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Review

The cost-effectiveness of agri-environment schemes for biodiversity conservation: A quantitative review

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ABSTRACT

Agri-environment schemes (AES), where farmers receive payments in exchange for providing public goods and services such as biodiversity, account for a major proportion of conservation expenditure in agricultural landscapes around the world. The variable effectiveness of such schemes and increasing recognition of the importance of cost-effective conservation – maximizing conservation benefit for a fixed cost or minimizing cost of achieving a specific conservation outcome – has prompted calls over the past decade for integration of economic costs into evaluation. We reviewed the global agri-environmental evaluation literature to determine what proportion of studies evaluating biodiversity conservation effectiveness consider costs and cost-effectiveness and whether there has been an increase in this integration over time. Less than half of the studies reviewed made any reference to the costs of AES, and fewer than 15% included any measure of cost-effectiveness. Despite steady growth in the number of published AES evaluations over the past 15 years, and a gradual increase in the number of studies that acknowledge costs, the proportion of studies published annually that integrate economic data into evaluation remains largely unchanged. Various reasons have been identified for this poor integration, including limited understanding of, and access to, economic evaluation tools, data and training, and a philosophical aversion to the mixing of economics and conservation. We argue however that these reasons are no longer justified, and highlight several examples of the effective integration of economic and ecological data in evaluations to assist researchers and decision-makers in addressing this deficiency.

Contents

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1. Introduction

Balancing the agricultural development required to feed a growing global human population with the conservation of biodiversity is a key challenge for society (Green et al., 2005; Tilman et al., 2011). Agricultural development and intensification has been linked to biodiversity declines and other ecosystem impacts around the world (Donald et al., 2001; Stoate et al., 2009; Venter et al., 2006) and represents the largest single threat to biodiversity conservation globally (Secretariat of the Convention on Biological Diversity, 2014). Over the past three decades, governments have increasingly used incentive-based mechanisms to protect and restore biodiversity on farmland. Agri-environment schemes (AES), which broadly involve payments to farmers in exchange for environmental goods and services such as biodiversity conservation (Burrell, 2012), provide one such approach. Schemes range widely in scale, complexity and focus, from those that promote input reduction (e.g. organic farming), to land retirement and active habitat restoration, though they have the common broad objective of maintaining or improving specific environmental values such as biodiversity as well as water, soil and air quality (Barral et al., 2015; Rey Benayas and Bullock, 2012).

AES are now the focus of significant investment around the world, with agri-environmental investment in many countries often equal to, or surpassing that of other conservation expenditure (Batáry et al., 2015). In the past decade, the European Union and the US combined have spent more than USD$35 billion on AES (European Commission, 2014; USDA Farm Service Agency, 2015a). European Union member states are required under the Common Agricultural Policy (CAP) to establish AES. The CAP committed EUR95.58 billion to rural development over the next five years, the majority of which is dedicated to AES (European Commission, 2013). The United States Conservation Reserve Program (CRP), a long running land retirement initiative with an annual budget of approximately USD $2 billion (Stubbs, 2013), has more than 24 million acres (9.7 million hectares) enrolled (USDA Farm Service Agency, 2015b). In Australia, the Environmental Stewardship Program committed approximately AUD $152 million in payments to farmers for restoration and protection of priority ecosystems (Burns et al., in press). Significant schemes have also been implemented elsewhere in North America (McMaster and Davis, 2001) as well as within Latin America (Sierra and Russman, 2006), Africa (Kehinde and Samways, 2014) and Asia (Li et al., 2013).

The growth in AES investment has fueled ongoing debate over the effectiveness and efficiency of these schemes as strategies for biodiversity conservation in agricultural landscapes. While several studies have found biodiversity improvements in response to changed agricultural practices under AES programs (e.g. Knop and Kleijn, 2006; MacDonald et al., 2012), others have shown mixed or limited benefits (e.g. Feehan et al., 2005; Kleijn et al., 2004; Verhulst et al., 2007), and even negative biodiversity outcomes (e.g. Besnard and Secondi, 2014; Fuentes-Montemayor et al., 2011). Despite their mixed success, AES now represent the dominant policy instrument for conserving biodiversity in agricultural landscapes. Indeed, some have suggested AES provide the only realistic tool to address biodiversity declines in farmland (Donald and Evans, 2006). The continued political and public support for these initiatives requires increased confidence that they represent the best use of public funds. This requires consideration of cost-effectiveness, being a comparison between alternatives of the benefits per dollar spent or identification of the lowest cost alternative to achieve a specific outcome (Wätzold and Schwerdtner, 2005).

