Ecosystems services valuation:

Loss of wetland due to climate change and creation of wetland under proposed "sandscaping" coastal defence schemes

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1. Introduction

Salt marshes, mud flats and other types of saline coastal wetlands are widely recognised for the value of their ecosystem services (Costanza et al. 1997; Barbier et al. 2011). Salt marshes yield services across the four ecosystem services categories that consist of, the supply of pastureland and habitat (**provisioning**); carbon storage, coastal protection and filter nutrients and pollutants from terrestrial run-off (**regulating**); offer artistic inspiration, aesthetic beauty and educational opportunities (**cultural**) and enhance primary production, nutrient cycling, soil formation and biodiversity (**supporting**). However due to the 'public good' characteristics of these services, the ecosystem services provided by wetlands have been historically undervalued in both public and private decision-making. This has meant that saline coastal wetlands continue to be degraded, or worse, lost completely, across the globe. Historically, the most significant anthropogenic process contributing to the loss of saline coastal wetlands had been land reclamation and drainage, particularly landfilling and structures preventing or impeding tidal flow. These threats remain ongoing, and will be exacerbated by rapid population growth and climate change in the 21st century (Parry et al. 2007).

Wetland change due to climate change

Climate change is expected to have a large and wide-ranging impact on coastal wetlands and their provision of ecosystem services. Impacts due to climate change include sea-level rise, temperature rise and variability, which will affect plants and animals that are sensitive to temperature and drought. Relatively small increases in sea level, or evaporation can alter water levels that result in a large change in the size of the wetland. Rain events are expected to become more intense and lead to larger fluctuations in water level. Wetland species have a limited ability to migrate in response to these changes due to their specialization (Davis and Shaw 2001). However, the impacts as a result of climate change are not all predicted to be detrimental, and there are several possible positive benefits that could be realised. Higher carbon dioxide levels in the atmosphere will lead to higher plant growth rates and biomass accumulation. Additionally, in adapting to climate change, restoring or increasing the size of coastal wetlands could be an option undertaken by coastal managers as it will produce more space for rivers to flood into during high river flow events (Marchand 1993; Duel et al. 1995; Bischoff and Wolter 2001; Buijse et al. 2002).

Climate change will impact on the ability of the wetland to support and deliver ecosystem services, however at the local level the impact will vary spatially and be dependent on local and regional climate responses. There are currently no spatially detailed climate projections for wetlands in the UK.

Wetland change due to innovative coastal protection schemes

Beach recharge is a common coastal defence method, used to maintain local beach profiles. However, it is a small-scale solution to a much larger problem. Recently, consideration has been given to strategic, large-scale sediment recharge known as mega-recharge or “sandscaping”. Whilst a beach recharge scheme might consist of introducing around 2-3 million m^3 of sand to the shoreline, with an expected lifetime of 5 years, a sandscaping project would introduce around 20 million m^3 of sand, with an expected lifetime of 20 years. This form of large-scale intervention is also known as a sand motor or sand engine and, if undertaken, should provide greater physical resilience to extreme events such as storm surges (van Slobbe et al., 2013).

The effectiveness of a sandscaping scheme is currently being tested on the Dutch coast in a scheme that aims to improve coastal resilience by changing the sedimentary response and morphological evolution of the coastline under scrutiny (http://www.dezandmotor.nl/en/). As well as providing resilience benefits, there is potential for future sandscaping projects to contribute multiple additional benefits. Examples include, recreational hunting and fishing, non-consumptive recreation (e.g. kayaking, swimming etc.) and amenity and aesthetic value. Finally, there is also value and benefit from any sand motor intervention in the form of created habitat and improved biodiversity.

In order to strike a balance between the use of ecosystems and their preservation, a growing body of research has focused on the consequences of ecosystem change in terms of social welfare (Marre et al. 2015). Although society is yet to fully understand the services provided by the natural environment, economic valuation of ecosystems services provides a pragmatic approach to support decision-making in the domain of biodiversity conservation (Liu et al. 2010; Sukhdev 2008; Boyd and Banzhaf 2007; Costanza et al. 1997; Pearce and Moran 1994). Such valuation is designed to account for all the changes in ecosystem services which would usually occur outside the market and therefore without economic signals regarding their contributions to social welfare (Adamowicz 2004). Using a well-established non-market valuation technique, benefits transfer methodology, this report provides welfare estimates for three proposed sandscaping sites in the Northwest of England.

2. Method

Ecosystem services valuation and Benefits Transfer

Economic valuation provides policy makers, environmental managers and planners with information about the social benefits and costs associated with alternative coastal and marine policies (Torres and Hanley 2016). While a number of well-established methods exist to value the natural environment, such a process is costly, time consuming and requires moderate statistical training, items that are often outside the resource and skill sets available to policymakers and planners. At the same time, the number of coastal and marine settings where researchers have attempted to place a value on ecosystem services is rising fast (Torres and Hanley 2016).

The benefits transfer approach (also known as value transfer) to environmental valuation uses research results from pre-existing primary research to predict welfare estimates for other sites of policy significance, for which primary valuation estimates are unavailable (Johnston and Rosenberger 2009). It offers a quicker and lower cost approach than a specifically designed valuation study. Broadly speaking, benefits transfer may be described as the 'application of values and other information from a "study" site with data to a "policy" site with little or no data' (Rosenberger and Loomis 2000).

The methods currently used to perform benefits transfer can be divided into two categories (Johnston and Rosenberger 2009).

