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Special Section

The role of agri-environment schemes in conservation and environmental management

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Abstract: *Over half of the European landscape is under agricultural management and has been for millennia. Many species and ecosystems of conservation concern in Europe depend on agricultural management and are showing ongoing declines. Agri-environment schemes (AES) are designed partly to address this. They are a major source of nature conservation funding within the European Union (EU) and the highest conservation expenditure in Europe. We reviewed the structure of current AES across Europe. Since a 2003 review questioned the overall effectiveness of AES for biodiversity, there has been a plethora of case studies and meta-analyses examining their effectiveness. Most syntheses demonstrate general increases in farmland biodiversity in response to AES, with the size of the effect depending on the structure and management of the surrounding landscape. This is important in the light of successive EU enlargement and ongoing reforms of AES. We examined the change in effect size over time by merging the data sets of 3 recent meta-analyses and found that schemes implemented after revision of the EU's agri-environmental programs in 2007 were not more effective than schemes implemented before revision. Furthermore, schemes aimed at areas out of production (such as field margins and hedgerows) are more effective at enhancing species richness than those aimed at productive areas (such as arable crops or grasslands). Outstanding research questions include whether AES enhance ecosystem services, whether they are more effective in agriculturally marginal areas than in intensively farmed areas, whether they are more or less cost-effective for farmland biodiversity than protected areas, and how much their effectiveness is influenced by farmer training and advice? The general lesson from the European experience is that AES can be effective for conserving wildlife on farmland, but they are expensive and need to be carefully designed and targeted.*

Keywords: agricultural intensification, Common Agricultural Policy, Europe, European Union, farmland, field margin, grassland, organic management

El Papel de los Esquemas Agro-Ambientales en la Conservación y el Manejo Ambiental Batáry et al.

Resumen: *Más de la mitad de las tierras europeas está bajo manejo agrícola y así ha sido durante milenios. Muchas especies y ecosistemas de interés de conservación en Europa dependen del manejo agrícola y están mostrando una declinación continua. Los esquemas agro-ambientales (EAA) están diseñados en parte para encarar esto. Los esquemas son una gran fuente de financiamiento para la conservación dentro de la Unión Europea (UE) y el mayor gasto de conservación en Europa. Revisamos la estructura de los EAA actuales a lo largo del continente. Desde que en 2003 una revisión cuestionó la efectividad general de los EAA para la biodiversidad, ha habido una plétora de estudios de caso y meta-análisis que examinan su efectividad. La mayoría de las síntesis demuestran un incremento general en la biodiversidad de las tierras de cultivo en respuesta a los EAA, con la magnitud del efecto dependiente de la estructura y el manejo del terreno circundante. Esto es importante a la luz del crecimiento sucesivo de la UE y las continuas reformas a los EAA. Examinamos el cambio en la*

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magnitud del efecto a través del tiempo al fusionar los conjuntos de datos de tres meta-análisis recientes y encontramos que los esquemas implementados después de la revisión de los programas agro-ambientales de la UE en 2007 no fueron más efectivos que los esquemas implementados antes de la revisión. Además, los esquemas enfocados en las áreas fuera de producción (como los márgenes de campo y los setos vivos) son más efectivos en el mejoramiento de la riqueza de especies que aquellos enfocados en las áreas productivas (como los cultivos arables y los pastizales). Las preguntas sobresalientes de la investigación incluyen si los EAA mejoran los servicios ambientales, si son más efectivos en las áreas agrícolas marginales que en las áreas de cultivo intensivo, si son más o menos rentables para la biodiversidad de las tierras de cultivo que las áreas protegidas, y en cuánto influye sobre su efectividad los consejos y el entrenamiento dado a los granjeros. La lección general de la experiencia europea es que los EAA pueden ser efectivos para la conservación de la vida silvestre en las tierras de cultivo, pero son caros y necesitan ser diseñados y enfocados cuidadosamente.

Palabras Clave: Europa, intensificación agrícola, margen del campo, manejo orgánico, pastizal, Política Agrícola Común, tierra de cultivo, Unión Europea

Introduction

There is an obsession with farmland conservation in Europe that is not understood in other parts of the world (Stoate et al. 2009). Visiting conservationists are often amazed to discover that European national parks are grazed by livestock or actively cultivated and that the small remaining area of woodland may be cut for the sake of conservation. The core explanation is the long history of intensive human management. Europe has been occupied by humans for at least 700,000 years (Parfitt et al. 2005), while the domestication of crops in the Fertile Crescent of southwestern Asia about 10,000 years ago led to a rapid spread of agriculture across Europe and radical social and ecological change. Much of the recent European landscape was established by Roman times. As Rackham (1986) states "... England in 1945 would have been instantly recognizable by Sir Thomas More [1478–1535], and some areas would have been recognized by the Emperor Claudius [in AD 43]."

For thousands of years, European lowlands have been grazed and cultivated, wetlands cut for reed or sedge, and uplands grazed by livestock, while woodlands are largely coppiced (cut regularly at the base to provide poles) or pollarded (cut above grazing height to provide poles) and interspersed with large trees maintained as standards (felled when mature to provide large beams). As a result, over large areas there is little natural vegetation. Much of the European countryside is an artificial landscape, where areas are kept open not by natural disturbance and indigenous herbivores but by farming and farm animals.

This artificial landscape is loved by human residents and visitors from abroad. Many highly valued species require disturbance, and leaving habitats unmanaged to allow natural succession often results in dramatic loss of these species (Thomas 1991). As a result, many protected areas in Europe are managed in ways that reflect traditional agricultural practices. This represents an interesting cultural conflict. Although agricultural intensification is generally considered the most important driver of global terrestrial biodiversity loss, through habitat loss, habitat fragmentation, and habitat conversion (Foley et al. 2011), in Europe agriculture itself has long been understood as part of the solution. Much of current European nature conservation aims to halt the on-going loss of farmland biodiversity, evolved during millennia of extensive management (Sutherland 2004), and abandonment of agriculture is generally seen as a threat to biodiversity (Queiroz et al. 2014). In this sense, Europe is different from other continents, particularly the Americas, where areas of high biodiversity interest are rarely in use for commercial production of food, and agricultural practices are not prominent in conservation strategies (Boitani & Sutherland 2015 [this issue]).

Since the early 20th century, both the mass production of nitrogen fertilizers and the development of pesticides have greatly increased agricultural yields (Smil 1999). The increasing use of agrochemicals was accompanied by widespread mechanization, especially after the Second World War. This resulted in intensification at field scale as well as at larger scales (Batáry et al. 2011). The trajectories of change varied among countries, which differed in their political ideologies and biogeographies. In northwestern Europe, considerable areas of species-rich semi-natural grassland and heath were effectively destroyed by plowing, chemical application, and re-sowing (either with crops, grasses or, in some cases, commercial forest) during the 20th century (e.g., Fuller 1987). Since then, ongoing drivers of biodiversity loss have included the shift to autumn sown cereals, improved efficiency of pesticides, and specialization of farm systems, which has led to a loss of mixed farming and hedgerow removal to create larger fields, especially in arable areas (Robinson & Sutherland 2002). In the central and eastern countries of the Eastern Bloc, collectivization of farms resulted in large co-operatives, where field roads, hedgerows, and field margins were eliminated to merge small fields into large-scale agricultural systems (e.g., Báldi & Batáry 2011; Sutcliffe et al. 2015). In southern European countries around the Mediterranean, 20th century agricultural land-use change was characterized by abandonment of farmland, natural and artificial reforestation associated with declining rural population densities (e.g., Debussche et al. 1999; Padilla et al. 2010), and intensification of agriculture in accessible plains (as in central Spain). In all these contrasting contexts, agri-environment schemes (AES) are one of the main practical 21st century solutions to mitigate or reverse the consequent biodiversity loss because they directly support the necessary agricultural management.

For this paper, we reviewed the history, current use, and effectiveness of AES as a conservation tool in Europe. We considered the conceptual framework that has been developed to interpret the ecological findings and the implications of research on the human factors that influence farmer uptake or acceptance of the schemes. We conducted 2 new meta-analyses to determine whether AES are becoming more effective over time and whether changing management in productive or non-productive areas benefits biodiversity. We also identified outstanding policy-relevant research questions that cannot currently be answered using formal meta-analysis, due to data deficiency. Finally, we considered what can be learned about the use and cost-effectiveness of AES from the European experience.

A Short History of Agri-Environment Schemes in Europe

Although some northwestern European countries had agri-environment programs predating any European regulations, most European AES can be traced back to the Agricultural Structures Regulation of 1985 (European Union [EU] Regulation 797/85). They were conceived as a mechanism to compensate farmers for loss of income associated with appropriate, less intensive management of environmentally sensitive areas in response to the changes described above and largely driven by a few countries of the north and west (Hodge et al. 2015 [this issue]). In 1987 an amendment (EU Regulation 1760/87) allowed up to 50% of the cost of environmentally sensitive areas to flow from the Common Agricultural Policy (CAP), and in 1992 AES became compulsory for all EU Member States (EU Regulation 2078/92). They are one aspect of the Rural Development pillar of CAP. Each Member State designs its own schemes. Currently, a diversity of AES exists in the 28 Member States of the EU and in Switzerland and Norway, which are not Member States (Fig. 1a; Supporting Information). We confined our synthesis to 30 countries rather than the entire continent.

Because they provide income for conservation, AES have become the main tool to conserve biodiversity on European farmland and are often used to fund management in protected areas or designated sites. Within the EU, AES have always been, and remain, voluntary for land managers, although in the latest reform of CAP in 2014 certain management practices designed as AES became obligatory for farmers to qualify for their basic subsidy (Pe'er et al. 2014).

AES are important for conserving farmland areas designated by EU countries, Switzerland, and Norway as of "high nature value" (Lomba et al. 2014) in that they preserve genetic diversity of livestock, protect a diversity of agro-ecosystems types, and produce food with a lower environmental and ecological footprint. Many schemes have clear objectives to reduce water pollution, enhance access to the countryside and protect cultural landscapes and heritage, as well as protecting biodiversity. Almost all countries have AES that support organic farmers, based on an underlying assumption that organic farming is good for the environment (Tuck et al. 2014).

The role of AES schemes has shifted over time. Their initial purpose was to protect threatened habitats or landscapes. Over time, the emphasis changed to prevention of species' loss, especially farmland birds, across agricultural land. More recently, emphasis is shifting to the application of AES to improve and maintain ecosystem services, such as pollination and biocontrol (Ekroos et al. 2014).

Schemes can be classified as horizontal or zonal (i.e., targeted) (Kleijn & Sutherland 2003). Horizontal schemes usually combine environmental protection with nature conservation objectives and can be applied throughout a country. They are designed to fit easily into farm management systems; they are not too demanding or directly support management farmers are doing anyway, such as organic management. Zonal schemes target areas with high nature value. They generally require bespoke management for target species or ecosystems, and farmers are often obliged to seek expert advice in developing management plans.