Evaluating the cost-effectiveness of AES requires an understanding of not only the ecological effectiveness of schemes, but also understanding of the economic costs (hereafter referred to generally as costs). However, there remains a lack of integration between economic and ecological perspectives and techniques across conservation science in general, with crucial economic information (e.g. program costs) often ignored in program evaluation (Naidoo et al., 2006; Wortley et al., 2013). A review of 2000 restoration studies found that none performed any analysis of cost-effectiveness, and fewer than 5% provided 'meaningful' cost data (TEEB, 2009). Kleijn and Sutherland (2003) found that none of 62 European AES evaluation studies surveyed addressed issues of cost-effectiveness. These issues have prompted repeated calls over the past 15 years for the integration of economic and ecological factors in the evaluation of AES (Balana et al., 2011; Kleijn and Sutherland, 2003; Uthes and Matzdorf, 2013; Whitby, 2000). But have these calls been answered?

This paper aims to address these questions by reviewing, at a global scale, the extent to which studies evaluating the biodiversity benefits of agri-environment Schemes 1) acknowledge economic costs, and 2) provide any measure of cost-effectiveness. While there may be other public or private benefits of AES, we consider only evaluation of biodiversity-related benefits. We consider the nature of the AES employed, the type of evaluation tools used and the agricultural context in which they are applied to investigate whether there are biases in coverage of different AES. We also explore possible reasons behind observed trends in the integration of costs in AES evaluation and identify solutions to assist evaluators and program managers to improve future evaluations. To our knowledge, this is the first global scale, quantitative review of agri-environment schemes, and one of few studies to focus on the cost-effectiveness of agri-environmental policy (Balana et al., 2011; Claassen et al., 2008; Uthes and Matzdorf, 2013). By exploring the coverage of cost-effectiveness in the evaluation literature, we hope to draw further attention to an increasingly important issue which can ultimately improve the efficiency of conservation expenditure.

2. Methods

2.1. Literature search

We performed a quantitative review of the literature published up to, and including, 2014 using ISI Web of Science and Scopus databases. We aimed to identify studies focusing on the evaluation of the effectiveness, from a biodiversity conservation perspective, of conservation activities—for example planting for habitat, organic farming and sustainable grazing (hereafter referred to as 'interventions')—delivered through AES exclusively on agricultural land. We considered as AES any voluntary scheme that involved any payments (one-off or ongoing) made to landholders by any public or private funding body for any type of intervention. We did not consider schemes implemented under regulatory mechanisms (e.g., EU Nitrate Directive) that mandate or encourage adoption of conservation measures. We only included studies where the protection or restoration of populations, species, communities or ecosystems represented at least one objective of management.

Initial review of the literature revealed geographic bias in the use of the term 'agri-environment scheme', which is used extensively in Europe but less so elsewhere, particularly in the Americas. Our search terms therefore were broad in order to capture schemes labeled under different terms. The following search terms were used: (habitat$ OR bird$ OR amphibian$ OR mammal$ OR reptile$ OR plant$ OR invertebrate$ OR threaten* OR threatened$species) AND (farm* OR agricultur*) AND (agri-environment OR ecological$restoration OR restoration OR biodiversity$conservation OR biodiversity$protection OR conserv*) AND (cost* OR cost$effective* OR effective* OR evaluat* OR outcome$ OR monitor* OR success* OR assess* OR cost$benefit OR benefit$cost). To minimize the number of non-target articles, we excluded database categories that were of no relevance to the subject (e.g. engineering, medical, health, legal, political).

This search strategy identified 16,574 references (Scopus: 9529; Web of Science: 7045; searches performed on 4 February 2015) which were initially screened by journal title, article title and topic to remove those clearly not relevant to the study. This process identified 931 references which were then further screened through review of abstracts, excluding those that were: published in languages other than English; not considered AES by our definition (see above); focused solely on economic, social or public policy aspects; concerned with schemes targeting resource-extraction (i.e. agro-forestry, mining) and urban environments; or published as book chapters, conference proceedings, or in non-peer reviewed publications. We also excluded discussion-type studies and literature reviews from analysis but cross-referenced studies cited therein. This process reduced the list from 931 to 239 references which formed the basis of our analysis.

