both ES and SI reply upon the maintenance of natural capital.

This use of joint metrics of SI and ES is exemplified by a recent study of evidence for SI in the UK, that used indicators taken from the ES canon, but applied them to farms using their own data on agricultural practices and strategies (Firbank *et al.* 2013). This study took a single metric within the broader domains of food provisioning, climate regulation, air quality regulation, water quality regulation and the cultural service of biodiversity provision, and found evidence that some farms had indeed achieved increases in food production (estimated in terms of available energy per unit area) without reducing performance in any of the non-provisioning ES. No evidence was sought for impacts on NC.

However, not all approaches to SI adhere so strictly to an ES framework. The Sustainable Agriculture Initiative Platform is a global initiative bringing together major companies involved in the food chain at a pre-competitive level, and their work includes the development of metrics of sustainable agriculture. Their system for sustainability assessment involves the following high level indicator sets (Kuneman *et al.* 2014):

- Climate change and energy
- Pesticides
- Soil quality
- Water quantity
- Nutrients
- Biodiversity
- Land use
- Animal welfare
- Occupational Health and Safety

- Financial stability

Some of these sets correspond to ES, e.g water regulation and water quality. Others address natural capital rather than ES flows (e.g. soil quality, biodiversity), and others relate to the socio-economic capital of the farm (financial stability, occupational health and safety). The requirement for data on pesticides is particularly problematical, because pesticides are used in order to have ecological impacts, though their actual impacts on biodiversity and ES are variable and not necessarily linear: the same is true for the perception of pesticide residues in food. These discrepancies arise because the SAI paradigm addresses the sustainability of the farm and not just of the ecosystem service it delivers. This means that some SI metrics may be absent from, or only weakly related to, ES metrics (Table 2).

The problem of scale

The SI metrics are typically measured at farm scale, as they relate to the performance of the farm business, typically using one of the available toolsets to estimate farm performance from farm-scale financial and management data (e.g. Cool Farm Tool, Farmscoper etc). However, some of the more favoured options for sustainable intensification (Table 3) apply only to small areas of the farm e.g. optimise the use of marginal land, yet may have impacts that are both extremely local (e.g. biodiversity) and much more diffuse (e.g. regulation of water quality in the catchment). Such actions may be effective at controlling ecosystem services, yet are hard to capture in the current generation of modelled SI indicators (Firbank *et al.* 2013).

		ECOSYSTEM SERVICE METRICS (From UKNEA main report)															
SUSTAINABLE INTENSIFICATION METRICS		PROVISIONING					CULTURAL			REGULATING							
Primary metrics	Secondary metrics	Crops	Livestock / aquaculture	Fish	Trees, standing vegetation, peat	Water supply	Wild species diversity	Environmental settings (local)	Environmental settings (landscape)	Climate	Hazard	Disease and pests	Pollination	Noise	Water quality	Soil quality	Air quality
Food production		■	■									░	░			░	
	Volume/ weights	■	■									░	░			░	
	Energy content	■	■									░	░			░	
	Financial value	■	■									░	░			░	
	Health and mortality	■	■									░	░			░	
Animal welfare	Trained staff		■														
Carbon footprint	GHG emissions	■	■							■							
	GHG sequestration									■							
	Carbon storage				■					■						▩	
	Bioenergy production	░	░		░					■					░		░
	Reliance on renewables									■							
Air quality	Ammonia emissions		▩														■
Water quality	Nitrate runoff	▩	▩			▩									■		
	Sediment and P runoff	▩	▩			▩					▩				■		
	FAOs		▩			▩						▩			■		
Soil quality	SOM		▩			▩						▩			■	■	
Biodiversity	Functional diversity						■					▩	▩			▩	
	Charismatic taxa						■										
Landscape	Consistency with landscape character								■								
Amenity	Visits, leisure						░	▩	▩								
Employment	Numbers																
	Levels of training																
Business management	Planning																
	Audit trails																
Profitability	Current	░	░									░	░		░		

Table 2. Correspondence between ES variables and potential SI metrics. Black – direct correspondence, greys, indirect relationships.