Big Spending for Conservation

Budgets for AES are substantial and for most countries usually equal or exceed the amounts of money spent on wildlife conservation through other routes. For example, in 2005 the Dutch budget for conservation in protected areas was €48.8 million, while that for AES with biodiversity objectives was €42.1 million (MNP 2007). In England, total expenditure on AES, including measures with non-biodiversity objectives, was €375 million/year from 2007 to 2013 (European Network for Rural Development 2014). The total annual expenditure of the government's nature conservation agency for England was much lower, around €250 million in 2013–2014 (Natural England 2014). In new EU member states this difference can be larger. For example, in 2008 the Hungarian

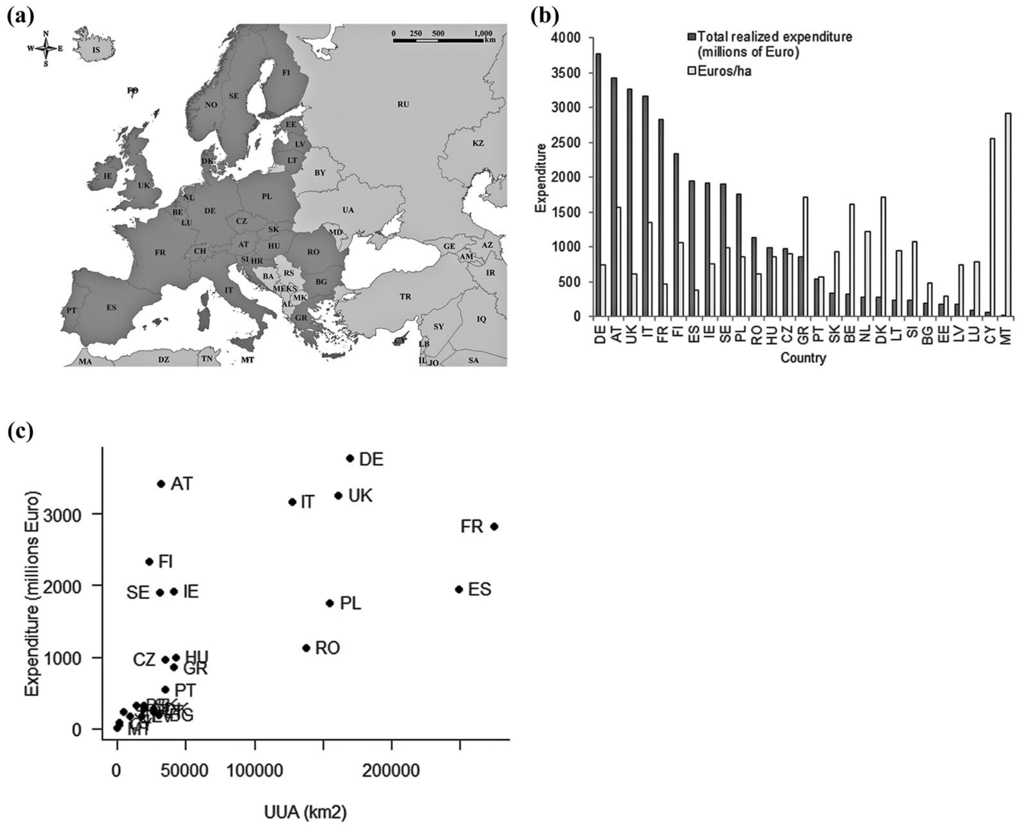

Figure 1. (a) Countries (codes defined in Supporting Information) in Europe where agri-environment schemes (AES) exist (dark gray). (b) Total realized expenditure spent on AES in 2007–2013 (dark gray) and total realized expenditure spent on AES in 2007–2013 per area under AES (light gray) (no data available for Croatia, Norway, and Switzerland). (c) Utilized agricultural area (UAA) relative to total realized expenditure on AES in 2007–2013. Data for (b) and (c) derived from European Network for Rural Development (2014).

budget for nature conservation was roughly €41.0 million (Hungarian Government 2009), while total expenditure on AES was €117.6 million (Hungarian Ministry of Agriculture and Rural Development 2009). The European Commission spent €3.23 billion on AES in 2012, a figure two orders of magnitude higher than the cost of managing Natura 2000 sites (Maiorano et al. 2015 [this issue]) that year, which was €39.6 million (Pe'er et al. 2014).

The total amount of public expenditure on AES in each EU Member State for 2007–2013, including co-financing at national levels, is strongly correlated with the amount of agricultural land in each country (Fig. 1c) (Spearman rank rho = 0.83, $P < 0.001$), although some countries are relative outliers. Spain and France spend less than would be expected from their agricultural area, while Austria spends more. The proportion of agricultural land under the schemes varies greatly across countries, from 6% in Denmark to 95% in Finland (Supporting Information). This means the intensity of spending also differs among countries, as illustrated by the amount of money spent per hectare of AES area (Fig. 1b); there is a tendency for more focused spending in smaller countries.

Future spending on AES is very likely to be lower in all countries, following reforms of CAP enacted at the end of 2013 (Pe'er et al. 2014). The budget for Rural Development Programmes, of which AES are part, will be 18% less by 2020. Moreover Member States have been given the choice to shift funds out of Rural Development to directly support farmers. In the coming years, differences among countries in AES spending will therefore increase.

Ecological Effectiveness of European Agri-Environment Schemes

Given the huge expenditure on European AES, it is important to ask whether they improve biodiversity outcomes. The first well-designed studies examining the ecological effects of AES were published in the early 2000s. Kleijn and Sutherland (2003) reviewed published peer-reviewed and gray literature on the effectiveness of AES with biodiversity targets and concluded that about half of the schemes lack positive effects on biodiversity. Successful schemes focus mainly on specific (rare) species and are often supervised by scientists or volunteers. Non-targeted schemes to enhance biodiversity usually benefit common species or have no overall impact.

Since that review there has been a wealth of published papers on the subject and a number of important Europe-wide reviews (Supporting Information). These demonstrate that AES generally enhance biodiversity locally, usually with modest increases in species richness or abundance of common species. Studies have been mainly of intensively farmed areas; little work has been done on effectiveness of schemes in areas with more extensive agriculture (Kampmann et al. 2012).

Based on these studies a theoretical framework has been developed. The effectiveness of AES at attracting wild species is influenced by landscape structure, land-use intensity, and the ecological contrast created by AES (Kleijn et al. 2011). The hypotheses on the relationship between effectiveness and landscape structure and between effectiveness and ecological contrast have both been confirmed (Batáry et al. 2011; Scheper et al. 2013; Hammers et al. 2015). In their meta-analysis, Batáry et al. (2011) found that in cropland areas AES are effective in simplified but not in complex landscapes. This was further confirmed in a meta-analysis on pollinators (Scheper et al. 2013) and by Tuck et al. (2014), who showed that the positive effects of organic farming on biodiversity increased as the amount of cropland increased. However, the suggested relationship between effectiveness and land-use intensity has not been confirmed, possibly because most research has been done in countries dominated by intensive farming, such as the United Kingdom and Germany (Dicks et al. 2013*a*), and has not specifically incorporated an intensification gradient. There is almost no evidence yet on whether this attraction of wild species to AES land represents a stabilization and increase of plant and animal populations or a local concentration of these populations with concurrent dilution in other nearby areas (but see Morandin & Kremen 2013).

We addressed 2 specific issues by merging the data sets of 3 recent meta-analyses on the effects of AES on species richness (Batáry et al. 2011; Scheper et al. 2013; Tuck et al. 2014). We imposed the following restrictions: only studies from the 28 European Member States, Norway, and Switzerland were included; studies were excluded if the number of replicates was fewer than three experimental or control areas; studies performed at plot level (i.e., within-field experiments) were excluded. This resulted in a data set with 284 observations from 103 studies (the entire data set is in Supporting Information).

We used the unbiased standardized mean difference (Hedges' *g*) as a common effect size in our analyses, originating from the above meta-analyses. Effect size was positive if species richness was higher in the AES than in the control fields. For the error estimate, we used the non-parametric variance estimates of each effect size, which is based on few assumptions and may be less constrained by the assumptions of large sample theory (Hedges & Olkin 1985). We carried out statistical analyses in the metafor package (Viechtbauer 2010) of R (R Development Core Team 2013). Funnel plots, regressions test for funnel plot asymmetry, and calculated fail-safe numbers all showed no sign of publication bias, either in the entire data set or in the 2 meta-analyses presented (Supporting Information). However, our meta-analyses shared with the three previous meta-analyses a strong geographic bias of study areas towards Northern and Western Europe. This issue was previously highlighted by Tryjanowski et al. (2011) and recently by Sutcliffe et al. (2015). They concluded that new eastern EU Member States had adopted Western European type AES designed for intensively farmed landscapes. In the extensively farmed areas in the new member states such AES seem to be ineffective or even have negative effects on biodiversity. Therefore, there is a great need for better locally adapted AES.

Effectiveness of Agri-Environment Schemes over Time

The regular reforms of CAP allow countries to use novel scientific insights and modify their agri-environmental programs to increase their efficiency. As a result national agri-environmental programs change substantially every 7 years. Dicks et al. (2013*b*) questioned whether scientific evidence was used to improve policy efficiency during the most recent CAP reform. After 25 years of AES in Europe and almost 15 years of high-quality research on their effectiveness, it is possible to ask whether the effectiveness of the schemes has improved as policy experience and scientific evidence accrued over time.

If evidence was being taken into account, findings from studies in the early 2000s, which mostly covered AES implemented in the 2000–2006 budget period or before, would be reflected in the designs of schemes in the 2007–2013 budget periods. This may be expected to result in increased effectiveness in the second budget period. To test this, we used a mixed-effects meta-regression model in which budget period was the moderator variable (Supporting Information).

We found that schemes implemented after 2007 were not more effective than schemes implemented before 2007 (Fig. 2a, Supporting Information). Although AES were effective in both periods, there was no sign of improvement in effectiveness over time.

Of course, we cannot conclude directly from this that science is not being used to improve design of the schemes. There are other possible explanations for the lack of improvement over time. We know that biodiversity is still degrading and agricultural landscapes are still changing in Europe, and both of these could potentially decrease the effectiveness of AES as a result of the reduced pool of species available to colonize and benefit

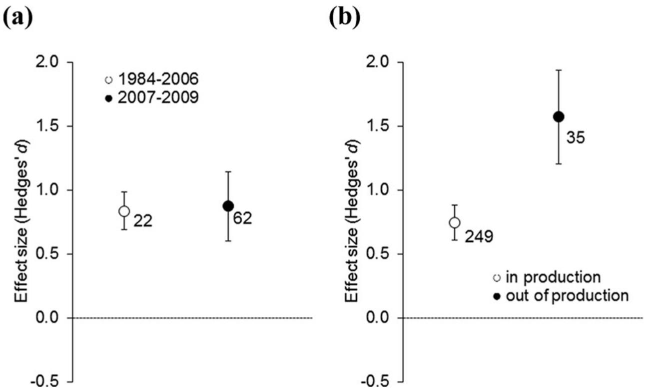

Figure 2. (a) Changes in effectiveness of agri-environment schemes over time as shown in studies published from 1984 to 2006 compared with studies published from 2007 to 2009 and (b) differences in species diversity between control areas and areas in production (such as fields under organic management) and areas out of production (such as field margins and hedgerows). Shown are mean effect sizes and 95% CI. The mean effect size is significantly different from zero if the CIs do not overlap with zero. Numbers near symbols indicate sample size.

from the scheme. Alternatively, there might be a time-delay effect, meaning that the positive effect of research on AES will appear farther in the future (Weis 2001).

It is unfortunate that there is no evidence yet of AES becoming more effective over time, as such a change might have compensated to some extent for forthcoming reductions in AES budgets (Pe'er et al. 2014). Policy makers might argue that elements of AES, such as field margins left out of production, become obligatory across Europe as "compulsory greening measures" under the direct payments pillar of CAP from 2014–2020 and that this would compensate for loss of AES coverage. However, recent analyses of the compulsory greening measures show that effective elements of AES have generally not been incorporated (Dicks et al. 2013*b*; Pe'er et al. 2014). Rather than being obligatory, the greening measures that are similar to AES (known as ecological focus areas) apply to just over half the farmed area of Europe, due to the exemption of farms of <15 ha of arable land (Pe'er et al. 2014).

Effectiveness of Agri-Environment Schemes in Productive versus Non-Productive Areas

AES can be classified according to whether they apply to non-productive areas, such as field boundaries and wildflower strips (sometimes called off-field practices [Garibaldi et al. 2014]), or productive areas, such as arable crops or grasslands (sometimes called on-field practices). Schemes targeting non-productive areas include hedgerows, sown or naturally regenerated field margins, or simply taking areas of land out of production for different conservation purposes. We call these out-of-production schemes (Supporting Information). In contrast, in-production schemes support environmentally sensitive approaches to the management of land that is used to grow crops or feed livestock. For example, the use of agrochemicals might be reduced or prohibited or certain management actions, such as mowing grassland, might be restricted. The most widespread in-production scheme is organic farming.

In our second meta-analysis, we used a mixed-effects meta-regression model with management type as a moderator variable. We found that out-of-production schemes were much more effective at enhancing species richness than in-production schemes (Fig. 2b, Supporting Information). A possible explanation may be that most of the out-of-production schemes we examined evaluated measures that take agricultural land out of production, such as the establishment of wild-flower strips. The conversion of crop monocultures to semi-natural habitat results in a much larger increase in resource availability (i.e., creates a larger ecological contrast) for a wider range of species than measures such as organic farming, reducing stocking rates, or restricting fertilizer application rates that are typical for in-production schemes. Schemes promoting the establishment of wildflower strips may also be better targeted to the conservation of a given species group than in-production schemes because they often specifically address a resource that is limiting population growth or size (e.g., floral resources for flower visiting insects). Many in-production schemes do not address specific species groups; rather, they aim to enhance biodiversity in general as one of several targets, alongside improvements in other ecosystem characteristics or services.

