The economics of peatland restoration

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Abstract

Restoration offers opportunities for securing and enhancing critical ecosystem services provided by peatlands, such as carbon storage, water retention and water quality, and support for biodiversity and wildlife. A comprehensive valuation encompassing the relevant public benefits of restoration and how these compare with it is lacking to date, leaving policy makers with little guidance with respect to the economic efficiency of restoring this climate-critical ecosystem. Using Scotland as a case study, this paper quantifies the non-market benefits of changes in peatland ecological condition associated with changes in ecosystem service provision and depending on the location of restoration efforts. Benefits on a per hectare basis are compared to varying capital and recurrent cost in a net present value space, providing a benchmark to be used in decision making on investments into peatland restoration. The findings suggest that peatland restoration is likely to be welfare enhancing. Benefits also exceed cost in appraisals of previous and future public investments into peatland restoration. The results thus strengthen the economic rationale for climate change mitigation through improved peatland management.

Keywords

climate change mitigation; ecosystem restoration; peatlands; choice experiment; benefit-cost assessment; net present value

1. Introduction

Peatlands provide critical ecosystem services including carbon storage (Joosten et al. 2009, Yu et al. 2010), water retention and water quality (Martin-Ortega et al. 2014a), and providing habitat supporting biodiversity and wildlife (D'Astous et al. 2013). Land use and management changes have been modifying the structure and function of peatlands. This process will likely be exacerbated by climate change. As a result, the global peatland greenhouse gas emission balance may potentially change from a carbon sink to a carbon source (Frolking et al. 2011) and threaten stocks of natural capital that have formed over millennia, undermining the adaptive capacity of peatland systems to climatic and other future change (Dise 2009) and compromising the delivery of the critical services they provide (Glenk et al. 2014). It has been calculated that the global CO_2 emissions from drained peatlands have increased by 20% between 1990 and 2008 (Joosten 2009).

These concerns have raised the attention of policy makers internationally. Peatlands are part of the Aichi 2020 targets of the UN Convention on Biological Diversity and can be accounted for in national targets under the UN Framework Convention on Climate Change (Cris et al. 2014). Increasingly, restoration programmes are being deployed across the globe (CBD 2014), and a Global Peatland Initiative has been launched by the UN Environmental

Programme[1]. However, ten years after the Stern Review addressing the economics of climate change (Stern, 2017), there is still no comprehensive economic analysis of this climate-critical ecosystem available to help guide restoration decisions.

To understand whether investments in the restoration of degraded peatlands are socially desirable from an economic efficiency perspective, the costs and benefits of restoration need to be understood. This implies an economic valuation of goods and services that are, at present, not traded in (well-functioning) markets. There has been an attempt to quantify the carbon benefits of peatland restoration using carbon values based on estimates of the abatement costs to be incurred to meet specific emissions reduction targets (Moxey and Moran, 2014). Few studies have quantified the non-market benefits and trade-offs associated with peatland management using stated preference methods. These comprise of Tolvanen et al. (2013), who use a choice experiment to assess trade-offs between allocating peatland area for timber production, peat production, protection, and restoration in Finland, and Bullock and Collier (2011), who undertook two stated preference surveys to investigate public preferences for Ireland's peatlands. These studies focus primarily on potential management conflicts associated with peatland management, including restoration. ~~Also, unlike the research presented in this paper, both studies do not make explicit links between peatland restoration and associated ES.~~

This paper contributes to the development of robust economic analysis underpinning investments into restoration by deriving estimates of the non-market benefits of peatland restoration using stated preference methods, and by comparing these benefits with a range of varying capital and recurrent costs of restoration providing what we refer to as a *space* of Net Present Values (NPVs). This provides information on cost-benefits that can also serve as a basis for private investment decisions, for example in the form of payments for ES.

This NPV space approach is applied here to Scotland. Around 9-15% of Europe's peatland areas are found in the UK, of which more than 77% are located in Scotland (Bain et al. 2011). Peatlands – mainly blanket bogs – cover more than 20% of Scotland's land surface. In the past, peatlands in Scotland were mainly seen as either a source of peat or as wastelands to be converted to other productive uses such as forestry or agriculture (Rotherham, 2011). As a consequence, a large share of Scottish peatlands has been degraded to some extent. More than two thirds of Scottish peatlands are thought to be damaged or degraded to some degree, and degradation is projected to continue if no action is taken (Bain et al. 2011). This has led to a recent surge in policy interest to restore degraded peatlands. Depending on the change in peatland condition, changes in the amount of greenhouse gas emissions from peatlands following restoration can be substantial with emission differentials of up to 22.8 $tCO_2eq\ ha^{-1}\ yr^{-1}$ for a change from actively eroding to near natural condition (Smyth et al. 2015), although emission savings will be lower in most cases. Bullock et al. (2012) report sequestration estimates of up to 5.9 $tCO_2eq\ ha^{-1}\ yr^{-1}$ or 16 $tCO_2eq\ ha^{-1}\ yr^{-1}$ of savings on previous losses of 11 $tCO_2eq\ ha^{-1}\ yr^{-1}$.

[1] http://www.globalpeatlands.org/

In its recent Draft Climate Change Plan (Scottish Government 2017), the Scottish Government has laid out ambitious targets to restore 20,000 hectares of peatlands each year over the next 15 years, supporting this aim through restoration grants available to land managers. This initiative follows a period of investment through the Peatland Action programme that resulted in the restoration of about 10,000 hectares (2013–2016). This paper will develop indicative benefit-cost comparisons for both previous and future public investment into restoring Scotland's peatlands.

Apart from providing important economic information to inform restoration decisions, this study adds value to the literature on natural capital valuation more broadly with respect to the way that changes in the provision of ES are valued through their association to the ecosystem's ecological condition. It is challenging, and to some extent questionable, to derive separate benefit estimates for different ES in cases where the management interventions impact on bundles of ES simultaneously; i.e., the provision of key ES is causally related through management interventions, and hence the associated ecological condition of an ecosystem. This is not only the case for peatland ecosystems but applies more generally to cases of ecosystem restoration (Bullock et al. 2011). Through a careful consultative transdisciplinary process with peatland experts and practitioners (Martin-Ortega et al. 2017), restoration outcomes in terms of changes in ecological condition were defined with simple narratives describing key patterns of the ecosystem's processes and associated ES. This approach allows a straight forward quantification of restoration benefits on a per hectare basis, making it appealing to use for decision makers, and facilitating further spatial analysis of benefit estimates.

