Spatial preferences for invasion management: a choice experiment on the control of Ludwigia grandiflora in a French regional park.

Douadia Bougherara, Pierre Courtois, Maia David, Joakim Weill

Spatial preferences for invasion management: a choice experiment on controlling *Ludwigia grandiflora* in a French regional park

Douadia Bougherara[*], Pierre Courtois[†], Maia David[‡], Joakim Weill[§]

October 29, 2021

Abstract

If individuals have spatially differentiated preferences for sites or areas impacted by an invasive alien species, effective management must take this heterogeneity into account and target sites or areas accordingly. In this paper, we estimate spatially differentiated preferences for the management of primrose willow (*Ludwigia grandiflora*), an invasive weed spreading in a French regional park. We use an original spatially explicit discrete choice experiment to evaluate individuals' willingness to pay (WTP) to control the invasion in different areas of the regional park. Our results indicate that WTP for management highly depends on the area considered, with areas where it is three times higher than others. We analyze the main factors explaining the heterogeneity of preferences and show that the closer respondents live to the park, the more they visit and/or practice activities in it, the higher their WTP and spatial preferences. Park residents and regular users have high WTP and unambiguous preferences for targeting control to specific areas. Non-residents and occasional users have much lower WTP and more homogeneous spatial preferences. These results suggest that implementing management strategies that spatially target invasion control according to public preferences is likely to produce significant utility gains. These gains are all the more important as the preferences taken into account are those

[*]CEE-M, Univ. Montpellier, CNRS, INRAE, Institut Agro, Montpellier, France.

[†]Corresponding author. CEE-M, Univ. Montpellier, CNRS, INRAE, Institut Agro, Montpellier, France.

[‡]Economie Publique, Université Paris-Saclay, INRAE, AgroParisTech, Thiverval-Grignon, France

[§]Agricultural and Resource Economics, University of California, Davis, CA 95616

of the stakeholders directly concerned by the invasion, the residents and regular park users. Ignoring these spatial preferences will lead to sub-optimal invasion management.

Keywords: Discrete choice experiments, Spatial heterogeneity, Cost assessment, Primrose willow, Invasive weed, Public preferences.

1 Introduction

Invasive alien species are tremendously impacting ecosystems, economic activities, and human welfare (Paini et al., 2016; Bradshaw et al., 2016; Diagne et al., 2020). Limited public funds (Scalera, 2010) make *where* and *how* to control a given invasive alien species a major management challenge (Potapov and Lewis, 2008; Epanchin-Niell and Wilen, 2012; McGeoch et al., 2016). To prioritize management efforts spatially, the bioeconomic literature has principally analyzed cost-effective allocations targeting efforts to minimize or slow the spatial spread of invasions (see Epanchin-Niell, 2017; Büyüktahtakin and Haight, 2018, for an extensive review of the literature). A few studies have analyzed the spatial allocation problem by maximizing net benefits through considering spatially heterogeneous management costs and/or benefits (Burnett et al., 2007; Epanchin-Niell et al., 2012; Jardine and Sanchirico, 2018). However, none of these studies used economic valuation methods based on individual preferences. Yet, these methods are relevant for estimating the value people place on the spatial benefits of management and, more generally, for prioritizing sites according to public preferences.

Invasive alien species often cause multiple losses of use and non-use values, making accounting approaches difficult to apply. Stated and revealed preference methods have been developed in economics to assess individual preferences through their willingness to pay (WTP). Among the stated preference approaches, which have the advantage of accounting for non-use values, discrete choice experiments (DCEs) provide an especially suitable framework to support decision-making. The method is based on assessing individual preferences for a discrete set of alternative options that differ by their *attributes* (see Hoyos, 2010, for a review). Analyzing respondents' choices enables scholars to estimate the implicit WTP for each attribute. When these attributes relate to spatial characteristics, the ranking of WTP allows spatial preferences for management to be ordered.