Targeting the needs and spatial distribution of specific species groups is most likely more important than whether schemes prescribe measures on or off land that is being used for farming. Targeted schemes tend to be more effective than untargeted schemes (Kleijn & Sutherland 2003; Wilson et al. 2009), and better spatial targeting of in-production schemes can greatly benefit rare and declining species (Pywell et al. 2012). In many countries, there is a move toward better targeting of AES, either toward particular declining species groups or landscapes where they are likely to be effective. As this is being incorporated into AES and implemented between now and 2020, one might expect a review similar to this one in 2025 to be able to show an increase in effectiveness of AES over time.

It is important to appreciate that species richness is just one measure of diversity, although this is the one most easily understood and used by policy makers. We think that the importance of this measure is overrated and other variables characterizing biodiversity should be applied in primary studies and analyzed (if sufficient studies are available) in meta-analyses (e.g., the meta-analysis on functional diversity by Flynn et al. [2009]). An additional fundamental point is that in-production and out-of-production options typically support different communities. In-production options select for species adapted to the highly disturbed, cropped areas of fields, for example, in contrast to out-of-production options (see the example of arable weeds in Storkey et al. [2012]).

The Human Factor

In addition to research on the ecological effectiveness of AES, there is a body of work on how to ensure that AES are palatable to farmers and therefore effective at changing farmer behavior. This is important because AES are always voluntary (but see recent CAP reform [Pe'er et al. 2014]). Uptake of specific AES options is a key element of their success and does not always correlate with ecological effectiveness. For example, Hodge and Reader (2010) found that the vast majority of options taken up in the first 5 years of entry level stewardship (a horizontal scheme) in England were the straightforward field corner and grass margin options that require little change of management or resource investment. Evaluation of synthesized evidence shows that these are not the most effective AES options for enhancing biodiversity (Dicks et al. 2013*b*).

Studies on motivations of farmers to take up AES or environmental management have repeatedly demonstrated that farmer attitudes are important in explaining uptake of environmental measures (e.g., Defrancesco et al. 2008; Sattler & Nagel 2010). As well as the effect of general attitude, scheme adoption is linked to utilitarian motivations, such as payment rate and ease of fit within existing farm practice (e.g., Defrancesco et al. 2008; Sutherland 2010). Many authors have pointed out that AES intended to support biodiversity should be designed with farmer circumstances and attitudes in mind (e.g., Herzon & Mikk 2007; de Snoo et al. 2013), indicating a need for ecologists and social scientists to work together. Herzon and Mikk (2007) found that views of biodiversity among Finnish and Estonian farmers were largely restricted to the realm of wild nature outside the farmed environment. This implies a need to demonstrate to farmers when they can directly benefit from measures to promote functional ecological groups of biodiversity, such as pollinators, natural enemies, or soil biodiversity.

Future Research

Effectiveness of AES at Enhancing Ecosystem Services

The value of ecosystem services to agriculture has been much discussed recently (e.g., Power 2010; Kremen & Miles 2012). For some services, such as food production, pest regulation, pollination, and soil nutrient cycling, farmers themselves are direct beneficiaries because their yields and input requirements are directly affected. Other services, such as air and water quality or enjoyment of cultural landscapes, are public goods (i.e., the main beneficiaries are outside the farm business). The role AES can and should play in maintaining ecosystem services is still under discussion. There is a clear mandate for CAP to support delivery of public goods from agriculture (European Commission 2010) but not to support actions that directly increase farm income.

The effectiveness of specific AES options at delivering ecosystem service benefits has only just started to be tested. For example, a small number of studies outside Europe have demonstrated benefits to crop pollination from wildflower strips or patches (Garibaldi et al. 2014), and there is some evidence that vegetated buffer strips can enhance water quality (Zhang et al. 2010). The combined effects of specific AES options on multiple ecosystem services are still poorly understood.

Effectiveness of AES in Agriculturally Marginal Areas versus Intensively Farmed Areas

In Europe agriculturally marginal areas, where the productivity of land is limited by biophysical or socioeconomic constraints, are currently home to the highest concentrations of biodiversity and host the largest populations of threatened species (Tryjanowski et al. 2011). Many of them typically occur in new central and eastern Member States (Sutcliffe et al. 2015). These areas are under pressure from agricultural intensification and abandonment. Counteracting farmland abandonment in marginal areas is an important objective of AES in many countries, yet surprisingly few studies have examined the effects of AES on marginal farmland. What limited evidence there is suggests that AES can be very effective on low-intensity farmland. Schemes effectively support threatened birds in low-input cereal steppes in Central Spain (Kleijn et al. 2006), bird richness in environmentally sensitive areas in Hungary (Kovács-Hostyánszki & Báldi 2012), and species-rich plant communities in the Swiss Alps (Kampmann et al. 2012). Weis (2001) conducted an illustrative study in the German Eiffel mountain range, where many low-productive species-rich grasslands had been abandoned or afforested since the late 1960s, but then AES were introduced in 1986 that paid farmers to reintroduce sheep grazing on abandoned grasslands. Weis (2001) compared trends in plant species richness in plots where grazing had recommenced and plots where sheep were kept out. In 1999 species richness in grazed plots had increased by 20%, while species richness in ungrazed plots had decreased by 17%. The population size of a range of threatened orchid species increased by 50–500% in grazed plots. However, it took 8–10 years before the first positive effects became apparent, which may explain why this has been an unpopular research topic. Previous AES were designed solely to maintain biodiversity (e.g., by reintroducing extensive management) and not to restore it completely (Kleijn et al. 2009), so it was cheaper to execute these schemes in marginal areas than in intensive areas. More studies are needed, however, before general conclusions can be drawn about the effectiveness of AES in agriculturally marginal areas.

Cost-effectiveness of Agri-Environment Schemes Compared with other Conservation Approaches

As a conservation strategy, AES focus on reducing the impact of agricultural activities on species that inhabit the agricultural landscape. They are not the only possible route to protect such species. Another major conservation tool is protected areas, which can also be applied in agricultural landscapes. In some countries, there are protected sites managed as working farms for farmland wildlife (e.g., Moyse 2013). Little is known about the relative efficiency of these different strategies to protect farmland biodiversity.

A notable exception is the case of meadow bird conservation in the Netherlands. In 2008 €21 million was spent on AES targeting meadow bird conservation on large areas of farmland. In the same year, meadow bird conservation in the spatially much more restricted protected areas cost €4 million (van Paassen & Teunissen 2010). Settlement densities are much higher in protected areas than on farmland with meadow bird schemes, resulting, at the national level, in slightly more meadow birds breeding in protected areas than on farmland with meadow bird schemes (PBL 2009). Furthermore, on average, meadow birds show positive trends in protected areas but negative trends on farmland with meadow bird schemes (van Egmond & de Koeijer 2006). This suggests that, for this particular species group, protected areas are much more efficient than AES. However, it might be that most protected areas in the Netherlands are too small to maintain viable meadow bird populations in the long run, especially when they are bordered by inhospitable high-intensity grasslands or built-up areas that are generally avoided by these ground-nesting birds. So the apparent higher cost-effectiveness might be an illusion, hiding an extinction debt.

The comparison in cost-effectiveness between AES and protected areas is important because both are funded with public budgets and both impact the potential for food production. Investing in one strategy does not necessarily mean there is less money available for the other strategy because the source of funds for AES has a very different underlying purpose – to support farm incomes and generate public goods from agriculture. Even so, cost-effective conservation is of interest to policy makers (further discussion in Supporting Information).

Importance of Training and Advice to the Effectiveness of Agri-Environment Schemes

There has been little research on the link between farmer training or advice and the effectiveness of AES. Farmers are trained in agricultural production and have seldom experienced specific training or education in environmental management. Yet managing land for environmental outcomes requires a different set of skills and knowledge. Zonal AES schemes usually incorporate an element of training or advice. In the United Kingdom, zonal schemes are much more beneficial to bird diversity per unit cost than simplified horizontal schemes, despite the fact that a much larger proportion of the funding goes into setting up and checking the implementation rather than directly to farmers (Armsworth et al. 2012).

Horizontal AES often do not incorporate farmer training or advice (but see Marja et al. 2014), and this could be a reason for their relatively low effectiveness. One research project in the United Kingdom demonstrated that training farmers increases their confidence and develops a more professional attitude to agri-environmental management (Lobley et al. 2013). The same project also demonstrated ecological benefits; there were more flower or seed resources and higher numbers of bees or birds on AES areas managed by trained farmers relative to untrained farmers (summarized in Dicks et al. [2013*a*]). It has been repeatedly demonstrated that farmer field schools, common in low and middle income countries, enhance uptake of beneficial integrated pest management practices, although the schools do not seem to spread practices through the farming community beyond the attendees (Waddington et al. 2014). Results-oriented AES is another approach with potential to generate long-term positive behavioral change by providing incentive for farmers to improve their skills (Burton & Schwarz 2013).

Learning from the European experience

Almost everywhere in the world except Europe, Australia, and New Zealand, cultivated farmland is still expanding and natural habitats continue to be lost. Even if further conversion to farmland can be stopped, there is strong evidence that the agricultural matrix between areas of natural habitat is used by many wild species and holds important resources for some (Attwood et al. 2009; Mendenhall et al. 2014). In this context, policies such as AES that encourage farming practices less harmful to wildlife could become a standard part of conservation policy more widely in the coming decades.

Conservation programs that provide incentives directly to farmers to protect and manage land for biodiversity are not unique to Europe. Other parts of the world with intensive agriculture have comparable schemes, such as the Conservation Reserve Program, the Environmental

Quality Incentives Program, and the Wetlands Reserve Program in the United States (Lambert et al. 2007) and the Landcare and Conservation Reserve Program in Australia (Hajkowicz 2009). The Australian program differs from European AES in that it aims to restore natural habitat (grasslands, shrublands, forests) on farmland rather than maintain the farmland itself. Compared with the amount of research in Europe, there is little information on the effectiveness of the Australian and U.S. schemes (but see, e.g., Riffell et al. [2008] and Attwood et al. [2009]). So what has been learned in Europe that could be applied in the rest of the world?

Research over the last 20 years shows that European AES have been generally beneficial for farmland biodiversity, leading in the majority of cases to a moderate increase in numbers of species present. There are suggestions that they have slowed the loss of farmland biodiversity in some countries (Carvalheiro et al. 2013).

Europeans have learned that the structure of the surrounding landscape and the degree of ecological contrast between land under schemes and the immediate surroundings are important moderators of this effectiveness. This understanding creates an opportunity to target AES toward areas where they are most likely to be effective, in intensively farmed landscapes of intermediate complexity, where they generate high ecological contrast by providing resources that are limited in the surroundings or potentially by buffering protected areas (although this is untested).

Europeans have also learned that AES are an expensive way to do conservation. As a policy tool, they are complex. It is not easy to improve their effectiveness in response to new research because they have to be easy to implement, feasible on a large scale, and palatable to farmers. As a result, it could be argued that AES should only be employed in parts of the world, such as Europe, where a high proportion of the unique or declining biodiversity depends directly on farmland or farming activities.

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Supporting Information

Characteristics of AES in Europe (Appendix S1); a summary of reviews of effectiveness of European AES (Appendix S2); a summary information for each observation included in the meta-analyses (Appendix S3); the funnel plot, regression test results, and fail-safe number (Appendix S4); a summary table of meta-analysis results (Appendix S5); country codes (Appendix S6); and further discussion of cost-effectiveness of AES (Appendix S7) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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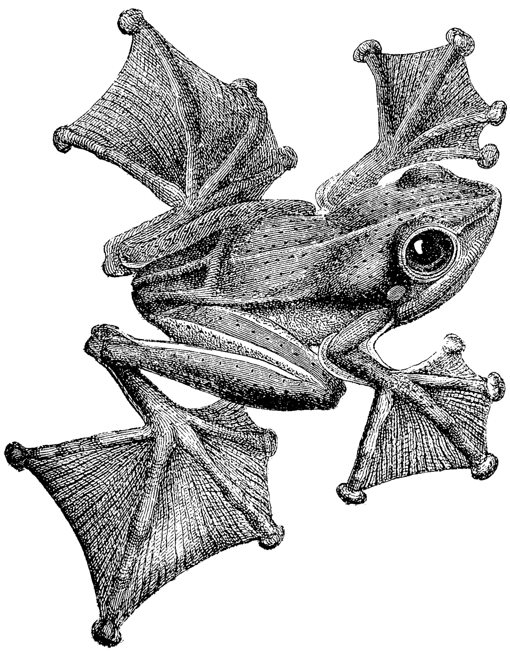

Supporting Information

Appendix S1. Characteristics of agri-environment programmes in European countries until the year 2013. UAA, Utilized Agricultural Area; AEP, agri-environment programme; AES, agri-environment scheme. Many countries have described some of their schemes as ‘horizontal’, which refer to broad and shallow, or lower tier schemes. UAA (2007) and area with AES (2012) data were derived from EU (2014). UAA (2012) data for Croatia, Norway and Switzerland were derived from FAOSTAT (URL: http://faostat3.fao.org). Further information on agri-environment programmes of EU countries for 2007-2013 can be found in the Rural Development Programmes of each member states at the EU website of European Network for Rural Development (URL: http://enrd.ec.europa.eu/enrd-static/policy-in-action/rural-development-policy-overview/national-and-regional-programmes/en/national-and-regional-programmes_en.html).

