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Abstract

Whilst a number of studies have examined the effects of biodiversity conservation on the delivery of ecosystem services, they are often limited in the scope of the ecosystem services (ES) assessed and can suffer from confounding spatial issues. This paper examines the impacts of nature conservation on the delivery of a full suite of ES across nine case studies in the UK, using expert opinion. The case studies covered a range of habitats and explore the delivery of ES from a 'protected site' and a comparable 'non-protected' site. By conducting pair-wise comparisons of ES delivery between comparable sites our study attempts to mitigate confounding cause and effect factors in relation to spatial context in correlative studies. The analysis showed that protected sites deliver higher levels of ecosystem services than non-protected sites, with the main differences being in the cultural and regulating ecosystem services. Against expectations, there was no consistent negative impact of protection on provisioning services across these case studies. Whilst the analysis demonstrated general patterns in ES delivery between protected and non-protected sites, the individual responses in each case study highlights the importance of the local social, biophysical, economic and temporal context of individual protected areas and the associated management.

Key words:

Biodiversity conservation, Conservation designation, Ecosystem services, Expert opinion, Protected Areas

1 Introduction

Recognition in the late 1980s and early 1990s of the limitations of traditional approaches to biodiversity conservation created the impetus for the uptake of new approaches to natural resource management (Haines-Young & Potschin, 2010), including the development of an Ecosystem Approach under the auspices of the Convention of Biological Diversity (CBD). The importance and value of ecosystems to society, and the consequences of their degradation for human health and well-being, however, weren't really brought to the fore of international policy until the publication of the Millennium Ecosystem Assessment (MEA, 2005), which characterised and linked ecosystems to the services and benefits they provide to humans. A more recent major shift in international conservation policy came with the tenth meeting of the Conference of the Parties to the CBD, (18-29 October 2010, Nagoya, Aichi Prefecture, Japan) which adopted a revised and updated Strategic Plan for Biodiversity for 2011-2020, including the Aichi Targets. These 'targets' focus on the conservation of ecosystem goods and services, as well as biodiversity. This overarching international strategy has more recently been translated into regional and national biodiversity strategies and action plans; for example, see the 2020 Challenge for Scotland's Biodiversity (Scottish Government, 2013) and the EU Biodiversity Strategy to 2020 (European Commission, 2011). This significant re-focusing of biodiversity conservation legislation and policy on ecosystem services (ES) appears to provide a mechanism by which the integration of biodiversity conservation into other policy sectors might be achieved. If biodiversity underpins the services which are the focus of multiple policy sectors (for example, food production, climate regulation and health), then for these sectors to deliver their own goals, biodiversity needs to be conserved. In this way the perception of biodiversity conservation changes from being an impediment to being essential for delivering many policies.

The corollary to this argument is that biodiversity conservation should be supported because it helps to deliver ecosystem services. However, the evidence base for this argument is weaker than might be expected, and sometimes equivocal. For example, carbon storage, agricultural value and recreation have been assessed as respectively negatively, positively and not associated with the richness of high conservation-value species in the UK, but these relationships change across regions (Anderson *et al.* 2009). Eigenbrod *et al.* (2009) found that protected areas appeared to have high levels of biodiversity and C storage, but low levels of recreation and agriculture in England. At the European scale, Burkhard *et al.* (2012) looked at the association of ES demand with different CORINE land classes, finding that important habitat classes for conservation, such as peat bogs and natural grassland, ranked highly for supply of, relative to demand for, regulating services, but low in terms of provisioning services. Castro *et al.* (2015) found that protected area networks in eastern Andalusia supplied only slightly higher levels of regulating services (climate regulation, erosion control and water flow maintenance) than non-protected areas and that the supply of these services varied spatially across the study area according to habitat/typographic features.

Unfortunately there are consistent problems with these types of large-scale correlative analyses. First, they are constrained in the number and range of ES analysed due to a lack of available datasets at relevant scales. Focusing on just two or three indicators of ES delivery (effectively a sub-sample) runs the risk of giving an incomplete or distorted picture of the full range of services (and disservices) that different ecosystems or land use types provide. Second, the lack of suitable metrics also means that there is often a reliance on 'imperfect' proxies to estimate and quantify ecosystem services, e.g. soil carbon stocks for climate regulation, which imposes limitations or caveats on findings, as acknowledged by Castro *et al.* (2015). Finally, they risk confounding spatial location with habitat type. For example, UK uplands are often under conservation designation and contain much of the UK's stored carbon (Reed *et al*. 2009), but are also often distant from areas of high population density. Consequently, we see a positive correlation of conservation with C storage and a negative correlation with recreation, but not because of any causal relationship between current conservation and service delivery. Likewise, the poor representation of ecosystem services (carbon storage, plant productivity and agricultural production) from Chile's protected area network was due to spatial bias, i.e. the PAs are concentrated in the south where there are large extents of rock and ice (Durán *et al.*, 2013). One of the greatest challenges in retrospective studies is the lack of base-line data on ES prior to protection (Ferraro *et al*, 2015). Whilst data on carbon is now relatively abundant and widespread to allow for global and regional modelling, data on the full suite of ES that protected areas provide is not, and there are still uncertainties in metrics and values used, even in well studied protected areas (e.g. Peh *et al.* 2014). In addition, ES, such as cultural services, show great spatial and temporal heterogeneity (Martín-López *et al.*, 2009) and are much more challenging to assess and value in a meaningful way for decision-making.

In order to control against confounding factors (co-variates), Ferraro *et al.* (2015) used matching analyses (using nearest neighbour analysis of co-variates between protected and unprotected forest parcels) to estimate the impact of protected areas on forest carbon storage in Brazil, Costa Rica, Indonesia and Thailand. Using this approach they estimated that an additional 1,000 Mt of carbon had been stored in these four countries due to protection.