- Unit value transfer (with or without adjustments)
- Value function transfer (using an estimated value function from a single site study)

Unit value transfers involve the transfer of a single number or set of numbers from pre-existing primary studies. Unit values can be transferred "as is" or adjusted using a variety of different approaches (e.g. for differences in income or purchasing power, or according to expert opinion). Function transfers, in contrast, derive information using an estimated, typically parametric, function derived from original research: a meta-analysis, that synthesizes results from multiple prior studies; or preference calibration that constructs a structural utility model using results from two or more prior studies (Johnston and Rosenberger 2009).

Wetland Valuation & Benefits Transfer

A recent review of meta-analyses of wetland valuation has found that the benefits transfer function, is the most appropriate to apply to policy sites in the UK to inform decision-making (Bateman et al. 2009). Brander et al. (2010) used the European CORINE land cover maps (https://www.eea.europa.eu/data-and-maps/data/clc-2000-vector-6) when classifying wetlands. This dataset classifies wetlands into five different types, two inland and three coastal, these are:

1. Inland Marshes
2. Peatbogs
3. Salt marshes
4. Intertidal mudflat
5. Salines (not applicable to the UK)

Using the CORINE dataset, there are 1,519 inland wetlands in the UK totaling about 601,500 hectares in area. Of these, 3% are inland marsh with the rest classified as peatbog. For coastal wetlands, 693 sites were identified with a total area of around 274,600 hectares, 16% of these are salt marshes and the remainder (84%) are classified as intertidal mudflats.

The CORINE uses different classifications for wetlands when compared to other datasets, such as the UK CEH Land Cover Map 2007 (LCM2007). For example, the CORINE class for inland marshes is equivalent to the “fen, marsh and swamp” categories in the LCM2007 dataset. While the total area of wetlands in the UK according to both datasets is similar, the higher resolution, and more detailed maps provided by LCM2007 have a narrower classification categories compared to the broad categories of CORINE. The categories of LCM2007 are detailed in the Appendix.

Brander et al. (2010) and other studies have used the CORINE dataset but given that similarity of the total wetland area and the greater detail of LCM2007, which reduces the chance of wetlands being inappropriately classified, LCM2007 was considered the appropriate dataset for this analysis.

The same overall method as Brander et al. (2010) was followed, with data on wetland type and area obtained from LCM2007 (rather than CORINE). To obtain the area of wetlands around a given policy site, a GIS tool was used to calculate the total area of classifications that match coastal wetlands for 50 km around the site of interest. Population data was obtained from the Office for National Statistics (ONS) and estimated within the same 50 km radius. Income per capita was obtained from the EUROSTAT database in 2014EUR and converted into 2014GBP and inflation adjusted to give 2017GBP.

The benefits function produced by Brander et al. (2010) required additional information to the above, in which ecosystem services provided by each type of wetland are identified and accordingly switched “on” or “off” within the function. If the service is positive, then it will provide an increased benefit effect in the analysis. Conversely a negative service reduces the benefit effect that the wetlands provides. These are mostly associated with resource and environment enhancement for positive effects and direct consumption and extraction activities for negative effects. These negative services do not have negative values in themselves but depress the overall value of wetlands in the benefits function when compared with services providing a positive influence (Morris and Camino 2011).

We have used the same assumptions as Morris and Camino (2011) in the type of ecosystem services that are provided by salt marsh and inter-tidal mudflats. Table 1 shows the list of services.

Table 1: Assumed ecosystem services provided by coastal wetlands in the UK (Morris and Camino 2011).

	Services typical of wetland type	
Services	**Salt marsh**	**Inter-tidal mudflat**
Resource and environmental enhancement services (positive impact)		
Flood control and storm buffering	Yes	Yes
Surface and ground water supply	No	No
Water quality improvement	No	No
Non-consumptive recreation	Yes	Yes
Amenity and aesthetics	Yes	Yes
Biodiversity	Yes	Yes
Direct consumption and resource extractive services (negative impact)		
Recreational fishing	No	Yes
Commercial fishing and hunting	Yes	Yes
Recreational hunting	Yes	Yes
Harvesting of natural materials	Yes	Yes
Material for fuel	No	No

A change in the extent of European wetlands and the impact on value is estimated by Brander et al. (2012). They illustrate a methodology to estimate the value of changes in ecosystem services due to climate change in Europe between 2000 and 2050. A meta-analytic function for wetlands has been estimated using data from 222 independent observations of wetland values for US and European temperate wetlands. 120 independent studies provided the observations, so multiple value estimates may originate from the same study. This only occurred if the same study provided genuinely independent values. If, for example, different data or valuation methodology was used. Values were only included if they could be standardised to the defined dependent variable, in this case US$ per hectare.

The meta-analytic regression model used the following equation:

$$\ln(y_i) = a + \ b_S X_{Si} + b_W X_{Wi} + b_C X_{Ci} + u_i$$

where:

y = vector of wetland values standardized to 2003 US$ per hectare per year.

i = subscript defining observations (1 to 222)

a = constant term

b_S, b_W and b_C = coefficients of the exploratory variables

u = vector of residuals

The exploratory variables consist of three categories:

1. The valuation study (X_S)
2. The valued wetland (X_W)
3. The socio-economic and geographical context (X_C)

The results of the meta-regression are shown in Table 2. Brander et al. (2012) performed a series of diagnostic tests that tested the robustness of the estimation.