Austria. (UAA: 3 189 110 ha; area with AES: 2 181 453 ha; AEP since 1995, previous programme outside the EU-context since 1972). The Austrian AES ÖPUL is a horizontal program that aims at a full coverage of the Austrian agriculture. Its focus is on the conservation of water, soil, climate, biodiversity and cultural landscapes. ÖPUL consists (in the version valid since 2007) in 29 measures, which are mostly offered throughout the entire country. In 2013, the scheme covered 91% of the Austrian UAA (except alpine pastures) and 109 000 agricultural businesses participated. *Highest uptake*: in 2013 (total uptake in Austria: 529 M€) environmental management (20.1%) and organic farming (18.5%). *Source*: Anonymous (2014a). *Information provider*: Stefan Schindler.
Belgium. (UAA: 1 374 430 ha; area with AES: 199 050 ha; AEP since 1994). Each of the three regions of Belgium has its own AEP. In the two regions with significant agricultural activities, among all schemes, some aim to preserve native breeds and elements of the ecological network and landscape (e.g. hedges, ponds, natural grasslands). Others aim to reduce fertilizers and pesticides inputs by limiting the quantities used in cereal crops or by keeping a low stocking rate, or to limit their leaching by installing a winter ground cover. A third main aim is to host natural flora and fauna on a portion of cultivated fields (e.g. flower strips, protection of river banks, beetle banks). *Source*: Anonymous (2005). *Information provider*: Pierre Rasmont and Sarah Vray.
Bulgaria. (UAA: 3 050 740 ha; area with AES: 388 888 ha; AEP since 2007). The main aims of the AEP, which can be applied across Bulgaria, are: maintenance of high nature value (HNV) arable land, organic farming, landscape characteristics, traditional farming and protection of soil and waters. The schemes include maintenance of HNV arable habitats for birds, with several zonal schemes for globally threatened bird species. *Highest uptake*: Two thirds of the AES budget went towards “protection of soil and waters” mainly in 2013. *Source*: Anonymous (2013a). *Information provider*: Edita Difova.

Croatia. (UAA: 1 327 730 ha; AEP since 2013). Croatia joined the EU in 2013. However, there was a comprehensive pre-accession Rural Development Programme that Croatia implemented until the end of the programming period 2007–2013. The pilot agri-environment programme were designed to address two major problems: 1.) Decline of landscape, habitats and species diversity due to loss of agricultural land, notably grassland; 2.) Environmental degradation caused by inappropriate agriculture practices including high consumption of fertilisers and pesticides, notably on arable and permanent crops. It included three site specific measures: preventing further natural succession on species-rich grasslands (Velebit Nature Park); restoring and maintaining wetland grassland (Lonjsko Polje Nature Park) and an arable farming pilot measure (Zagrebačka County). *Source*: IPARD (2013).
Cyprus. (UAA: 146 000 ha; area with AES: 24 028 ha; AEP since 2004). The Agro-environmental Commitments consists of eight sub-measures: 1.) Reduction of chemical weeding in vineyards; 2.) Reduction of pesticides and fertilisers in potatoes; 3.) Reduction of pesticides and chemical weeding in citrus fruits; 4.) Increasing soil fertility and quality as well as reduction of the use of pesticides and fertilisers in arable crops; 5.) Preservation of traditional vineyard varieties and endangered species; 6.) Preservation of landscape with traditional trees and bushes, such as almond trees, carob trees, hazelnut trees and Rosa damaskina; 7.) Encouraging organic production both in animal and plant sector; 8.) Preservation of habitats necessary for the reproduction of wild fauna, provision of the necessary biomass for wild birds and mammals feeding. *Source*: RDP Cyprus (2013).
Czech Republic. (UAA: 3 518 070 ha; area with AES: 1 069 741 ha; AEP since 2004). AES in the Czech Republic has 3 sub-schemes, which are divided into–1. Environmentally friendly farming methods (organic farming, integrated farming), 2. Grassland maintenance (with special titles targeted at specific priority grassland habitats), 3. Landscape Care (conversion of arable to grassland, cover crops, wildlife strips). The basic condition for receiving payments under the AES is closing five-year commitment. *Highest uptake*: Organic farming ca. 25 % AES budget for 2007–2013; Pastures ca. 20 % AES budget for years 2007–2013. *Source*: Černá et al. (2007). *Information provider*: Jarmila Kostiuková and Jana Dandová.
Denmark. (UAA: 2 662 590 ha; area with AES: 160 817 ha; AEP since 1992, previous schemes under regulation 797/85 since 1990). Danish agri-environmental schemes have following main targets: First, to avoid eutrophication of water bodies. These schemes are both horizontal (reduction of fertilizer and pesticides, conversion to organic farming) and geographically specific (mandatory buffer zones are compensated, and establishment and up-keeping wetlands are subsidised). You may also see subsidies to energy crops partly in this category, as they are perennial. Second, to support biodiversity. These schemes both horizontal (subsidy for grazing and mowing of various types of grassland and nature areas) or targeted at Natura 2000 areas, such as subsidies for clearing of areas for grazing, or establishment and up-keeping of natural hydrology. *Highest uptake*: Various forms of grassland schemes (grazing, mowing, extensive use), which compose 92 % of the non-organic schemes. *Source*: Anonymous (2014b). *Information provider*: Pia Frederiksen and Gregor Levin.

Estonia. (UAA: 906 830 ha; area with AES: 600 041 ha; AEP since 2004). Estonian AEP consists of five sub-measures which can be applied across Estonia. The objectives of the AEP are to: promote the implementation and continuous use of environmentally friendly management methods in agriculture; preserve and increase biological and landscape diversity; help farmers act in an environmentally favourable way whilst maintaining an adequate income; increase environmental awareness. Three of the sub-measures are horizontal schemes: organic farming, environmentally friendly management (basic and additional scheme) and maintenance of semi-natural habitats. In addition, there are schemes to support growing one local plant variety and keeping animals of four local endangered breeds. *Highest uptake*: Environmental Friendly Management has the *Highest uptake* – 57% from AEP budget in 2012 (about 77% from AEP farmland area in 2012). *Source*: Anonymous (2008). *Information provider*: Riho Marja.
Finland. (UAA: 2 292 290 ha; area with AES: 2 181 247 ha; AEP since 1995). The Finnish AEP comprises two tiers, basic and additional, and a special package. The lower tier is a prerequisite to all participants in the AEP, includes basic conditions for environmentally friendly production (e.g., soil nutrient analysis, buffer strips; in 2009, environmental fallow was added). On top of the basic, participants must choose at least one or two (depending on the region) measures from the additional package (e.g. more stringent fertilization limits, winter cover options). The special package includes among others organic production, management of semi-natural grasslands, traditional breeds and varieties. *Highest uptake*: 90 % of the farmers (92 % of the UAA) had AEP contracts (basic level) in 2010. *Source*: Anonymous (2013b). *Information provider*: Irina Herzon.
France. (UAA: 27 476 930 ha; area with AES: 6 000 000 ha; AEP since 1992, previous schemes under regulation 797/85 since 1989). The French AEP includes national, regional and more locally focused measures. Within the period 2007-2013, the schemes aimed to preserve biodiversity and water resource quality. The schemes were defined at national or regional scales (horizontal schemes; e.g. organic management, maintenance of extensively managed grasslands, mixed-farming systems, crop rotations), and can be adapted locally (zonal schemes; e.g. grassland managed for bird nesting protection, mountainous grassland maintenance through pastoralism). *Source*: Anonymous (2012a). *Information provider*: Aliette Baillod.
Germany. (UAA: 16 931 900 ha; area with AES: 5 039 302 ha; AEP since 1992, previous schemes under regulation 797/85 since 1985). Each of the 16 federal states of Germany has its own AEP resulting in a variety of different measures. German AES can be divided in two main types. First, schemes aimed at making agricultural production more environmentally friendly (horizontal schemes; e.g. organic management, grassland extensification, flower strips) and second, schemes aimed at preservation of specific biotopes or species (zonal schemes; e.g. management of calcareous grasslands, orchard meadows or bird resting areas). All federal states provide additional, but different AES without the co-funding of the EU. *Highest uptake*: Examples of uptake for two states: organic management in Lower Saxony and Bremen (32% of AEP budget on 19% of AEP area) and organic management in Bavaria (23% of AEP budget). *Source*: Thomas et al. (2009). *Information provider*: Péter Batáry, Sebastian Klimek and Christian Wagner.

Greece. (UAA: 4 076 230 ha; area with AES: 500 000 ha; AEP since 1995, previous schemes under regulation 797/85 since 1986). Greece applied four schemes for the whole country (organic farming and organic animal husbandry, conservation of indigenous animal breeds and conservation of plants), five schemes for Natura 2000 wetland sites, two for landscapes, two for landscape features, and two for intensive practices (set aside and fertilization reduction). *Highest uptake*: The most popular measure is the organic scheme (36% of AEP budget). *Source*: Anonymous (2014c). *Information provider*: Theodora Petanidou.
Hungary. (UAA: 4 228 580 ha; area with AES: 1 153 910 ha; AEP since 2004). Hungarian AES can be divided in two main types. First, there are schemes aimed at making agricultural production more environmentally friendly (horizontal schemes): Wetland scheme, Grassland scheme, Organic production scheme, Integrated production scheme, Agri-environmental basic scheme. Second, there are zonal (regional) schemes for areas with low production potential but significant natural value. Scheme measures vary between areas and include conversion of arable land to grassland, use of extensive farming methods, maintenance of endangered breeds, habitat restoration and development, landscape reconstruction measures and provision of favourable condition for important bird species (e.g. great bustard and red-footed falcon). *Highest uptake*: In 2012 the integrated production scheme had the highest uptake in terms of area (52% AEP area). *Source*: Anonymous (2009), NHRDP (2011). *Information provider*: Péter Batáry, Anikó Kovács-Hostyánszki.
Ireland. (UAA: 4 139 240 ha; area with AES: 2 526 950 ha; AEP since 1994). The Irish Agri-Environment Option Scheme contains three objectives; one is contribution to halting biodiversity decline. There are actions at three levels: Primary Environmental Actions (Species rich grassland, Traditional hay meadows, Establishment & Maintenance of Habitats, Wild Bird Cover); Complementary Actions (e.g. Riparian Margins, Traditional Orchards, Coppicing hedgerows); Additional Actions (e.g. Planting of new hedgerows, Arable Margins, Minimum Tillage). *Source*: Anonymous (2010a). *Information provider*: John A. Finn.
Italy. (UAA: 12 744 200 ha; area with AES: 2 356 962 ha; AEP since 1994/5). Each of the 20 Italian regions has its own rural development plans resulting in a variety of different measures. The large majority of schemes are aimed at making agricultural production more sustainable (horizontal schemes such as organic management), while schemes aimed at preservation of specific biotopes or species are rarer (e.g. conservation of wetlands or dry grasslands). *Highest uptake*: Scheme uptake of the different regions does not present a geographical trend. The three regions with the highest participation to the schemes are Bolzano (41% of AEP budget), Basilicata (32% of AEP budget), and Sicily (31% of AEP budget). *Source*: Anonymous (2014d). *Information provider*: Lorenzo Marini.
Latvia. (UAA: 1 773 840 ha; area with AES: 235 050 ha; AEP since 2004). There were four AES sub-measures available in Latvia. One scheme ("Maintenance of Biological Diversity in Grasslands") was zonal and aimed at preventing further loss and degradation of semi-natural grasslands and was the only truly biodiversity oriented AES in the country. The rest of the schemes ("Development of Biological Farming", "Introducing and Promoting Integrated Horticulture" and "Stubble Field in Winter Period" were horizontal and aimed at promoting certain environment friendly farming practices, including reduction of use of agrochemicals and reduction of nutrient leakage. *Highest uptake*: Development of Biological Farming (74% of AES budget). *Source*: Anonymous (2013c). *Information provider*: Ainars Aunins.