Insights on the potential impacts of nature conservation on ecosystem services can also be found from recent restoration projects or studies looking at the impacts of different management regimes on protected land. We again, see a range of ES responses. For example, changes in ES delivery depend on the land management option applied in agri-environment schemes (Bradbury *et al.* 2010). The delivery of supporting and regulating ecosystem services and biodiversity was found to be higher in restored than in degraded systems, but lower than in undamaged reference systems (Rey Benayas *et al.* 2009). A study of Natura 2000 sites, found that although some regulating (pollination) and cultural services (aesthetics, tourism/recreation, education) were highly influenced by within-habitat changes in condition, other service types (provisioning and regulating) were less affected (Bastian, 2013). This is because for these latter services, 'rough' vegetation structure and land cover type are more important than species diversity or specific habitat type. An increasing number of studies, however, have shown significant improvements in regulating services, for example water quality and storage, carbon sequestration, and pest and disease regulation following restoration (Economics for the Environment Consultancy , 2009; Grand- Clement *et al*. 2013; Marton *et al*., 2014; Gilbert, 2013; Morandin *et al*. 2014; Meli *et al*. 2014; Barral *et al*. 2015). The meta-analysis by Meli *et al.* (2014), which looked at the effects of wetland restoration on biodiversity and ecosystem services, showed that biodiversity was 19% higher and ES supply 43% higher in restored wetlands than in degraded ones.

The conclusions of De Groot *et al.* (2010) are still relevant; overall, and despite the importance of understanding the relationship between land use and management – including that targeted at biodiversity conservation - and ES delivery, we are short of information. Furthermore, from a conservation perspective it is clear that we need to gain a more comprehensive understanding of the relationships between biodiversity conservation actions and ecosystem service delivery. This is in order to avoid the risk of policy bias by focusing on a subset of ES which are easier to quantify such as food, water and climate regulation at the expense of those ES that are more difficult to quantify (Maes *et al.* (2012).

In this study we carry out a rapid assessment to look at the effect of nature conservation on all ES categories, using expert opinion. Specifically, we use a standardised approach to examine nine paired case studies covering a range of environments and habitats in the United Kingdom for 24 different ecosystem services. We assess current existing differences between ES delivery on sites managed for nature conservation versus sites in the same or comparable locality but with alternative land-use or management. This contrasts with other approaches that have explored projected changes in ES following a policy change to landscape conservation using counterfactual scenario planning (Hodder *et al.* 2014). We use the analysis to further explore whether the effects are the same across different habitats and different localities.

2. Methodology

2.1 The case studies

In order to explore how nature conservation affects the delivery of ecosystem services, nine different case studies across the UK were selected. The case studies represent a wide range of different types of habitats/ecosystems (and their associated ecosystem services) and included rivers, coastal and chalk grasslands, montane heaths, raised bogs and Scots pine woodlands. A summary of each case study can be found in Table 1. Seven of the case studies comprised pair-wise comparisons between a protected area, or site, and a non-protected area. One case study explored the difference between land managed under agri-environmental schemes and land outside the scheme (Loweswater).The Abernethy case study assessed the effects of protection over-time (temporal), before and after 1988 when the RSPB purchased Abernethy forest from a previous shooting/forestry estate. See Table 1 for the IUCN conservation management categories of the protected areas used in the study.

The choice of paired sites for each case study was based on expert knowledge of i) the ecosystems in question, ii) the localities, iii) the current and past land use and iv) the underlying bio-physical features. This allowed the assessors to make credible and reasonable assessments of ES delivery. By having the paired sites in close proximity to one another, we aimed to mitigate against potential confounding effects (i.e. land capability, abiotic factors, socio-economic factors). The comparison of paired protected versus non-protected sites allowed for a comparative assessment of the delivery of ecosystem services from land with and without protection (designation) or incentive mechanism, but having similar land and socio-economic characteristics. This allowed us to test the effects of protection where the confounding effects of land-use or spatial context were minimised. In effect the non-protected site within the pair provided a counterfactual for what would have happened had the site not been protected (although the temporal nature of the Abernethy study does not allow for this).

2.2 The delivery of ecosystem services from protected and non-protected sites

2.2.1 Individual case studies

We used an ES classification based on the MEA (2005) as a framework for assessing ES delivery from the paired case studies. This included 24 ecosystem services classified into one of four broad categories: provisioning, cultural, regulating and supporting. We chose the MEA over other typologies for its ease in communicating and conveying the concept of ES to the assessors (UK NEA, 2011; TEEB, 2010; Haines-Young & Potschin, 2013). As the study was specifically looking at the effects of nature conservation, a specific ES category of environmental stewardship was added under cultural services. This category included specific activities relating to the conservation of species and habitats e.g. conservation volunteering.

The assessment of ecosystem service delivery was conducted by the expert(s) using a four step process. The experts included all the authors, with some supplementary information being provided by local experts (i.e. data on visitor numbers). Clear guidance was provided to the experts and the methodology was discussed as a group to ensure consistency in scoring approach. In the first step, the expert was asked to select the ecosystem services which would have formed the basis of the original protected area designation (i.e. qualifying features) of the protected site. This was so that the impact of the qualifying features could be accounted for in the overall assessment. Second, the expert was asked to rate (by distributing one hundred points) the relative importance of the ecosystem services being delivered from the ecosystems at that particular location. Third, the delivery of each ecosystem service was ranked (low, low-medium, medium-high, high) for the protected and unprotected site in each case study.

Ideally the experts would have assessed the supply or demand (or both) of ES for each case study. However, this was not possible as the current indicators available for assessing all ES vary, in that, whilst some related to the flow of a service as per Villamagna *et al.* (2013), and can be considered as the ‘real’ supply of ecosystem services rather than the potential supply or stock (Burkhard *et al.* 2014). Others, such as a number of the cultural services, specifically education, tourism and recreation and stewardship, the ES delivery scored are analogous to ecosystem service demand (Burkhard *et al.* 2014). In the last step the expert scored the confidence in the evidence available for the assessment. The confidence options were: Low= Expert opinion only; Medium=Research or observations on related ES delivery changes from related ecosystems; High=Research on actual or similar changes in ES delivery in ecosystems. An example of a completed framework for the North Uist case study is shown in Table 2.