Methodologically, this paper contributes to the stated preference literature on the analysis of preferences for spatial attributes of ecosystem service provision. Particularly, we estimate how non-market benefits of restoration differ depending on characteristics of the ecosystems that have a spatial dimension that is unrelated to distance effects and substitute availability as the two theoretically and empirically most prominent spatial concepts in the environmental economics literature (Schaafsma et al. 2012).

2. Methods

2.1 Benefits

2.1.1 Stated preference study design

To obtain estimates of social (non-market) benefits of peatland restoration, we employ data from a choice experiment study in Scotland. Choice experiments are a quantitative survey-based technique used to elicit preferences by asking individuals to directly state their preference over hypothetical options representing environmental goods to be valued. The options are described by a number of attributes, which allows investigation of whether these attributes have a significant influence on respondents' choices. If one attribute represents a change in income of the respondent (i.e. through incurring a cost), the monetary value associated with a change in a non-cost attribute can be estimated as the marginal rate of substitution between the two attributes (Adamowicz et al. 1998). Selection and operationalization of attributes reflecting the complexity of peatlands in a manner that could be understood by the public required an intensive consultative process with a range of peatland specialists and repeated testing of the survey instrument with the public (Martin-Ortega et al. (2017) provide details on this process, the full range of actors consulted, and information regarding the focus groups carried out with the public and the development of the survey instrument).

In the final choice experiment set up, survey respondents were asked to choose from two peatland restoration alternatives characterize by five attributes, described as outcomes of a restoration programme by the year 2030. Two attributes described percentage shifts in ecological condition relative to the share of peatlands in each condition in a business as usual (BAU) scenario. We considered three ecological conditions: poor, intermediate and good. Improvements in peatland condition are associated with an increase in ecosystem service provision related to climate change mitigation (carbon storage), water quality improvement and changes to wildlife. This approach therefore differs from ecosystem service valuation studies that attempt to value ES individually, despite them being causally related (in this case with restoration action). To present a rigorous picture of what restoration can entail in terms of outcomes, a narrative was developed that explained how changes in ecosystem condition lead to changes in ecosystem service provision. The narrative was developed to convey complex information in a comprehensible manner (see Supplementary Materials S1 and Figure 1 for an overview of the peatland ecological conditions and associated ecosystem service impacts shown to respondents)[2].

INSERT FIGURE 1 HERE

The current share of peatlands in each of three ecological conditions, how these shares develop under a BAU scenario, and the range of feasible shifts in area under a certain condition, were determined in a consensual focus group with Scottish peatland experts since observed data on peatland extent and condition is lacking (Martin-Ortega et al. 2017). The experts estimated that currently one fifth of Scotland's land surface, approximately 1.6 million hectares, is covered by peatlands. 30% of peatlands were perceived to be in poor ecological condition (40% by 2030); 40% in intermediate (40% by 2030) and 30% in good ecological condition (20% by 2030). The maximum scope for potential restoration was defined as up to 75% of peatlands in intermediate and bad condition by 2030 that could be transformed to good ecological condition.

Two additional attributes correspond to two spatial criteria aimed at capturing people's preferences with respect to areas where restoration should be prioritized. Two criteria emerged to be relevant in preparatory focus groups with the public (Byg et al. 2017;

[2] The survey, and in particular the information materials, received a lot of positive feedback from respondents (discussed in Martin-Ortega et al. 2017). This caused us to develop the (slightly modified) version of the whole information package provided in the survey up to the description of choice scenarios into a communication tool, to be accessed here: http://www.see.leeds.ac.uk/peatland-modules/?type=learning

Martin-Ortega et al. 2017): 1) the degree of peatland concentration in an area and 2) the degree of remoteness or accessibility of a peatland. With respect to the first criterion (degree of peatland concentration), participants found it relevant to preserve either 'the heart of peatlands' or 'the little that is left'. While the first aspect ('heart of it') captures concerns about the integrity of peatlands as a whole, the latter ('little left') reflects the value of preserving peatlands in areas where the habitat is relatively scarce.

With respect to the second spatial criterion (degree of remoteness or accessibility of a peatland), some participants argued for peatlands to be restored where they should remain undisturbed, while others expressed a preference of restoring them in accessible areas where they can be easily enjoyed. The two spatial criteria were then operationalized in attributes as focusing restoration in i) areas where peatlands cover more or less than 30% of the land surface (high or low 'concentration') and ii) remote and inaccessible areas ('wild land areas') or relatively accessible areas. Maps were created to illustrate the attribute to respondents (Figure 2).

INSERT FIGURE 2 HERE

The restoration alternatives included a monetary trade-off in the form of a cost to the tax payer towards a hypothetical Peatland Trust fund responsible for implementing a restoration programme that would deliver the proposed improvements and be in place over a period of 15 years, reflecting relevant planning periods in national climate change policy (Scottish Government 2017). Each respondent was presented with eight choice situations in which they were asked to choose between the 'business as usual scenario' (at no additional cost) and two scenarios of improved peatland condition in exchange for that cost. 1 summarizes the choice experiment attributes and levels (an example choice set is shown in Figure 3).

INSERT TABLE 1 HERE

INSERT FIGURE 3 HERE

Apart from information on peatlands, ecological condition, restoration and associated benefits and the choice experiment, the survey collected data on reasons for supporting (or not supporting) restoration, perceptions of peatlands including links to cultural identity, general attitudes towards the environment and socio-demographic information about the respondents.