Lithuania. (UAA: 2 648 950 ha; area with AES: 251 837 ha; AEP since 2004). The Lithuanian AEP comprises two major groups of schemes. The first is for environmental friendly/sustainable and extensive agricultural production (e.g. organic and sustainable management, expansion of grasslands, increasing crop diversification). The second has a more explicit conservation focus in agricultural areas (e.g. protection of water, soil, biodiversity and landscape, Natura 2000 habitat, protective zones close water bodies, wetlands and melioration programmes, afforestation). *Source*: Anonymous (2013d). *Information provider*: Ligita Baležentienė.
Luxembourg. (UAA: 130 880 ha; area with AES: 118 335 ha; AEP since 1996). Luxembourg has several types of agri-environmental measures. Payments are for measures such as 1.) promotion of organic agriculture; 2.) management of agricultural landscape (e.g. maintenance of permanent grassland, adequate arable land fertilization); 3.) environmental friendly practices (e.g. delayed grass mowing, diverse crop rotation) and others (e.g. set-aside land, maintenance of traditional orchards). *Highest uptake*: management of agricultural landscapes (about 80% of all AES budget). *Source*: Anonymous (2007a).
Malta. (UAA: 10 330 ha; area with AES: 2 042 ha; AEP since 2004). The AES contain the following sub-measures: 1.) use of the environmentally friendly plant protection methods in vineyards; 2.) traditional crop rotation including the cultivation of sulla (Hedysarum coronarium); 3.) low input farming; 4.) suppress the use of herbicides in vineyards and fruit orchards; 5.) establishment and maintenance of conservation buffer strips; 6.) conservation of rural structures providing a natural habitat for fauna and flora; 7.) providing a healthy forage area for bees; 8.) organic farming. *Source*: RDP Malta (2013).
Netherlands. (UAA: 1 914 330 ha; area with AES: 228 303 ha; AEP since 1992, previous schemes partly under regulation 797/85 and partly outside the EU-context since 1981). The Dutch AEP has a variety of schemes targeting meadow birds, farmland passerines, European Hamster *Cricetus cricetus*, wintering geese, grassland flora and arable flora. Most schemes aim to promote the targeted species groups by prescribing measures that extensify farming activities. Examples include delaying first seasonal activities for meadow birds, reducing or prohibiting agro-chemical use for flora, planting wild bird seed mixtures for wintering farmland passerines or providing early and late season cover for European Hamster. *Highest uptake*: With about 60% of the total area covered by agri-environment schemes, meadow bird schemes are most popular in terms of uptake. *Source*: Anonymous (2010b). *Information provider*: David Kleijn.
Norway. (UAA: 991 700 ha; area with AES: 990 200 ha; AEP since 1990). There are AEP-schemes on national, regional and community level. The schemes aim to reduce the effect of agricultural practice on the environment, to preserve specific landscapes, biotopes, agriculural practices, grazing, organic farming, and to reduce pollution etc. The biggest scheme, the acreage- and cultural landscape scheme, takes up around 80 percent of the total AEP-budget. On a regional level there are two schemes directed at preserving specific environmental and cultural landscape qualities, to reduce water-pollution, contribute to biological diversity and public access to areas of recreational value. On a community level, there is a scheme directed towards preserving specific nature and cultural heritage elements and reduction of pollution from agriculture. *Highest uptake*: 98 percent of all farmers (2013) were obliged to take up the acreage- and cultural landscape scheme. The percentage was lower for other schemes. *Source*: Anonymous (2012b). *Information provider*: Oddmund Hjukse and Agnar Hegrenes.

Poland. (UAA: 15 477 190 ha; area with AES: 2 048 430 ha; AEP since 2004). Agri-environment schemes in 2007-2013 included nine projects (packets) divided into 49 variants: Sustainable Agriculture, Organic farming, Extensive permanent grassland, Protection of endangered bird species and habitats outside Natura 2000 sites, Protection of endangered bird species and habitats in Natura 2000 areas, Preservation of endangered plant genetic resources in agriculture, Preservation of endangered animal genetic resources in agriculture, Protection of soil and water, Buffer zones. *Source*: Brodzińska (2009). *Information provider*: Piotr Tryjanowski.
Portugal. (UAA: 3 472 940 ha; area with AES: 954 134 ha; AEP since 1994). The Portuguese Rural Development Plan includes two main AES. One scheme - Enhancement of production methods - is applied horizontally and aimed at promoting the sustainable development of rural areas, it supports: (i) organic farming and integrated production, (ii) conservation of traditional livestock breeds, (iii) conservation and improvement of genetic resources, including local varieties of plants and animal breeds, and (iv) soil conservation, in particular through use of direct seeding. The other scheme - Integrated Territorial Interventions - is zonal and addresses the conservation of biodiversity and cultural landscapes in Natura 2000 areas and in the Douro Wine region. *Highest uptake*: Organic farming and integrated production was implemented on 333 059 ha. 51% of these farms were in the North region and 61% of the area was located in Alentejo. *Source*: MAMAOT (2012). *Information provider*: Vânia Proença.
Romania. (UAA: 13 753 050 ha; area with AES: 1 840 559 ha; AEP since 2007). There is one AEP for the whole country, but different measures are spatially restricted. The largest measure in terms of budget and extent is focussed on High Nature Value (HNV) grasslands and arable land: in 2007-2013 the eligible area was 2.4 million ha (18 % UAA), this is likely to increase from 2014 onwards. There is also an "add-on" package for the use of traditional cultivation methods (e.g. hand scything, horse ploughing), which are still relatively widespread in the country. Further measures focus on the habitats of species of conservation concern (e.g. *Crex crex*, *Maculinea spp*.) and green cover crops. *Highest uptake*: HNV package with 1.11 million ha within the measure in 2012. *Source*: MARD (2014). *Information provider*: Laura M. E. Sutcliffe.
Slovakia. (UAA: 1 936 620 ha; area with AES: 357 175 ha; AEP since 2004). The Rural Development Programme (RDP) 2007-2013 includes 10 agri-environmental measures: Basic scheme; Erosion prevention on arable land; Erosion prevention in vineyards; Erosion prevention in orchards; Arable land grassing; Integrated production; Ecological agriculture; Protection of biotopes of semi-natural and natural grasslands; Protection of biotopes of selected birds species; Breeding and maintenance of threatened animal species. *Highest uptake*: Besides the basic scheme (300 000 ha), the largest area was supposed for Protection of biotopes of selected birds species (261 000 ha), Organic farming (150 000 ha), Erosion prevention (100 000 ha) and Protection of biotopes of semi-natural and natural grasslands (96 000 ha). *Source*: Baránková et al. (2010). *Information provider*: Lubos Halada.

Slovenia. (UAA: 488 770 ha; area with AES: 217 749 ha; AEP since 2004). The measures are horizontal and intended for all farmers in Slovenia. The measure of compensatory allowances may be applied only for areas designated under this programme as Less Favoured Areas. Certain spatial restrictions apply also for some specific agri-environmental sub-measures, which are protection regimes or management requirements for the preservation of individual habitat types. In the period 2007-2013 there were 24 measures divided into three groups according to the objectives to be achieved by individual measures: Reducing the negative impacts of agriculture on the environment, Conservation of natural resources, biodiversity, soil fertility and traditional cultural landscape, Conservation of Protected Areas. *Highest uptake*: *Highest uptake* is in the most agricultural areas, of the north east. However, programs dedicated to conservation on grassland are much more present in Western part of Slovenia. *Source*: Anonymous (2007b). *Information provider*: Mitja Kaligarič and Jure Čuš.
Spain. (UAA: 24 892 520 ha; area with AES: 5 091 250 ha; AEP since 1993). In Spain, AEPs are implemented by the 17 individual regional governments and the National Rural Network by the Spanish government. Horizontal schemes and specific measures, responding to different regional situations are included in each AEP. The development of the AEPs is coordinated by the Spanish government to ensure the consistency of the Spanish strategy for rural development throughout the territory. *Highest uptake*: Extremadura is the region of Spain that has more surface with agri-environment payments (9% of the UAA, which represents 31% of the total surface with AEP). *Source*: Anonymous (2012c). *Information provider*: F. Xavier Sans.
Sweden. (UAA: 3 118 000 ha; area with AES: 1 907 589 ha; AEP since 1995, previous schemes outside the EU-context since 1986). The Swedish RDP 2007-2013 consists of four ‘axes’, of which one focuses on ‘enhancing environment and landscape’ (axis 2). The main objectives of this axis are to conserve biodiversity, to maintain naturally and culturally valuable and varied landscapes, and to minimize pesticide use and nutrient leaking. Most AEP’s in axis 2 are zonal or combine zonal and horizontal schemes. Similarly to the previous period, AEP’s aiming at maintaining open landscapes and conservation of semi-natural grasslands and cultural elements are most popular. *Highest uptake*: Perennial ley farming (44% of AEP area), organic farming (21%) and maintenance of semi-natural grasslands (20%). *Source*: SJV (2014). *Information provider*: Juliana Dänhardt.
Switzerland. (UAA: 1 528 700 ha; area with AES: 129 889 ha; AEP since 1993). Farmers need to farm at least 7% of their land according to the guidelines for ecological focus areas (EFA) in order to qualify for subsidies (this is a ‘cross-compliance’ mechanism, set at 3.5% for horticultural farms). They can choose from a suite of 16 different EFA types. For eight EFA types, criteria for ecological quality have been defined (based on indicator plants and structural diversity). If quality criteria are met, the farmer is entitled to bonus payments (result oriented scheme). In addition, farmers as a group can propose a project in which they formulate measures to increase the share, quality and connectivity of EFA in order to promote selected target species. Participation in such a project is remunerated by bonus payments. *Highest uptake*: The share of EFA tends to be higher in mountain areas: 28% of UAA on average in the highest mountain farming region. *Source*: Anonymous (2014d). *Information provider*: Felix Herzog.

United Kingdom. (UAA: 16 130 490 ha; area with AES: 5 312 613 ha; AEP since 1992, previous schemes under regulation 797/85 since 1987). England and Wales both had two-tier schemes. Entry Level Stewardship (ELS, in England, now ended) or Glastir Entry (Wales) were flexible and untargeted, allowing farmers to select from a wide variety of management actions to meet a threshold score. Agreements were for five years. Higher Level Stewardship (HLS) or Glastir Advanced agreements were carefully targeted for specific biodiversity objectives, implemented with advice from experts on priority sites selected at regional level. HLS agreements lasted 10 years. Scotland had a single tier, Rural Stewardship Scheme, in which farmers could select from a range of objective-driven management options, based on a whole farm environmental audit. Agreements lasted at least five years (now ended). Northern Ireland has a single tier, whole-farm Countryside Management Scheme, open to all farmers. *Highest uptake*: England had 68% of farmland under Entry Level Stewardship in 2012. 16% of English farmland was under Higher Level Stewardship in 2012, but most was also in the Entry Level scheme. *Source*: Defra (2013). *Information provider*: Lynn V. Dicks.

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Appendix S2. Summary of reviews of effectiveness of European agri-environment schemes.

