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Preferences for Blue-Green or Grey Infrastructure to Reduce Flood Risk: A Choice Experiment

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Abstract
Flood reduction infrastructure is a vital aspect of many urban and peri-urban areas. To date, the majority of flood reduction projects use traditional "grey" materials and techniques. However, the use of blue-green infrastructures (BGI) is becoming more popular. This paper explores residents' preferences for BGI or grey infrastructure projects to reduce flood risk. A discrete choice experiment using a split sample methodology was employed to determine if residents of the Carlingford Lough catchment in Ireland prefer either type of infrastructure to reduce flood risk. A random parameter logit was applied to the data. The results reveal that for the average person, they have a preference for flood risk reduction resulting in a flooding event once every 25 years rather than once every five years. The average respondent also holds a preference for BGI based solutions as opposed to a grey infrastructure solution. However, respondent living in a flood-prone area show no greater preference for a BGI solution.

1. Introduction

Flooding events can have serious impacts on social, economic and environmental systems. This coupled with a rising risk of flooding events (Stocker et al., 2013) has meant that an increased need for infrastructure to combat climate change events is becoming an ever more pressing issue for governing and planning bodies. Two dominant methods of dealing with flooding events are grey infrastructure and Blue-Green Infrastructure (BGI). BGI increase the resilience of ecosystems and in turn ensures the continued, or new, provisioning of important services including coastal and flood protection (Naumann, Kaphengst, McFarland, & Stadler 2014).

BGI, sometimes referred to as green infrastructure or nature-based solutions, have been defined as "an interconnected network of waterways, wetlands, wildlife habitats, and other natural areas; greenways, parks, and other conservation lands; working farms, ranches, and forests; and wilderness and other open spaces that support species, maintain natural ecological processes, sustain air and water resources, and contribute to the health and quality of life" (Mell, 2008). Concerning flood risk management BGI are natural or semi-natural structures that reduce the prevalence of flooding events or provide a means of dealing with stormwater. These include restorations of floodplains or wetlands, bioswales and rooftop gardens. Although BGI are becoming more popular, they are still less common than traditional grey infrastructure.

Traditional grey infrastructure, which are much more widely used, provide an effective means of dealing with flooding events. Grey infrastructure, such as removable flood barriers and permanent walls, have a proven track record. Grey infrastructure planning is often easier as planners have an established range of tools and development strategies which makes construction and design much easier (Dhakal & Chevalier, 2017; Di Marino, Tiitu, Lapintie, Viinikka, & Kopperoinen, 2019). This can make the planning stage and cost-benefit analysis relatively straightforward for a grey infrastructure project in comparison to a BGI project. BGI, on the other hand, offers many additional benefits that traditional structures do not. These include increased biodiversity (Ghofrani et al., 2017), carbon sequestration (Davies, Edmondson, Heinemeyer, Leake, & Gaston, 2011), building a micro-climate (Razzaghmanesh, Beecham, & Salemi, 2016) and improved scenic quality (Nurmi, Votsis, Perrels, & Lehvävirta, 2016). However, BGI planners may need to overcome

barriers that planners of traditional infrastructures do not encounter. BGI planners face uncertainties over the science and engineering related to their construction and maintenance (O'Donnell, Lamond, & Thorne, 2017; Roy et al., 2008). BGI projects also tend to have more issues with transdisciplinary work (Hoang & Fenner, 2016) and planners often suffer from a general lack of understanding of the concepts of BGI (Matthews, Lo, & Byrne, 2015).

A standard course of action for comparing flood reduction projects is cost-benefit analysis, where the costs and benefits of each project are quantified and compared. However, due to the types of additional benefits that BGI provides, it can be difficult to appropriately estimate the value of BGI to the public. The difficulty in quantifying these benefits is due to issues relating to the estimation of values for non-market benefits such as quality of life, public health, and carbon sequestration (Foster et al. 2011). Conversely, there may be disutilities associated with grey infrastructure projects that are not included in the traditional cost-benefit analysis such as reduced scenic value. Consequently, it is often difficult to determine which of the two types of structures provides the greatest net benefit to the public of interest.

This paper aims to add additional information that is necessary for an appropriate comparison of BGI and grey infrastructure for flood risk reduction. This is achieved by estimating resident's preferences and associated willingness to pay (WTP) for a BGI project as opposed to a grey infrastructure project in which both projects provide the same level of flood protection. In addition to providing this valuable insight for governing bodies this paper also provides an important contribution to the literature. A comparison between these two types of structures has yet to be made and provides valuable information on how BGI solutions are regarded by the public.

To estimate the appropriate non-market benefit values associated with a flood risk reduction project a discrete choice experiment (DCE) was used. Residents of the Carlingford Lough catchment in Ireland (the majority of the catchment is in Northern Ireland and a small portion is in the Republic of Ireland) were asked to complete a survey containing the DCE. To test whether there are different preferences for BGI or grey solutions to a flood risk reduction project, a split sample methodology was employed. One group was informed that the flood reduction would be because of a

BGI project while the other group were informed that the reduction would be through traditional grey infrastructure. Importantly, the stated flood risk reduction benefits achieved were the same no matter the infrastructure used.