Table 1: A summary of the case studies

(SSSI=Site of Special Scientific Interest; SAC=Special Area of Conservation; SPA= Special Protection Area; NNR=National Nature Reserve; RSPB=Royal Society for the Protection of Birds reserve; E=England; S=Scotland). IUCN protected area (PA) management categories assigned based on Crofts *et al.* (2014).

Case study	Lat/Long	Description	IUCN PA Category	Key habitats/species of 'protected' site	Key habitat/species of non-'protected' site
North Uist (Western Isles, S)	57°32'00.0"N 7°22'45.0"W	North Uist Machair SSSI/SPA/SAC/RSPB reserve compared with adjacent non-protected area	IV	Coastal machair, dunes and lochs, breeding and non-breeding birds	Adjacent coastal grasslands
Sletill Peatlands (Caitheness/ Sutherland, S)	58°22'56.5"N 3°47'20.6"W	Sletill Peatlands SSSI (part of Caithness and Sutherland Peatlands SAC, SPA, Ramsar, Flows NNR) compared with adjacent ex-forestry plantation	IV	Blanket bog, breeding birds	Ex-forestry plantation, habitat restoration ongoing for 15 years
Rora Moss (Aberdeenshire, S)	57°33'16.1"N 1°55'53.3"W	Rora Moss SSSI compared with Middlemuir Moss	IV	Degraded raised bog (partially historically cutover)	Cut over peat bog
Beinn Eighe Wester Ross, S	57°36'26.5"N 5°22'28.2"W	Beinn Eighe NNR/SSSI/SAC/compared with surrounding upland areas	II, IV	Alpine heathland, Scots pine-forest, oceanic bryophytes, Golden Eagle	Heathland, grassland, blanket bog
Abernethy Inverness, S	57°13'42.5"N 3°38'29.2"W	RSPB Abernethy Nature Reserve CNP/NNR/SAC/SPA/SSSI (before and after designation in 1988)	II, IV and V	Scots pine, Capercaillie, Osprey, alpine heath, raised bogs, fresh water lochs	Scots pine, Capercaillie, Osprey, alpine heath, raised bogs, fresh water lochs
Parsonage Down Wiltshire, E	51°10'19.5"N 1°55'27.2"W	Parsonage Down NNR (Salisbury Plain) compared with adjacent improved grasslands	IV	Species-rich calcareous grassland	Ploughed, sown with agricultural grasses and fertilised
Drumochter Perth and Kinross, S	56°52'00.0"N 4°11'30.0"W	Drumochter Hills (SAC) compared adjacent Dalnacardoch	IV, V	Alpine heathland, late snow bed vegetation, high altitude grasslands, blanket bog, Assemblages of artic and upland breeding birds	Upland/montane vegetation comprising mainly of a heather/grass mosaic (predominantly wet heath and blanket bog) - of European importance
Loweswater Cumbria, E	54°35'08.9"N 3°21'11.0"W	A comparison between land with and without agri-environmental schemes in the Loweswater catchment (Lake District National Park)	V	Upland bog, heathland, acid grassland, broadleaved woodland, lake (under agri-environmental schemes)	Upland bog, heathland, acid grassland, broadleaved woodland, lake
River Dee Aberdeenshire, S	57°03'20.0"N 3°04'30.0"W	River Dee Catchment SAC compared with River Don (partial SAC)	IV, V	Otter, salmon, freshwater pearl mussel	Otter, salmon, freshwater pearl mussel

Table 2: A completed ecosystem service delivery assessment for the North Uist case study (*This category includes the wide range of benefits that people get from seeing, hearing and experiencing nature as well as species and habitats of national and European conservation importance.* [1]*A relative importance rating; each ES is rated in relation to another ES, Total = 100 points.*[2] *There are 4 categories or ranks: Low, Medium-Low, Medium-High and High.* [3]*The confidence in evidence for each ES delivery assessment: Low, Medium, High)*

ES	ES sub-category	Goods and Services	Key benefits	Reason for designation?	Assessor importance rating[1]	Ecosystem Services Delivery Rank[2]			
						Non-protected site	Protected site	Difference between delivery	Confidence in the evidence[3]
Cultural	Aesthetics*	Machair flowers, landscape, national and international important species and habitats	Biophilia, psychological and physical benefits	y	15	Med-low	Med-high	↑	Med
	Artistic	Inspiration for art	Livelihood, inspiration	n	3	Med-high	Med-high	→	Low
	Heritage	Traditional knowledge, skills	Sense of place, heritage, social capital	n	18	Med-high	Med-high	→	Med
	Education	Education and research	Knowledge, cognitive development, self-esteem	n	5	Low	Med-high	↑	Med
	Stewardship	Volunteering, rare species conservation	Social capital, identity, existence	n	5	Med-low	Med-high	↑	Med
	Religious	n/a	n/a	n	0	Med-low	Med-low	→	Low
	Tourism/Recreation	Reserve for recreation	Livelihood, heritage, artistic, material	n	12	Med-low	Med-high	↑	Med
Provisioning	Energy	n/a	n/a	n	0	Low	Low	→	High
	Fibre	Fleeces; wool, felt	Livelihood, material wealth, inspiration	n	1	Med-low	Med-low	→	Med
	Food	Beef, lamb	Food, livelihood	n	1	Med-high	Med-high	→	High
	Fresh water	Water supply	Aquatic habitats, psychological and physical benefits	n	5	Med-high	Med-high	→	Med
	Genetic resources	Local landraces of oats/barley	Genetic pool for crop improvement, heritage	n	0	Med-high	Med-high	→	Med
	Raw materials	n/a	n/a	n	2	Low	Low	→	High
Regulating	Air quality	Gas regulation, air quality improvement	Health and well-being	n	0	High	High	→	Med
	Climate	Carbon sequestration	Climate change mitigation	n	0	Med-high	Med-low	↓	High
	Hazard	Coastal defences, soil stabilisation	Flood risk mitigation, sand blow amelioration	n	12	Med-high	Med-high	→	Med
	Water quality	Filtering/buffering of agricultural pollutants	Fishing – recreation/food, aesthetics	n	3	Med-high	Med-high	→	Med
	Pollination	Pollination of wild species	Food source for great yellow bumblebee	n	3	Med-low	Med-high	↑	Med
	Pests/Diseases	n/a	n/a	n	0	Low	Low	→	High
	Soil quality	Erosion prevention, nutrient retention	Crop production, livelihoods,	n	3	Med-high	Med-high	→	Med
Supporting	Soil formation	Sand dune formation, organic matter acc.	Coastal defence, security, agri. production	n	3	Med-low	Med-low	→	High
	Nutrient cycling	Breakdown, assimilation and storage	Fertile soils, decomposition of organic matter	n	2	Med-high	Med-high	→	Med
	Water cycling	Water cycling	-	n	2	Med-low	Med-low	→	High
	Primary production	Silage, hay for livestock/food for wild species	Silage, hay, livelihoods	n	5	Med-high	Med-high	→	High