Years	*Topic*	*Conclusions*	*Reference*
1983-2000	Overview of state of AES in 26 European countries	AES varied markedly between countries. Highest uptake of AES in extensive agricultural areas. Research studies only in 6 countries with a dominance of UK and NL. Majority of studies was inadequate to assess reliably the effectiveness of the schemes. Nevertheless more than the half of examined species (groups) demonstrated increases in species richness or abundance compared with controls.	Kleijn and Sutherland (2003)
1986-2002*	Meta-analysis on the effects of organic management on biodiversity	Organic farming had on average 30% higher species richness and 50% more organisms than conventional farming systems (ca. three-quarters of all data from Europe), but results were highly variable between studies and organism groups. They proposed that the effects of organic farming are larger in intensively managed landscapes than in small-scale diverse landscapes with many non-crop biotopes.	Bengtsson et al. (2005)
1994-2008*	Meta-analysis on landscape moderation effect on effectiveness of agri-environment management (AEM)	AEM significantly increased species richness and abundance of plants and animals (ca. 80% of all data from Europe). In croplands, species richness but not abundance was significantly enhanced in simple but not in complex landscapes. In grasslands, AEM effectively enhanced species richness and abundance regardless of landscape context. They concluded that AEM should be adapted to landscape structure.	Batáry et al. (2011)
1994-2011*	Meta-analysis on the landscape moderation effect on AES effectiveness in case of pollinators (complementing Batáry et al. 2011)	They found that the ecological contrast in floral resources created by schemes drives the response of pollinators to AES (only European studies). This response is moderated by landscape context and farmland type, with more positive responses in croplands (vs. grasslands) located in simple (vs. cleared or complex) landscapes.	Scheper et al. (2013)
1986-2011*	Meta-analysis on benefits of organic farming to biodiversity (also updating Bengtsson et al. 2005)	Organic farming increased species richness by about 30% (ca. 84% of all data from Europe). This result was robust over the last 30 years of published studies and shows no sign of diminishing. Organic farming had a greater effect on biodiversity as the percentage of the landscape consisting of arable fields increased, i.e. in more intensively farmed regions.	Tuck et al. (2014)

*: based on years of publication of primary papers.

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Appendix S3. Summary information for each observation included in the meta-analyses.
We split the data of a large EU project, called EASY, according to the study regions per country (observations from this project are marked by star). Source shows from which meta-analysis the data is coming (1: Batáry et al. 2011; 2: Scheper et al. 2013; 3: Tuck et al. 2014). Study year: for analysing the budget period, we considered always the last year of the studies. AES: I = in production scheme, O = out of production. N: sample size of AES plus control. g: Hedges' g. np var g: non-parametric variance estimate of Hedges' g.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Aavik & Liira 2010	3	2008	Estonia	Plants	Cereal	I	42	1.037	0.111
Aavik & Liira 2010	3	2008	Estonia	Plants	Cereal	I	42	0.074	0.111
Albrecht et al. 2007*	2	2004	Switzerland	Butterfly	Grassland	I	26	0.517	0.154
Albrecht et al. 2007*	1	2004	Switzerland	Hoverfly	Grassland	I	26	1.158	0.154
Albrecht et al. 2007*	1	2004	Switzerland	Solitary bee	Grassland	I	26	0.974	0.154
Albrecht et al. 2007b*	2	2003	Switzerland	Bees	Grassland	I	26	0.456	0.154
Albrecht et al. 2010*	2	2004	Switzerland	Bees	Grassland	I	48	1.271	0.083
Alvarez et al. 2001	1	1997	United Kingdom	Collembola	Cropland	I	22	0.347	0.188
Aude et al. 2003	3	2001	Denmark	Plants	Unspec	I	26	1.938	0.154
Aviron et al. 2009	2	2004	Switzerland	Butterflies	Cropland	O	150	0.811	0.027
Aviron et al. 2009	2	2004	Switzerland	Butterflies	Grassland	I	531	0.149	0.008
Aviron et al. 2010	2	2004	Switzerland	Butterflies	Cropland	O	43	2.375	0.088
Batáry et al. 2010	1	2008	Germany	Bird	Grassland	I	20	0.365	0.200
Batáry et al. 2010	1	2008	Germany	Bird	Cropland	I	20	0.491	0.200
Batáry et al. 2012	1	2008	Germany	Carabid	Grassland	I	20	0.432	0.200
Batáry et al. 2012	1	2008	Germany	Carabid	Cropland	I	20	0.763	0.200
Batáry et al. 2012	1	2008	Germany	Grasshopper	Grassland	I	18	0.180	0.222
Batáry et al. 2012	1	2008	Germany	Plant	Cropland	I	20	2.090	0.200
Batáry et al. 2012	1	2008	Germany	Plant	Grassland	I	20	0.949	0.200
Batáry et al. 2012	1	2008	Germany	Spider	Cropland	I	20	2.018	0.200
Batáry et al. 2012	1	2008	Germany	Spider	Grassland	I	20	1.031	0.200
Brittain et al. 2010	2	2006	Italy	Butterflies	Cropland	I	30	0.340	0.333
Brittain et al. 2010	2	2006	Italy	Solitary bees	Cropland	I	30	-0.113	0.333
Bruggissere et al. 2010	3	2005	Switzerland	Arthropods	Orchard	I	25	-0.357	0.250
Bruggissere et al. 2010	3	2005	Switzerland	Arthropods	Orchard	I	25	-0.324	0.250
Bruggissere et al. 2010	3	2005	Switzerland	Arthropods	Orchard	I	25	0.152	0.250
BTO 1995	3	1994	United Kingdom	Arthropods	Unspec	I	15	-0.355	0.268
Caballero-Lopez et al. 2010	3	2004	Spain	Plants	Cereal	O	8	4.549	0.500
Carvell et al. 2007	2	2004	United Kingdom	Bumblebees	Cropland	O	12	0.845	0.333
Carvell et al. 2007	2	2004	United Kingdom	Bumblebees	Cropland	O	12	3.560	0.333
Christensen et al. 1996	3	1987	Denmark	Birds	Mixed	I	8	0.480	0.500
Clough et al. 2007a*	1	2003	Germany	Carabid	Cropland	I	12	-0.096	0.333
Clough et al. 2007a*	1	2003	Germany	Carabid	Cropland	I	12	0.887	0.333
Clough et al. 2007a*	1	2003	Germany	Carabid	Cropland	I	14	-0.089	0.286
Clough et al. 2007a*	1	2003	Germany	Spider	Cropland	I	12	0.000	0.333
Clough et al. 2007a*	1	2003	Germany	Spider	Cropland	I	12	-0.412	0.333
Clough et al. 2007a*	1	2003	Germany	Spider	Cropland	I	14	0.201	0.286
Clough et al. 2007b*	1	2003	Germany	Rove beetle	Cropland	I	12	0.313	0.333

Appendix S3. Continued.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Clough et al. 2007b*	1	2003	Germany	Rove beetle	Cropland	I	12	0.388	0.333
Clough et al. 2007b*	1	2003	Germany	Rove beetle	Cropland	I	14	0.170	0.286
Concepción et al. 2008*	1	2003	Spain	Bee	Cropland	I	6	0.163	0.667
Concepción et al. 2008*	1	2003	Spain	Bee	Cropland	I	14	0.373	0.286
Concepción et al. 2008*	1	2003	Spain	Bee	Cropland	I	14	-0.238	0.286
Danhardt et al. 2010	3	2005	Sweden	Birds	Mixed	I	12	0.986	0.333
Danhardt et al. 2010	3	2005	Sweden	Birds	Mixed	I	12	-0.191	0.333
de Snoo et al. 1998	2	1992	Netherlands	Butterflies	Cropland	O	40	1.318	0.238
Diekötter et al. 2010	3	2007	Germany	Arthropods	Cereal	I	6	1.019	0.667
Diekötter et al. 2010	3	2007	Germany	Arthropods	Cereal	I	6	-1.167	0.667
Diekötter et al. 2010	3	2007	Germany	Arthropods	Cereal	I	12	-0.092	0.333
Dietschi et al. 2007	1	2003	Switzerland	Plant	Grassland	I	31	1.940	0.130
Döring et al. 2003	3	1999	Germany	Arthropods	Cereal	I	20	1.297	0.220
Döring et al. 2003	3	1999	Germany	Arthropods	Cereal	I	20	1.938	0.220
Döring et al. 2003	3	1999	Germany	Arthropods	Cereal	I	14	1.450	0.292
Döring et al. 2003	3	1999	Germany	Arthropods	Cereal	I	14	1.951	0.292
Ekroos et al. 2008	1	2003	Finland	Bumblebee	Grassland	I	55	0.539	0.092
Ekroos et al. 2008	1	2003	Finland	Butterfly	Grassland	I	55	-0.040	0.092
Ekroos et al. 2010	3	1998	Finland	Butterfly	Grassland	I	26	0.668	0.163
Ekroos et al. 2010	3	1998	Finland	Butterfly	Grassland	I	22	-0.271	0.259
Feber et al. 1996	3	1991	United Kingdom	Butterfly	Grassland	O	8	1.610	0.250
Feber et al. 1996	3	1991	United Kingdom	Butterfly	Grassland	O	8	0.600	0.250
Ekroos et al. 2010	1	1998	Finland	Butterfly	Grassland	I	26	4.105	0.163
Ekroos et al. 2010	1	1998	Finland	Butterfly	Grassland	I	22	1.357	0.259
Feber et al. 1998	1	1995	United Kingdom	Spider	Cropland	I	18	1.118	0.222
Feber et al. 2007	3	1996	United Kingdom	Spider	Cropland	I	20	0.906	0.200
Feber et al. 2007	3	1996	United Kingdom	Spider	Cropland	I	20	1.264	0.200
Fischer et al. 2011a	3	2008	Germany	Birds	Cropland	I	29	0.300	0.138
Fischer et al. 2011a	3	2008	Germany	Birds	Cropland	I	31	0.311	0.129
Fischer et al. 2011a	3	2008	Germany	Birds	Cropland	I	30	0.578	0.208
Fischer et al. 2011a	3	2008	Germany	Birds	Cropland	I	30	0.553	0.208
Fischer et al. 2011b	3	2008	Germany	Small mammals	Cropland	I	22	-0.078	0.182
Flohre et al. 2011	3	2008	Germany	Earthworms	Cropland	I	24	-0.796	0.167
Flohre et al. 2011	3	2008	Germany	Plants	Cropland	I	24	6.417	0.167
Fuentes-Montemayor et al. 2011	2	2008	United Kingdom	Macromoths	Cropland	O	36	0.141	0.125
Fuentes-Montemayor et al. 2011	2	2008	United Kingdom	Macromoths	Cropland and grassland	O	36	0.000	0.154
Fuentes-Montemayor et al. 2011	2	2008	United Kingdom	Macromoths	Cropland and grassland	O	36	0.414	0.125
Gabriel et al. 2010	3	2008	United Kingdom	Birds	Cereal	I	16	-0.787	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Birds	Cereal	I	16	-0.779	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Cereal	I	16	1.604	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Cereal	I	16	2.018	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Cereal	I	16	0.334	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Cereal	I	16	0.184	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Grass	I	16	0.803	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Grass	I	16	0.256	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Grass	I	16	0.289	0.250
Gabriel et al. 2010	3	2008	United Kingdom	Plants	Grass	I	16	0.020	0.250
Gabriel et al. 2006*	1	2003	Germany	Plant	Cropland	I	12	2.692	0.333
Gabriel et al. 2006*	1	2003	Germany	Plant	Cropland	I	12	3.054	0.333