Table 2: Results of the Brander et al. (2012) meta-regression model of wetland values

	Variable	Coefficient
Dependent Variable	(constant)	-0.970
Study variables		
Valuation method	Contingent valuation	0.317
	Choice experiment	-0.524
	Hedonic pricing	-2.328
	Travel cost method	-0.705
	Replacement cost	-0.383
	Net factor income	-0.125
	Production function	-0.091
	Market prices	-0.215
	Opportunity cost	-1.164
	Marginal valuation	0.828
Wetland variables		
Wetland type	Inland marshes	-0.211
	Peatbogs	-2.266
	Salt marshes	0.073
	Intertidal mudflats	-0.239
Wetland size	Wetland size before change, ha (ln)	-0.218
Ecosystem service	Flood control and storm buffering	0.626
	Surface and groundwater supply	-0.106
	Water quality improvement	0.514
	Commercial fishing and hunting	0.042
	Recreational hunting	-1.355
	Recreational fishing	-0.119
	Harvesting of natural materials	-0.153
	Fuel wood	-0.959
	Non-consumptive recreation	0.218
	Amenity and aesthetics	0.432
	Natural habitat and biodiversity	1.211
Context variables		
	Real GDP per capita US$ (ln)	0.430
	Human Population within 50 km radius (ln)	0.503
	Wetland within 50 km radius (ln)	-0.125

The estimated coefficients have the expected signs. For the wetland abundance variable, (area of wetlands of same type within 50 km of the policy site) the coefficient sign is negative. This shows that as the abundance of wetland increases the value of each hectare of wetland decreases. This is mirrored in the coefficient corresponding to wetland size indicating that with increasing wetland area the value of creating new wetlands decreases. This means that increasing the size of a large wetland area results in a lower increase in total value than would be achieved by increasing the area of a smaller wetland by the same amount. In terms of positive coefficients, Brander et al. (2012) found that Gross Domestic Product (GDP) per capita and population density were both positive and statistically significant, showing that an increase in GDP and population results in a higher value associated with the wetland. It was also found that marginal per hectare values (those derived from incremental increases in wetland area) tend to be higher than average per hectare values (derived from valuation of services from the total area of wetland). This was unexpected because marginal values are lower than average values, as unit value decreases with an increasing area or abundance of the wetland. It was surmised (Brander et al.,2012) that this was due to small marginal changes being less constrained by positive coefficients, such as household income, than the total valuation (due for example to total loss of the wetland) from which the average value is calculated.

Application to UK Sites

Three areas in the Northwest of England have been identified as potential sites for mega-recharge interventions (Knight et al., 2017), these are located at: Barrow-in-Furness; Fleetwood; and an offshore site which would result in the creation of an island in Morecambe Bay (Figure 1). To better understand the potential impact of wetland loss due to climate change, a salt marsh in the Southeast of England,near Bradwell-on-Sea, known as Dengie marshes, is also being considered (Figure 2).

The CEH LCM2007 dataset was used to spatially model wetland ecosystems across the three sites. The LCM2007 dataset provides a 25 m high-resolution land use dataset with a broad range of different categories corresponding to different land use classes. Whilst previous research has used the European Environment Agency's CORINE dataset (Brander et al. 2010; Brander et al. 2012; Morris and Camino 2011), LCM2007 was selected in this instance as it is more up to date and UK focused, with a total area of categorized wetland comparable to CORINE.

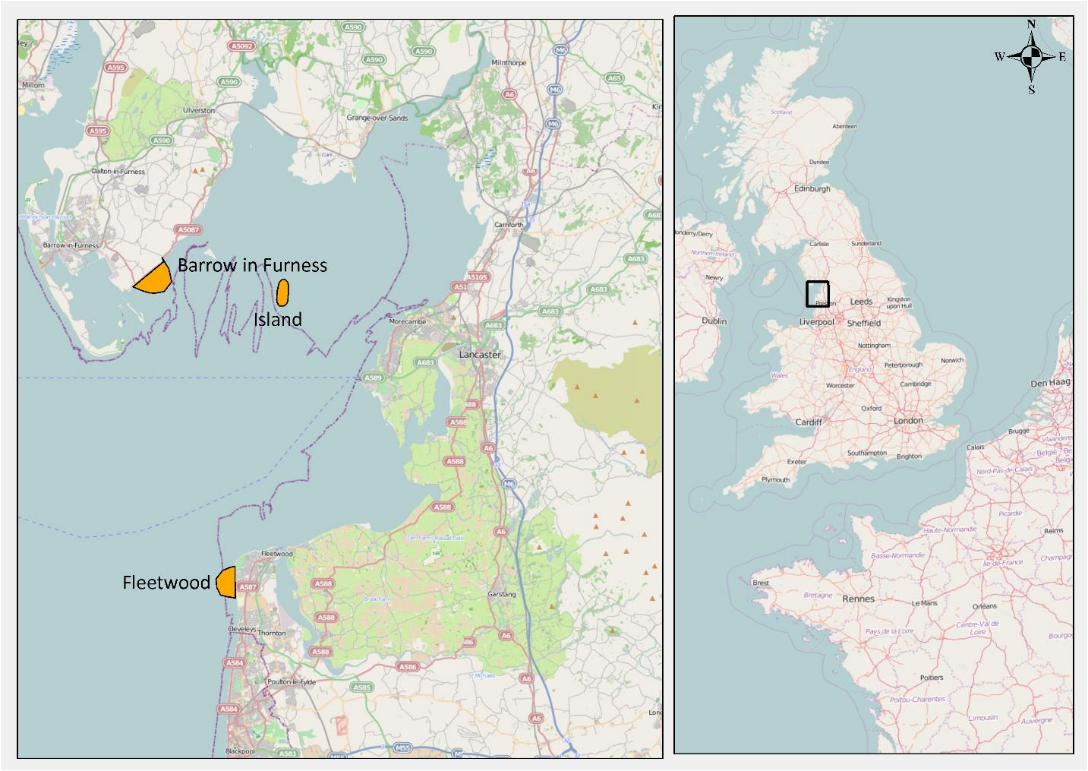

Figure 1: Location and shape of proposed sandscaping options.