2.2. Literature analysis

Our approach scaled the level of analysis to the relevance of the paper using a three-tiered system. Group 1 included all (239) studies that provided some evaluation of conservation effectiveness. A subset of these (Group 2) comprised studies that made any reference to the cost of interventions and/or the cost of the AES policy as a whole. This included any use of the cost-related terms and symbols identified through full text searches (e.g. expenditure, budget, cost, economic, investment, dollars, $) and did not require identification of actual expenditure. Lastly, Group 3 was a subset of Group 2 that included studies that explicitly considered cost-effectiveness. To be included within this group, studies needed to use any cost data in any form in their evaluation of the AES. We included studies that used any economic evaluation technique, regardless of complexity, and including techniques using both monetized (i.e. cost-benefit analysis) and non-monetized benefits (i.e. cost-effectiveness analysis or multi-criteria analysis). This approach allowed us to address our key research questions by identifying the proportion of studies that consider cost and cost-effectiveness across the AES evaluation literature. We then explored the types of techniques used and the context in which they were implemented.

Details of the information extracted from studies under each group are provided in Supplementary information (Table S1). In summary, for Group 1, we extracted general information such as publication details, as well as details of the study, the scheme and its objectives. We also identified the effectiveness measure/s used and whether or not costs were considered. For Group 2 we further described the cost data used, and for Group 3 we extracted information relating to the type of economic evaluation used to assess cost-effectiveness.

3. Results

3.1. General information (Group 1)

The 239 Group 1 studies were published between 1992 and 2014, with 53% published since 2010. The studies were from 67 journals, though four journals (*Agriculture, Ecosystems and Environment*,*Biological Conservation*, *Journal of Applied Ecology* and *Journal of Wildlife Management*) accounted for 41% of total publications (Supplementary information, Table S2).

Studies were conducted on AES across 25 countries covering each of the major geographic regions. The majority of the studies were concerned with AES in Europe (160 studies; 67%), of which most studies were in England (40 studies), France (19), Netherlands (16), Switzerland (15) or Germany (10). North America was the second most studied region (67 studies; 28%), of which most were undertaken in the United States. While studies were also conducted on AES within Asia, Africa, Oceania and Latin America, combined they only represent 5% of studies reviewed. Consistent with the geographic focus of the studies reviewed, more schemes were aligned to the EU Common Agricultural Policy than with any other initiative (69 studies; 29%), followed by the US CRP (50 studies; 20.9%) and Switzerland's Ecological Compensation Areas scheme (13 studies; 5%). Interestingly, 47 studies (19.7%) did not identify the particular AES on which the study was undertaken.

Cropping-dominated landscapes (104 studies; 43.5%) were represented more strongly than those dominated by

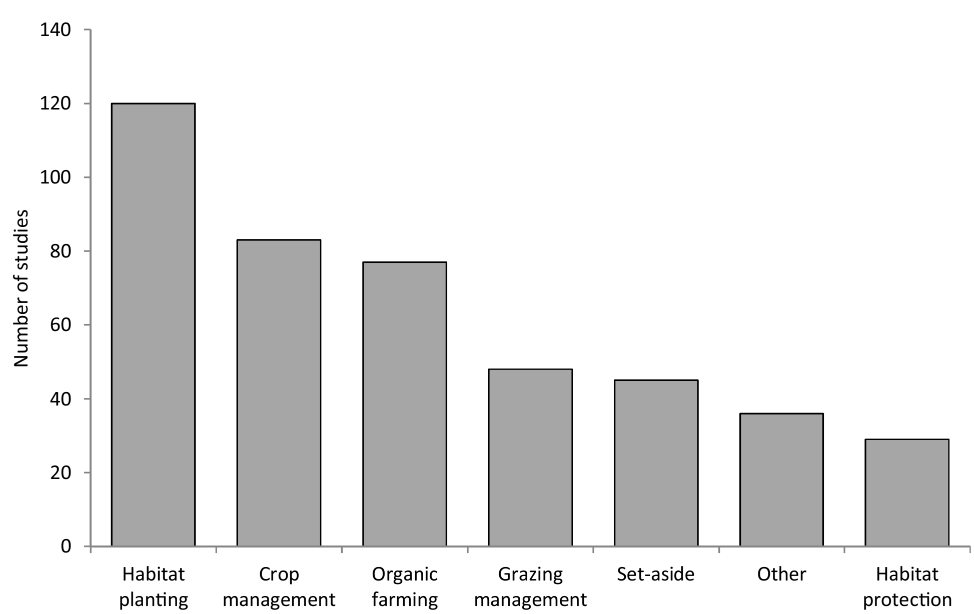

Fig. 1. Types of interventions applied in the agri-environment schemes under evaluation. Note: many studies covered schemes involving multiple interventions. See Supplementary information (Table S1) for further information on categories.