Table 3. 2015 version of SI options

SI intervention	Applicability	IFM element	Tested at
1. Grow crop varieties with increased tolerance to stress	Arable only	Water/ Crop health	
2. Reduce tillage to minimum or no till	Arable only	Soil	Allerton, Morley, Nafferton
3. Incorporate cover crops, green manures and other sources of organic matter to improve soil structure	Arable only	Soil	Allerton, Nafferton, Morley
4. Improve animal nutrition to optimise productivity (and quality) and reduce the environmental footprint of livestock systems	Livestock only	Animal husbandry	Nafferton
5. Reseed pasture for improved sward nutrient value and / or diversity	Livestock only	Animal husbandry	North Wyke and Duchy Henfaes
6. Predict disease and pest outbreaks using weather and satellite data, and use this information to optimise inputs	All	Husbandry/ Crop health	
7. Adopt precision farming: using the latest technology (e.g. GPS) to target delivery of inputs (water, seeds, pesticides, fertilisers, livestock manures)	All	Water/ Crop health/ Soil/Pollution control	
8. Monitor and control on-farm energy use	All	Energy efficiency	
9. Optimise the use of agriculturally marginal land to promote ecosystem services and support biodiversity	All	Landscape & nature	
10. Provide training for farm staff on how to improve sustainability / environmental performance without compromising yields	All	Organisation & planning	

Conclusions

The work for this report was undertaken in 2015 and the final report produced in the early part of 2016. The work was subsequently expanded on and taken forward in a paper (Gunton et al 2016) and the report also helped to inform the development of SIP as it progressed. The two main conclusions drawn from the research are firstly that scale is a vital consideration when we come to consider SI both conceptually and in terms of indicators. The second is that there is no inherent contradiction between an SI and an ES approach.

However, in order to ensure that SI is considered at the appropriate scale and does not become too narrowly agronomic in its conceptualisation, requires the development of appropriate tools such as the Dynamic Typology tool developed under SIP which is designed to facilitate landscape scale decision making.

References

Alix, A., Bradascio, R., Tescari, E. & Deacon, S. (2014) Use of 1,3-D in tomato crop production: An analysis of its role using an ecosystem services approach. *Acta Horticulturae*, pp. 345-352.

Andersson, G.K.S., Rundlöf, M. & Smith, H.G. (2012) Organic farming improves pollination success in strawberries. *PLoS ONE,* **7**.

Azqueta, D. and Sotelsek, D. (2007) Valuing nature: From environmental impacts to natural capital, *Ecological Economics,* **63**, 22-30.

Baar, J. (2012) The value of mycorrhizal fungi for sustainable and durable soils. *Fungi: Types, Environmental Impact and Role in Disease*, pp. 127-139.

Bastian, O., Syrbe, R.U., Rosenberg, M., Rahe, D. & Grunewald, K. (2013) The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services,* **4,** 15-24.

Bateman, I.J., Brouwer, R., Davies, H., Day, B.H., Deflandre, A., Di Falco, S., Georgiou, S., Hadley, D., Hutchins, M., Jones, A.P., Kay, D., Leeks, G., Lewis, M., Lovett, A.A., Neal, C., Posen, P., Rigby, D. & Turner R.K, R.K. (2006) Analysing the agricultural costs and non-market benefits of implementing the Water Framework Directive. *Journal of Agricultural Economics,* **57,** 221-237.

Bateman, I.J., Harwood, A.R., Mace, G.M., Watson, R.T., Abson, D.J., Andrews, B., Binner, A., Crowe, A., Day, B.H., Dugdale, S., Fezzi, C., Foden, J., Hadley, D., Haines-Young, R., Hulme, M., Kontoleon, A., Lovett, A.A., Munday, P., Pascual, U., Paterson, J., Perino, G., Sen, A., Siriwardena, G., Van Soest, D. & Termansen, M. (2013) Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science,* **341,** 45-50.

Bechmann, M. (2014) The effect of phosphorus application and balance on concentrations in streams from agricultural dominated catchments in Norway. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science,* **63,** 162-171.

Bieling, C. & Plieninger, T. (2013) Recording Manifestations of Cultural Ecosystem Services in the Landscape. *Landscape Research,* **38,** 649-667.

Blaauw, B.R. & Isaacs, R. (2014) Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. *Journal of Applied Ecology,* **51,** 890-898.

Blokhuis, H.J., Van Fiks Niekerk, T., Bessei, W., Elson, A., Guémené, D., Kjaer, J.B., Maria Levrino, G.A., Nicol, C.J., Tauson, R., Weeks, C.A. & Van De Weerd, H.A. (2007) The LayWel project: Welfare implications of changes in production systems for laying hens. *World's Poultry Science Journal,* **63,** 101-114.