Figure 2: 50 km area around salt marsh site at Bradwell-on-Sea. The salt marsh itself is highlighted in orange.

Two of the proposed sand motors, Barrow-in-Furness and Fleetwood) take the form of bell shaped lobes, building out from the existing shoreline, similar to the Dutch scheme (http://www.dezandmotor.nl/en/), whilst the Island is elliptical (Figure 1). At the Barrow-in-Furness location the created area extends approximately 3000 m along the coast and offshore by around 1400 m, equating to the creation of 210 ha of new wetland. The proposed option for Fleetwood extends approximately 2100 m along the coast with an offshore extent of 900 m, creating around 95 ha of new wetland. Finally, the creation of the island results in an ellipse with axes of 1300 m and 600 m, with the potential to create 78 ha of new wetland.

Each of the sites requires the calculation of wetland abundance, population and the average GDP of that population for an area of 50 km around the sites. Figure 3 shows the 50 km circles around each of the proposed sites, it can be seen that there will be some variation in the population and wetland abundance for each site.

Figure 3: 50 km circles surrounding each proposed sandscaping location.

The wetland abundance variable is defined as the total area of the specified wetland type in the area within 50 km of the centre-point of each newly created wetland site. As per the method followed by Brander et al. (2011), the analysis currently does not distinguish between different wetland types and all wetlands within the 50 km are counted. Figure 4 indicates that three wetland typesare located within 50 km of Barrow-in-Furness. These are salt marsh, intertidal mudflat and a small area of inland fen, marsh and swamp habitat. By far the biggest area of wetland is intertidal mudflat at 26,838 ha, followed by salt marshes at 7,360 ha. Finally, the small amount of land classified as fen, marsh and swamp makes up 81 ha. This gives a total wetland area of 34,279 hectares, which is used as a context variable in the analysis.

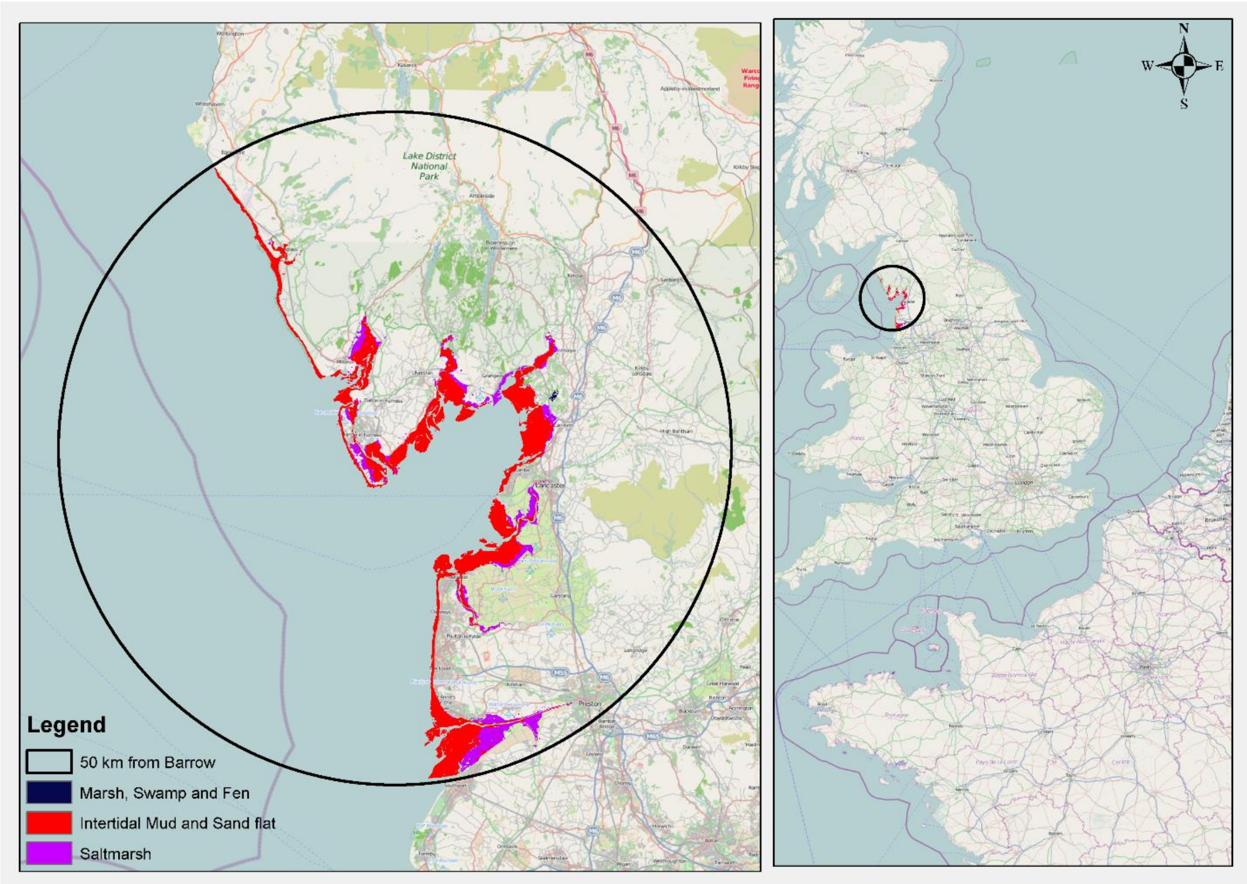

Figure 4: Map showing location of different wetland types within 50 km of the Barrow-in-Furness site.