pasture-grazing systems (37 studies; 15.4%), though 29.7% of studies were conducted in mixed (grazing and cropping) landscapes. The most dominant intervention type was habitat plantings (120 studies; 50%), predominantly involving wildflower or grass buffers or strips around crop margins, followed by crop management interventions (83 studies; 35%), including measures such as retention of crop stubble (e.g. Suárez et al., 2004) and altering timing of agricultural practices (Adams et al., 2013) (Fig. 1).

The most common reported objective of the AES under evaluation was biodiversity in general (118 studies; 49%). The conservation of a single species was the focus of AES in 16 studies (7%), whereas the schemes evaluated in 39 studies (16%) were targeted at multiple species, particularly groups of similar species (e.g. waterbirds; Wilson et al., 2007). Accordingly, the objective of most evaluations (rather than the objective of the scheme itself) was the effectiveness of the AES on multiple species (190 studies; 79%), varying from whole taxonomic groups (e.g. butterflies; Aviron et al., 2011) to as few as two species (Conover et al., 2011). Forty-five studies (18%) focused on the benefits for single species. Similar numbers of studies were concerned with broader biodiversity benefits (32 studies) or habitat and/or ecosystem-related objectives (45 studies).

Birds were the most commonly studied species (123 studies; 51%), followed by plants, (101 studies; 42%) and invertebrates (62 studies; 26%). Only 13 (5%) studies were concerned with mammals, 5 (2%) focused on herpetofauna and 1 (<1%) on fish. Evaluations mostly used multiple measures of effectiveness (189 studies; 79%), combining measures such as abundance, breeding success and habitat quality (e.g. Blank et al., 2011), compared to those using only a single measure (50 studies; 21%). Direct measures of effectiveness were dominant (201 studies; 84% of total), with variables such as abundance, richness and vegetation cover most commonly used. The 34 studies that used proxies or indirect measures of effectiveness predominantly focused on spatial area (e.g., amount of land enrolled) (15 studies). Benefit indices were also used as surrogates (6 studies), predominantly in model-based evaluations. For example, Uthes et al. (2010) used an aggregate index combing multiple environmental values (biodiversity, soil, water and landscape) to compare the cost-effectiveness of alternative interventions and spatial targeting approaches.

Most studies were conducted at a single scale, with the majority focused on the 'landscape or regional' scale (187 studies; 78%), followed by 'farm' scale (48 studies; 20%) and 'field' scale (4 studies; 2%). The remaining studies were conducted across multiple scales, most commonly at the farm and landscape or regional scales (15 studies; 6%). More than 200 (87%) of the studies were undertaken during or after the implementation of the scheme(s) (*ex post*), whereas only 36 studies (15%) included an *ex ante* component, typically involving modelling of likely biodiversity outcomes (e.g. Chiron et al., 2013).

3.2. Consideration of cost (Group 2)

Of the 239 studies reviewed, only 115 (48%) made some reference to the cost associated with the AES (see Methods). These articles were spread across 50 journals, though two journals, *Agriculture, Ecosystems and Environment* (16 articles) and *Biological Conservation* (11), represented almost a quarter of studies. The average annual percentage of Group 1 studies that referred to costs (i.e. Group 2) was 46.5% ± 27% (mean ± S.D, n = 19), and did not significantly increase over time (linear regression, r = 0.05, p = 0.8, n = 19) (Fig. 2).