Bommarco, R., Kleijn, D. & Potts, S.G. (2013) Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology and Evolution,* **28,** 230-238.

Breeze, T.D., Bailey, A.P., Balcombe, K.G. & Potts, S.G. (2011) Pollination services in the UK: How important are honeybees? *Agriculture, Ecosystems and Environment,* **142,** 137-143.

Brévault, T. & Bouyer, J. (2014) From integrated to system-wide pest management: Challenges for sustainable agriculture. *Outlooks on Pest Management,* **25,** 212-213.

Brittain, C., Williams, N., Kremen, C. & Klein, A.M. (2013) Synergistic effects of non-Apis bees and honey bees for pollination services. *Proceedings of the Royal Society B: Biological Sciences,* **280,** 1-7.

Brown, M.W. (2012) Role of biodiversity in integrated fruit production in eastern North American orchards. *Agricultural and Forest Entomology,* **14,** 89-99.

Buckingham, D.L., Giovannini, P. & Peach, W.J. (2015) Manipulating grass silage management to boost reproductive output of a ground-nesting farmland bird. *Agriculture, Ecosystems and Environment,* **208,** 21-28.

Buckwell, A. et al. (2014) *Sustainable intensification of European agriculture*, London IEEP.

Casalegno, S., Inger, R., DeSilvey, C. & Gaston, K.J. (2013) Spatial Covariance between Aesthetic Value & Other Ecosystem Services. *Plos One,* 8.

Cavigelli, M.A., Mirsky, S.B., Teasdale, J.R., Spargo, J.T. & Doran, J. (2013) Organic grain cropping systems to enhance ecosystem services. *Renewable Agriculture and Food Systems,* **28,** 145-159.

Chamen, T.W.C., Moxey, A.P., Towers, W., Balana, B. & Hallett, P.D. (2015) Mitigating arable soil compaction: A review and analysis of available cost and benefit data. *Soil and Tillage Research,* **146,** 10-25.

Chen, Z.z., Zhang, Y.q., Wu, B., Li, Z.p., Geng, X.g., Feng, J.y., Tian, S.y. & Lei, N. (2012) Evaluation of ecosystem services function value of farmland shelterbelts in Shandong Province. *Chinese Journal of Ecology,* **31,** 59-65.

Church, A., Fish, R., Haines-Young, R., Mourato, S., Tratalos, J., Stapleton, L., Willis, C., Coates, P., Gibbons, S., Leyshon, C., Potschin, M., Ravenscroft, N., Sanchis-Guarner, R., Winter, M. & Kenter, J. (2014) Cultural ecosystem services and indicators. *UK National Ecosystem Assessment Follow-on*. UNEP-WCMC, LWEC, UK.

Compton, J.E., Harrison, J.A., Dennis, R.L., Greaver, T.L., Hill, B.H., Jordan, S.J., Walker, H. & Campbell, H.V. (2011) Ecosystem services altered by human changes in the nitrogen cycle: A new perspective for US decision making. *Ecology Letters,* **14,** 804-815.

Cong, R.G., Hedlund, K., Andersson, H. & Brady, M. (2014) Managing soil natural capital: An effective strategy for mitigating future agricultural risks? *Agricultural Systems,* **129,** 30-39.

Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & vandenBelt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature,* **387,** 253-260.

Courty, P.E., Smith, P., Koegel, S., Redecker, D. & Wipf, D. (2015) Inorganic Nitrogen Uptake and Transport in Beneficial Plant Root-Microbe Interactions. *Critical Reviews in Plant Sciences,* **34,** 4-16.

Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies, Z.G., Rouquette, J.R., Maltby, L.L., Warren, P.H., Armsworth, P.R. & Gaston, K.J. (2012) Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *Bioscience,* **62,** 47-55.

Davis, A.S., Hill, J.D., Chase, C.A., Johanns, A.M. & Liebman, M. (2012) Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health. *PLoS ONE,* **7**.

De Deyn, G.B., Shiel, R.S., Ostle, N.J., McNamara, N.P., Oakley, S., Young, I., Freeman, C., Fenner, N., Quirk, H. & Bardgett, R.D. (2011) Additional carbon sequestration benefits of grassland diversity restoration. *Journal of Applied Ecology,* **48,** 600-608.