To calculate the population in the vicinity of the wetland under consideration, the ONS provides data on population density at the small area level (Lower Layer Super Output Areas, http://geoportal.statistics.gov.uk/datasets/da831f80764346889837c72508f046fa_1). Data on population density for 2011 was used to calculate the population within 50 km of each wetland of interest (Figure 5).

GDP per capita was calculated using EUROSTAT statistics for GDP per inhabitant at the NUTS (nomenclature of territorial units for statistics) level 3 for 2014 (http://ec.europa.eu/eurostat/web/regions/data/database). EUROSTAT administrative map was used to highlight the relevant areas within 50 km of the wetland policy site and the mean value of GDP per inhabitant across all regions covered by the 50 km circle for each site was used as the input parameter for this study (Figure 6).

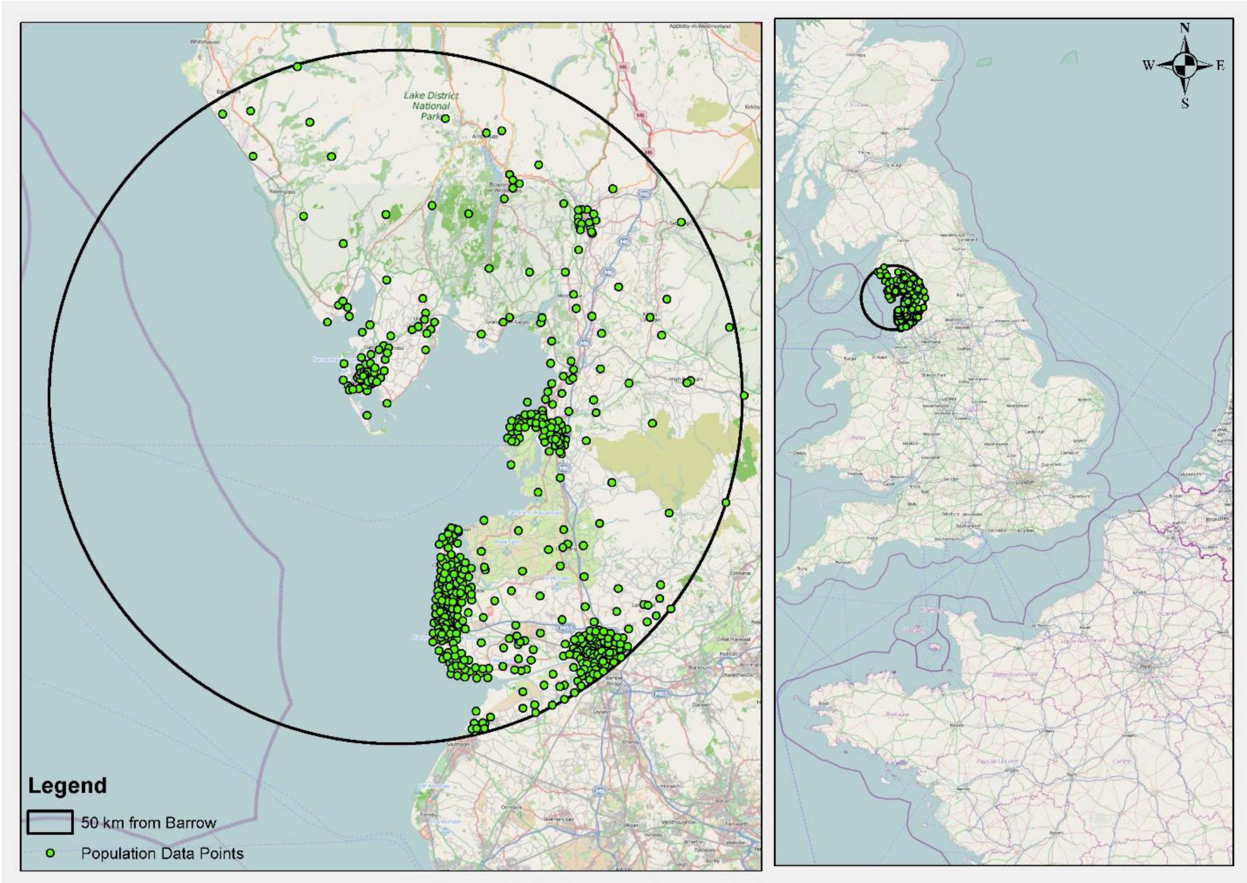

Figure 5: showing location of all the areas with population information within 50 km of the Barrow-in-Furness site. Each point shows the centre of a defined region with a listed population.