2.1.2. Survey implementation

The experimental design was a D-efficient Bayesian design created using NGene Software optimised for an MNL model using prior estimates of parameters based on a pilot study (N=100). The 40 choice sets of the design were blocked into five versions which were randomly assigned so that each respondent faced eight choice situations, whose order of appearance was again randomised across respondents. The survey was implemented online using a professional market research company with 585 adult Scottish citizens[3] between February/March 2016. A quota-based approach was used to sample from the online panel with age and gender as 'hard' quotas and a 'soft' quota for social grade. The sample was representative of the population of Scotland in terms of gender, age, and the rural/urban split. In terms of educational attainment, higher educational levels are slightly over-represented, as well as are respondents with higher employment-based social grade (see Table 2).

INSERT TABLE 2 HERE

2.1.3 Econometric Approach

Respondents to the choice experiment were repeatedly asked to choose between three options. Two options described possible restoration programmes, characterised by attributes describing the changes in the area of peatland condition resulting from restoration $\boldsymbol{x}$, attributes describing areas where peatland restoration efforts should focus on $\boldsymbol{z}$, and a cost attribute p. The third option was a 'business as usual' (BAU) or status quo option, describing changes to take place in the absence of additional restoration at no extra cost to respondents.

Following random utility theory, a utility function is characterised by the attributes of the experimental design in addition to a random error term ε. Cost p and changes in the area of peatland condition $\boldsymbol{x}$ enter the utility function as main effects, whereas the attributes defining the spatial focus of restoration efforts $\boldsymbol{z}$ are interacted with $\boldsymbol{x}$. Following Johnston and Duke (2009), this avoids obtaining a fixed utility impact for location of restoration even if changes in shares of peatland condition are zero. It also allows preferences for location of restoration efforts to be different depending on the type of change in peatland condition, thusderiving marginal WTP estimates for % shifts in the area under a specific peatland ecological condition depending on the location of restoration. Since we observe two shifts in ecological condition (poor to good; intermediate to good) and two spatial criteria for prioritization of restoration action with two mutually exclusive options (wild land area or not; high or low concentration of peatlands), we ultimately obtain a total of eight marginal WTP estimates for potential further use in benefit-cost appraisals.The utility function U for respondent n and policy option i in choice task t can then be written as:

$$U_{nit} = -\alpha_n p_{nit} + \boldsymbol{\beta}_n{}'\boldsymbol{x}_{nit} + \boldsymbol{\vartheta}_n{}'\boldsymbol{z}_{nit}\boldsymbol{x}_{nit} + \varepsilon_{nit} \quad (1)$$

where α, $\boldsymbol{\beta}$ and $\boldsymbol{\vartheta}$ are parameters to be estimated. The random error term ε is assumed to be identically and independently distributed (*iid*) and related to the choice probability with a Gumbel distribution with error variance $\mathrm{Var}(\varepsilon_{ni}) = \mu_n^2(\pi^2/6)$, where μ_n is a respondent specific scale factor.

If Equation (1) is divided by μ_n a scale-free utility function is derived that has a new error term, which is constant across respondents (Train and Weeks 2005):

[3] The sample analysed here was part of larger sample of 1,795 individuals comprising of three different split-samples for methodological purposes outside the scope of this paper.

$$U_{nit} \;=\; -(\alpha_n/\mu_n)p_{nit} + (\boldsymbol{\beta}_n/\mu_n)'\boldsymbol{x}_{nit} + (\boldsymbol{\vartheta}_n/\mu_n)'\boldsymbol{z}_{nit}\boldsymbol{x}_{nit} + \;\varepsilon_{nit} \qquad (2)$$

where ε_{nit} is *iid* with constant error variance $\pi^2/6$. Defining $\gamma_n = \alpha_n/\mu_n$, $\boldsymbol{c}_n = \boldsymbol{\beta}_n/\mu_n$ and $\boldsymbol{\zeta}_n = \boldsymbol{\vartheta}_n/\mu_n$ as parameters to be estimated provides what Train and Weeks (2005) refer to as the model in preference space. However, the distribution of marginal willingness to pay (WTP) can be estimated directly in a model in WTP space. Because marginal WTP for changes in the share of peatland condition is $\boldsymbol{w}_n = \boldsymbol{c}_n/\gamma_n$ and marginal WTP for changes in the share of peatland condition depending on location of peatland restoration efforts is $\boldsymbol{l}_n = \boldsymbol{\zeta}_n/\gamma_n$ the utility function in WTP space is:

$$U_{nit} \;=\; -\gamma_n p_{nit} + (\gamma_n \boldsymbol{w}_n)'\boldsymbol{x}_{nit} + (\gamma_n \boldsymbol{l}_n)'\boldsymbol{x}_{nit}\boldsymbol{z}_{nit} + \;\varepsilon_{nit}. \qquad (3)$$

Let the sequence of choices over T_n choice tasks for respondent n be defined as $\boldsymbol{y}_n = \langle i_{n1}, i_{n2}, \dots, i_{nT_n}\rangle$. The random parameter logit (RPL) model enables estimation of heterogeneity across respondents by allowing γ_n and $\boldsymbol{w}_n$ to deviate from the population means following a random distribution. The unconditional choice probability of respondent n's sequence of choices (y_n over T_n choice tasks) is:

$$\Pr(\boldsymbol{y}_n|\gamma_n, \boldsymbol{w}_n) = \int \prod_{t_1=1}^{T_n} \frac{\exp(-\gamma_n p_{nit} + (\gamma_n \boldsymbol{w}_n)' x_{nit} + (\gamma_n \boldsymbol{l}_n)' x_{nit} z_{nit})}{\sum_{j=1}^{J} \exp(-\gamma_n p_{njt} + (\gamma_n \boldsymbol{w}_n)' x_{njt} + (\gamma_n \boldsymbol{l}_n)' x_{njt} z_{njt})} f(\boldsymbol{\eta}_n|\boldsymbol{\Omega}) d\boldsymbol{\eta}_n \qquad (4)$$

where $f(\boldsymbol{n}_n|\boldsymbol{\Omega})$ is the joint density of the parameter vector for cost and non-cost attributes, $[\gamma_n, \boldsymbol{w}_n, \boldsymbol{l}_n]$, $\boldsymbol{\eta}_n$ is the vector comprised of the random parameters and $\boldsymbol{\Omega}$ denotes the parameters of these distributions (e.g. the mean and variance). The integral in Equation (4) does not have a closed form and thus requires approximation through simulation (Train, 2003), which were based on 2,000 Halton draws. In the estimation, we allow for correlation of all random parameters (full covariance). Starting values for the model with full covariance are derived from a model with uncorrelated coefficients (Hess and Train 2017).