2. Literature Review

DCEs have been widely applied to ecosystem service benefit valuation (Adamowicz, Louviere, & Williams, 1994; Hynes, Tinch, & Hanley, 2013; Oleson et al., 2015), blue-green infrastructures (Shr, Ready, Orland, & Echols, 2019; Valasiuk et al., 2018) and flood risk reduction (Brouwer et al., 2016; Doherty, Murphy, Hynes, & Buckley, 2014). However, the DCE method has not been used to compare estimates of resident's WTP for blue-green infrastructure (BGI) or grey infrastructure for the same primary purpose.

Applications of the DCE method to marine and fluvial related ecosystem services have examined the value of various environmental improvements (Hampson, Ferrini, Rigby, & Bateman, 2017; Pienaar, Soto, Lai, & Adams, 2019), types of water bodies preferred (Doherty et al., 2014), water-based recreational services (Deely, Hynes, & Curtis, 2018, 2019) as well as exploring more methodological issues such as transferability of benefit estimates across different geographic areas (Brouwer et al., 2016) and foregoing time as opposed to money to pay for flood risk reduction (Ando, Cadavid, Netusil, & Parthum, 2020). Common amongst the attributes of interest examined included in DCEs applied to marine and fluvial ecosystems are water quality (Doherty et al., 2014) recreational opportunities (Brent, Gangadharan, Lassiter, Leroux, & Raschky, 2017; Vollmer, Ryffel, Djaja, & Grêt-Regamey, 2016) and flood risk (Brouwer, Tinh, Tuan, Magnussen, & Navrud, 2014; Reynaud, Nguyen, & Aubert, 2018).

Looking at flood risk, in particular, Doherty et al., (2014) examined flood risk as a consequence of erosion on three different water bodies types; sea, river or lake and found that welfare impact was greatest for risk reduction at river bodies, followed by at lakes and finally for flood risk reduction in coastal areas by the sea. Doherty et al., (2014) obtained positive values for less erosion (and therefore less flooding). As the authors' sample was Irish their results may give some indication as to how the current samples may view flood risk reduction.

Brouwer et al (2016) looked at the transferability of DCE results across three geographic regions, Austria, Hungary and Romania. The paper found that there was a positive association between choice and flood risk reduction for only one of the areas, Austria. For the other two areas, flood risk reduction did not have a significant impact on choice. Overall, the results were not found to be transferable across the study sites, raising the question of the general transferability of DCE models and results from one geographic area to another.

Elsewhere, Reynaud and Nguyen (2016) decomposed the normally standalone attribute of flood risk (or flood risk reduction) into its effects on an individual using attributes such as loss of property and loss of life. The study highlighted the fact that the often-used flood risk reduction variable used in DCEs is, in itself, a set of attributes that impact a person's choice for flood risk reduction. Others (Brouwer et al., 2014; Reynaud et al., 2018; Wouter Botzen & Van Den Bergh, 2012) have examined how WTP for flood risk reduction schemes are impacted by the payment vehicle and respondent's attitudes to risky behaviour (Wouter Botzen & Van Den Bergh, 2012; Brouwer et al., 2014). Some authors (Ando et al., 2020; Pienaar et al., 2019) have also used scenarios in their DCE where flood risk reduction is the result of a BGI project.

The demand for flood risk insurance has been explored by several authors (Wouter Botzen & Van Den Bergh, 2012; Brouwer et al., 2014; Reynaud et al., 2018). These papers have aimed to estimate the level of premiums respondents are willing to pay for different types of coverage under varying amounts of flood risk. Some authors (Wouter Botzen & Van Den Bergh, 2012; Brouwer et al., 2014) have also incorporated risk avoidance/risk-seeking metrics into their analysis of flood insurance. The concept of incorporating latent risk factors into DCE analysis for flood risk reduction has not been uniquely applied to insurance. Glatt, Brouwer, and Logar (2019) examined the correlation between risk attitudes and willingness to pay for flood risk reduction from residents of Switzerland's largest city, Zurich.

The literature has also explored physical methods by which flood risk reduction can be achieved, some of which include reduction through BGI. Using survey responses from residents of Melbourne and Sydney, Australia, Brent et al., (2017) looked at the

value placed on the ecosystem services delivered from distributed BGI which provide stormwater management. Although the authors examined the use of BGI, no specific project or BGI was described to the respondents. Instead, they focused on the ecosystem services provided by a range of different BGI and described flood risk reduction as either having a number of flash floods in a 5-year period or flash floods being almost no-existent. The study found positive and significant benefit values for flood protection through BGI.

Elsewhere, Pienaar et al., (2019) assessed the preferences of residents of Palm Beach County, Florida to conserve natural habitats and ecosystems. In their DCE, flood risk reduction would be achieved through a program aimed at conserving and restoring ecosystem services in urban areas. In relation to flood risk reduction, colour photos of three different sites were used to demonstrate what was meant by wetlands. The authors note that flood protection was a challenging attribute to describe owning to residents' inability to understand what was meant by a 100-year flood. Consequently, the authors stated that a flooding event would occur with different probabilities over a 30-year period. The respondents were also informed that natural areas can reduce the risk of flooding by absorbing heavy rains and stormwater runoff. The author's found positive and significant WTP values for flood risk reduction.