2.2.2 Data analysis across all case studies

All analyses were performed using the *stats* package of R (ver. 2.12.1, R Development Core Team 2010).

The data from all the nine individual case studies were analysed in three ways. First, the ecosystem service delivery ranks were compared between the protected and the non-protected sites. The data were converted from the 'low', 'medium-low', 'medium-high' and 'high' classifications into ordinal scores from 1 to 4. Our null hypothesis was that there was no difference in ranks between designated and non-designated areas; that is, nature protection does not affect the delivery of ES. To test this hypothesis, and given the data's ordinal nature, a Friedman test (a non-parametric equivalent to a one-way analysis of variance with blocks) was conducted, with protected/non-protected as the explanatory variable and case study as the blocking factor.

Second, for each service the ordinal rating scores were multiplied by the relative importance rating and the resulting products summed across all services. The totals were then tested using an analysis of variance with protected/non-protected as the fixed effect and case study as the blocking factor.

Third, and for all pairs of services, we tested for correlations in changes in their delivery ranks between protected and non-protected sites. A positive correlation meant that delivery of the two services responded in the same way to protection, a negative correlation that they responded in opposite directions to protection. This enabled identification of groups of services that can be considered as 'bundles' in that they respond in the same way to changes in land management, or services that show trade-offs (i.e. negative correlations). As the data were ordinal, a Spearman rank correlation was used to assess this relationship.

3 Results

3.1 Individual case studies

The completed ecosystem service assessment frameworks for each of the nine case studies can be found in the supplementary data (Appendix 1). In addition, detailed discussions on each case study assessment can be found in Eastwood *et al.* (2013). As an example, a summary of the assessment for the North Uist Machair case study is shown in Table 2, with a summary narrative in Box 1.

3.2 A combined analysis across all case studies

Analysis of the individual ecosystem delivery ratings (Table 3) showed that there were consistent differences in ranking between protected and non-protected sites for 8 of the 24 services. In all cases these differences were positive, i.e. protected sites had higher mean ratings than the non-protected sites. Our assessment clearly indicates that protected sites are delivering higher levels of ecosystem services than non-protected sites, with the difference mainly dependent on higher levels of cultural and regulating services. Against expectations, there was no consistent negative impact of protection on the provisioning services across the case studies.

Box 1. The North Uist Machair case study (Outer Hebrides, Scotland)

The case study assessed the delivery of ES from the mosaic of coastal dunes, machair and lochs on the most westerly point of North Uist. Land use for both the protected and non-protected sites focusses on rotational cultivation of machair, and winter grazing of the machair and dunes. The protected site has a number of international and national designations for species such as corncrake (*Crex crex*) and Greenland barnacle goose (*Branta leucopsis*), and habitats such as machair, naturally nutrient-rich lochs and dune systems. Machair is a coastal grassland listed in Annex 1 of the EU Habitats Directive. These biodiversity goods were categorised under the sub-category cultural services-aesthetics*. According to the assessment there were differences beteween the protected and non-protected sites for 6 of the 24 services. The protected site delivered more cultural services than the unprotected site; namely aesthetics, education, stewardship, and tourism/recreation (deriving mainly from investment in site facilities and activities). It also delivered higher in one regulating service – pollination – due to targeted management for plant diversity. One service in which the protected site ranked lower was climate regulation. This is due to the relatively higher levels of rotational-arable agriculture carried out on the protected site which reduces carbon build up in the soil. In all the other eighteen ES assessed there was no difference between the protected site and non-protected site.

The confidence level associated with the changes of delivery varied between the types of ecosystem services being evaluated. For example, due to recent biological and social research on North Uist (e.g. Lewis *et al.* 2014a,b; Pakeman *et al.* 2011), the assessor had high confidence in the expected changes to the ES relating to soil functions and regulation, but low confidence in the impact of change on artistic cultural services.

* *Cultural–aesthetics. This category includes the wide range of benefits that people get from seeing, hearing and experiencing nature as well as those species and habitats of national and European conservation importance and value.*

The main reason for site designation related to the presence of species and habitats valued for their national and international conservation importance. Thus biodiversity is valued as a good *per se* and this includes the appreciation of wildlife, such as iconic eagles, and scenic beauty (see Mace *et al.* 2012). In our assessment we included this type of service under the cultural-aesthetics category which was broad and included all the benefits people get from seeing, hearing and being in nature. It is therefore not surprising that this sub-category were identified by the analysis as differing between the two types of site. Table 3 also shows the mean confidence of the assessors in making these ratings. These ranged from 1.22 to 2.78 (minimum = 1 = low confidence; maximum = 3 = high confidence). There appears to be no relationship between confidence and significance, with low and high confidences distributed across all the service categories. Lowest confidence was in artistic and religious services. The total service delivery was significantly higher on the protected sites (296) compared to the non-protected sites (229, scale minimum = 100, maximum = 400).

Our assessment indicates that protected sites are delivering higher levels of ecosystem services than non-protected sites, with the difference mainly dependent on higher levels of cultural and regulating services.