To our knowledge, six DCEs have been applied to invasive alien species management (Adams et al., 2011; Rolfe and Windle, 2014; Chakir et al., 2016; Sheremet et al., 2017; Subroy et al., 2018; Japelj et al., 2019), of which only two have a spatial dimension. Rolfe and Windle (2014) analyzed spatial preferences for the control of imported red fire ants in Brisbane, Australia, and assessed WTP for eradication versus containment strategies in public, private, and protected areas. They showed unambiguous preferences for eradication in public areas, such as schools and parks. Japelj et al. (2019) elicited WTP for different removal strategies over a set of invasive alien species impacting Slovenian forests. Considering three control methods in two distinct locations (urban and forest), they analyzed the heterogeneity of public preferences using a latent class model.

Although not applied to invasive alien species management, several studies introduced spatial considerations into DCEs. They focused foremost on two aspects: (1) the spatial characteristics of the respondents, in particular their location in relation to the area of interest, and (2) the identification of spatially explicit preferences. Concu (2007) and more recently Glenk et al. (2020) reviewed the extensive literature on the theoretical and empirical foundations of distance decay (i.e., the decrease in WTP due to the distance of respondents from the area of interest). Their reviews showed that the decay is mainly explained by travel and accessibility costs, information and search costs, availability of substitute sites, and moral obligations and motivations. The second aspect received less attention from the literature. Several studies assessed spatial preferences using DCE based on geographical maps. Johnston et al. (2002) were the first to synthesize management options in stylized maps to analyze alternative plans to develop rural lands in four towns in southern New England (U.S.). Applying a related method using cartographic attributes, Brouwer et al. (2010) assessed preferences for water quality improvements in different parts of a river basin in Spain. They showed that even though respondents are willing to pay for water quality throughout the entire river basin, they are willing to pay more to reach a condition better than "good" only in some sub-basins (see also Martin-Ortega et al., 2012).

In this paper, we conduct a DCE to obtain the public's spatial preferences for the management of primrose willow (*Ludwigia grandiflora*), an invasive weed with a negative impact on biodiversity and activities in an emblematic marsh of a French regional park. The marsh is publicly owned, and local taxes fund the management of the invasion. The management strategy is entirely in the custody of the park office, which selects the areas of the marsh to prioritize. This strategy, however, concerns also the inhabitants and the main users of the park who suffer the effects of the invasion and finance its management.

We aim to analyze primrose willow management from a public preferences perspective. We ask how much residents and non-residents of the park are willing to pay for invasion control in five different areas of the marshland. As in Johnston et al. (2002) or Brouwer et al. (2010), we synthesize choice options in the form of stylized maps and define a DCE setting in which attributes correspond to different geographical areas of the marshland. We assess WTP for invasion control in the different areas considered and estimate how this WTP varies between residents and non-residents, regular and occasional users of the park, and people living further away. Our spatial analysis is twofold: (1) highlight the heterogeneity of preferences for the management of primrose willow in different spatial areas of the marshland (by allowing respondents to choose between different *maps*), and (2) take into account the spatial characteristics of the population surveyed, analyzing how spatial preferences vary according to the location of the respondents (distance-decay effect).

The principal results are to provide estimates of WTP to inform spatial management of primrose willow based on individual preferences and to investigate the drivers of public preferences. We find that WTP is significant but highly heterogeneous across the areas considered. Respondents are willing to pay annually from 5 € for the lowest-valued area to 17 € for the highest-valued area to reduce the invasive alien species from a medium to a low invasion level. They are willing to pay 17 € for the lowest-valued area and 28 € for the highest-valued area annually to reduce the invasive alien species from a high to a medium invasion level. Three categories of area can be distinguished based on public preferences: two priority areas, two intermediate areas, and one secondary area. In intermediate areas, management is valued twice as much as in the secondary area. Management in priority areas is valued three times as much. We also find in the study that WTP is very heterogeneous among respondents. We show that the closer respondents live to the regional park, the more they visit or practice activities in it and the more they value it. We also show that the closer respondents live to the regional park, the more heterogeneous their spatial management preferences are (i.e., the more they prefer to target management efforts in priority areas).

The main policy implication of these results is that (1) management in priority areas of the regional park would produce greater utility gains, and (2) this is all the more true as the preferences assessed are those of frequent users and/or of people living in the park.