Deguines, N., Jono, C., Baude, M., Henry, M., Julliard, R. & Fontaine, C. (2014) Large-scale trade-off between agricultural intensification and crop pollination services. *Frontiers in Ecology and the Environment,* **12,** 212-217.

Douglas, M.R., Rohr, J.R. & Tooker, J.F. (2015) Neonicotinoid insecticide travels through a soil food chain, disrupting biological control of non-target pests and decreasing soya bean yield. *Journal of Applied Ecology,* **52,** 250-260.

Duc, G., Agrama, H., Bao, S., Berger, J., Bourion, V., De Ron, A.M., Gowda, C.L.L., Mikic, A., Millot, D., Singh, K.B., Tullu, A., Vandenberg, A., Vaz Patto, M.C., Warkentin, T.D. & Zong, X. (2015) Breeding Annual Grain Legumes for Sustainable Agriculture: New Methods to Approach Complex Traits and Target New Cultivar Ideotypes. *Critical Reviews in Plant Sciences,* **34,** 381-411.

Dumont, B., Fortun-Lamothe, L., Jouven, M., Thomas, M. & Tichit, M. (2013) Prospects from agroecology and industrial ecology for animal production in the 21st century. *Animal,* **7,** 1028-1043.

Edgar, J.L., Mullan, S.M., Pritchard, J.C., McFarlane, U.J.C. & Main, D.C.J. (2013) Towards a 'good life' for farm animals: Development of a resource tier framework to achieve positive welfare for laying hens. *Animals,* **3,** 584-605.

Eubanks, M.D. & Finke, D.L. (2014) Interaction webs in agroecosystems: Beyond who eats whom. *Current Opinion in Insect Science,* **2,** 1-6.

Evans, T.A., Dawes, T.Z., Ward, P.R. & Lo, N. (2011) Ants and termites increase crop yield in a dry climate. *Nature Communications,* **2**.

Ewing, P.M. & Runck, B.C. (2015) Optimizing nitrogen rates in the midwestern United States for maximum ecosystem value. *Ecology and Society,* **20**.

Farmer, J.R., Chancellor, C., Robinson, J.M., West, S. & Weddell, M. (2014) Agrileisure: Farmers' markets, CSAs, and the privilege in eating local. *Journal of Leisure Research,* **46,** 313-328.

Firbank, L., Elliott, J., Drake B., Y.., C. & Gooday, R. (2013) Evidence of sustainable intensification among British farms. *Agriculture, Ecosystems and Environment,* **173,** 58-65.

Fisher, B., Turner, R.K. & Morling, P. (2009) Defining and classifying ecosystem services for decision making. *Ecological Economics,* **68,** 643-653.

Ford, H., Garbutt, A., Jones, D.L. & Jones, L. (2012) Impacts of grazing abandonment on ecosystem service provision: Coastal grassland as a model system. *Agriculture, Ecosystems and Environment,* **162,** 108-115.

Foresight (2011) *The Future of Food and Farming: Challenges and choices for global sustainability*. The Government Office for Science, London.

Francis, C.A., Jordan, N., Porter, P., Breland, T.A., Lieblein, G., Salomonsson, L., Sriskandarajah, N., Wiedenhoeft, M., DeHaan, R., Braden, I. & Langer, V. (2011) Innovative education in agroecology: Experiential learning for a sustainable agriculture. *Critical Reviews in Plant Sciences,* **30,** 226-237.

Frank, S., Fürst, C., Koschke, L., Witt, A. & Makeschin, F. (2013) Assessment of landscape aesthetics - Validation of a landscape metrics-based assessment by visual estimation of the scenic beauty. *Ecological Indicators,* **32,** 222-231.

Franks, J.R. (2014) Sustainable intensification: A UK perspective. *Food Policy,* **47,** 71-80.

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H. & Gaston, K.J. (2007) Psychological benefits of greenspace increase with biodiversity. *Biology Letters,* **3,** 390-394.

Garibaldi, L.A., Aizen, M.A., Klein, A.M., Cunningham, S.A. & Harder, L.D. (2011) Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences of the United States of America,* **108,** 5909-5914.