Ando et al., (2020) also examined the use of BGI for stormwater management in two US cities; Chicago, Illinois and Portland, Oregano. The valuation of the project was framed in traditional monetary terms as well as a time metric. To incorporate the time metric (labelled 'willingness to volunteer' in Ando et al.'s (2020) paper) an attribute was included in the choice experiment which referred to the amount of time the respondent would be willing to spend on the upkeep of BGI structures in their neighbourhood. The concept of volunteering time is particularly important for BGI projects as maintenance and lack of community engagement can be barriers to the successful implementation of a BGI project (O'Donnell et al., 2017). The authors found that time spent volunteering provides positive utility to the respondents. If such a result holds in other geographic areas maintenance costs for BGI projects could be easily reduced through voluntary resident assistance.

Although numerous studies have explored a variety of different aspect of flood risk reduction, to date no paper has used a split sample to determine if there is a different preference and WTP for BGI as opposed to grey infrastructure for flood risk reduction. This paper will enrich the literature by providing such an analysis.

3. Methodology

In the DCE methodology, a hypothetical market is created in which the respondent states their preference for one alternative over several other alternatives. This process is repeated multiple times. Each iteration is referred to as a choice occasion. Each alternative is comprised of a set of attributes. These attributes are the same for each alternative but vary in terms of their levels. One of the alternatives is generally a status quo option. This is unchanging between choice occasions and represents either the present state of the ecosystem services being measured or a future state when no action is taken. A cost attribute is usually included as an attribute in each alternative. Generally, for the status quo alternative, there will be no additional cost. By including a cost attribute, the trade-off respondents are willing to make between their money and the other attributes of interest can be estimated. This gives rise to the common use of WTP estimates for the non-market attributes found in the DCE.

The data collected from DCE can be analysed using Mcfadden's (1973) random utility model (RUM). In the RUM, utility is composed of an observable component $\beta' x_{ni}$ and a random component ε_{ni}. Utility can then be expressed as:

$$U_{ni} = \beta' x_{ni} + \varepsilon_{ni}$$

(1)

Where β' represents a vector of coefficients describing preferences for the attributes denoted by x, n represents individual n and i is the choice option The RUM takes the form of a conditional logit (CL) (Mcfadden, 1973) when the error terms are independently and identically drawn (IID) from an extreme value distribution. Choice probability under the CL model can be expressed as:

$$P_{ni} = \frac{exp\,(\beta' x_{ni})}{\Sigma_j exp(\beta' x_{nj})}$$

(2)

To overcome some of the restrictive properties of the CL model more flexible specification such as the random parameter logit (RPL) can be applied to DCE data.

As noted by Train, (2003), by decomposing the error term the restrictive property of IID is overcome. The newly decomposed error term has two distinct components, the first is correlated over alternatives and is heteroskedastic, the second is IID over alternatives and individuals. The corresponding utility equation can be written as:

$$u_{in} = \beta' x_{ni} + [\eta_{in} + \varepsilon_{in}]$$

(3)

Where η_{in} is a zero-mean random term, which may be correlated across alternatives, and individuals, ε_{in} remains IID. Unlike the CL, the parameter estimates for the RPL can vary across individuals with a density of $f(\beta)$. The corresponding unconditional choice probability represents the logit probabilities over all possible values of β_n. The choice probability for the RPL can be presented as a product of logits:

$$P_{nit} = \int \prod_{t=1}^{T} \left(\frac{\exp(\beta' x_{ni})}{\sum_j \exp(\beta' x_{nj})} \right) f(\beta) \, d\beta$$

(4)

T represents the number of choice occasions for each respondent. This "time" dimension, given by T, is included to account for the panel structure of the data. Parameters estimates are constant across choice occasions for each individual. This suggests that each individual's choice preference remains constant over the DCE but individual preference may vary across respondents (Hynes et al., 2008).

A concern when estimating coefficients from choice data is scale heterogeneity. Scale heterogeneity occurs when variation exists across decision-makers in relation to the impact of variables included in the model relative to variables not included. This leads to differences in coefficient magnitudes between respondents (Hess and Train 2017). As suggested by a reviewer of this paper, to relieve this concern the model presented within this paper is specified such that there is full correlation among utility coefficients."

WTP was estimated using the following equation:

$$WTP = \frac{\beta_n}{-\beta_{tc}}$$

(5)

Where β_n is the coefficient of the attribute of interest for individual n and $-\beta_{tc}$ is the cost coefficient. The price coefficient is specified as a fixed parameter implying that each individual has the same marginal utility of income. It is common, where possible, to allow the price coefficient to be specified as a random parameter with a log-normal

distribution (Daly et al. 2012). In the case of the present study, specifying a log-normal distribution for the price coefficient led to unrealistically large WTP estimate. The issue of unrealistically large WTP estimates as a consequence of using a log-normal distribution has been noted in a number of studies previously (Sillano and Dios Ortúza 2005; Hensher and Greene 2003). Estimates for interaction terms follows the approach used by (Nahuelhual, Loureiro, and Loomis (2004):

$$WTP = \frac{\beta_n + \sum_i \frac{\beta_{mi}}{s}}{-\beta_{tc}}$$

(6)

where β_n is the coefficient of one of the attributes of interest, β_{mi} represents the coefficient of the interaction term for individual i and s denotes the sample size. WTP estimates were made using simulated draws based on the model outputs.