Fifty-six of the 115 Group 2 studies (49%) reported specific costs, of which 42 provided the total cost of the scheme in question, the remainder providing only costs of components of the scheme (e.g. incentive payment rates; Elts and Lohmus, 2012). Thirty-three studies gave actual costs, the remainder used estimated costs or did not specify. There was a strong focus on public expenditure, with 21 of the 56 studies that reported cost information providing public costs exclusively, or in combination with private costs (14 studies), both in terms of privately funded (e.g. nongovernment organizations) and costs incurred by the farmer. The remaining 21 studies did not specify the source of the cost data provided. Twenty-two of 56 studies (39%) measured the opportunity cost to the farmer of enrollment in AES. For example, Wynn (2002)

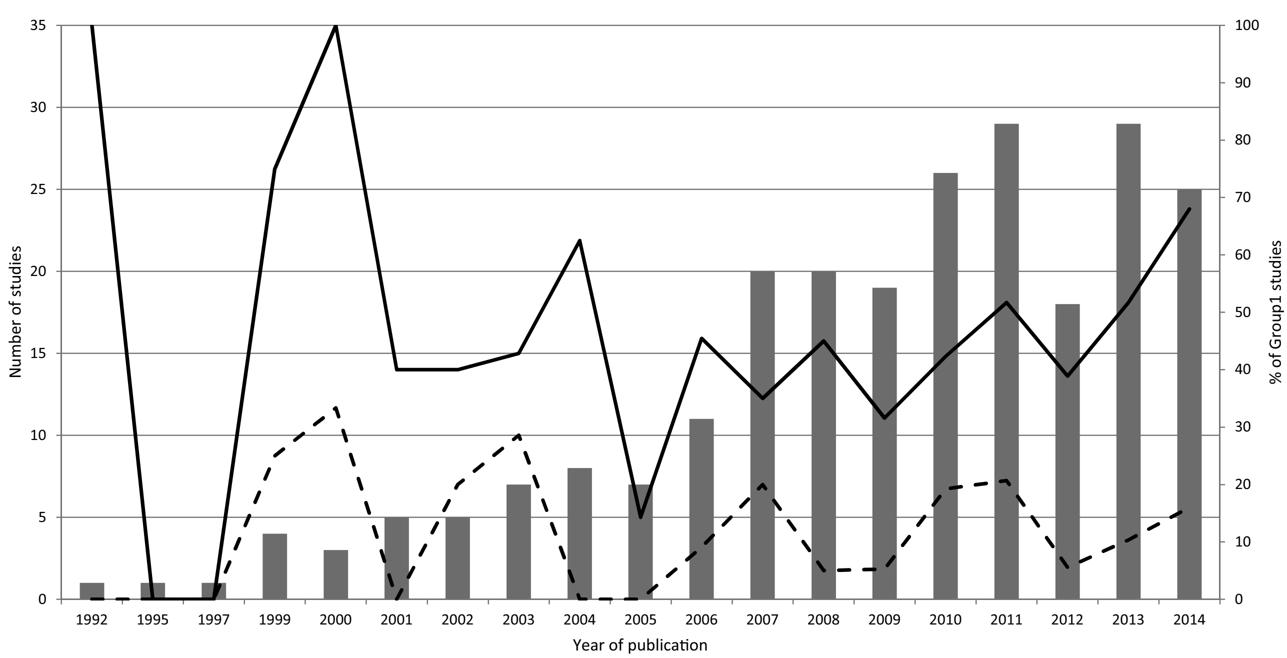

Fig. 2. 'Temporal trends in publication of agri-environment scheme evaluations. The year of publication for all 239 studies included in the review (categorized as Group 1 in text) is shown in columns. Of the Group 1 studies, the annual percentage that acknowledge economic costs (Group 2) is displayed in the solid line, whereas the percentage that include some measure of cost-effectiveness (Group 3) appears as the dashed line.

calculated per hectare opportunity costs of enrollment in the UK Environmentally Sensitive Areas scheme to the farmer through a regression of reduced gross margin with area enrolled.

3.3. Evaluation of cost-effectiveness (Group 3)

Of the 239 Group 1 studies, only 31 (13%) involved some form of evaluation of cost-effectiveness (Fig. 2; see Methods for criteria). These studies were published from 1999 to 2014, 61% of them since 2010. The studies were published in 21 journals, though more than a quarter were published in *Ecological Economics* (5 studies) and *Biological Conservation* (3 studies). The average annual proportion of Group 1 studies that integrate cost data in analysis (i.e. Group 3) was 11.5% ± 10.7% (mean ± S.D, n = 19), and did not significantly increase over time (linear regression, r = 0.18, p = 0.47, n = 19) (Fig. 2).