Garnet, T, and Godfray, C. (2012) *Sustainable intensification in agriculture Navigating a course through competing food system priorities, A report on a workshop,* 1Food Climate Research Network

Geiger, F., de Snoo, G.R., Berendse, F., Guerrero, I., Morales, M.B., Oñate, J.J., Eggers, S., Pärt, T., Bommarco, R., Bengtsson, J., Clement, L.W., Weisser, W.W., Olszewski, A., Ceryngier, P., Hawro, V., Inchausti, P., Fischer, C., Flohre, A., Thies, C. & Tscharntke, T. (2010) Landscape composition influences farm management effects on farmland birds in winter: A pan-European approach. *Agriculture, Ecosystems and Environment,* **139,** 571-577.

Ghaley, B.B., Vesterdal, L. & Porter, J.R. (2014) Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy,* **39,** 139-149.

Gibbons, S., Mourato, S. & Resende, G.M. (2014) The Amenity Value of English Nature: A Hedonic Price Approach. *Environmental and Resource Economics,* **57,** 175-196.

Glover, J.D., Culman, S.W., DuPont, S.T., Broussard, W., Young, L., Mangan, M.E., Mai, J.G., Crews, T.E., DeHaan, L.R., Buckley, D.H., Ferris, H., Turner, R.E., Reynolds, H.L. & Wyse, D.L. (2010) Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability. *Agriculture, Ecosystems and Environment,* **137,** 3-12.

Guerrero, I., Morales, M.B., Oñate, J.J., Geiger, F., Berendse, F., Snoo, G.D., Eggers, S., Pärt, T., Bengtsson, J., Clement, L.W., Weisser, W.W., Olszewski, A., Ceryngier, P., Hawro, V., Liira, J., Aavik, T., Fischer, C., Flohre, A., Thies, C. & Tscharntke, T. (2012) Response of ground-nesting farmland birds to agricultural intensification across Europe: Landscape and field level management factors. *Biological Conservation,* **152,** 74-80.

Gunton, R.M. (2011) Integrating associational resistance into arable weed management. *Agriculture Ecosystems & Environment,* **142,** 129-136.

Gunton, R.M. Firbank, L.G. Inman, A. and Winter, D.M. (2016) How scalable is sustainable intensification? *Nature Plants*, May **4**;2(5):16065. doi: 10.1038/nplants.2016.65.

Hernández-Morcillo, M., Plieninger, T. & Bieling, C. (2013) An empirical review of cultural ecosystem service indicators. *Ecological Indicators,* **29,** 434-444.

Hjalager, A.M. & Johansen, P.H. (2013) Food tourism in protected areas - sustainability for producers, the environment and tourism? *Journal of Sustainable Tourism,* **21,** 417-433.

Holzschuh, A., Dudenhöffer, J.H. & Tscharntke, T. (2012) Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. *Biological Conservation,* **153,** 101-107.

Home, R., Angelone, S., Hunziker, M. & Bolliger, J. (2014) Public preferences for ecosystem-enhancing elements in agricultural landscapes in the Swiss lowlands. *Journal of Integrative Environmental Sciences,* **11,** 93-108.

Jääskeläinen, T., Kauppinen, T., Vesala, K.M. & Valros, A. (2014) Relationships between pig welfare, productivity and farmer disposition. *Animal Welfare,* **23,** 435-443.

Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Henrik, H.N., Alves, B.J.R. & Morrison, M.J. (2012) Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agronomy for Sustainable Development,* **32,** 329-364.

Jorge Servín, R., José Quintana, L., Marie Casaubon, H., Mariano González, A. & Susana Rojas, M. (2013) Assessment of two female broiler rearing systems (traditional and modern) and their repercussion on Wellbeing, corticosterone concentration, lesions in adrenal glands and productive parameters. *International Journal of Poultry Science,* **12,** 353-357.

Kloppenburg, J., Wubben, D. & Grunes, M. (2008) Linking the land and the lunchroom: Lessons from the wisconsin homegrown lunch project. *Journal of Hunger and Environmental Nutrition,* **3,** 440-455.

Kokkinidis, I. & Hodges, S.C. (2013) Calculating ecosystem services provided by agricultural land using GIS and remote sensing methods. *2013 2nd International Conference on Agro-Geoinformatics: Information for Sustainable Agriculture, Agro-Geoinformatics 2013*, pp. 164-169.