4. Survey Design and Data collection

4.1 Carlingford Lough Catchment

Carlingford Lough is located on the east coast of the island of Ireland (displayed in Figure 1). The surrounding catchment area ($470km^2$) lies prominently in Northern Ireland ($426km^2$). The catchment holds 78,219 people with approximately 6% living in the Republic of Ireland. The area supports several commercial and recreational activities such as agriculture, fishing (commercial and recreational), transport, forestry, aquaculture and other recreational activities. It is also a well-visited tourist destination. However, only one Blue Flag has been award to the area and no Green Coast Flags have been awarded. The area also hosts a wide variety of fauna and flora species. However, there are many areas in the catchment where water quality improvement would facilitate improved recreation, particularly secondary and primary contact water activities.

Figure 1. Map of Carlingford Lough Catchment

Map was produced using ArcGIS® software by Esri

The survey[1] design was initially informed by a managerial stakeholder meeting. The stakeholder meeting consisted of 15 managers of the ecosystem services in the Carlingford Lough catchment. The managers included members of local county councils, individuals working for local water authorities and employees of the NI Department of Agriculture, Environment and Rural Affairs as well as other agencies protecting different attributes of the catchment's environment. These managers highlighted the ecosystem services that were important in the catchment. These included; loss of species and habitat, damage to forestry, water quality, drought and flooding. Following this, two focus groups were created. The first focus group used five individuals who lived in the catchment area, some of whom had prior experience developing surveys that examined resident's views on local ecosystem services and related issues. After redrafting the survey based on the information acquired from the

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[1] The full survey can be seen in the appendix of this paper.

first focus group, a second focus group was conducted. The second focus group was comprised of individuals from the target population. This focus group was made up of 12 participants, six males and six females, ranging in age from 18 to 69 and comprising different jobs and socio-demographic status. Participants for the second focus group were paid £35 each for their time. In both focus groups, participants helped to inform the language used, the attributes and levels included in the DCE, the payment vehicle and appropriate increases in the related cost attribute.

The final survey was conducted by trained professionals at the respondents homes. Participation was voluntary and took approximately 20 minutes to complete. The respondents were initially informed of what a catchment is. They were then shown a map so they understood the boundaries of the catchment and where the respondent is situated in the catchment followed by information about the ecosystem services in the area and how they are managed. Following this, respondents were asked questions about the environmental services in the catchment, their relationship to them, their views on the current state of the environment in the catchment and its management.

The next section informed the respondents about the ecosystem services they would be presented within the choice experiment. The attributes and their levels (presented in table 1) were explained to each respondent. The respondents were also given information not contained in the choice cards. For example, what a habitat is, what constitutes primary and secondary contact for recreational activities and how flood reduction could be provided were all briefly explained. The respondents were asked if they understood each attribute after it had been explained to them. If a respondent did not understand an attribute or its level the interviewer would explain it again.

The payment vehicle was then explained to the respondents. The same payment vehicle was used for both the Northern Irish and respondents from the Republic of Ireland, but its title was slightly different for each group. In both cases, it was an increase in household tax. Household taxes are referred to as household rates in Northern Ireland and property taxes in Ireland. These taxes should be well known to all the respondents and already cover the management of ecosystem services. The respondents were then informed about how the DCE was to be completed. They were

then shown 6 choice cards, followed by questions relating to their choices and, finally, demographic questions.

Table 1: Attributes and Levels

Attributes	Levels
Habitat protection	• **Habitat protection is Poor** 10% of habitats are lost over the next 10 years. • **Habitat protection is Moderate** 5% of habitats are lost over the next 10 years. • **Habitat protection is Good** 0% of habitats are lost over the next 10 years.
Maintenance of water quality for recreation opportunities	• **Water quality is Poor** the catchment is visual amenity only • **Water quality is Moderate** the catchment can be used for secondary contact recreation • **Water quality is Good** the catchment can be used for all recreation types.
Management of banks or shoreline for prevention of flooding events through natural solutions/ engineered solutions	• **Flood prevention is Poor** extreme flooding event once every 5 years • **Flood prevention is Moderate** extreme flooding event once every 10 years • **Flood prevention is Good** extreme flooding event once every 25 years
Cost*	• £0 or €0 • £5 or €6 • £10 or €12 • £20 or € 23 • £30 or €35 • £40 or €47 • £60 or €70

*£ and € are used as Northern Ireland uses pound sterling for their currency and the Republic of Ireland uses euro

As shown in Table 1, the attributes presented to the respondents were habitat protection, water quality for recreation, and flood prevention. Each has three levels; poor to good, with the status quo option always being poor for each attribute. The cost attribute has six levels, not including the £0/€0 payment for the status quo option. This results in a total of 162 possible combinations, far too many for any individual to

address. D-efficient design was used to maximize the efficiency of the choice cards. Twelve choice sets with two alternatives plus the status quo were constructed using Ngene software. The choice sets were blocked into two sets of six to make completion more manageable for the respondents.