The majority of the Group 3 studies (24 studies; 77%) used cost-effectiveness analysis or variants thereof, where the measure of effectiveness was not monetized (e.g., species richness, area). These varied from a simple comparison of biodiversity response with estimated costs, to more sophisticated model-based approaches. Wilson et al. (2007), for example, simply compared the average cost to produce one additional breeding pair of waders between three different subsidy levels under the UK's Environmentally Sensitive Areas scheme. In contrast, Barraquand and Martinet (2011) used a dynamic ecological-economic model to test the cost-effectiveness of a grassland conservation subsidy, comparing it to a compliance-based (i.e. taxation) measure, revealing the complex relationship between costs and benefits and highlighting the importance of accounting for spatio-temporal variability in evaluation.

Five studies (16%) used cost-benefit analysis –type methods, where costs of the scheme were compared to a measure of benefit assigned a monetary value. For example, Chabé-Ferret and Subervie (2013) conducted separate cost-benefit analyses on each of five AESs, deriving estimates of social value for each scheme from the literature and comparing this to costs of implementation. Hansen (2007) combined estimates of the social value of habitat for wildlife viewing and hunting to generate a monetized measure of benefit in an analysis of the CRP.

Most (18 of 31) of the Group 3 studies were *ex ante* evaluations, using estimated costs, whereas the majority of the 13 *ex post* studies used actual costs. Most (20) studies used proxies for measures of ecological effectiveness, with only 11 involving direct measurement. Area-based measurements (e.g. amount of land enrolled; Thompson et al., 1999) were most common among those using proxies, followed by the use of benefit indices (e.g. Stoneham et al., 2003). Studies using direct measures of effectiveness tended to use actual costs in the analysis (6 of 11), whereas those involving proxies focused on estimated costs (16 of 20). However, authors of some of the modelling-based evaluations urged field-based research to validate conclusions (e.g. Bamière et al., 2013; Barraquand and Martinet, 2011).

4. Discussion

The benefits of considering cost in the planning and evaluation of conservation programs have been well demonstrated by several key studies (Boyd et al., 2015; Joseph et al., 2009; Stoneham et al., 2003). And yet this review shows that the integration of economic and ecological data in evaluations is significantly lacking and shows no indication of improving. Less than half of the studies reviewed here included any reference to costs of agri-environment schemes, and only 13% considered issues of cost-effectiveness. Below we consider the potential reasons behind this lack of integration and highlight several studies that illustrate the benefits of considering cost-effectiveness.

4.1. The AES evaluation literature

The AES evaluation literature in general reflects the focus of agri-environmental investment and research around the world. While there were studies from each major geographic region, there was a strong bias towards European and North American studies, explained by those regions committing billions of dollars annually to AES (European Commission, 2013; USDA Farm Service Agency, 2015a). The emphasis on arable landscapes, and on measures involving restoration of vegetative buffers around crop margins, further reflects the focus of conservation investment within those regions. Unfortunately this translates to limited measures of biodiversity effectiveness, with a focus on a small number of taxa, particularly grassland or open field birds and plants. This taxonomic bias, evident across the broader conservation literature (Fazey et al., 2005), comes at the expense of knowledge of the benefits of AES to other taxonomic groups, such as mammals and reptiles, that could potentially benefit through restoration measures on farmland (MacDonald et al., 2007). This may reflect difficulties in obtaining sufficient sample sizes of these taxa in farmland, or alternatively could be indicative of a focus of AES towards certain taxonomic groups, possibly due to concerns over potential impacts of certain species, particularly mammals, on agricultural production (Reid et al., 2007).

There was a strong focus on *ex post* evaluations which are considered important because they allow assessment of whether anticipated benefits materialized, and can be used to inform the design of future programs to improve effectiveness and efficiency (OECD, 2012). Such evaluations, however, may underestimate benefits if carried out too soon after scheme completion owing to the long time lags that can occur before ecological outcomes are achieved (Burrell, 2012). *Ex ante* evaluations can address this by using expected costs and benefits to model cost-effectiveness in advance of the scheme and can improve the effectiveness and efficiency of AES expenditure through spatial targeting of conservation measures (e.g. Reynolds et al., 2006), selecting between policies or delivery mechanisms (e.g. Bamière et al., 2013), or maximizing the biodiversity benefits of individual measures (e.g. Delattre et al., 2010). Such evaluations have the added advantage of being less resource intensive than field-based *ex post* approaches, but are subject to different challenges such as uncertainty in biodiversity outcomes and accounting for future costs (OECD, 2012; Robbins and Daniels, 2012).