To ensure positivity of the marginal utility of income, the cost attribute parameter is assumed to follow a lognormal distribution. The marginal WTP parameters of the remaining non-cost attribute effects are assumed to follow a normal distribution. An alternative specific constant (ASC) for the business as usual (BAU) option is also specified as a random parameter following a normal distribution.

Although the focus of this paper is on deriving WTP estimates for use in benefit-cost appraisal, we also analyse whether individual characteristics have a systematic influence on WTP estimates. Based on the RPL model we calculate 'individual-specific' WTP values for each sampled respondent based on individual conditional distributions. Making use of Bayes' theorem, the expected value of marginal WTP for individual n can be approximated by simulation (Train 2003). A discrete approximation of respondent n's conditional means may be written as

$$E_n\widehat{(\boldsymbol{w}, \boldsymbol{l})} = \frac{\sum_{r=1}^{R} L(\boldsymbol{y}_n|\boldsymbol{w}_r, \boldsymbol{l}_r)\boldsymbol{w}_r, \boldsymbol{l}_r}{\sum_{r=1}^{R} L(\boldsymbol{y}_n|\boldsymbol{w}_r, \boldsymbol{l}_r)} \qquad (5)$$

where $\boldsymbol{w_r}$ and $\boldsymbol{l_r}$ are independent and multi-dimensional draws from $f(\boldsymbol{\eta}|\boldsymbol{\Omega})$ (the joint density of the attribute parameter vector). It should be noted that the conditional estimates reflect the respondent’s most likely position on the estimated distribution of marginal WTP given their sequence of choices made. This implies that respondents with the same sequence of choices to identical choice sets will have the same conditional (posterior) WTP. Nevertheless, across the whole sample, the conditional mean WTP estimates are useful in shedding light on systematic differences in preferences depending on individual characteristics.

This is done by using ordinary least square regressions with conditional marginal WTP estimates as dependent variables and consider as independent variables a range of socio-economic characteristics (age, gender, education), whether respondents’ place of residence is located in urban rather than rural areas, perceived consequentiality of the survey, and perceived credibility of choice scenarios.

2.2 Cost

Peatland restoration comes at a cost to the private land manager. These costs include upfront capital costs required to implement restoration practices, recurring costs associated with the maintenance and monitoring of restoration sites, and transaction costs. Further, the private land manager faces an opportunity cost in terms of income forgone from alternative land uses.

A variety of restoration techniques is available. Frequently applied techniques include, for example, blocking grips, drains and gullies, re-profiling of peat, or stabilisation of bare peat through reseeding or the use of jute mats. In case a peatland is being used for forestry, trees need to be removed before preparing the area for restoration. The cost of applying each technique can vary greatly and also depending on the type of machinery used and accessibility of the peatland area. At present, data on capital costs associated with restoration are essentially anecdotal. Moxey and Moran (2014) refer to an indicative range of £200/ha to £10,000/ha.

The Scottish Government has funded about 10,000 hectares of peatland restoration since 2013 through the voluntary Peatland Action scheme administered by Scottish Natural Heritage (SNH). Through the application process and reporting, some information was obtained on restoration cost. However, the information collection process was not specifically designed up to derive per hectare values of restoration costs, and did not systematically capture the variety of techniques vis-à-vis peatland condition. Therefore, additional judgment was obtained from the SNH Peatland Action manager (A. McBride, pers. comm.) to translate the information obtained into indicative per hectare costs. The resulting implementation and management costs vary greatly and span from about £300/ha for restoration of dry heath peatlands to about £5,000/ha for restoration of sites of peat extraction, or where bare peat dominates. Including all project management costs and a wide range of restoration activities including expensive forest to bog and bare peat restoration, the average cost per hectare over the 3 years of the Peatland Action scheme is reported to be about £830 per hectare for all types of restoration.

Regarding recurring costs, Moxey and Moran (2014) use a range of £25/ha to £400/ha for aggregate average annual on-going costs. They argue that the lower bound value reflects minimal monitoring costs and no management and opportunity costs, while the upper bound value would be associated with substantial opportunity costs and/or high costs of management and monitoring. As pointed out by Moxey (2016), the opportunity costs of restoring peatlands very much depends on circumstances and hence may only be revealed throughout a period of observation following restoration, collecting detailed information on management changes from individual land managers. Profitability of livestock grazing and grouse management as two prominent land use options on peatlands typically lie in the range of £20/ha to £140/ha, but there is great variation and upland farm enterprises may actually face negative gross margins (Moxey, 2016; Smyth et al. 2015), and early restoration action often takes place in areas of low productivity. An additional important consideration regarding opportunity costs is if land under restoration or previously restored would continue to be eligible for Pillar I payments under the EU Common Agricultural Policy. The current policy climate with respect to eligibility of land for subsidy payments following peatland restoration in Scotland appears to be favourable (Moxey, 2016), but the magnitude and structure of potential payments *post* Brexit is uncertain.

Given that costs appear to be highly variable and that specific information in relation to peatland condition and spatial criteria is unavailable, we will NPVs on a per hectare basis under varying capital and recurring costs. This provides a picture of the combinations of cost elements that still yield an outcome that generates net benefits to society, thereby enabling decision makers to flexibly use this information across a variety of restoration decisions. Policy makers are provided with a space to understand how costs affect economic efficiency of national level programmes. Individual project managers, who are likely to have a more precise idea of the cost of their projects, can locate their projects in this space to assess its NPV.