2 Material and methods

2.1 Case study

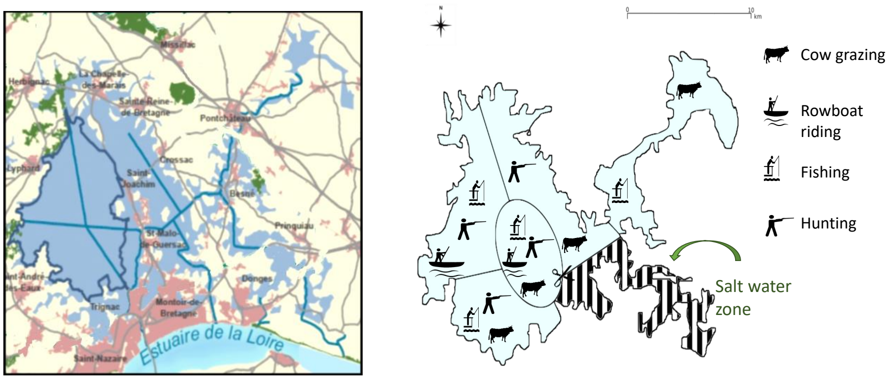
The regional park of *Brière* is located on the West coast of France, in *Loire-Atlantique*, a subregion with a population of 1.42 million inhabitants[1], at the extreme north of the *Pays de la Loire* region. The regional park covers more than 50,000 hectares (500 square kilometers) and includes several villages and pastures. The special feature of the park is its 1,700 hectares of wetlands, a marshland consisting of a network of navigable canals, and water bodies (see Figure 1A).

The marsh offers multiple recreational and tourist activities, such as hiking, fishing, waterfowl hunting, and rowboat rides.[2] Pasture lands scattered between

[1] In the Nomenclature of Territorial Units for Statistics (NUTS) (https://ec.europa.eu/eurostat/web/nuts/background), this subregion is NUTS3. In France, NUTS2 is the "*région*" level, NUTS3 is the "*département*" level, and LAU (Local Administrative Unit) is municipalities or groups of municipalities. There are 18 NUTS2 regions in France divided into 101 NUTS3 regions, which are administrative entities similar to U.S. counties.

[2] The regional tourism turnover in 2019 is estimated at 3.2 billion € with 16,000 direct tourist jobs (source https://www.paysdelaloire.fr/). Although tourism activity is mainly concentrated on the coast, the park has many visitors, with 284 accommodation facilities, 95 restaurants, 30

Figure 1: The marsh and the activities practiced



A **Brière marsh** **B** **Activities practiced**

canals provide grazing areas for cows, a breeding activity associated with a local production label (the "*Valeurs Parc Naturel Régional*" label). Located south of the regional park is the international harbor of *Saint-Nazaire*, one of France's most important trade hubs. The proximity to globalized markets has put the park under tremendous pressure from invasive alien species.

The most worrisome invasion by far is that of the primrose willow, *Ludwigia grandiflora*, an amphibious plant first reported in the park in 1994.[3]. The plant initially spread from the southwest to the center of the marsh and is denser in these areas. It is now present throughout the marsh, except for the southeastern area, which is too saline for primrose willow. If left uncontrolled, primrose willow has such an explosive proliferation that canals become inoperable, halting rowboat rides and fishing, two recreational activities crucial to the economy of the wetland.

Furthermore, when canals and waterbeds are highly invaded, the plant spreads along the banks and edges of the surrounding pastures. The result is a series of economic losses for farms that use the marsh as grazing land for their herds. First, primrose willow is toxic to livestock and makes grazing impossible in the invaded areas. The obstruction of the canals also makes it difficult to access pastures. Second, the loss of grazing land could threaten cattle ranchers' ability to use the regional production label, which requires that breeding and grazing of cows occur

heritage sites, and 7 main natural sites, all located in the wetland.