Correlation analysis across the 24 services involved 276 correlations, giving a high likelihood of apparently significant correlations occurring by chance (i.e. in 13.8 out of 276 tests with the significance threshold set at P=0.05). We found significant correlations in 24 cases (Table 4). This indicates that overall there was no great level of correlation – either positive or negative - between the services being impacted by nature protection. However, within the cultural services category, 6 out of the 21 possible correlations were significant and positive: for example between stewardship and tourism/education. This pattern was not repeated across the other service categories.

Other notable features of the correlation matrix included the significant positive correlation between genetic resources and a number (3) of cultural services, and significant negative correlations (4) between regulating services/cultural services and fibre (wool and pulp) production. Also notable was the number of significant correlations (4) between the supporting service water cycling and a range of different cultural, provisioning and regulating services.

Table 3: Test of the differences between individual service delivery between designated and non-designated sites. *The final row indicates a test for the overall difference in service delivery for the combined services. p-values are from a Friedman test, with significance levels indicated by * $0.05 \le p < 0.01$, ** $0.01 \le p < 0.001$. Also shown are the proportion of cases where it was thought that the service was an influence on designation and the mean confidence score of the assessors (scale from a minimum of 1- low confidence to a maximum of 3-high confidence).*

Category	Services	p-value	Significance	Proportion of cases where service was a reason for designation	Mean confidence of assessors
Cultural	Aesthetics	0.008	**	1.00	2.78
	Artistic	0.025	*	0.11	1.67
	Cultural heritage	1.000		0.22	2.00
	Education	0.005	**	0.44	2.22
	Religious	0.317		0.00	1.22
	Stewardship	0.008	**	0.22	2.22
	Tourism/Recreation	0.059		0.11	2.22
Provisioning	Energy	0.157		0.00	2.33
	Fibre	0.317		0.11	2.22
	Food	0.564		0.11	2.33
	Freshwater	0.083		0.00	1.89
	Genetic Resources	0.025	*	0.00	1.78
	Raw Materials	0.564		0.00	2.33
Regulating	Air Quality	0.157		0.00	1.78
	Climate	0.103		0.11	2.22
	Diseases/Pests	0.157		0.00	1.89
	Hazard	0.157		0.00	1.67
	Pollination	0.025	*	0.11	1.78
	Soil Quality	0.025	*	0.11	2.11
	Water Quality	0.045	*	0.00	1.89
Supporting	Nutrient Cycling	0.083		0.00	1.89
	Primary Production	0.564		0.11	2.11
	Soil Formation	0.157		0.00	2.22
	Water Cycling	0.083		0.00	2.11
Total	All Services	0.005	**	-	-

Table 4: Spearman rank correlation coefficients for the difference between rankings of designated and non-designated sites. *For probability levels between 0.05 and 0.01, r_s values are shown in **bold**, whereas for levels between 0.01 and 0.001 they are in **bold** and **underlined**. Critical values for the Spearman rank correlation are p = 0.05 r_{crit}= 0.700, p = 0.01 r_{crit}= 0.833, p = 0.001 r_{crit}= 0.933.*

		CULTURAL							PROVISIONING						REGU		
		AESTHETICS	ARTISTIC	CULTURAL HERITAGE	EDUCATION	SPIRITUAL/RELIGIOUS	STEWARDSHIP	TOURISM/RECREATION	ENERGY	FIBRE	FOOD	FRESHWATER	GENETIC RESOURCES	RAW MATERIALS	AIR QUALITY	CLIMATE	DISEASES/PESTS

		CULTURAL							PROVISIONING						REGU			
		AESTHETICS	ARTISTIC	CULTURAL HERITAGE	EDUCATION	SPIRITUAL/RELIGIOUS	STEWARDSHIP	TOURISM/RECREATION	ENERGY	FIBRE	FOOD	FRESHWATER	GENETIC RESOURCES	RAW MATERIALS	AIR QUALITY	CLIMATE	DISEASES/PESTS	
CULTURAL	AESTHETICS	-																
	ARTISTIC	0.42	-															
	CULTURAL HERITAGE	0.00	0.47	-														
	EDUCATION	0.19	0.68	0.43	-													
	SPIRITUAL/RELIGIOUS	0.44	0.32	**0.75**	0.07	-												
	STEWARDSHIP	0.09	**0.73**	0.29	**0.90**	-0.07	-											
	TOURISM/RECREATION	0.34	**0.76**	0.35	**0.76**	0.15	**0.81**	-										
PROVISIONING	ENERGY	-0.27	0.06	0.57	0.65	0.19	0.44	0.17	-									
	FIBRE	-0.44	-0.32	**-0.75**	-0.07	1.00	0.07	-0.15	-0.19	-								
	FOOD	-0.25	-0.21	-0.44	0.34	-0.57	0.34	0.13	0.37	0.57	-							
	FRESHWATER	0.54	0.63	0.50	0.14	0.50	0.10	0.30	-0.19	-0.50	**-0.71**	-						
	GENETIC RESOURCES	0.45	**0.91**	0.48	**0.73**	0.36	**0.73**	0.61	0.22	-0.36	-0.22	0.53	-					
	RAW MATERIALS	-0.29	-0.21	0.00	-0.64	0.08	-0.48	-0.33	-0.55	-0.08	-0.68	0.05	-0.24	-				
REGULATING	AIR QUALITY	0.66	0.00	0.13	-0.32	**0.75**	-0.40	-0.13	-0.28	**-0.75**	-0.42	0.25	0.06	0.12	-			
	CLIMATE	0.66	0.58	0.00	0.41	0.31	0.41	0.33	0.00	-0.31	0.16	0.20	0.65	-0.51	0.46	-		
	DISEASES/PESTS	0.66	0.47	0.63	0.34	**0.75**	0.13	0.23	0.28	**-0.75**	-0.42	**0.75**	0.54	-0.37	0.50	0.46	-	
	HAZARD	0.28	0.48	0.57	0.38	0.66	0.33	0.57	0.29	-0.66	0.06	0.19	0.33	-0.31	0.43	0.46	0.43	
	POLLINATION	0.54	-0.19	0.25	-0.13	0.60	-0.26	-0.11	0.11	-0.60	-0.32	0.30	-0.07	-0.15	0.65	0.10	0.65	0
	SOIL QUALITY	0.54	0.19	0.25	0.06	0.60	0.05	0.13	0.11	-0.60	-0.02	0.30	0.16	-0.45	0.65	0.59	0.65	0
	WATER QUALITY	0.28	0.39	0.61	-0.02	0.61	0.02	0.08	0.00	-0.61	-0.69	**0.82**	0.33	0.11	0.31	0.08	**0.71**	0
SUPPORTING	NUTRIENT CYCLING	0.54	0.16	0.00	-0.05	0.50	-0.05	-0.05	-0.19	-0.50	-0.27	0.00	0.39	0.16	**0.75**	0.61	0.25	0
	PRIMARY PRODUCTION	-0.01	0.21	-0.38	0.46	-0.66	0.50	0.36	0.12	0.66	**0.72**	-0.11	0.07	**-0.70**	-0.60	0.20	-0.16	-0
	SOIL FORMATION	0.66	0.00	-0.50	-0.02	-0.19	-0.10	-0.13	-0.28	0.19	0.12	0.25	0.0	-0.49	0.22	0.46	0.34	-0
	WATER CYCLING	**0.86**	0.26	0.16	0.07	0.57	-0.10	0.03	-0.06	-0.57	-0.32	0.60	0.34	-0.37	0.70	0.60	**0.86**	0