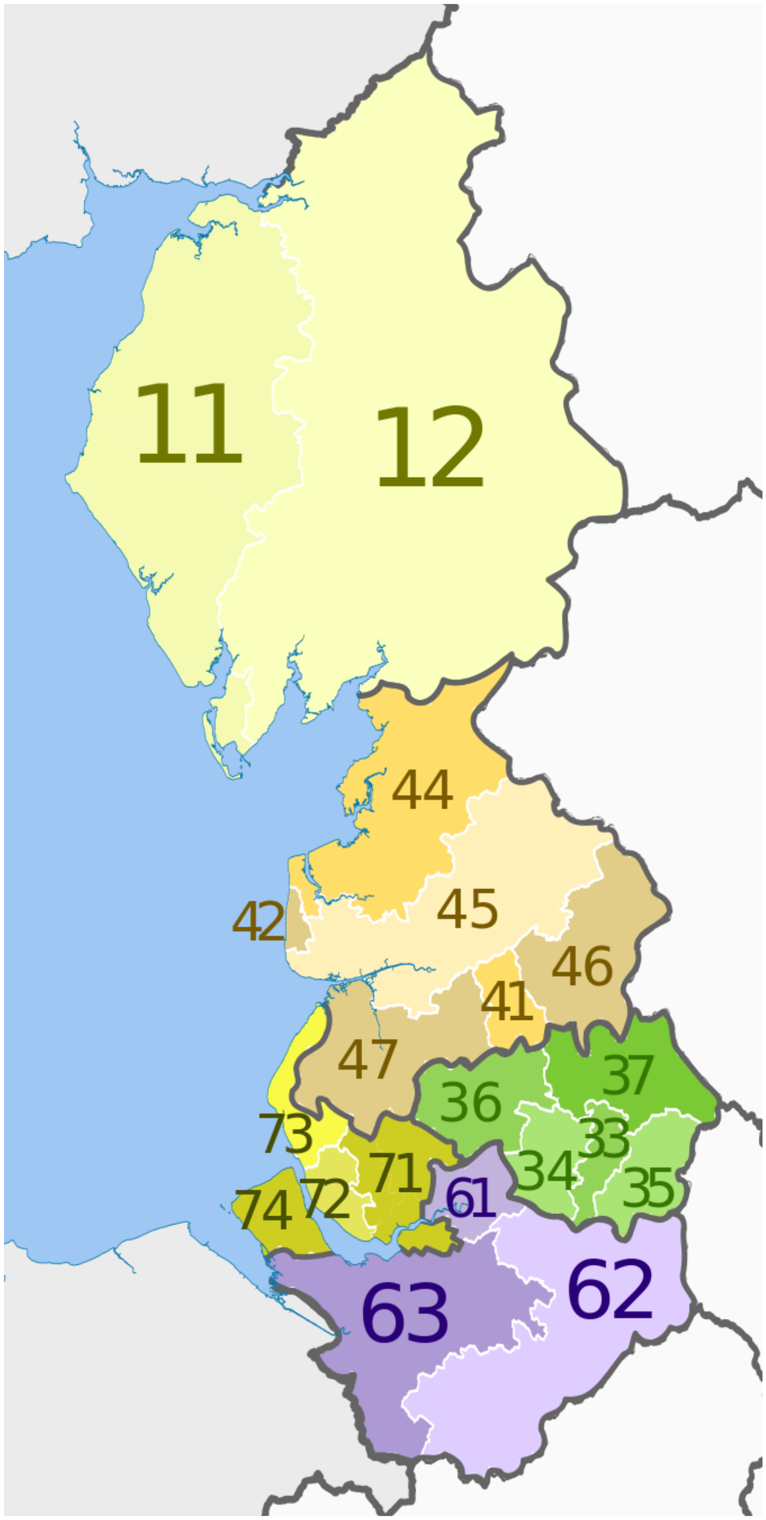

Figure 6: NUTS3 regions highlighted for the Northwest of England. Regions that were within 50 km of each of the wetland sites were used to calculate the average GDP per inhabitant value.

3. Results

To calculate the value lost due to the reduction in area of salt marsh at Bradwell-on-Sea, the meta-analytic benefits function was used to assign per-hectare values to the wetland under the current (no climate change) and possible future (climate change resulting in a 10% decrease in salt marsh area) scenarios. This was achieved by calculating the marginal benefit of creating an area of wetland for the current site area and of creating an area of wetland for a site 10% smaller than the current area. The mean of these marginal benefits was then multiplied by the area lost under a climate change scenario to give the value that would be lost annually all costs and benefits if the salt marsh was reduced in size by 10%. The values of key variables is shown in Table 7.

For the three sites with sandscaping proposals, the marginal benefit of creating an additional hectare of wetland on the site without the sandscaping proposal was calculated and then recalculated for an initial area which included the wetland created as a result of sandscaping. The mean of these two values was calculated and multiplied by the area created through sandscaping to give the annual marginal benefit achieved due to the creation of new wetland.

The natural log (ln) of the context variables, wetland abundance, population and average GDP per capita and the variables in Table 3 were used as input context variables to the meta-regression analysis. These are the parameters that tune the regression making it specific to a region of the UK. For the section of the table labelled “Valuation method”, only one option should be selected. For this study, it was marginal valuation. The “Wetland type” is also selected, either salt marsh (for the Bradwell-on-Sea location) or intertidal mudflats (for the sandscaping sites). Finally, the ecosystem services that are relevant to the wetland type are selected, in this case they include, for example: flood control and storm buffering; non-consumptive recreation; and natural habitat and diversity, for both wetland types, whilst recreational fishing is only selected for the sandscaping locations.

Table 3: Results of Brander et al. (2011) meta-regression model of wetland values applied to example policy site (Bradwell-on-Sea), where 1 indicates coefficient is being used in analysis and 0 indicates it is not used. For size and context variables the natural log (ln) of the parameter is shown.