Kragt, M.E. & Robertson, M.J. (2014) Quantifying ecosystem services trade-offs from agricultural practices. *Ecological Economics,* **102,** 147-157.

Kremen, C. & Miles, A. (2012) Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. *Ecology and Society,* **17**.

Kuneman, G., Fellus, E., Ywema, E., Elferink, E., van der Wal, E., van Vliet, J., Terryn, L., Lindsay, B. & van der Schans, F. (2014) Sustainability Performance Assessment Version 2.0: Towards Consistent Measurement of Sustainability at Farm Level. pp. 69. CLM / SAI Platform.

Lal, R. (2013) Intensive Agriculture and the Soil Carbon Pool. *Journal of Crop Improvement,* **27,** 735-751.

Lautenbach, S., Volk, M., Strauch, M., Whittaker, G. & Seppelt, R. (2013) Optimization-based trade-off analysis of biodiesel crop production for managing an agricultural catchment. *Environmental Modelling and Software,* **48,** 98-112.

Lehman, R.M., Cambardella, C.A., Stott, D.E., Acosta-Martinez, V., Manter, D.K., Buyer, J.S., Maul, J.E., Smith, J.L., Collins, H.P., Halvorson, J.J., Kremer, R.J., Lundgren, J.G., Ducey, T.F., Jin, V.L. & Karlen, D.L. (2015) Understanding and enhancing soil biological health: The solution for reversing soil degradation. *Sustainability (Switzerland),* **7,** 988-1027.

Leinfelder, M.M., Merwin, I.A. & Brown, M.G. (2012) Soil health indicators, apple tree growth, and carbon sequestration differ among orchard groundcover management systems. *Acta Horticulturae* (eds G.E. Welbaum, R. Fernandez-Escobar, J.A. Monteiro & P.A. Nektarios), pp. 333-340.

Linquist, B., Van Groenigen, K.J., Adviento-Borbe, M.A., Pittelkow, C. & Van Kessel, C. (2012) An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology,* **18,** 194-209.

Marquès, M., Bangash, R.F., Kumar, V., Sharp, R. & Schuhmacher, M. (2013) The impact of climate change on water provision under a low flow regime: A case study of the ecosystems services in the Francoli river basin. *Journal of Hazardous Materials,* **263,** 224-232.

Martin, E.A., Reineking, B., Seo, B. & Steffan-Dewenter, I. (2013) Natural enemy interactions constrain pest control in complex agricultural landscapes. *Proceedings of the National Academy of Sciences of the United States of America,* **110,** 5534-5539.

McKenzie, A.J., Vickery, J.A., Leifert, C., Shotton, P. & Whittingham, M.J. (2011) Disentangling the effects of fertilisers and pesticides on winter stubble use by farmland birds. *Basic and Applied Ecology,* **12,** 80-88.

Meehana, T.D., Hurlbert, A.H. & Gratton, C. (2010) Bird communities in future bioenergy landscapes of the Upper Midwest. *Proceedings of the National Academy of Sciences of the United States of America,* **107,** 18533-18538.

Mitchell, M.G.E., Bennett, E.M. & Gonzalez, A. (2014) Agricultural landscape structure affects arthropod diversity and arthropod-derived ecosystem services. *Agriculture, Ecosystems and Environment,* **192,** 144-151.

Muir, W.M., Cheng, H.W. & Croney, C. (2014) Methods to address poultry robustness and welfare issues through breeding and associated ethical considerations. *Frontiers in Genetics,* **5**.

Nicholls, C.I. & Altieri, M.A. (2013) Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. *Agronomy for Sustainable Development,* **33,** 257-274.

Øgaard, A.F. (2014) Nitrogen balance and nitrogen use efficiency in cereal production in Norway. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science,* **63,** 146-155.

Peach, W.J., Dodd, S., Westbury, D.B., Mortimer, S.R., Lewis, P., Brook, A.J., Harris, S.J., Kessock-Philip, R., Buckingham, D.L. & Chaney, K. (2011) Cereal-based wholecrop silages: A potential conservation measure for farmland birds in pastoral landscapes. *Biological Conservation,* **144,** 836-850.

Pereira-Peixoto, M.H., Pufal, G., Martins, C.F. & Klein, A.M. (2014) Spillover of trap-nesting bees and wasps in an urban-rural interface. *Journal of Insect Conservation*.