[3]Primrose willow is one of the 37 key preoccupying invasive alien species reported in EU regulation list 2016/1141 adopted on July 13, 2016.

in the marsh. Finally, if farmers do not graze their herds in the marshland, they eventually lose the subsidies from the European Common Agricultural Policy's agri-environmental schemes.[4]

In addition to the impacts on recreational, tourism, and agricultural activities, the invasion reduces the local biodiversity of the wetland, impacts the landscape, and increases the risk of flooding. In particular, several endangered and critically endangered species (e.g., pike perch, chub, lamprey) are directly threatened by primrose willow. These negative impacts on use and non-use values make this invasion a public bad that requires a management strategy to limit its extent.

An important feature of the marsh is that it is not privately owned but belongs to the 21 municipalities that make up the park.[5] The marshland pastures also belong to the 21 municipalities but can still be used free of charge by local ranchers. Local taxes fund the management of the primrose willow[6]. Management is delegated to the park management office, which is fully accountable for management strategy and operations. The annual budget allocated to management is approximately 110,000 €. The invasion can only be addressed in part because control is costly. Management is based on manual or mechanical removal and takes place each year during the flowering periods of primrose willow. Because of its deep roots and ability to reproduce, eradicating the invasion is impossible unless resorting to salinization, which would completely disrupt the environment and be disastrous for local biodiversity. The management strategy of the park office, particularly the site prioritization strategy, is poorly documented and, in the opinion of the managers, geared towards adopting partial but extensive control of all areas, with a particular focus on the navigability of canals. Public preferences are not currently taken into consideration in this strategy.

Yet, the population and especially the residents are relevant stakeholders, and their preferences should be taken into account. Individuals living in the park are not uniformly distributed in space and may have spatial preferences for control in their vicinity. In particular, the population density is higher in the south and center of the marsh. Agricultural and recreational activities are also area-specific (see Figure 1 B), and users of the park may have spatial preferences based on habits or ease. The central and western areas of the marsh are more frequented

[4]The payment received for agri-environment-climate commitments pertains to the class of incentives for grazing practices, sub-measures Herb1-2-3-4 now entitled 10.1.4 Grassland GS1-17. In 2015, for example, 20 landowners received 235,507 € for their commitment to using 1,193 hectares of grazing land, of which 38,588 € had to be repaid due to the invasion of 195 hectares by primrose willow, which made grazing impossible.

[5]This idiosyncrasy is due to a decision by Francois II, Duke of Brittany, in 1461 (François II, 1461).

[6]Namely, housing and employment taxes of Saint Nazaire Metropolis, a Local Administrative Unit of approximately 127,000 fiscal households (INSEE, 2017).

and popular than other areas.

Hunting is practiced mostly on water bodies and is therefore concentrated in the western and central parts of the marsh. Fishing can be practiced anywhere, although fishers poorly use the northeastern part of the marsh. Cow grazing cannot be practiced in the northern part of the marsh, and major agricultural activities occur in the central and southern parts. Finally, rowboat-riding activities are located in the central and northwestern parts. As these last two activities generate significant economic output for the park, one may expect a preference for preserving those areas. Non-use values, particularly biodiversity, are uniformly impacted by the invasion because the marsh as a whole constitutes a biodiversity hotspot. Therefore, it is not preferable to control the invasion in one area rather than another in this respect except to avoid very high invasion densities, which would harm the biodiversity due to the covering capacity of the primrose willow.

2.2 The choice experiment

DCEs involve presenting a set of choice tasks to respondents. Each task consists of several alternatives, usually limited to three (see Louviere et al., 2000, for a review). Respondents are asked to pick their favorite alternative within each choice task. Alternatives comprise different attributes, and each attribute can take different levels of provision. When one of the attributes is either a price or a cost, the method allows for eliciting the WTP for changes in the levels of the other attributes. This feature makes DCEs an attractive method to estimate preferences for goods or amenities that do not have a market price, such as environmental amenities (Adamowicz et al., 1994).