3. Results

3.1. Choice experiment results

Of the 585 respondents, 53 were found to be serial non-participants; i.e. they chose the BAU option in all eight choice tasks. Using debriefing questions on motives for choosing the BAU option in all tasks enabled us to identify those respondents having protest motives (N=19), which were omitted from subsequent analysis as is standard practice. Protest motives included the following arguments: “others should pay”; “I don’t trust the money would be used for peatland restoration”.

We also investigated the data set for the use of decision rules that suggest that respondents might not have been making trade-offs between all alternatives or have not been trading off costs against restoration outcomes. Four respondents chose either restoration option A or restoration option B in all eight choice tasks. Further, 73 respondents (12.5% of the sample) always chose the cheapest of the two restoration options across the majority of choice sets, else the status quo. Because their choice behaviour strongly suggests that they systematically did not make trade-offs between non-monetary attributes and cost, we omitted them from the sample, resulting in a final sample used for analysis of 489 respondents[4].

The modelling results are reported in Table 3. The goodness-of-fit of the RPL model can be considered to be good (Pseudo R-squared value: 0.31) and is considerably improved compared to a conditional logit (CL) model that assumes homogeneity of preferences. Estimates of the alternative-specific constant (*ASC*) are positive and significantly different from zero. This suggests a tendency among respondents to choose the restoration options over the business as usual for reasons unexplained by the attributes themselves. The mean WTP indicators for changes from poor and intermediate condition to good condition (*poor*; *int*) are positive and significantly different from zero, with parameters for changes from poor condition being considerably larger in magnitude relative to parameters for changes from intermediate condition. This indicates sensitivity to scope amongst respondents as theoretically expected. Regarding the interaction terms between condition and spatial criteria (*poor x conc*; *poor x wild*; *int x conc*; *int x wild*), parameters show opposite signs for interactions related to changes from intermediate to good condition compared to those related to changes from poor to good condition, although parameters for *poor x conc* and *poor x wild* are not significantly different from zero. The spatial criteria therefore affect marginal WTP differently depending on the starting condition for restoration. The magnitude of parameter estimates in WTP terms indicates that respondents show greater differentiation between spatial criteria for changes from intermediate to good condition compared to changes from poor to good condition. The high *t*-values for all standard deviation parameters and their magnitude relative to estimates of the mean suggest the presence of considerable (unobserved) heterogeneity in preferences.

INSERT TABLE 3 HERE

The improvements presented were always associated together with the two spatial criteria reflecting prioritization of restoration effort. In other words, restoration has to always take place in areas characterized by one out of the four combinations of spatial criteria. To be meaningful, it is therefore necessary to estimate WTP for the combinations of changes in the share of peatland condition relative to the 2030 baseline and spatial attribute estimates. These values are reported in Table 4 based on model results. The values, expressed in GBP per 1% shift in condition per household and year, again highlight a greater differentiation among spatial criteria for changes from intermediate to good condition. WTP is greatest for a shift from intermediate to good condition in relatively remote and inaccessible areas (‘wild land areas’) where peatlands make up a large proportion of the land cover (‘high peatland concentration’). WTP is not found to be significantly different from zero for a shift from intermediate condition in relatively accessible areas with low concentration of peatlands.

[4] It is important to note that, using a probit model, no selection bias could be detected that would indicate a systematic effect of a broad range of socio-demographic characteristics on choosing the cheapest alternative in all choice tasks (see Supplementary Materials S2).

The WTP values for a 1% shift in condition per household and year are transformed to annual per hectare values by aggregating the values to the relevant population (2.4 million households), adjusted by the percentage of the sample giving protest answers, and by then dividing this value by the number of hectares that corresponds to a 1% shift in peatland condition relative to the business as usual baseline in 2030 (approximately 6,300 hectares). The results are shown in the lower part of Table 4.

INSERT TABLE 4 HERE

3.2. Preference heterogeneity

Table 5 reports summary statistics of explanatory variables used in the ordinary least squares (OLS) regressions. Explanatory variables include *Age* (continuous), *gender* (=1 if female), *education level* (=1 if university degree (BSc, MSc or PhD)), annual after tax household income (*Medium income*: =1 if in interval [£20,00;£41,599]; *High income*: =1 if > £41,600), and residence in an urban settlement (=1). Dummies were used to indicate if respondents did not provide information on income or education (*Incmiss*; *Edumiss*).

Scenario credibility is meant to capture respondent perceptions of the credibility of the hypothetical choice scenarios using the following four-scale item (1=completely disagree; 4=completely agree): “The peatland restoration alternatives presented in the choice situations were credible to me”. *Policy consideration* is meant to capture perceived consequentiality of surveys conducted in the context of peatland restoration on policy makers. It is measured using the following four-scale item (1=completely disagree; 4=completely agree): “I believe that the results of surveys like this one will be ignored in policy discussions on peatland restoration”.

INSERT TABLE 5 HERE

Results of the OLS regressions are shown in Table 6 below. Across all eight combinations of peatland condition changes and prioritized restoration locations, being female has a negative effect on WTP (*Gender*). Higher perceived credibility of the hypothetical choice scenario (*Scenario credibility*) shown in the survey also has a positive effect on WTP. If respondents believe that surveys such as the one conducted do not have influence on related policy discussions (*Policy consideration*), WTP is affected negatively.

INSERT TABLE 6 HERE

3.3. NPV space

Variability in cost and lack of biophysical information on the distribution of peatland condition are barriers to a spatially specific analysis of the economic efficiency of peatland restoration. Yet, an understanding of costs and benefits is needed to make informed decisions on further investments and policy development. We therefore provide information on the 'space' of NPVs depending on actual costs.

Using the per hectare benefit estimates reported in Table 4, we estimated NPVs on a per hectare basis under varying capital and recurring costs for the eight combinations of peatland condition and spatial criteria. In line with 2003 UK government guidance we used an annual discount rate of 3.5% over the 15 year time period to derive NPVs. A value of NPV > 0 and a corresponding benefit-cost (B/C) ratio > 1 indicate that the programme or policy would generate welfare gains to society. This analysis, represented in Figure 4, reveals those combinations of costs and benefits that likely yield an outcome that generates net benefits to society.