AES evaluation studies have increased over the past two decades, particularly from 2000 onwards. Uthes and Matzdorf (2013) found a similar trend in the publication of AES-related studies in Europe. This is most likely a reflection of the increased investment in the CAP (European Commission, 2013) and the entrenchment of AES in EU policy in 2000, making them mandatory for EU member states (Uthes and Matzdorf, 2013). Annual funding for Rural Development under the CAP, for which AES are the dominant mechanism, has increased from approximately EUR 2 billion in 1990 to closer to EUR15 billion in 2014 (European Commission, 2013). Similarly, total annual rental payments under CRP increased from USD$82.9 million in 1987 to $1.63 billion in 2014 (USDA Farm Service Agency, 2015a). This growth in agri-environmental policy does not appear, however, to have been matched with a commensurate increase in economic evaluations, or at least integration of economic data into evaluation. As a proportion of total studies published annually, the number looking at issues of cost-effectiveness has remained low since calls were made to consider economic issues in AES evaluation (Kleijn and Sutherland, 2003; Whitby, 2000).

4.2. AES cost-effectiveness studies

The few studies reviewed that integrated cost information demonstrate the versatility in approaches and agricultural land use contexts in which evaluations can be undertaken, including cropping-dominated systems (e.g. Santangeli et al., 2014), as well as grazing (e.g. Boitani et al., 2010; Wynn, 2002) and mixed-enterprise landscapes (e.g. Bamière et al., 2011).

As also noted by Wätzold and Schwerdtner (2005), we observed a focus on spatiotemporal allocation of conservation measures in the AES literature, possibly in recognition of the high variability in cost and benefits in space and time. Spatial variation in effectiveness can be a major factor influencing the variable cost-effectiveness of conservation measures (Kimball et al., 2015). The studies reviewed here show this variation operates at all scales, from within individual farms and even fields (e.g. Pietzsch et al., 2013) to landscapes and across states (e.g. Hansen, 2007). This is further complicated by variability in cost, largely as a result of variation in productivity and therefore opportunity costs, which can be substantial. For example, Klimek et al. (2008) reported 600% variation in the conservation costs identified by farmers in a scheme targeting protection of plant diversity.

Many studies focussed on the efficiency of scheme delivery mechanisms, often contrasting fixed rate, area-based payments with alternatives such as auctions (e.g. Bamière et al., 2013; Stoneham et al., 2003) or spatial targeting approaches (e.g. Lewis et al., 2009; Thompson et al., 1999). Stoneham et al. (2003) found that a fixed-price AES delivered 25% less biodiversity benefit than the same budget administered using an auction mechanism. Bamière et al. (2013) reported a cost saving of 50% using an auction-based approach in the conservation of avian habitat, potentially doubling the amount of conservation that could be achieved with the same budget using a simple area-based subsidy. A 'payment by results' approach achieved a 17% saving compared to fixed payments in the conservation of remnant habitats on agricultural land (White and Sadler, 2012). While more sophisticated delivery mechanisms such as these can be more cost-effective (Thompson et al., 1999), the increased transaction costs associated may decrease overall program efficiency (Klimek et al., 2008; Lewis et al., 2009). Uthes et al. (2010) also suggested that such approaches are less cost-effective than more general ('horizontal') approaches when multiple environmental objectives are involved.

The complex relationship between cost and benefit is also further illuminated by these studies. While some show an increase in benefit with increasing cost (e.g. Wilson et al., 2007), others show benefits varying independent of cost (e.g., Wynn, 2002) and provide further evidence that greater investment does not equate to greater biodiversity outcomes. Benefit-cost relationships may even differ significantly between co-occurring species within the same taxonomic group (e.g. Holzkämper and Seppelt, 2007), further stressing the importance of considering costs and benefits specific to the particular scheme and its objectives.