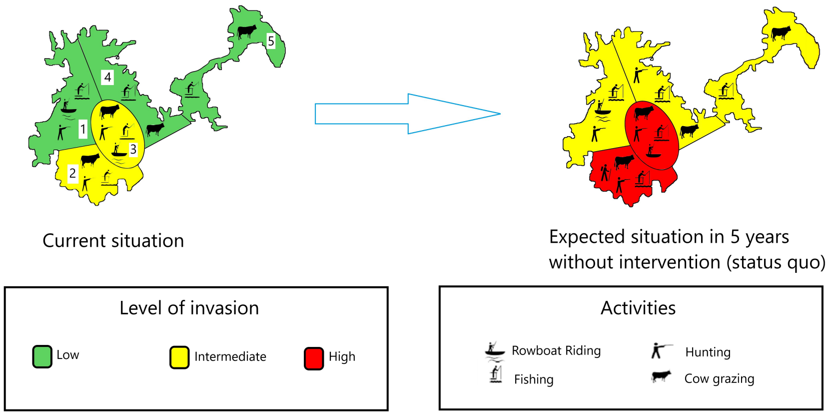
2.2.1 Attributes and their levels

The first components of a DCE are the attributes that compose each alternative and their possible values (levels). As Hanley et al. (2002) explained, the number of attributes must be small to limit the cognitive burden imposed on respondents. Because the objective of our DCE is to assess respondents' WTP for spatial control of primrose willow in the marsh, we assume two categories of attributes: (1) spatial attributes delineating areas of interest for management and (2) a cost attribute to evaluate the WTP for each alternative.

To define our spatial attributes, we relied on expert advice from park managers and a pilot study. We divided the marsh into five main areas of interest for invasion management, resulting in five spatial attributes numbered 1–5 (see Figure 2, left-hand side).[7] To avoid preferences being influenced by size effects, we set the areas to be of equal size, which was explicitly made clear to respondents at the

[7]Note that these five areas have no physical existence as such and are defined only for the

Figure 2: Actual and predicted invasion with area numbers and activities associated with each area



beginning of the survey. Area boundaries were defined by the experts to best distinguish between uses, levels of invasion prevalence, and the location of major villages that might impact respondents' preferences. The resulting areas are five cohesive units that can be managed independently of each other.

For each spatial attribute, we set three possible values corresponding to the level of primrose willow prevalence and its impact on use and non-use values. Levels are presented to respondents with traffic-light colors (see Figure 2)[8]. The color green is used to represent *Low* levels of primrose willow involving almost no impact on activities and biodiversity. The color yellow is used to represent *Medium* levels of invasion. Some canals are clogged; their banks and some water bodies are partially invaded. The users of the park can practice activities but are likely to be disturbed by the primrose willow and must modify their habits. Biodiversity is impacted without the ecosystem being radically modified. The color red is used to represent *High* levels of invasion. The invasion clogs all canals and largely covers water bodies. The banks are colonized. Accessibility is compromised, and human activities become impossible. Biodiversity is also greatly impacted. We carefully explained the meaning of these different prevalence levels at the beginning of the survey and highlighted the current level of invasion and the level expected in five years if no action is taken (the so-called *status quo* scenario) (see Figure 2, right-hand side).

The sixth attribute is monetary in the form of a yearly tax increase, which

purposes of the study. No physical barriers or property rights define those areas. The sum of these five areas constitutes the entire area of the marsh where primrose willow is susceptible to management by the park management office.

[8]For the black and white version, red is dark grey, yellow is light grey, and green is the intermediate grey.

allows us to estimate WTP for different levels and spatial patterns of invasion. This attribute can take 5 different levels: 0 €/year, 5 €/year, 15 €/year, 30 €/year, and 60 €/year. These levels were also chosen based on expert opinions and our pilot study.

As a result, the different management alternatives, distinguished by the location and extent of the control of the invasion, take the form of different maps, each associated with a cost.[9] Each choice task consists of selecting a preferred management option from three alternatives. For each task, one of the three available alternatives is to do nothing (with a zero cost) and let the invasion spread, the so-called "status quo" option represented by the alternative on the right-hand side of each card. Figure 3 presents three different examples of a choice task.