Appendix S3. Continued.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Gabriel et al. 2006*	1	2003	Germany	Plant	Cropland	I	14	2.611	0.286
Galvan et al. 2009	3	2005	Netherlands	Microbes	Veg	I	10	0.198	0.400
Galvan et al. 2009	3	2005	Netherlands	Microbes	Veg	I	10	0.111	0.400
Gathmann et al. 1994	2	1990	Germany	Solitary bees	Cropland	O	8	0.000	0.500
Gathmann et al. 1994	2	1990	Germany	Solitary bees	Cropland	O	8	0.000	0.500
Genghini et al. 2006	1	1998	Italy	Bird	Cropland	I	41	1.161	0.105
Granqvist 1999	3	1998	Sweden	Plants	Cereal	I	16	0.146	0.250
Granqvist 1999	3	1998	Sweden	Plants	Grass	I	16	-0.540	0.250
Haenke et al. 2009	2	2006	Germany	Hoverflies	Cropland	O	14	1.791	0.286
Haenke et al. 2009	2	2006	Germany	Hoverflies	Cropland	O	14	3.135	0.286
Hawes et al 2010	3	2007	United Kingdom	Plants	Mixed	I	40	1.789	0.119
Hawes et al 2010	3	2007	United Kingdom	Plants	Mixed	I	40	1.667	0.119
Hodgson et al. 2010	2	2008	United Kingdom	Butterflies	Cropland	I	16	0.051	0.250
Hodgson et al. 2010	2	2008	United Kingdom	Butterflies	Grassland	I	16	-0.094	0.250
Hodgson et al. 2010	2	2008	United Kingdom	Butterflies	Cropland	I	16	0.000	0.250
Hodgson et al. 2010	2	2008	United Kingdom	Butterflies	Grassland	I	16	0.408	0.268
Hokkanen & Holopainen 1986	3	1984	Germany	Arthropods	Veg	I	7	1.213	0.583
Holzschuh et al. 2007*	1	2003	Germany	Bee	Cropland	I	12	2.792	0.333
Holzschuh et al. 2007*	1	2003	Germany	Bee	Cropland	I	12	1.537	0.333
Holzschuh et al. 2007*	1	2003	Germany	Bee	Cropland	I	14	0.654	0.286
Holzschuh et al. 2010*	2	2004	Germany	Solitary bees	Cropland	I	46	0.354	0.087
Hutton & Giller 2003	1	2000	Ireland	Dung beetle	Grassland	I	8	2.281	0.500
Hyvönen et al. 2003	3	1999	Finland	Plants	Cereal	I	105	3.373	0.039
Irmler 2003	1	1995	Germany	Carabid	Cropland	I	32	0.438	0.237
Jonasson et al. 2011	3	2009	Sweden	Arthropods	Cereal	I	60	1.308	0.075
Jonasson et al. 2011	3	2009	Sweden	Plants	Cereal	I	60	1.855	0.075
José-María & Sans 2011	3	2008	Spain	Plants	Cereal	I	30	1.254	0.133
José-María & Sans 2011	3	2008	Spain	Plants	Cereal	I	30	2.512	0.133
Kleijn et al. 1999	2	1998	Netherlands	Bees	Grassland	I	14	-0.086	0.286
Kleijn et al. 1999	2	1998	Netherlands	Butterflies	Grassland	I	14	-0.269	0.286
Kleijn et al. 1999	2	1998	Netherlands	Hoverflies	Grassland	I	14	0.171	0.286
Kleijn et al. 2001	1	2000	Netherlands	Plant	Grassland	I	44	0.414	0.091
Kleijn et al. 2004	2	2000	Netherlands	Bees	Grassland	I	78	0.867	0.182
Kleijn et al. 2004	2	2000	Netherlands	Bees	Grassland	I	78	0.740	0.125
Kleijn et al. 2004	2	2000	Netherlands	Bees	Grassland	I	78	0.957	0.200
Kleijn et al. 2004	2	2000	Netherlands	Hoverflies	Grassland	I	78	0.378	0.182
Kleijn et al. 2004	2	2000	Netherlands	Hoverflies	Grassland	I	78	0.697	0.125
Kleijn et al. 2004	2	2000	Netherlands	Hoverflies	Grassland	I	78	0.361	0.200
Kleijn et al. 2006*	1	2003	United Kingdom	Bee	Cropland	I	14	0.767	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Bee	Cropland	I	14	0.632	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Bee	Cropland	I	14	-0.447	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Bird	Cropland	I	14	-0.237	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Bird	Cropland	I	14	0.393	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Bird	Cropland	I	14	1.066	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Plant	Cropland	I	14	1.001	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Plant	Cropland	I	14	0.283	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Plant	Cropland	I	14	1.140	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Spider	Cropland	I	14	0.062	0.286
Kleijn et al. 2006*	1	2003	United Kingdom	Spider	Cropland	I	14	0.000	0.286

Appendix S3. Continued.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Kleijn et al. 2006*	1	2003	United Kingdom	Spider	Cropland	I	14	0.535	0.286
Kleijn et al. 2006*	1	2003	Germany	Bird	Cropland	I	12	0.180	0.333
Kleijn et al. 2006*	1	2003	Germany	Bird	Cropland	I	12	0.390	0.333
Kleijn et al. 2006*	1	2003	Germany	Bird	Cropland	I	14	-0.242	0.286
Kleijn et al. 2006*	1	2003	Germany	Grasshopper	Cropland	I	12	0.458	0.333
Kleijn et al. 2006*	1	2003	Germany	Grasshopper	Cropland	I	12	0.000	0.333
Kleijn et al. 2006*	1	2003	Germany	Grasshopper	Cropland	I	14	0.123	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Bee	Grassland	I	14	-0.578	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Bee	Grassland	I	14	0.141	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Bee	Grassland	I	12	0.000	0.333
Kleijn et al. 2006*	1	2003	Netherlands	Bird	Grassland	I	14	-0.345	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Bird	Grassland	I	14	0.703	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Bird	Grassland	I	12	0.000	0.333
Kleijn et al. 2006*	1	2003	Netherlands	Grasshopper	Grassland	I	14	-0.475	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Grasshopper	Grassland	I	14	0.000	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Grasshopper	Grassland	I	12	-0.331	0.333
Kleijn et al. 2006*	1	2003	Netherlands	Plant	Grassland	I	14	0.368	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Plant	Grassland	I	14	0.429	0.286
Kleijn et al. 2006*	1	2003	Netherlands	Plant	Grassland	I	12	0.132	0.333
Kleijn et al. 2006*	1	2003	Netherlands	Spider	Grassland	I	12	0.285	0.333
Kleijn et al. 2006*	1	2003	Netherlands	Spider	Grassland	I	8	-0.232	0.500
Kleijn et al. 2006*	1	2003	Spain	Bird	Cropland	I	14	0.564	0.286
Kleijn et al. 2006*	1	2003	Spain	Bird	Cropland	I	14	0.566	0.286
Kleijn et al. 2006*	1	2003	Spain	Bird	Cropland	I	14	0.644	0.286
Kleijn et al. 2006*	1	2003	Spain	Grasshopper	Cropland	I	6	0.693	0.667
Kleijn et al. 2006*	1	2003	Spain	Grasshopper	Cropland	I	14	0.000	0.286
Kleijn et al. 2006*	1	2003	Spain	Grasshopper	Cropland	I	14	-0.323	0.286
Kleijn et al. 2006*	1	2003	Spain	Plant	Cropland	I	6	2.339	0.667
Kleijn et al. 2006*	1	2003	Spain	Plant	Cropland	I	14	1.172	0.286
Kleijn et al. 2006*	1	2003	Spain	Plant	Cropland	I	12	0.600	0.333
Kleijn et al. 2006*	1	2003	Spain	Spider	Cropland	I	6	0.753	0.667
Kleijn et al. 2006*	1	2003	Spain	Spider	Cropland	I	14	1.773	0.286
Kleijn et al. 2006*	1	2003	Spain	Spider	Cropland	I	14	0.237	0.286
Kleijn et al. 2006*	1	2003	Switzerland	Bird	Grassland	I	14	0.313	0.286
Kleijn et al. 2006*	1	2003	Switzerland	Bird	Grassland	I	14	0.517	0.286
Kleijn et al. 2006*	1	2003	Switzerland	Bird	Grassland	I	14	0.173	0.286
Knop et al. 2006*	1	2003	Switzerland	Bee	Grassland	I	14	0.560	0.286
Knop et al. 2006*	1	2003	Switzerland	Bee	Grassland	I	14	0.985	0.286
Knop et al. 2006*	1	2003	Switzerland	Bee	Grassland	I	14	0.650	0.286
Knop et al. 2006*	1	2003	Switzerland	Grasshopper	Grassland	I	14	1.804	0.286
Knop et al. 2006*	1	2003	Switzerland	Grasshopper	Grassland	I	14	0.664	0.286
Knop et al. 2006*	1	2003	Switzerland	Grasshopper	Grassland	I	14	0.000	0.286
Knop et al. 2006*	1	2003	Switzerland	Plant	Grassland	I	14	0.408	0.286
Knop et al. 2006*	1	2003	Switzerland	Plant	Grassland	I	14	1.053	0.286
Knop et al. 2006*	1	2003	Switzerland	Plant	Grassland	I	14	2.158	0.286
Knop et al. 2006*	1	2003	Switzerland	Spider	Grassland	I	14	-0.148	0.286
Knop et al. 2006*	1	2003	Switzerland	Spider	Grassland	I	14	0.280	0.286
Knop et al. 2006*	1	2003	Switzerland	Spider	Grassland	I	14	0.406	0.286
Kohler et al. 2008*	2	2005	Netherlands	Bees	Grassland	O	16	1.411	0.220

Appendix S3. Continued.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Kohler et al. 2008*	2	2005	Netherlands	Hoverflies	Grassland	O	16	2.071	0.220
Kovács-Hostyánszki et al. 2011	2	2008	Hungary	Bees	Cropland	O	33	-1.796	0.229
Kovács-Hostyánszki et al. 2011	2	2008	Hungary	Butterflies	Cropland	O	33	3.547	0.229
Krauss et al. 2011	3	2008	Germany	Plants	Cereal	I	30	4.291	0.133
Krauss et al. 2011	2	2008	Germany	Bumblebees	Cropland	I	30	2.624	0.133
Krauss et al. 2011	2	2008	Germany	Butterflies	Cropland	I	30	1.117	0.133
Krauss et al. 2011	2	2008	Germany	Hoverflies	Cropland	I	30	2.241	0.133
Kruess & Tscharntke 2002a	1	1996	Germany	Auchenorrhyncha	Grassland	I	12	0.673	0.333
Kruess & Tscharntke 2002a	1	1996	Germany	Coleoptera	Grassland	I	12	2.292	0.333
Kruess & Tscharntke 2002a	1	1996	Germany	Heteroptera	Grassland	I	12	1.186	0.333
Kruess & Tscharntke 2002a	1	1996	Germany	Hymenoptera Parasitica	Grassland	I	12	1.349	0.333
Kruess & Tscharntke 2002b	1	1996	Germany	Caelifera	Grassland	I	12	1.348	0.333
Kruess & Tscharntke 2002b	1	1996	Germany	Ensifera	Grassland	I	12	0.873	0.333
Kruess & Tscharntke 2002b	1	1996	Germany	Plant	Grassland	I	12	0.184	0.333
Kruess & Tscharntke 2002b	1	1996	Germany	Trap nesting bee	Grassland	I	12	0.603	0.333
Kruess & Tscharntke 2002b	2	1996	Germany	Butterflies and Burnet moths	Grassland	I	12	1.473	0.333
Kvarnbäck 2009	2	2008	Sweden	Bumblebees	Cropland	O	12	1.046	0.400
Kvarnbäck 2009	2	2008	Sweden	Butterflies	Cropland	O	12	1.225	0.400
Macfadyen et al. 2009	3	2006	United Kingdom	Arthropods	Cereal	I	20	1.237	0.200
Macfadyen et al. 2009	3	2006	United Kingdom	Arthropods	Cereal	I	20	1.031	0.200
Macfadyen et al. 2009	3	2006	United Kingdom	Plants	Cereal	I	20	1.084	0.200
Mand et al. 2001	2	2000	Estonia	Bumblebees	Cropland and grassland	I	24	0.821	0.167
Manhoudt et al. 2007	1	2003	Netherlands	Plant	Grassland	I	10	1.984	0.417
Manhoudt et al. 2007	1	2003	Netherlands	Plant	Grassland	I	28	1.084	0.146
Marshall et al. 2006*	1	2003	United Kingdom	Grasshopper	Grassland	I	14	0.323	0.286
Marshall et al. 2006*	1	2003	United Kingdom	Grasshopper	Grassland	I	14	1.332	0.286
Marshall et al. 2006*	1	2003	United Kingdom	Grasshopper	Grassland	I	14	1.138	0.286
Meek et al. 2002	2	1999	United Kingdom	Butterflies	Cropland	O	8	-0.037	0.500
Meek et al. 2002	2	1999	United Kingdom	Butterflies	Cropland	O	8	0.971	0.500
Merckx et al. 2009	2	2006	United Kingdom	Larger moths	Cropland	O	48	1.369	0.500
Merckx et al. 2009	2	2006	United Kingdom	Larger moths	Cropland	O	48	1.553	0.500
Moreby et al. 1994	1	1991	United Kingdom	Plant	Cropland	I	62	3.160	0.065
Muchow et al. 2007	2	2006	Germany	Bees	Cropland	O	45	1.995	0.278
Muchow et al. 2007	2	2006	Germany	Butterflies	Cropland	O	18	2.054	0.278
Nickel & Achtziger 2005	1	1996	Germany	Leafhoppers	Grassland	I	8	0.962	0.667
Nickel & Achtziger 2005	1	1996	Germany	Leafhoppers	Grassland	I	9	2.198	0.643
Öberg 2007	1	2004	Sweden	Linyphiidae	Cropland	I	8	-1.541	0.533
Peter & Walter 2001	1	2000	Switzerland	Grasshopper	Grassland	I	304	0.301	0.013
Petersen et al. 2006	1	2002	Denmark	Plant	Grassland	I	40	1.352	0.100
Ponce et al. 2011	3	2008	Spain	Arthropods	Cereal	I	56	0.578	0.071
Ponce et al. 2011	3	2008	Spain	Plants	Cereal	I	56	1.907	0.071
Power & Stout 2011	3	2009	Ireland	Plants	Grass	I	20	1.007	0.200
Power & Stout 2011	2	2009	Ireland	Bees	Grassland	I	20	0.609	0.200
Power & Stout 2011	2	2009	Ireland	Hoverflies	Grassland	I	20	0.127	0.200
Purtauf et al. 2005	3	2002	Germany	Arthropods	Cereal	I	24	-0.269	0.167
Pywell et al. 2005	2	2003	United Kingdom	Bumblebees	Cropland	O	76	2.725	0.125
Pywell et al. 2005	2	2003	United Kingdom	Bumblebees	Cropland	O	86	2.334	0.071
Pywell et al. 2006	2	2004	United Kingdom	Bumblebees	Cropland	O	64	1.363	0.063
Pywell et al. 2006	2	2004	United Kingdom	Bumblebees	Cropland	O	64	2.888	0.075

Appendix S3. Continued.