4 Discussion

4.1 Methodology to conduct ecosystem service assessments

For each case study the assessment was based on expert knowledge from one expert, although in many cases this was supplemented with additional information from local experts. Understandably, the level of confidence assigned by our assessors varied between ecosystem services and across case studies. For some case studies extensive knowledge and research in a range of social, ecological, environmental and economic indicators gave high levels of confidence across all the ecosystem services (e.g. Loweswater case study). In others, only data from biodiversity and land management indicators were used to make the assessment, resulting in low confidence across the majority of ecosystem services (e.g. Drumochter Hills). Differences in confidence could also be attributed to inherent differences between individual assessors' confidence in their knowledge/expertise on how habitats and species of conservation concern contribute to these services relative to other types of land use. What our assessment do reveal, however, is which ES require further research so as to increase confidence in the assessments.

Greater accuracy and confidence in the evidence could be achieved by including more experts (from different disciplines) and stakeholders in the assessment using group techniques such as facilitated deliberation, expert panels or Delphi methods (see Martin *et al.* 2012 for a review on the elicitation of expert knowledge). However, this still does not solve the problem of the lack of empirical data for many ecosystem services at local scales. To quote De Groot *et al*. (2010) '*Empirical information on the quantitative relationship between land use and ecosystem management and the provision of ES at the local and regional scale is, however, still scarce*'.

Despite the limitations of our method, it does demonstrate that this approach can assess ecosystem services delivery in an holistic and practical way across a diverse range of habitats and management regimes. It makes use of existing data, where available, and expert knowledge, rather than excluding services where data are hard to collect or waiting until costly and lengthy '*de novo*' assessments and valuations have been completed. This is of particular benefit to national conservation and land use agencies that need timely and responsive evidence to make policy decisions which sometimes cannot wait until more data is available (which was the initial impetus for this work (Eastwood *et al*., 2013). The assessments and the framework can also be revised as new data become available.

By incorporating the full suite of possible ecosystem services and associated benefits, our approach ensures that assessments and comparative studies are conducted in a more holistic, simultaneous manner which reflects more the complexity of human-ecosystem interactions. This is particularly pertinent because, as our study has shown, there appear to be few correlations between the 24 individual ES. There is a risk, therefore, that studies which base their assessments on just a few ES indicators (e.g. Duran *et al*., 2013; Eigenbrod *et al*., 2009; Naidoo *et al*., 2008), will come to incomplete or inaccurate conclusions on the overall effects of nature conservation/biodiversity on ES delivery. Where possible, studies should use as many indicators across the full suite of cultural, provisioning, regulatory and supporting services. Considering that many ecosystem services produce multiple benefits, co-produce cultural benefits (e.g. stalking deer provides both cultural and provisioning benefits) and are often interdependent (Chan *et al.*, 2012; Daniel *et al.*, 2012) our approach goes some way towards the recommendations in Chan *et al.* (2012) who believe that ecosystem service assessments and valuations should be conducted simultaneously. However, what our current framework doesn't fully incorporate appropriately are cultural benefits arising from the other services such a provisioning services. In this sense it is similar to many of the current ES typologies.

Our results do indicate, however, that some cultural services do bundle (e.g. education and stewardship, tourism/recreation and stewardship) and there could be a case for reducing the number of ES indicators in this ES category. However, one must also remember that whilst some cultural services may bundle, the actual benefits arising from them may respond very differently. In addition, our results are based on a limited number of case studies from the UK and a wider range of studies taking this approach would be needed to test the generality of such patterns.

The paired protected and unprotected sites were selected by each expert; based on the proximity of the sites and knowledge of historical land cover, land features and management. Knowledge of historical land use was essential as, in some cases, there was great divergence in land use between the protected and non-protected site (i.e. blanket bog had become plantation forestry). Using this method we made the assumption that confounding variables were minimised (land capability, socio-economic context, baseline land cover pre-protection) and that protection was the main causal mechanism for the observed or perceived differences in ES delivery. Whilst it was not possible to test the robustness of the method (expert knowledge) in selecting paired sites in the time frame of the study, quantitative matching methods such as that used by Andam *et al.* (2010) and Ferraro *et al.* (2015) could be a method to test the expert based approach, and control further for confounding factors in the future.