Perkins, A.J., Maggs, H.E., Watson, A. & Wilson, J.D. (2011) Adaptive management and targeting of agri-environment schemes does benefit biodiversity: a case study of the corn bunting Emberiza calandra. *Journal of Applied Ecology,* **48,** 514-522.

Perkins, A.J., Maggs, H.E., Wilson, J.D. & Watson, A. (2013) Delayed mowing increases corn bunting Emberiza calandra nest success in an agri-environment scheme trial. *Agriculture, Ecosystems and Environment,* **181,** 80-89.

Pescott, O.L. & Stewart, G.B. (2014) Assessing the impact of human trampling on vegetation: A systematic review and meta-analysis of experimental evidence. *PeerJ,* **2014**.

Plieninger, T., Dijks, S., Oteros-Rozas, E. & Bieling, C. (2013) Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy,* **33,** 118-129.

Pote, D.H. & Meisinger, J.J. (2014) Effect of poultry litter application method on ammonia volatilization from a conservation tillage system. *Journal of Soil and Water Conservation,* **69,** 17-25.

Rhymer, C.M., Robinson, R.A., Smart, J. & Whittingham, M.J. (2010) Can ecosystem services be integrated with conservation? A case study of breeding waders on grassland. *Ibis,* **152,** 698-712.

Rivas Casado, M., Mead, A., Burgess, P.J., Howard, D.C. & Butler, S.J. (2014) Predicting the impacts of bioenergy production on farmland birds. *Science of the Total Environment,* **476-477,** 7-19.

Robert Kiefer, L., Menzel, F. & Bahrs, E. (2015) Integration of ecosystem services into the carbon footprint of milk of South German dairy farms. *Journal of Environmental Management,* **152,** 11-18.

Robertson, G.P., Gross, K.L., Hamilton, S.K., Landis, D.A., Schmidt, T.M., Snapp, S.S. & Swinton, S.M. (2014) Farming for ecosystem services: An ecological approach to production agriculture. *BioScience,* **64,** 404-415.

Rodenburg, T.B., Tuyttens, F.A.M., Sonck, B., De Reu, K., Herman, L. & Zoons, J. (2005) Welfare, health, and hygiene of laying hens housed in furnished cages and in alternative housing systems. *Journal of Applied Animal Welfare Science,* **8,** 211-226.

Rótolo, G.C., Francis, C., Craviotto, R.M., Viglia, S., Pereyra, A. & Ulgiati, S. (2014) Time to re-think the GMO revolution in agriculture. *Ecological Informatics*.

Ruark, M.D., Kelling, K.A. & Good, L.W. (2014) Environmental Concerns of Phosphorus Management in Potato Production. *American Journal of Potato Research,* **91,** 132-144.

Saltmarsh, N., Meldrum, J. & Longhurst, N. (2011) The impact of community supported agriculture. *Soil Association CSA Support Project, Making Local Food Work*. Soil Association.

Sandhu, H.S., Wratten, S.D. & Cullen, R. (2010) The role of supporting ecosystem services in conventional and organic arable farmland. *Ecological Complexity,* **7,** 302-310.

Schipanski, M.E., Barbercheck, M., Douglas, M.R., Finney, D.M., Haider, K., Kaye, J.P., Kemanian, A.R., Mortensen, D.A., Ryan, M.R., Tooker, J. & White, C. (2014) A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agricultural Systems,* **125,** 12-22.

Scholte, S.S.K., van Teeffelen, A.J.A. & Verburg, P.H. (2015) Integrating socio-cultural perspectives into ecosystem service valuation: A review of concepts and methods. *Ecological Economics,* **114,** 67-78.

Schowalter, T.D. (2013) *Insects and Sustainability of Ecosystem Services*, CRC Press, Florida.

Seufert, V., Ramankutty, N. & Foley, J.A. (2012) Comparing the yields of organic and conventional agriculture. *Nature,* **484,** 229-232.

Smith, P. (2013) Delivering food security without increasing pressure on land. *Global Food Security,* **2,** 18-23.

Snapp, S.S., Gentry, L.E. & Harwood, R. (2010) Management intensity - not biodiversity - the driver of ecosystem services in a long-term row crop experiment. *Agriculture, Ecosystems and Environment,* **138,** 242-248.

Society, R. (2009) Reaping the benefits: Science and the sustainable intensification of global agriculture. pp. 72. Royal Society, London.