During the survey, the sample was randomly split to test whether individuals have a preference for BGI solutions to flooding or grey solutions. Group A was informed that the flood prevention method would be through grey solutions. They were read the following statement:

"Management of banks or shorelines can be achieved by hard-engineered waterproof walls or other flood barriers which can be constructed at strategic sites to reduce flood risk. Some examples include:

- Hard-engineered waterproof permanent walls: walls that remain in place year-round and provide protection during flooding events or,

- Removable flood barriers: barriers that can be risen from an underground position during flooding events or that can be put in place prior to a flooding event and removed once the flooding event is over."

Group B was informed that BGI would be used and were read the following statement:

"Management of banks or shoreline can be achieved through natural solutions which can be used at strategic sites to reduce flood risk. Natural solutions are strategically planned natural and semi-natural areas designed and managed to deliver, in this case, flood prevention. Some examples include:

- Restoration of floodplains/wetlands which allow excess floodwater to be stored so that rivers do not rise in flood risk areas causing damage or,

- Natural sloping landscapes with permeable rock beds above drainage systems which can be used to ensure that excess water is funnelled to an area specifically designed to deal with such events, safely removing unwanted water."

The terms hard-engineered solution instead of grey infrastructure, and natural solution instead of BGI, were used as the focus groups indicated that these were more familiar concepts and easier to understand. On each choice card, the respondent was reminded that the flood reduction either came from hard-engineered solution or a natural solution. The example choice card presented in table 2 relates to the natural solution group.

The decision to use a split sample methodology as opposed to including a BGI or grey infrastructure attribute in the DCE was based on several factors. It was felt that the cognitive burden associated with an additional attribute may have impacted parameter estimation. Previous research has demonstrated that this type of cognitive burden can lead to attribute non-attendance (Hensher et al., 2005). Additionally, detailed explanations were used to explain the BGI and grey infrastructure solutions. Presenting both solutions to the respondents may have led to mental fatigue before beginning the choice experiment. Given the topic and survey methodology i.e. in person interviews, "yea saying" was of considerable concern. It may have been the case that some respondents would feel obliged to select the blue-green option, regardless of cost, given the current media coverage and global political debate. Furthermore, the background information in the survey and leading up to the DCE discussed ecosystem services and the natural environment. Respondents may have then felt that the "correct" response was to select the BGI option. There was also some concern that a BGI infrastructure variable would be highly correlated with the water quality/recreation and habitat protection attributes. Also, neither infrastructure can be considered an ecosystem service. It is the tool used to deliver the ecosystem services. As is good practice, only services are included as attributes. Finally, if an infrastructure variable was included as an attribute it would act as a label on the alternatives in the choice card and respondents may reach their choices solely on the basis of that 'label' (Doherty et al., 2014).

5. Results

5.1 Sample statistics

Both the Northern Ireland and Republic of Ireland sample characteristics were compared to the demographic-based quotas from the most up to date census for their respective small area population areas (see table 3). The Northern Irish sample constitutes approximately 90% of the total sample[2]. This is a slight oversampling of Republic of Ireland residents as they only account for approximately 6% of the total population of the catchment. This was a purposeful decision to allow a reasonable number of Republic of Ireland respondents to examine differences between the groups. If a respondent selected the status quo option every time, they were asked why they only selected this option. These respondents were given a list of pre-specified reasons or an "other" option to fill in a reason not listed. Respondents who demonstrated that their constant selection of the status quo option was a protest bid were removed from the data set. After this process, 449 respondents were left.

As can be seen in Table 3, half of the sample is female. The average age is 45 years old. Although respondents were asked about their income level, about half (51%) chose not to answer that question. As such, summary stats on income are not presented. However, socio-economic code (social class), which is highly correlated with income, was recorded for all individuals. Socio-economic data is in line with census data for the area of interest. Upper middle class (A) and middle class (B) accounts for about 9% of the data, lower-middle-class workers (C1) make up 34%, skilled manual labour (C2) constitutes 18% and the remainder is made up of semi and unskilled labour (D) and those classified as non-working (E).

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[2] After removing protest bids the total percentage of Republic of Ireland respondents increased to approximately 12%.

Table 3. Socio-Demographic Characteristics

Attribute	Mean (Standard deviation)	Census Data*
Northern Irish	0.88 (0.32)	
Female	0.50 (0.50)	0.50
Age		
18 - 39	0.43	0.38
40 – 64	0.38	0.41
65+	0.19	0.21
Socio-economic code		
AB, C1	0.42 (0.50)	44
C2, DE	0.57 (0.50)	56
Average Number of Dependents (under 16) Per Household	0.62(0.90)	
Education		
Primary	0.04 (0.21)	
Secondary	0.62 (0.49)	
University	0.34 (0.47)	
Work Status		
Working Full-Time	0.51 (0.50)	
Working Part-Time	0.08 (0.27)	
Homemaker	0.11 (0.31)	
Retired	0.18 (0.39)	
Student	0.08 (0.27)	
Unemployed/Unable to Work	0.04 (0.21)	
Home-Owner Status		
Owner-occupier	0.66 (0.47)	
Private Rented	0.26 (0.44)	
Public Housing	0.08 (0.27)	
Area Flooded in last 5 years	0.13 (0.34)	
Respondents	449	

*Census data were taken for the republic of Ireland taken from CSO [2016 estimates] and NISRA for the Northern Irish data [2017 estimates].