In some of the case studies, the assessors found it difficult to compare the delivery of services spatially or temporally, and also found some difficulties in differentiating and quantifying the causal effects (e.g. the effect of external drivers) of the differences in ES delivery between protected and non-protected sites. This was most evident in the temporal Abernethy case study, where there has been a marked increase in the levels of tourism to the whole region, as well as to the protected area over the past few decades. This problem of causal factors, and the absence of time-series data, could be mitigated through deliberative discussion to gain broader consensus on the assessment or applying averages across a number of assessors.

4.2 The effects of protection and conservation management on ecosystem service delivery

The key determinant governing changes in ecosystem service delivery and/or biodiversity at a specific site or location is land use or land management differences between the compared sites. Nature conservation through interventions such as site protection, habitat or species management, and/or incentive mechanisms ultimately influences (to varying degrees) the management of these sites compared to adjacent non-protected sites. Based on our findings, protected areas, in general, provided higher levels of ecosystem service delivery than non-protected areas of potentially similar habitat type. Our findings are in contrast to those of Naidoo *et al*. (2008) who found that on a global scale high biodiversity regions provided no more ES than regions chosen randomly. However, as the authors themselves recognised, their preliminary analyses were greatly constrained by the lack of spatial data available on global scales, and had to be limited to just four ES: carbon sequestration, carbon storage, grassland production of livestock, and water provision.

4.2.1 Provisioning services

One of the notable findings from the combined analysis of the nine case studies, and against expectations, was that there was no consistent negative impact of nature protection on provisioning services. This is contrary to the often-cited trade-off between biodiversity conservation and the delivery of provisioning services such as arable crops, timber and livestock (e.g. Burkhard *et al*., 2012; Power, 2010, Willemen *et al.* 2013). Although the non-protected sites, in most cases, delivered more in terms of provisioning services (e.g. timber, meat, fuel, arable crops, and dairy), these differences were not significant, and at the individual case study level, were only marginal, and not equal across all the types of provisioning services. This result may reflect the fact that, apart from the Parsonage Down case study (chalk grassland), the land use on the majority of our sites is limited in its potential to deliver provisioning services by the inherent low productivity of the land. In the UK, as in many other countries, protected areas tend to be located on lower quality agricultural land.

Another possible reason to explain our contrasting result is that the majority of the PAs in our study, a reflection of those prevalent in the UK, are either category IV (habitat/species management area) or V (protected landscape) according to the IUCN protected area management categories. These types of protected areas, particularly in the UK where the majority of habitats are semi-natural and have been managed by humans for centuries, are very different in their management objectives than category I and II type protected areas. Here human intervention is kept to a minimum so as to keep underlying ecological processes as ‘natural’ as possible, thereby limiting opportunities for provisioning services.

One of the exceptions to the general pattern regarding provisioning services is the temporal comparison in the Abernethy case study. In this case, pre-protection levels of livestock husbandry were very low and since protection, these have virtually been eliminated. However, food provisioning has actually increased due to the increases in deer stalking, and hence venison, as part of the reserve’s woodland management regime. It is also interesting to note that whilst provisioning services for finite resources/goods - such as traditional and commercial peat for fuel/horticulture illustrated by the Sletill Peatlands and Rora Moss case studies - may be higher initially on non-protected sites, the ability to continue delivering these goods is dependent on the extraction rate of a finite resource.

4.2.2 Cultural Services

Excluding cultural aesthetics (in the broad sense of biodiversity as a good, see Mace *et al*., 2012), as this was identified as the main reason given for the original designation by all nine experts, the main effect of nature protection has been an increase in three cultural services namely artistic, education/research and conservation stewardship. This is supported by the combined analysis of the individual ecosystem delivery rankings (see Table 3). The effect of site protection on cultural services is most apparent in National Nature Reserves, namely Beinn Eighe, Abernethy, and Parsonage Down. All of these reserves, since designation, have invested significantly in public access, amenity and education facilities, resulting in enhanced delivery of many of these cultural services. One of the main goals of national nature reserves in the UK is to provide opportunities for people to engage and enjoy nature and so visitors and researchers are encouraged.

Notwithstanding the results of individual case studies, the analysis of service delivery across all the nine case studies (Table 3) showed that overall protected areas did not deliver significantly higher in terms of recreation/tourism or cultural-heritage. Our result is contrary to Eigenbrod *et al.* (2009) who found that conservation had a negative association with tourism at a national level. We suggest that the reason for this disparity is because we have removed the confounding effects of spatial context, i.e. both protected sites and non-protected sites were in proximity to each other. The strength of a paired approach is confirmed in Ferraro and Hanauer (2014), who, when controlling for confounding covariates (through matching) to explore how protected areas affect poverty, found that nearly two-thirds of poverty reduction could be causally attributed to eco-tourism.

4.2.3 Regulating Services

From the combined analysis across all case studies; three of the regulating services, pollination, soil quality and water quality ranked significantly higher in the protected areas than in the non-protected sites. This was primarily due to the improved condition or prevention of further degradation of priority habitats such as dwarf shrub heath, semi-natural grasslands and, raised and blanket bogs. For example, the raised bog case study, Rora Moss, provided higher levels of regulating services in terms of carbon sequestration, water quality, pollination and soil quality than the nearby cut-over and exploited bog, Middlemuir Moss. The condition of peat forming habitats such as raised bogs, blanket bogs and heathlands is particularly important for carbon sequestration as peat deposition is dependent upon the presence of a healthy acrotelm layer. The significant improvement of regulating services such as water quality, water provision and carbon storage has also been shown in a number of peatland and wetland restoration studies (Economics for the Environment Consultancy, 2009; Grand-Clement *et al*. 2013; Marton *et al*., 2014; Meli *et al.* 2014). In addition a recent, large scale European study, looking at Natura 2000 sites in the EU, also demonstrated, using multinomial logistic regression models, that habitats in favourable conservation status had a higher potential to supply regulating services than habitats in unfavourable condition (Maes *et al.*, 2012).

4.3 The role of context in ES delivery

The combined analysis for all the case studies assessed demonstrates that protected areas scored higher in their overall delivery of ecosystem services than non-protected sites. This was primarily due to higher delivery of cultural and regulatory services. However, the individual responses in each specific case study highlight the importance of the social, biophysical, economic and temporal context of the protected areas in question, and crucially the management objectives of the site.