	Variable	**Coefficient**	**Bradwell-on-Sea**	**Sandscaping Sites**
Dependent Variable	(constant)	-0.970	1	1
Study variables				
Valuation method	Contingent valuation*	0.317	0	0
	Choice experiment*	-0.524	0	0
	Hedonic pricing*	-2.328	0	0
	Travel cost method*	-0.705	0	0
	Replacement cost*	-0.383	0	0
	Net factor income*	-0.125	0	0
	Production function*	-0.091	0	0
	Market prices*	-0.215	0	0
	Market prices*	-0.215	0	0
	Opportunity cost*	-1.164	0	0
	Marginal valuation	0.828	1	1
Wetland variables				
Wetland type	Inland marshes**	-0.211	0	0
	Peatbogs**	-2.266	0	0
	Salt marshes	0.073	1	0
	Intertidal mudflats	-0.239	0	1
Wetland size	Wetland size, ha (ln)	-0.218		
Ecosystem service	Flood control and storm buffering	0.626	1	1
	Surface and groundwater supply	-0.106	0	0
	Water quality improvement	0.514	0	0
	Commercial fishing and hunting	0.042	1	1
	Recreational hunting	-1.355	1	1
	Recreational fishing	-0.119	0	1
	Harvesting of natural materials	-0.153	1	1
	Fuel wood	-0.959	0	0

Table 3 (continued): Results of Brander et al. (2011) meta-regression model of wetland values applied to example policy site (Bradwell-on-Sea), where 1 indicates coefficient is being used in analysis and 0 indicates it is not used. For size and context variables the natural log (ln) of the parameter is shown.

	Variable	Coefficient	Bradwell-on-Sea	Sandscaping Sites
Ecosystem service	Non-consumptive recreation	0.218	1	1
	Amenity and aesthetics	0.432	1	1
	Natural habitat and biodiversity	1.211	1	1
Context variables				
	Real GDP per capita EUR (ln)	0.430	10.196	
	Population in 50 km radius (ln)	0.503	14.824	
	Wetland area in 50 km radius,	-0.125	10.472	

*methods of valuation not used in this study **types of wetland not assessed in this study

The context variables for each site: wetland abundance; population; and average GDP per capita, are listed in Table 4.. Although the sandscaping sites are located fairly close to each other, and have similar areas of wetland and values for GDP per capita, due to the 50 km circle moving to reflect the position of the site, population varies widely due to the large population centres surrounding Fleetwood compared with the Barrow-in-Furness site.

The output of the meta-regression model is in natural log Euros per hectare per year (EUR/ha/yr (ln)). The base year for the Euros is 2014. Therefore, the output needs to be converted to 2017GBP by first converting back to 2014EUR from natural log (ln), converting to 2017EUR and finally to GBP. Table 5 shows of the steps in this process.

Table 4: Policy Site variables derived from datasets for each site

Variable	Bradwell-on-Sea	Barrow-in-Furness	Fleetwood	Island
Current wetland area at site (ha)	568	2641	2880	9842
Real GDP per capita (EUR)	26,798	26,400	26,545	26,400
Human Population within 50 km radius	2,742,000	872,685	2,030,436	1,119,680
Wetlands within 50 km radius (ha)	35,332	34,279	35,710	34,801

Table 5: Example of results from meta-analysis

Variable	Bradwell-on-Sea
EUR/ha/yr (ln)	10.101
EUR/ha/yr (2014EUR)	24,375
2014 Jan Price Index	996.5
2017 Feb Price Index	1058.8
EUR/ha/yr (2017EUR)	25,898
EUR to GBP Rate	0.865332
£/ha/yr (2017GBP)	22,409

Table 6: Marginal annual value of an additional hectare of wetland at each study location (given to nearest £)

Site	£/ha/yr Before (2017GBP)	£/ha/yr After (2017GBP)	£/ha/yr Mean (2017GBP)	Additional wetland created (ha)	Value Added (GBP2017/yr)
Barrow-in-Furness	5,841	5,745	5,793	210	1,216,530
Fleetwood	8,741	8,680	8,711	95	827,498
Island	4,970	4,961	4,966	78	387,309

The marginal annual value of an additional hectare of wetland added to study site is shown in Table 6. All schemes add a large amount of value to the area, with the Barrow-in-Furness site providing the most value, primarily due to the larger area of wetland created. Fleetwood creates a lot more value per hectare than the other sites. This is predominantly due to the higher population within 50 km of this site.

An estimate of the value lost to the Bradwell-on-Sea region due to a projected 10% erosion of the Dengie Peninsula salt marshes is presented in Table 7. The estimation assumes that the population and GDP per capita would not change in the region. It is assumed that all wetlands have the same loss of 10% within 50 km. Table 7 indicates that the value lost is over a million pounds per year for a 10% loss in wetland area. This shows that the loss of small areas of wetland can have a large impact on a region.

Table 7: Numbers used to calculate value of lost salt marsh at Bradwell-on-Sea and value lost due to 10% reduction in salt marsh area

Variable	**Value**
Current salt marsh area	568 ha
Saltmarsh area under climate change	511 ha
Current wetland abundance (50 km radius)	35,332 ha
Wetland abundance under climate change (50 km radius)	31,799 ha
Human population (50 km radius)	2,742,000
GDP per capita (EUR)	26,798
Current value per hectare (GBP)	22,409
Value per hectare under climate change (GPB)	23,236
Mean value per hectare (GBP)	22,823
Change in salt marsh area	-57 ha
Value of 10% loss in area (GBP/yr)	-1,300,900

Sources of Uncertainty

Ideally it would be possible to provide a complete and quantified measure accommodating all sources of uncertainty that arise as a result of the study, i.e. an interval around the calculated £/ha/yr value and a probability that the true value falls within that interval. However, to compute these intervals a large amount of information would be required from each of the studies that make up the meta-analysis in the study (Brander et al., 2012) from which the values were taken. Since the meta-analysis has resulted in an aggregation of uncertainties from many different studies and sources it is important to understand the impact this could have on the final result. Possible sources of error are generalization measurement errors.