The majority of households (63%) have no dependents under the age of 16. Only one household has four dependents, with the rest having one, two or three children. On average, there are 0.62 children per household surveyed. The majority of the respondents had received secondary level education (62%) with only 4% obtaining only primary education. Approximately one-third received a university education. Almost 50% of the respondents are in full-time employment, with another 8% in part-time employment. Homemakers account for 11% of the sample, students 8% and retirees 18%. Only 4% are unemployed or unable to work. Two-thirds of those sampled owned their own home, a quarter rent and the remainder are in public housing.

To gauge whether respondents live in an area that is prone to flooding, respondents were asked: "has the area you live in been affected by flooding in the last 5-years?" If the respondent had not lived in the area for the last five years, the data collector was instructed to allow the respondent to answer for the time period they had lived there. Of the sample, 13% stated they lived in an area that has flooded.

The respondents were asked a number of questions to better understand how they interact and perceive the natural environment they live in. Table 4 presents the results of these questions. As can be seen above, most of the respondents (67%) consider the environmental quality of the catchment as fairly good or very good, with only about 10% rating it as fairly poor or very poor. Notably, about a quarter of the respondents were unable/unwilling to rate the environmental quality of the catchment. Approximately the same proportion were unable to rate how well the environment in the catchment is managed and how future changes to the environment will impact them. About two-thirds of the respondents rated the management of the environment in the catchment as fairly good or very good and only 2% rated it as fairly poor or very poor. Almost half of the respondents believe that changes to the natural environment would have no effect on them and only 3% thought it would have a major effect.

Table 4. Opinions on Catchment's Ecosystem Services and Management

Attribute	Percentage of Sample
How would you rate the environmental quality of the catchment?	
Very Good	22%
Fairly Good	45%
Neither Good nor Poor	7%
Fairly Poor	9%
Very Poor	0%
Don't Know	23%
How well is the catchment managed?	
Very Good	19%
Fairly Good	46%
Neither Good nor Poor	7%
Fairly Poor	2%
Very Poor	0%
Don't Know	26%
Do you think that possible future changes to the natural resources and wildlife of the catchment affect you?	
Major Effect	3%
Some Effect	26%
No Effect	48%
Don't Know	23%
Most beneficial ecosystem services provided by the catchment*	
Scenic Value	48%
Recreation	46%
Tourism	41%
Biggest threat to the natural environment in the catchment*	
Plastic and Litter	77%
Industrial Pollution	52%
Temperature Change	48%
Uses catchment for recreation	25%
Average uses per year	28 uses

*These benefits and threats were rated in respondents top three most important.

Respondents were given a list of the 13 most well-known environmental service benefits provided by the Carlingford Lough catchment. They were then asked to rate the three most important service benefits to them. Table 4 presents the service benefits that appeared in the respondents most important benefits by the largest percentage of

people. Almost half of the respondents placed both scenic value and recreational value in their three most important benefits. About 40% rated tourism in their top three. Approximately 18% of the sample rated wildlife habitats in their three most important benefits.

The respondents were also given a list of 12 possible threats to the catchment's natural environment. The respondents were asked to rate the three they felt posed the biggest threat. Plastics and litter were seen as the biggest threat by a large amount with more than three-quarters of the respondents rating it in their top three. More than half saw industrial pollution as a large threat and just under a half believe temperature change is a threat worthy of their top three. Approximately one quarter thought flooding posed a big enough risk to be in their top three.

A quarter of the respondents use the natural environment in the catchment for recreational activities. Of the respondents who use the catchment for recreation, walking was the most popular activity.

5.2 Model Results

Table 5 presents the results of the RPL model applied to the DCE data collected from residents of the Carlingford Lough catchment. A dummy is used for each level of the attributes presented to the respondents in the DCE except for the price variable which is treated as continuous. A dummy called StatusQuo indicates whether the respondents are more or less likely to pick the status quo than either of the options that have environmental changes and a positive cost. In an RPL model, by specifying coefficients to vary across individuals, individual taste preferences can be captured. The status quo variable and the variables directly associated with each attribute from the DCE are specified as random. The model was run with 1000 draws, as this was enough to demonstrate the precision of the parameter estimates (Hensher & Greene, 2003). The random parameters are specified to follow a normal distribution. All other variance is capture using interaction terms.