For example, in some case studies (Loweswater and Drumochter Hills), the effect of protection or broader conservation actions (such as agri-environment schemes) had little or no apparent effect on the delivery of ecosystem services. The Drumochter Hills and Loweswater may be typical for many upland areas where nutrient poor soils limit the delivery of provisioning services, and their isolation constrains them in their ability to offer a significant tourist attraction. In fact, heritage and recreation services may actually be reduced under protection because the main conservation action (reducing wild and domestic herbivore numbers to improve habitat condition), could reduce opportunities for recreation such as deer stalking. Note that the habitats on the Drumochter Hills are in very similar condition (mostly unfavourable) to that in the adjacent non-protected area and so there are no enhanced benefits, at least not currently, in terms of regulating services. In contrast, in the Parsonage down case study, the land use divergence, between the protected and non-protected site (due to the greater potential productivity of chalk grassland and other socio-economic factors), has led to greater differences in ES delivery, especially in terms of provisioning services.

Cultural services, and to different degrees other services, are co-produced by the interaction of humans with the ecosystem (Chan *et al*., 2011). The spatial and social context of a protected area or non-protected area is therefore critical in determining cultural service delivery and associated values. Their importance and value is largely based on their close proximity to people and their accessibility, which again highlights the importance of scale and context with regards to ecosystem service delivery. A protected area may have a high stock of some services, such as exceptional biodiversity, a suite of charismatic species or high levels of endemism. However, the protected area may be located in a remote area with poor accessibility and infrastructure, which limits the number of beneficiaries and, therefore the conversion of these stocks into services. The benefits may therefore be limited to existence and intrinsic values.

One of the case studies (Abernethy) highlighted the importance of time-scales when assessing the delivery of certain ES such as carbon sequestration in trees. For example, whilst the current difference in the delivery of regulating services between the forested protected site (a RSPB reserve) and previously un-protected highland forestry estate is negligible, the result would have different if it had been scored in 10 years' time. This is primarily due to the time taken for forests to reach harvestable age in the highlands of Scotland (circa 70-80 years). In the next 10 years the majority of the forest planted in the 1950s will start to reach harvestable age, and will be harvested and replanted. Under this future scenario, carbon would not only be locked up in the timber harvested and used for construction, but new plantations would sequester more carbon than the older mature pines. In this future counterfactual scenario the forestry estate would deliver greater in terms of carbon sequestration.

4.4 Trade-offs and synergies

The low proportion of significantly negative correlations (1.8%) across all the ecosystem services indicates that there are very few general trade-offs (associated dis-services) associated with designating sites for nature conservation. In contrast there were more significantly positive correlations or synergies (6.9%), amongst ecosystem services as a consequence of nature protection (through protected areas or agri-environmental schemes). A number of these are clustered or 'bundled' within the cultural services, which indicates that there may be opportunities, if resources are limited, to reduce the number of cultural services assessed. In our study there are particularly strong correlations between conservation stewardship and education, as well as between conservation stewardship and tourism/recreation. However, these correlation patterns may be restricted to our study, which focuses on the effects of nature conservation interventions, and may not be applicable to other ES assessments.

The high positive correlation between genetic resources and some of the cultural services (artistic=0.91) may be partly due to the fact the some of the UK's iconic wild species such as Scots pine and salmon, often a source of artistic inspiration, are also assumed to be important potential genetic resources for future breeding programmes. Biodiversity as well as being the fundamental resource for bio-prospecting (European Academies Science Advisory Council, 2009), also provides us with those iconic species strongly associated with cultural benefits, both of which would be affected by protection.

4.5 Conclusions

Whilst there have been a number of correlative studies exploring the delivery of ES from protected areas and non-protected areas (see introduction) ours is one of the few studies which attempts to mitigate the confounding cause and effect factors in relation to the spatial context of the sites used in the analysis by selecting pairwise comparisons in similar locations. In fact the strong spatial bias of protected areas in Chile was the main factor suggested by Durán *et al*. (2013) for the under-representation of ecosystem services, and for that matter biodiversity, across the Chilean protected area system.

Uniquely, our study illustrates an attempt to assess the delivery of the full suite of ecosystem services, which we believe is crucial if we wish to gain a broader or more holistic understanding of how ecosystem service delivery is affected by interventions for protecting nature. It recognises the complexity of human-ecosystem interactions that lead to benefits and trade-offs. Our approach also reveals that there is clear identified need for more comprehensive research on how best to implement assessments which incorporate all of the cultural and regulatory benefits of nature conservation/biodiversity. There is a need to focus on new approaches to assessing services where conventional scientific data is costly and slow to collect, using more appropriate methods based on eliciting knowledge from local stakeholders and experts. A refinement of our approach may provide a mechanism for conservation managers to recognise and understand the full range of trade-offs, services and disservices associated with a specific protected site. This may put them in a better position to evaluate the potential effects of a particular conservation action, not only on biodiversity but also on other benefits related to wider policy objectives such as health and flood risk mitigation.

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Appendix 1: Supplementary Data

The supplementary data associated with this article can be found in the online version at

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Table

Ecosystem Service Assessment: North Uist

* This category includes the wide range of benefits that people get from biod

[1] A relative importance rating where each ES is rated in relation to other ES.

[2] There are 4 categories or rank: Low, Medium-Low, Medium-High and High

[3] The confidence in evidence for ES delivery ranks: Low, Medium, High

ES main category	ES sub-category	Goods or Services
CULTURAL	**Aesthetics***	Machair flowers, wading birds, UK and European priority species (corncrake, corn bunting, great yellow bumblebee) and habitats, landscape aesthetics
	Artistic	Inspiration for art and crafts
	Heritage	Traditional knowledge, skills, activities, seasons, natural life cycles
	Education	Educational facilities
	Environmental Stewardship	Volunteers.
	Religious	N/A
	Tourism and Recreation	Nature reserve for recreation and amentity
	Energy	N/A