Publication	*Source*	*Study year*	*Country*	*Organism*	*Habitat*	*AES*	*N*	*g*	*np var g*
Reddersen 1997	3	1988	Denmark	Arthropods	Cereal	I	34	3.462	0.118
Risberg 2004	2	2002	Sweden	Bumblebees	Cropland	I	10	0.140	0.400
Romero et al. 2008	1	2004	Spain	Plant	Cropland	I	36	2.044	0.111
Roschewitz et al. 2005	1	2002	Germany	Plant	Cropland	I	24	2.310	0.167
Roth et al. 2008	2	2000	Switzerland	Butterflies	Cropland and grassland	I	87	0.448	0.048
Rundlöf & Smith 2006	2	2004	Sweden	Butterflies and Burnet moths	Cropland	I	24	0.561	0.333
Rundlöf & Smith 2006	2	2004	Sweden	Butterflies and Burnet moths	Cropland	I	24	1.890	0.333
Rundlöf et al. 2010	3	2004	Sweden	Plants	Mixed	I	14	2.761	0.286
Rundlöf et al. 2010	3	2004	Sweden	Plants	Mixed	I	14	2.196	0.286
Rundlöf et al. 2010	3	2004	Sweden	Plants	Mixed	I	14	2.927	0.286
Rundlöf et al. 2008a	2	2005	Sweden	Butterflies and Burnet moths	Cropland	I	16	3.867	0.250
Rundlöf et al. 2008b	2	2004	Sweden	Bumblebees	Cropland	I	24	0.648	0.333
Rundlöf et al. 2008b	2	2004	Sweden	Bumblebees	Cropland	I	24	2.289	0.333
Salonen & Hyvönen 2011	3	1999	Finland	Plants	Cereal	I	595	1.922	0.016
Salonen et al. 2001	3	1999	Finland	Plants	Cereal	I	30	0.272	0.133
Schmidt et al. 2005	1	2002	Germany	Spider	Cropland	I	24	-0.143	0.167
Sepp et al. 2005	1	2002	Estonia	EArthropodsworm	Cropland	I	15	0.074	0.300
Sepp et al. 2005	1	2002	Estonia	EArthropodsworm	Cropland	I	15	0.073	0.300
Shah et al. 2005	1	1994	United Kingdom	Carabid	Cropland	I	20	-0.771	0.200
Shah et al. 2005	1	1994	United Kingdom	Rove beetle	Cropland	I	20	0.000	0.200
Sjödin et al. 2008	2	2004	Sweden	Bees	Grassland	I	16	0.081	0.250
Sjödin et al. 2008	2	2004	Sweden	Butterflies and Burnet moths	Grassland	I	16	-0.111	0.250
Sjödin et al. 2008	2	2004	Sweden	Hoverflies	Grassland	I	16	0.652	0.250
Smith et al. 2010	3	2005	Sweden	Birds	Cereal	I	24	1.032	0.167
Smith et al. 2010	3	2005	Sweden	Birds	Cereal	I	24	-0.153	0.167
Steffan-Dewenter & Tscharntke 1997	2	1992	Germany	Butterflies	Cropland	O	8	5.942	0.500
Steffan-Dewenter & Tscharntke 1997	2	1992	Germany	Butterflies	Cropland	O	8	2.341	0.500
Steffan-Dewenter & Tscharntke 2001	2	1993	Germany	Bees	Cropland	O	8	1.425	0.500
Steffan-Dewenter & Tscharntke 2001	2	1993	Germany	Bees	Cropland	O	8	-0.464	0.500
Ulber et al. 2009	3	2007	Germany	Plants	Cereal	I	16	0.850	0.250
Van der Gast et al. 2011	3	2003	United Kingdom	Microbes	Mixed	I	18	0.549	0.222
van Diepingen et al. 2006	3	2001	Netherlands	Microbes	Mixed	I	28	0.854	0.143
van Diepingen et al. 2006	3	2001	Netherlands	Nematodes	Mixed	I	28	0.572	0.143
Verbruggen et al. 2010	3	2007	Netherlands	Microbes	Cereal	I	26	0.844	0.154
Weibull & Östman 2003	3	1998	Sweden	Arthropods	Mixed	I	16	-0.075	0.250
Weibull & Östman 2003	3	1998	Sweden	Arthropods	Mixed	I	16	0.962	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.027	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.278	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-1.058	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.096	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.611	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.817	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.369	0.250
Weibull & Östman 2003	3	1999	Sweden	Arthropods	Mixed	I	16	-0.062	0.250
Weibull & Östman 2003	3	1998	Sweden	Plants	Mixed	I	16	0.301	0.250
Weibull & Östman 2003	3	1998	Sweden	Plants	Mixed	I	16	-0.190	0.250
Winqvist et al. 2011	3	2007	Sweden, Estonia, W+E Germany, Netherlands	Arthropods	Cereal	I	151	0.065	0.030
Winqvist et al. 2011	3	2007	Sweden, Estonia, W+E Germany, Netherlands	Birds	Cereal	I	151	0.227	0.030
Winqvist et al. 2011	3	2007	Sweden, Estonia, W+E Germany, Netherlands	Plants	Cereal	I	151	0.451	0.030
Yeats et al. 1997	3	1994	United Kingdom	Protozoa	Grass	I	6	0.285	0.667

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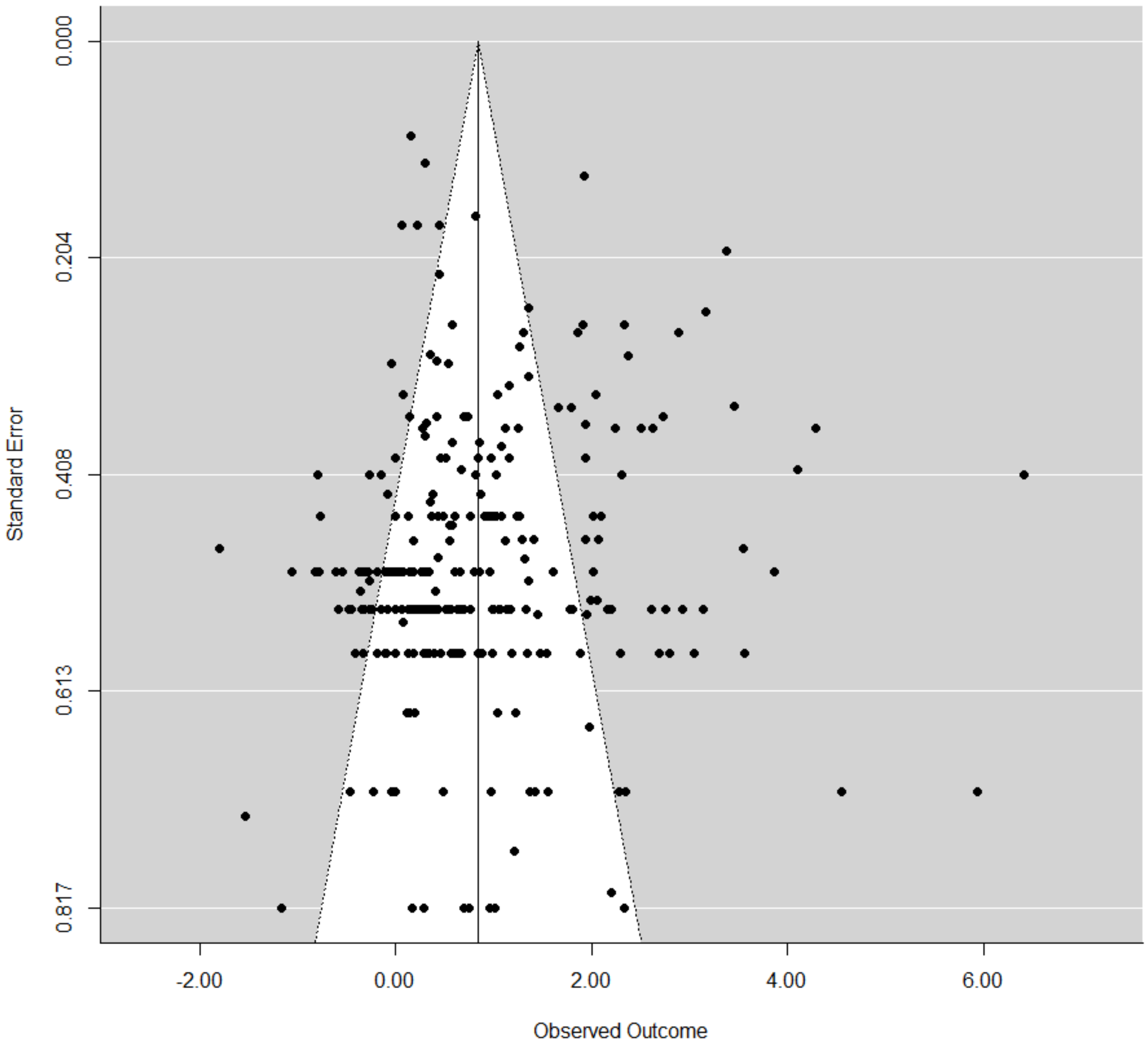
Appendix S4. Funnel plot, regression test and fail-safe number.



Regression test for funnel plot asymmetry in meta-analysis with the moderator budget period (predictor: sample size): z = 0.834, p = 0.405

Regression test for funnel plot asymmetry in meta-analysis with the moderator AES type (predictor: sample size): z = 0.815, p = 0.415

Rosenthal fail-safe number (target level p = 0.05): 111848

Appendix S5. Summary table of meta-analyses showing tests of moderator and residual heterogeneities and inconsistency indexes.

	d.f.	*Q*	*P*	I^2 (%)
Period				
Moderator	1	0.06	0.814	85.6
Residual	282	1975.41	<0.001	
AES type				
Between groups	1	17.20	<0.001	84.8
Within groups	66	1889.49	<0.001	

Appendix S6. ISO2 codes with country names for the 30 countries having AES in the continent. Further country codes are available at URL: https://www.iso.org/obp/ui/#search

Code	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
UK	United Kingdom

Appendix S7. Further discussion on "How cost-effective are AES compared to other conservation approaches such as protected farmland areas?"

AES and protected areas do not have to be opposing strategies. With careful spatial planning, they can work together as co-ordinated landscape-scale conservation. For example, AES can be used to create lower-intensity buffers around protected areas to increase their effective size. So far, AES have rarely been targeted in this fashion and the effectiveness of such an approach is entirely untested.

On the other hand, in given cases, AES and protected areas as opposing strategies cannot be separated. For example, in Hungary about 10-20 % of the income of some national park directories with significant areas of semi-natural grasslands comes from AES (István Szentirmai, Őrség National Park Directorate, pers. comm.). This means that AES are used to maintain the protected areas (Báldi et al. 2013).

In principle, AES could also be used to take larger areas of farmland out of production, to protect or restore wild habitats or deliver ecosystem services at catchment scale. Both types of spatial AES planning could be implemented by promoting collaboration between neighbouring farmers. This is already in action in Switzerland (Anonymous 2014), and has been proposed as part of the new AES offer in England (McKenzie et al. 2013).

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