A dummy indicating that the respondent was told that flood protection would be through a BGI solution was interacted with the StatusQuo variable. This interaction term is named StausQuo_BGI in Table 5. A negative value indicates that those who

were informed that flood relief would be achieved through a BGI are less likely to choose the status quo option in comparison to those who were told flood relief would be through grey infrastructure. The second interaction term used interacts the variable StausQuo_BGI with the binary variable that denotes if the area the respondent lives in has flooded in the last five years. A negative coefficient indicates that those who were informed that flood relief would be achieved through a BGI and who have encountered flooding previously are less likely to choose the status quo option. This variable is referred to as StausQuo_BGI_InFloodArea.

To account for preferences for flood relief varying based on previous flooding events, the variables for good and moderate flooding prevention are interacted with the dummy the signifies the respondent lives in an area that has flooded in the previous five years. Finally, three interactions terms were used to test whether the marginal disutility of cost varies by social class. These variables interact social class with the continues price variable. If negative and significant, these dummies indicate that those in social class other than AB have a higher disutility associated with an increase in the taxes presented in the DCE.

As expected, the price coefficient is negative and significant, indicating that individuals would prefer to increase their taxes by less, ceteris paribus. The interaction terms Price_Social Class suggest that there was no greater disutility from an increase in taxes between the social classes. The StatusQuo variable indicates that, on average, respondents prefer an option where there is improvement to local ecosystem services.

Amongst the attributes found in the DCE, the results conform to prior expectation. Both moderate and good levels of habitat protection were positive and significant. This suggests that the average respondent would prefer that no habitat loss (or at least less than 5%) occur over the next 10 years.

Table 5. Results of Random Parameter Logit Model

	Mean Coefficient	Standard Deviation
Random Parameters		
Habitat_Good	0.93 (0.19) ***	2.58 (0.26) ***
Habitat_Moderate	0.80 (0.20) ***	2.90 (0.28) ***
WaterQuality_Good	1.49 (0.20) ***	2.88 (0.27) ***
WaterQuality_Moderate	0.48 (0.15) ***	1.69 (0.23) ***
FloodPrevention_Good	0.57 (0.10) ***	0.62 (0.16) ***
FloodPrevetion_Moderate	0.16 (0.11)	0.72 (0.16) ***
StatusQuo	-1.55 (0.25) ***	1.75 (0.27) ***
Fixed Parameters		
Price	-0.044 (0.01)***	
Price_Social class C1	0.00 (0.01)	
Price _Social class C2	0.01 (0.01)	
Price _Social class DE	0.00 (0.01)	
StausQuo_BGI	-1.02 (0.31) ***	
StausQuo_BGI_InFloodArea	0.44 (0.57)	
FloodPrevention_Good_InFloodarea	0.97 (0.26) ***	
FloodPrevetion_Moderate_InFloodarea	0.09 (0.26)	
Loglikelihood	-2135	
AIC	4355	
BIC	4656	
Observations	8082	

*** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level

A good level of water quality for recreational purposes has the largest coefficients of any of the DCE attributes. This variable demonstrates that respondents value waters that allow them to swim, kayak and perform other primary contact activities. Preferences for water quality for secondary contact was also positive and significant. However, the estimated coefficient for good water quality is approximately two and a half times as large as for moderate water quality.

Flood prevention was positive and statistically significant at good level but not the moderate level. This suggests that there is a preference for flood prevention that reduces flood risk from once every five years to at least once every 25 years. The

interaction term FloodPrevention_Good_InFloodarea suggests that respondents who live in a flood prone area have a greater preference for flood prevention that reduces flood risk to once every 25 years in comparison to those not living in a flood prone area.

To test whether presenting a BGI solution, as opposed to a grey infrastructure solution, to the respondents, impacted their decision to choose an option that improves local ecosystem services, two interaction terms were created. The first interacts a dummy that indicates that the respondent was informed that flood prevention would be through a BGI with the status quo dummy. The second interacts the previous interaction term with a dummy indicating the respondent lived in a flood prone area. The coefficient for the first term implies that individuals were less likely to select the status quo option if flood prevention was achieved using a BGI. However, presenting individuals from a flood prone area with a BGI solution did not have any additional impact on their decision to pick an option other than the status quo.

5.3 Welfare Estimates

Displayed in Table 6 are the statistically significant WTP estimates derived from the results of the RPL model. For the average respondent, the largest WTP is for good water quality which enables primary contact water activities. The average respondent is WTP £33.77 per year for water quality that allows primary contact activities. However, one group in the data set is WTP more for good flood prevention (flooding once every 25 years). Those who live in flood-prone areas are WTP £34.84 per year for good flood protection. The second largest WTP is for a good level of habitat protection at £21.04, followed by the moderate level of habitat protection. Of the statistically significant variables, an increase in water quality such that secondary contact activities could be undertaken had the lowest associated WTP at £10.92 per year. Finally, if a respondent was presented with a BGI solution, they were willing to pay £23.10 per year more than those presented with the grey solution for improvements to the ecosystem.