Soussana, J.F. & Lemaire, G. (2014) Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. *Agriculture, Ecosystems and Environment,* **190,** 9-17.

Squire, G.R., Hawes, C., Valentine, T.A. & Young, M.W. (2015) Degradation rate of soil function varies with trajectory of agricultural intensification. *Agriculture, Ecosystems and Environment,* **202,** 160-167.

Stott, A.W., Vosough Ahmadi, B., Dwyer, C.M., Kupiec, B., Morgan-Davies, C., Milne, C.E., Ringrose, S., Goddard, P., Phillips, K. & Waterhouse, A. (2012) Interactions between profit and welfare on extensive sheep farms. *Animal Welfare,* **21,** 57-64.

Sumner, D.A., Gow, H., Hayes, D., Matthews, W., Norwood, B., Rosen-molina, J.T. & Thurmanl, W. (2011) Economic and market issues on the sustainability of egg production in the United States: Analysis of alternative production systems. *Poultry Science,* **90,** 241-250.

Swinton, S.M., Rector, N., Robertson, G.P., Jolejole-Foreman, M.C.B. & Lupi, F. (2015) Farmer decisions about adopting environmentally beneficial practice. *The Ecology of Agricultural*

Ecosystems: Long-Term Research on the Path to Sustainability (eds S. Hamilton, J. Doll & G. Robertson). Oxford University Press.

Syswerda, S.P. & Robertson, G.P. (2014) Ecosystem services along a management gradient in Michigan (USA) cropping systems. *Agriculture, Ecosystems and Environment,* **189,** 28-35.

Taube, F., Gierus, M., Hermann, A., Loges, R. & Schönbach, P. (2014) Grassland and globalization - challenges for north-west European grass and forage research. *Grass and Forage Science,* **69,** 2-16.

Triplett, S., Luck, G.W. & Spooner, P. (2012) The importance of managing the costs and benefits of bird activity for agricultural sustainability. *International Journal of Agricultural Sustainability,* **10,** 268-288.

UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

UKNEA (2011) *United Kingdom National Ecosystem Assessment: Technical Report*. UNEP-WCMC, Cambridge.

Van Berkel, D.B. & Verburg, P.H. (2014) Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. *Ecological Indicators,* **37,** 163-174.

Van Zanten, B.T., Verburg, P.H., Koetse, M.J. & Van Beukering, P.J.H. (2014) Preferences for European agrarian landscapes: A meta-analysis of case studies. *Landscape and Urban Planning,* **132,** 89-101.

Vosough Ahmadi, B., Stott, A.W., Baxter, E.M., Lawrence, A.B. & Edwards, S.A. (2011) Animal welfare and economic optimisation of farrowing systems. *Animal Welfare,* **20,** 57-67.

Whitmore, A.P., Goulding, K.W.T., Glendining, M.J., Dailey, A.G., Coleman, K. & Powlson, D.S. (2012) Nutrient management in support of environmental and agricultural sustainability. *Sustainability,* **4,** 2513-2524.

Williams, A. & Hedlund, K. (2013) Indicators of soil ecosystem services in conventional and organic arable fields along a gradient of landscape heterogeneity in southern Sweden. *Applied Soil Ecology,* **65,** 1-7.

Williams, A. & Hedlund, K. (2014) Indicators and trade-offs of ecosystem services in agricultural soils along a landscape heterogeneity gradient. *Applied Soil Ecology,* **77,** 1-8.

Wu, D., Liu, M., Song, X., Jiao, J., Li, H. & Hu, F. (2015) Earthworm ecosystem service and dis-service in an N-enriched agroecosystem: Increase of plant production leads to no effects onyield-scaled N2O emissions. *Soil Biology and Biochemistry,* **82,** 1-8.

Zhang, F., Cui, Z., Fan, M., Zhang, W., Chen, X. & Jiang, R. (2011) Integrated soil-crop system management: Reducing environmental risk while increasing crop productivity and improving nutrient use efficiency in China. *Journal of Environmental Quality,* **40,** 1051-1057.

Zimmermann, J., Styles, D., Hastings, A., Dauber, J. & Jones, M.B. (2014) Assessing the impact of within crop heterogeneity ('patchiness') in young Miscanthus × giganteus fields on economic feasibility and soil carbon sequestration. *GCB Bioenergy,* **6,** 566-576.