INSERT FIGURE 4 HERE

Illustrative benefit-cost analyses are being conducted for two specific policies. For both, the capital cost of restoration is assumed to be £830/ha, with an additional £100/ha per year recurring cost reflecting management costs and income forgone in the middle of the range reported in the literature. The first appraisal aims at an *ex-post* evaluation of the Peatland Action programme, through which 10,000 hectares of peatlands were restored within three years (2013-2016). NPV for this programme using average benefit estimates across peatland conditions is estimated to be £7.9 million with a corresponding B/C ratio of 1.39. Using the 95% confidence interval of the benefit estimates, the lower bound NPV becomes negative at 1.9 million and the B/C ratio is 0.9, while upper bound values are £17.7 million for the NPV and a B/C ratio of 1.88.

The second illustrative benefit-cost appraisal concerns the target of restoring 10,000 hectares in 2017 and subsequently 20,000 hectares per year over the following 14 years defined in the Draft Climate Change Plan for Scotland. The NPV is calculated to be £79.6 million for average benefit estimates (B/C ratio: 1.15). NPV is £-12.9 million and £287.6 million if the lower and upper bound benefit estimates are applied (B/C ratios: 0.75; 1.56).

4. Discussion

Choice experiment results indicate that the Scottish public perceives significant benefits for improving the condition of peatlands associated with changes in the provision of ecosystem services (ES) such as carbon sequestration, water quality and support for wildlife habitat. Non-market benefits of peatland restoration are found to vary depending on initial peatland condition and focal areas for restoration.

The two theoretically and empirically most well-founded spatial relationships in the environmental valuation literature are distance decay of benefit estimates and the availability of substitutes as an indication of scarcity. Distance decay predicts that values for environmental goods decrease with increasing distance of an individual to that site and hence limited or more costly consumption possibilities (Bateman et al. 2006). Relative scarcity of an environmental good decreases as more substitutes become available to an individual, which *ceteris paribus* is expected to result in lower values for the good in question (Hoehn and Loomis, 1993; Whitehead and Blomquist, 1995). The two phenomena have strong theoretical motivations for goods that are directly consumed and hence provide direct use values, such as recreational benefits, and have been demonstrated in numerous studies to date. Even if we recognise that spatial effects can be more complex and involve, for example, directional heterogeneity (Schaafsma et al, 2012), little evidence was found in the preparatory phase of this study (in the focus groups) that people adhere to the two relationships when expressing preferences for where peatland restoration should take place. Rather, respondents were concerned with spatial characteristics of the ecosystem that are not necessarily related to distance effects and substitute availability, i.e. restoring the 'heart' of Scottish peatlands (or where there is little left) and where they have a greater chance of remaining undisturbed (or not). The included attributes are also different from studies to investigate spatial preference heterogeneity through attributes indicating the administrative geographical units or locations where the proposed changes are to take place (Jacobsen and Thorsen (2010); Jørgensen et al. (2013); Brouwer et al. (2010)).

Additionally, the relevance placed on spatial criteria, and the average preferences, differed markedly depending on the type of change in ecosystem condition resulting from restoration. Respondents were less sensitive to spatial criteria for changes from poor to good condition compared to changes from intermediate to good condition. This appears plausible: if the current state of the ecosystem is severely deteriorated, results suggest that it should be improved regardless of its location. Our findings are different from Brouwer et al. (2010), who also compare WTP across locations depending on the magnitude of environmental change. In their study on water quality improvements in two Spanish catchments, the authors did not find differences in WTP in for improving water bodies to moderate or good ecological condition in the two locations, but found that respondents' WTP was significantly higher for improvements to very good condition in the catchment were respondents resided than in a neighbouring catchment. Together, the findings demonstrate that spatial dimensions of preferences for ecosystem changes may be complex and go beyond the theoretically most widespread concepts. It is possible, and worth of further investigation, that this finding might not be unique to peatlands, but applicable more broadly to ecosystems which are relatively unfamiliar to respondents and have a relatively low use value associated with direct experience of the ecosystem.

Our approach, which valued changes in ecosystem condition associated with changes in the provision of bundles of individual ecosystem service, allowed a straight forward quantification of ecosystem restoration benefits on a per hectare basis, making it comparable with costs of restoration. Martin-Ortega et al. (2017) show that this approach proved to be useful in conveying peatland systems' complexity in a sufficiently simple manner for the public while remaining rigorous from a biophysical perspective. The approach therefore addresses challenges associated with the valuation of individual final ES where ecological production functions would need to be understood by respondents, which has been shown to not always be the case (Johnston et al. 2017); and where specific ecological production functions are not confidently quantified. In the case of peatland restoration, this may at best be the case for carbon emissions (Evans et al. 2014), while data on potentially important ES such as water quality or flood risk mitigation downstream is less established (Martin-Ortega et al. 2014). The generation of production functions is further complicated by the spatially explicit nature of many ES (Glenk et al. 2014).

Drawing on the benefit estimates derived from the choice experiment, the NPV space analysis shows how variation in capital and recurrent costs affects net benefits from restoration depending on peatland baseline conditions and location of restoration. Given a lack of accurate cost estimates, the NPV space can serve as a first reference point for general policy appraisal. As better information on costs and the spatial distribution of peatland condition becomes available, the NPV space can be updated and narrowed down to different locations, peatland conditions, restoration activities and applied to relevant policy scales. Because policy concerning peatland management is developing rapidly, we however believe that the analysis reported in this paper provides reasonably robust estimates to assist initial national level policy decisions on investments in peatland restoration. Moreover it can already be used for individual project appraisal, where costs are likely to be well understood by project managers.