Possible measurement errors include weak methodologies, unreliable data, analyst errors and the range of bias and inaccuracy that is a result of the method followed (Rosenberger and Stanley 2006). Measurement error is inherent in primary research and cannot be controlled by research undertaken after the primary work has been completed (Rosenberger and Stanley 2006). Care has been taken to ensure the primary study sites research is of good quality and suitable to use in benefits transfer studies.

Generalization errors arise from applying the benefits transfer methodology without fully accounting for differences between study and policy sites. These errors are inversely related to the degree of correspondence between primary study sites and the site under consideration.

Therefore, the more primary sites used and the closer the site under study is to these primary sites the better. As the benefits transfer model used in this work has a large number of primary study sites (120) and they are located in similar regions (temperate climate zones) these errors are likely to be minimal.

Another source of uncertainty is any bias in the selection of primary study sites and observations used in the meta-analysis. This can result from publication bias, which favours studies that are novel and statistically significant rather than those replicating previous studies. It has been shown by Hoehn (2006) that meta-analysis of wetland sites with this bias can lead to over estimation of the mean wetland values.

Finally, there is a degree of uncertainty attached to the GIS data and spatial modelling underlying the spatial variables included in the calculation. Whilst the selected datasets are reliable, the data may not have the highest precision, due to the requirement for regional scale coverage.

The values given could also be improved by including some measure of ecosystem quality, i.e. will the wetland created at Barrow-in Furness be of higher or lower quality than that created at Fleetwood or destroyed at Bradwell-on-Sea, and how might this affect the valuation? Ecosystem assessment is not practicable for the current study as it would rely on biological, physical and chemical data which are unavailable for the study and policy sites.

4. Conclusions

Using a well-established, non-market, valuation technique, benefits transfer methodology, this report provides welfare estimates for three proposed sandscaping sites in Northwest England. This paper uses a methodology proposed by Brander et al. (2010) and further refined by Brander et al. (2012) that scales up values for changes in ecosystem service provision to assess the value added by implementing mega-recharge schemes that would result in wetland creation. The value lost for salt marsh around the Dengie Peninsula if 10% of the wetland was lost due to climate change impacts such as sea-level rise was also investigated.

It was found that the loss of 10% of salt marsh in the vicinity of Bradwell-on-Sea would represent a cost to the region of about £1,300,000 per year. If a mega-recharge scheme was built in Barrow-in-Furness, it could bring benefits of more than £1,200,000 per year. For the Fleetwood example, this reduces to £830,000 per year. Despite the wetland area created at Fleetwood being less than half the area of the Barrow-in-Furness option, the ‘value added’ amount is only reduced by a third. This is due to the larger population within 50 km of the proposed Fleetwood site. Finally, the option of an island in the middle of Morecambe Bay creates the smallest new area of wetland and has a lower population within 50 km of the site than Fleetwood, it therefore has the lowest added value of £390,000 per year.

These figures are gross annual figures, i.e. the value added to the region annually so long as the area of created wetland remains the same. It is expected that the additional area of wetland would reduce over time and would at some point in the future need to be recharged. The amount of reduction annually and time between recharges would be dependent on the initial design, for example sediment particle size will affect the longevity of the wetland (see sandscaping modelling report). Further modelling could be carried out to investigate the annual size of the wetland area, and the time until recharge would be required, these figures could then be used to give a more accurate annual figure.

This work has shown that the loss of wetlands due to climate change could have a large impact on the region in terms of the benefits that the wetlands currently provide. This impact could be mitigated by proposed large-scale sandscaping interventions that create wetland and restore value to the region whilst offering the direct benefit of protection against coastal erosion and flooding.

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6. Appendix:

LCM2007 Categories:

The categories of the Land Cover 2007 dataset are detailed in Table A1 below:

Table 1A: Categories of the Land Cover 2007 dataset, Aggregate class number and LCM2007 class number are used for the 1 km (not used in this study) and 25 m raster datasets respectively.

Aggregate class	Aggregate class number	Broad habitat	LCM2007 class	LCM2007 class number
Broadleaf woodland	1	Broad leaved, Mixed and Yew Woodland	Broadleaved woodland	1
Coniferous woodland	2	Coniferous Woodland	Coniferous woodland	2
Arable	3	Arable and horticulture	Arable and horticulture	3
Improved grassland	4	Improved grassland	Improved grassland	4
Semi-natural grassland	5	Rough grassland	Rough grassland	5
		Neutral grassland	Neutral grassland	6
		Calcareous grassland	Calcareous grassland	7
		Acid grassland	Acid grassland	8
		Fen, marsh and swamp	Fen, marsh and swamp	9
Mountain, heath, bog	6	Dwarf shrub heath	Heather	10
		Heather grassland	Heather grassland	11
		Bog	Bog	12
		Montane habitats	Montane habitats	13
		Inland rock	Inland rock	14
Saltwater	7	Saltwater	Saltwater	15
Freshwater	8	Freshwater	Freshwater	16
Coastal	9	Supra-littoral rock	Supra-littoral rock	17
		Supra-littoral sediment	Supra-littoral sediment	18
		Littoral rock	Littoral rock	19
		Littoral sediment	Littoral sediment	20
			Saltmarsh	21
Built-up areas and gardens	10	Built-up Areas and Gardens	Urban	22
			Suburban	23