The inclusion of economics can reveal some 'ugly truths' of AES investment, such as significant windfall effects for farmers (Bamière et al., 2013; Chabé-Ferret and Subervie, 2013; Sierra and Russman, 2006), ineffective schemes (Boitani et al., 2010) and inefficiencies in expenditure where more cost-effective options are available to that commonly employed (Santangeli et al., 2014). While this contributes to criticisms of AES, such learnings are critical to enable future improvements.

4.3. The poor integration of economics and ecology

This review provides further evidence of limited integration of economics into biodiversity conservation. While indicative of a wider trend in the conservation sciences (TEEB, 2009; Wortley et al., 2013), it is particularly troubling in the evaluation of agri-environmental policy given the magnitude of investment allocated globally each year and the high variability in effectiveness (Batáry et al., 2015). There are several potential reasons for this limited integration.

Firstly, a lack of integration of the disciplines of economics and conservation may be a key factor (Aronson et al., 2010). Holl and Howarth (2000) identified perceived differences in the beliefs, techniques and language of economic and conservation disciplines as possible barriers. They suggested a philosophical aversion of some conservationists to the integration of economics with the conservation of nature, led by a belief that biodiversity shouldn't be valued in monetary terms (see Parks and Gowdy, 2013). This may stem in part from the misguided belief that the integration of economics with conservation necessitates the assignment of monetary value to natural assets (e.g. biodiversity), and that the primary goal is to 'weigh up' conservation over other outcomes. The challenges of assigning monetary value to outcomes or benefits for which there is no ready market value are not unique to conservation. The health care field has overcome these challenges through the use of non-monetary evaluation techniques such as cost-effectiveness analysis, thereby avoiding the technical and ethical challenges of monetizing the quality or quantity of human life (Medvecky, 2015). Several studies in this review demonstrate that conservation benefits can be obtained through the use of non-monetary techniques such as cost-effectiveness analysis. Increased promotion and education on economic principles and techniques may further improve uptake. However, as noted by Medvecky (2015), there is a significant lack of training within tertiary institutions in conservation economics, observing that none of the 21 top universities surveyed offered a dedicated conservation economics course, whereas 17 offered health economics.

Another potential factor is the shortcomings typical in the design of conservation programs. AES are often characterized by poorly defined objectives (Kleijn et al., 2006), which makes the design and implementation of monitoring and evaluation studies difficult. Uthes and Matzdorf (2013) suggested that the absence of clear objectives of AES explains the absence of cost-effectiveness analyses which, by their nature, require objectives against which to measure the efficiency of interventions.

A third key factor includes the limited availability of cost data (Holl and Howarth, 2000; Robbins and Daniels, 2012), particularly spatially explicit costs (Naidoo and Ricketts, 2006). As noted by Kimball et al. (2015) in the field of ecological restoration, the practitioner and researcher are seldom the same individual or organization. The former may be aware of costs but not undertake the research. The latter's expertise lies in evaluation, but not costs. Funding institutions may also fail to collect, or disseminate cost information (Boitani et al., 2010). Where accurate cost data are not available and is critical for the particular analysis, such as cost-benefit analysis (Boardman et al., 2010), costs can be estimated using surrogates such as agricultural production value (i.e. opportunity cost) (e.g. Bamière et al., 2011; Lewis et al., 2009), and area-based approaches (e.g. Chabé-Ferret and Subervie, 2013). Where the objective of evaluation is to identify the most cost-effective intervention from a range of potential options, the use of actual data is less critical than the use of standardized costs across interventions, enabling comparison of the *relative* cost-effectiveness.

5. Conclusions

If AES investment is to be more effective, conservation actions and conservation research need to shift its focus to align with global priorities (Lawler et al., 2006). Current global economic realities dictate cost-effective conservation as one of those priorities. Despite repeated calls for a shift towards more integrated evaluation of AES, to date only a small proportion of studies consider economics when measuring the overall effectiveness of these major investments. Whatever the reasons for this lack of integration in the past, it is clear that many are no longer valid. There is a growing awareness of the benefits of multidisciplinary evaluation of conservation programs (Cullen and White, 2013), and a wealth of practical guidance intended to bridge the divide between the economics and conservation disciplines (see Duke et al., 2013; Naidoo and Ricketts, 2006; Naidoo et al., 2006; Robbins and Daniels, 2012). With careful, but minor, modification to the experimental design of scheme evaluations, the collation or estimation of costs, and simple analytical approaches, the potential for substantial biodiversity gains from future schemes become possible.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.04.008.

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