Improved knowledge on the spatial distribution of peatland conditions, ideally related to information on greenhouse gas emissions and provision of other ES, will be crucial for more targeted restoration decisions and hence a more efficient resource allocation. The same applies to data on restoration costs, which is currently very limited. This becomes increasingly important as commitments are being made to considerably scale up peatland restoration efforts. Capital costs may increase in the short term if increasing demand for restoration services cannot be met by a limited number of suppliers of such services. However, careful planning and adaptive learning from individual projects may help to reduce capital costs over time due to economies of scale and development of more efficient restoration techniques. On the other hand, if early adopters implement restoration on unproductive land, opportunity costs associated with income forgone are likely to increase at some point. Given the information currently available, our findings suggest that greater scrutiny should be applied to identifying costs restoration projects in locations associated with lower benefit values, because they are at greater risk of costs exceeding benefits

It should be noted that our study also shows that preference heterogeneity is large in magnitude, suggesting that different respondents likely held opposing views regarding their preferences for (spatial) prioritization of efforts. This is coherent with findings from complementary qualitative work (Byg et al. 2017), which found that public perceptions of peatlands are ambivalent and multi-facetted (e.g. they can be perceived as bleak wastelands, beautiful wild nature and as a cultural landscape). The multiple and ambivalent views of ecosystems such as peatlands may be linked to biophysical characteristics, history, trade-offs between different uses and differences in personal relationships with nature.

5. Conclusions

A comprehensive valuation encompassing the public benefits of peatland ecosystems and how these compare with the costs of restoration has been lacking to date. This means that policy makers have thus far had very little guidance with respect to the economic efficiency of investments into restoration of this climate-critical ecosystem on its own or compared to competitive government spending for climate change mitigation and adaptation related to land use or in other sectors. Additionally, the lack of an economic rationale for restoration hampers the potential for developing market-based financing mechanisms such as payments for ecosystem services that could potentially complement publicly financed peatland restoration aimed at climate change mitigation.

The economic analysis presented in this paper provides the basis for understanding whether peatland restoration is likely to provide overall welfare gains to society, i.e. whether it is economically efficient to invest in restoration. We recommend the findings to serve as a benchmark for national level policy appraisals, and as a starting point for more detailed assessments of projects on a case by case basis, which should make use of more detailed information on peatland baseline condition and more refined data on restoration costs. Such assessments should also aim to recognise the multi-faceted nature of public perceptions (Byg et al. 2017), issues of fairness and equity in payments made to land owners and potential shared social and cultural value arising from restoration to different groups within society (Reed et al. 2017).

The benefit-cost assessments of previous and future investment decisions into peatland restoration in Scotland reported in this paper suggest that peatland restoration has been and will likely be welfare enhancing. This provides justification for the ambitious restoration targets set out in Scotland's Draft Climate Change Plan and underpins, from an economic perspective, the great potential of peatland restoration to contribute to climate change mitigation as well as to provide numerous ecosystem services to society. As restoration efforts gain pace, the important question to be addressed should hence move towards identifying the conditions under which peatland restoration will yield the greatest benefits to society.

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Table 1. Description of the choice experiment attributes and levels

Attributes	**Label**	**Levels**[a]
Improvement of peatland share from poor ecological condition to good ecological condition[a]	*poor*	0%, 25%, 50%, 75%
Improvement of peatland share from intermediate ecological condition to good ecological condition[a]	*int*	0%, 25%, 50%, 75%
Focus on peatland restoration in wild land areas	*wild*	Yes, No
Focus on peatland restoration in areas with high or low 'concentration' of peatlands	*conc*	High, Low
Cost (annual tax, GBP per household and year)	*price*	10, 25, 50, 75, 150, 250

Note: [a] Shifts are relative to the business as usual shares of peatlands for each ecological condition (poor: 40%; Intermediate: 40%; good: 20%)

Table 2. Socio-demographic characteristics of the sample compared to the overall Scotland's population

Variable	Sample	Overall Population (Scotland)[a]
Gender distribution		
Female	50.3%	51%
Male	49.7%	49%
Age distribution (years old)		
18-24	6.8%	11.9%**
25-44	36.2%	33.0%
45-64	34.7%	34.2%
≥ 65	22.3%	20.9%
Yearly household income		
GBP per year	£39,615	£38,337
Educational attainment (highest achieved Scotland census level)[b]		
Level 0	13.1%	26.8%
Level 1	20.8%	23.1%
Level 2	18.5%	14.3%
Level 3 and above	45.3%	36.0%
Prefer not to tell	2.4%	–
Social grade (employment-based)[c]		
Higher and intermediate	19.0%	19.0%
Supervisory, clerical, junior	43.2%	32.0%
Skilled manual	9.7%	22.0%
Semi-skilled, un-skilled	18.1%	28.0%
Prefer not to tell	8.3%	–
Average household size		
Persons per household	2.34	2.25
Urban/Rural population		
Urban	65.13%	69.9%
Rural	34.87%	30.1%

Note: [a] Scotland Census (2011) by National Records of Scotland (http://www.scotlandscensus.gov.uk/); [b] Population figures include population 16 years old or older while our survey includes respondents 18 years old or older. The under-representation of the lowest age range and education level is partly explained by this different lower age bound; [c] Lower representation of lower levels of social grade might be explained by 'prefer not to tell' answers which are more likely to correspond to lower rather than higher social grades.

Table 3. Conditional logit (CL) and random parameter logit (RPL) model results

	CL		**RPL**			
	mean		mean		SD	
ASC_{BAU}	-0.2247	**	-0.4721	***	0.9935	***
	(-2.58)		(-3.88)		(8.5)	
poor	0.0036	**	0.0075	***	0.017	***
	(2.71)		(6.59)		(12.81)	
int	0.0031	**	0.0048	***	0.0115	***
	(3)		(5.75)		(10.87)	
poor x wild	-0.0009		-0.0000		0.0026	***
	(-1.17)		(-0.15)		(3.5)	
int x wild	0.0039	***	0.0039	***	0.0055	***
	(4.43)		(6.06)		(5.55)	
poor x conc	-0.0005		-0.0008		0.0035	***
	(-0.73)		(-1.51)		(4.22)	
int x conc	0.0028	***	0.0026	***	0.0038	***
	(3.47)		(5.03)		(5.14)	
price (neg)	0.8357	***	1.0314	***	0.6766	***
	(15.43)		(11.44)		(6.97)	
Log-L	-3964.6		-2951.3			
Rho Square	0.077		0.313			

Note: The cost attribute was re-scaled and entered the model as 1/100 of the values in GBP shown on choice cards. Correspondingly, to arrive at estimates in terms of WTP, parameters should be multiplied by 100. *poor*, *int* and *price* entered the choice models as continuous variables, *wild* and *conc* as effects coded variables taking 1 for Yes (*wild*) and High (*conc*), else -1. *t*-values in parentheses; asterisks indicate if parameters are significantly different from zero: *** at the 0.1% level; ** at the 1% level; * at the 5% level.