Table 6. Welfare estimates (£ per household per year)

Attributes	RPL	
Habitat_Good	21.04	(11.62 – 40.00)
Habitat_Moderate	18.19	(8.98 – 35.48)
Water_Good	33.77	(21.34 – 60.99)
Water_Moderate	10.92	(4.15 – 22.37)
FloodPrevetion_Good	12.92	(7.44 – 24.59)
FloodPrevetion_Moderate	-	
StausQuo_BGI	-23.10	(-48.27– -8.73)
FloodPrevention_Good_InFloodarea	21.92	(10.00 – 44.13)

95% confidence intervals shown in parenthesis, *these values calculated using formula 6. A dash indicates non-significant

6. Discussion

The results demonstrate that the residents of the Carlingford Lough catchment have positive preferences for the ecosystem service benefits that the catchment provides. The respondents routinely chose ecosystem services when there was a trade-off with increased tax rates. For all attributes, there was a positive and significant preference for the "good" level which in turn led to positive estimates of WTP for "good" provisioning of these services.

The main purpose of this paper was to explore whether individuals prefer a BGI solution to flooding as opposed to a grey infrastructure solution. The average respondent was less likely to pick the status quo option if presented with a BGI solution to flooding. This suggests that the respondents are more willing to pay for a flood risk reduction project if it comes from a BGI solution as opposed to a grey infrastructure solution. There did not seem to be an increased preference for a BGI solution if an individual lived in a flood prone area. However, those who lived in a flood prone area and were presented with a BGI solution account for less than 3% of the sample, so further analysis may be warranted.

In comparison to previous work, the results presented here bear some similarities to other Irish studies. For example, Doherty et al. (2014) estimated the value of good water quality at €42 (£33 pounds at the 2014 exchange rate) and moderate water quality at €30 (£24). As can be seen in Table 6, good water quality has been estimated to be almost the same value as in Doherty et al., (2014) but their value for moderate water quality is larger. Heath of ecosystem, from Doherty et al.'s (2014) study, which is broadly similar to habitat preservation in the present study, was estimated at €25 (£20) for the good level and €30 (£24) at the moderate level. Both results are similar to those presented above.

Buckley et al. (2016) estimate the value of good water quality as €19 (£16), about half the value estimated for the Carlingford Lough residents. However, this was a study across the Republic of Ireland, where, as the respondents were informed, only 31.5% of the rivers being valued did not already reach the "good ecological status" (GES). Elsewhere, Hynes & O'Donoghue (2020) estimated that the average person in Ireland was WTP €19.87 per year to ensure that the water body in their own catchment of residence achieved GES.

In the more recent studies looking at WTP for flood risk reduction using BGI, the results are a little more difficult to compare due to difference in the manner in which the reductions were presented. However, like the present study, Brent et al.'s (2017) study found that flood risk occurring half as often (comparable to the moderate level in this study) did not present with a statistically significant WTP estimate. In Brent et al.'s (2017) study, if flood risk dropped to zero, respondents living in Sydney had an estimated WTP of $85 (£48) whereas, their Melbourne counterparts did not have a statically significant WTP. Although the authors' estimate is larger than the one presented here, there may be a considerable difference in the minds of the respondents between a flooding event once every 25 years and flooding events never happening. Pienaar et al.'s (2019) estimation of WTP for a reduction in flooding as part of a conservation project in Florida is equally difficult to compare. They estimated that a 1% reduction in the probability of flood risk at $2.58 and a 2% reduction at $7.27. Ando et al.'s (2020) found statistically significant but comparatively small values for a 1% reduction in flood risk across two U.S. cities. The authors estimated a value of about $0.60 per year for the 1% reduction. Given the different scales over which the

flood risk reduction has been proposed to their respective respondents, it is difficult to tell how the results presented here compare to papers with samples outside of the Island of Ireland.

7. Conclusions

In this paper, we aimed to explore whether residents of the Carlingford Lough Catchment have a preference for a BGI or grey infrastructure solution to flooding events. The analysis suggests that when presented with a BGI solution respondent are more likely to pick an option reduces flood risk. However, those living in a flood prone area had no greater preference for a BGI solution in comparison to those not living in a flood prone area.

Future research should aim to build on this current study by exploring the underlying mechanism of the current finding. What attributes of a BGI are appealing to those at risk of flooding? Conversely, is it some aspect of grey infrastructure that these respondents find unappealing? It would also be interesting to discover if BGI solutions would be preferred to grey infrastructure solutions for other climate change-related events, or if this result is a phenomenon of flood reduction alone.

In this study comparison has been made between BGI solutions and grey infrastructure solutions while controlling for the level of water quality, habitat preservation and flood risk. A primary benefit that BGI solutions have over grey solutions is that they can provide multiple ecosystem services at once. A traditional grey infrastructure solution that provides flood risk mitigation typically only provides that one service. Providing water treatment would incur additional cost. Grey infrastructures which reduce flood risk and treat water would likely cause a reduction in the amount of wildlife habitat areas, which may need to be offset by a third project. A BGI project, on the other hand, can provide all three ecosystem services simultaneously. The results of this study demonstrate that the resident of the Carlingford Lough catchment would be willing to pay a premium for a BGI and that they value the additional benefits that are an intrinsic quality of a BGI for flood risk reduction. As such, BGI solutions for flood risk reduction may provide a more cost-effective means of provisioning multiple ecosystem services.

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