Table 4. WTP estimates (GBP per year) relative to the 2030 baseline and spatial attributes

Per household estimates for a 1% shift in peatland condition

Condition change	**Peat con-centration**	**Wild land area**	**95% confidence interval**			
			mean		lower	upper
Poor to Good	Low	No	0.835	***	0.593	1.077
Poor to Good	Low	Yes	0.817	***	0.540	1.093
Poor to Good	High	No	0.682	***	0.418	0.946
Poor to Good	High	Yes	0.664	***	0.364	0.963
Intermediate to Good	Low	No	-0.177		-0.392	0.039
Intermediate to Good	Low	Yes	0.61	***	0.36	0.860
Intermediate to Good	High	No	0.35	***	0.152	0.548
Intermediate to Good	High	Yes	1.136	***	0.880	1.391

Per hectare estimates

Condition change	**Peat con-centration**	**Wild land area**	**95% confidence interval**		
			mean	lower	upper
Poor to Good	Low	No	304.2	216.0	392.4
Poor to Good	Low	Yes	297.6	196.7	398.2
Poor to Good	High	No	248.5	152.3	344.6
Poor to Good	High	Yes	241.9	132.6	350.8
Intermediate to Good	Low	No	0	0	0
Intermediate to Good	Low	Yes	222.2	131.2	313.3
Intermediate to Good	High	No	127.5	55.4	199.6
Intermediate to Good	High	Yes	413.9	320.6	506.8

Note: Asterisks indicate if mean WTP estimates are significantly different from zero: *** at the 0.1% level; ** at the 1% level; * at the 5% level.

Table 5. Summary statistics of independent variables used in OLS regressions

Variable	Mean	Std. Dev.	Min	Max
Age	48.348	16.241	18	87
Gender	0.505	0.500	0	1
Education level	0.636	0.482	0	1
Edumiss	0.022	0.148	0	1
Medium income	0.368	0.483	0	1
High income	0.249	0.433	0	1
Incmiss	0.153	0.361	0	1
Urban	0.648	0.478	0	1
Scenario credibility	3.076	0.624	1	4
Policy consideration	2.591	0.725	1	4

Note: N=489 except Policy consideration (N=487)

Table 6. OLS regression results of conditional WTP estimates on individual specific variables (N=483)

	Poor to Good Condition				**Intermediate to Good Condition**			
	Low/NoWild	**Low/Wild**	**High/NoWild**	**High/Wild**	**Low/NoWild**	**Low/Wild**	**High/NoWild**	**High/Wild**
Age	-0.006	-0.004	-0.002	0.000	-0.003	-0.008	0.002	-0.002
	(0.004)	(0.004)	(0.005)	(0.005)	(0.002)	(0.004)	(0.002)	(0.004)
Gender	-0.268 **	-0.318 **	-0.349 **	-0.399 **	-0.122 **	-0.222 *	-0.197 ***	-0.299 **
	(0.125)	(0.139)	(0.145)	(0.163)	(0.062)	(0.133)	(0.075)	(0.136)
Education	0.046	0.084	0.092	0.129	0.021	0.02	0.083	0.081
level	(0.129)	(0.144)	(0.150)	(0.169)	(0.064)	(0.138)	(0.078)	(0.141)
Edumiss	0.041	0.032	0.154	0.145	0.006	-0.019	0.083	0.058
	(0.396)	(0.441)	(0.461)	(0.517)	(0.196)	(0.423)	(0.24)	(0.432)
Medium	-0.083	-0.098	-0.126	-0.141	-0.009	-0.085	-0.055	-0.131
income	(0.154)	(0.171)	(0.179)	(0.201)	(0.076)	(0.165)	(0.093)	(0.168)
High income	0.079	0.109	0.061	0.091	0.031	0.119	0.026	0.114
	(0.173)	(0.193)	(0.202)	(0.226)	(0.086)	(0.185)	(0.105)	(0.189)
Incmiss	0.065	0.069	0.002	0.006	0.08	0.06	0.009	-0.011
	(0.192)	(0.214)	(0.224)	(0.251)	(0.095)	(0.206)	(0.116)	(0.21)
Urban	0.049	0.048	0.045	0.044	0.006	0.08	-0.002	0.072
	(0.123)	(0.137)	(0.143)	(0.160)	(0.061)	(0.131)	(0.074)	(0.134)
Scenario	0.642 ***	0.744 ***	0.772 ***	0.874 ***	0.296 ***	0.627 ***	0.383 ***	0.714 ***
credibility	(0.092)	(0.102)	(0.106)	(0.119)	(0.045)	(0.098)	(0.055)	(0.1)
Policy	-0.244 ***	-0.282 ***	-0.289 ***	-0.327 ***	-0.11 ***	-0.215 **	-0.154 ***	-0.259 ***
consideration	(0.08)	(0.089)	(0.093)	(0.104)	(0.039)	(0.085)	(0.048)	(0.087)
Constant	-0.161	-0.491	-0.747	-1.076 *	-0.605 ***	-0.339	-0.483 *	-0.217
	(0.457)	(0.509)	(0.532)	(0.597)	(0.226)	(0.489)	(0.277)	(0.498)
R^2	0.125	0.134	0.132	0.136	0.109	0.107	0.132	0.131

Note: standard errors in parentheses. *,**,*** indicates signifcance at 10%, 5%, 1% level

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