2.2.2 The experimental design

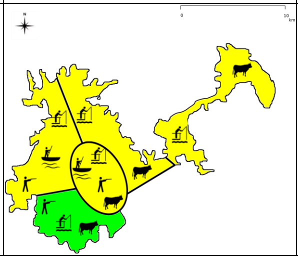
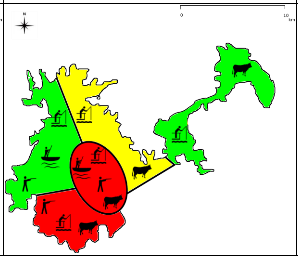
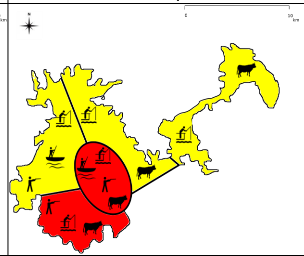
With three levels associated with the five spatial attributes and five levels associated with the cost attribute, the full factorial range of combinations is too wide to collect respondents' opinions on all of them. We selected a statistically optimal subset of these combinations using a Bayesian D-optimal design (see experimental design techniques in Louviere et al., 2000; Street et al., 2005) using the *NGene* software, which is standard in the literature. We used a fractional factorial efficient design[10] adapted for a random parameter logit model with parameters following a normal distribution. The design further accounted for two constraints: (1) in each area, the alternatives cannot present a worse invasion level than the *status quo* situation, and (2) the tax levels in the non *status quo* alternatives are strictly positive, implying that improving over the *status quo* has a cost.

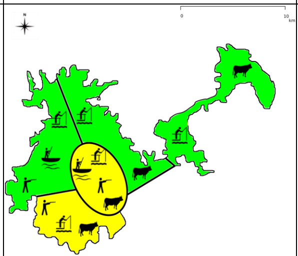
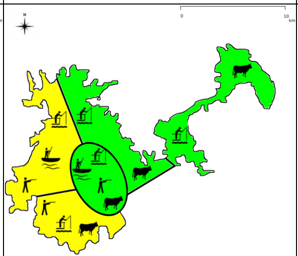
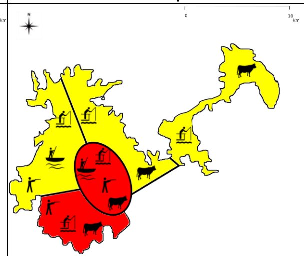
This experimental design led to 16 different choice sets. As is usual (see ChoiceMetrics, 2018), these were blocked into two groups to reduce the cognitive load, so the final questionnaire presented 8 choice sets to each respondent. Respondents were randomly assigned to one of the two groups. The order of the choice sets was randomized to avoid declining attention systematically impacting the responses to specific choice sets. The program used for the experimental design and the 16 associated choice sets are available upon request.

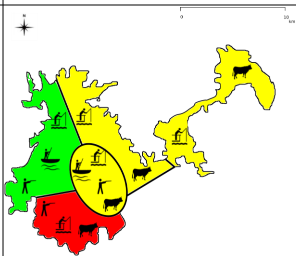
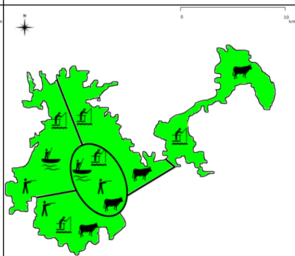
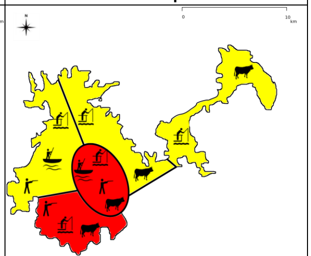
[9]Note that our pilot study showed that using five different areas was tractable to respondents. Compared with a classical DCE with six attributes, our spatial DCE generates less cognitive bias (i.e., requires less concentration from respondents) because five of the attributes are visually synthesized through a map, making the information easier to process.

[10]Efficient designs have been empirically shown to lead to smaller standard errors in model estimation compared with orthogonal designs (Greiner et al., 2014; Bliemer and Rose, 2010, 2011).

Figure 3: Examples of choice sets

Options	A	B	Status quo
Situation in 5 years			
Yearly cost	Tax + 15 €	Tax + 5 €	Tax + 0 €
Your choice	○	○	○

Options	A	B	Status quo
Situation in 5 years			
Yearly cost	Tax + 60 €	Tax + 60 €	Tax + 0 €
Your choice	○	○	○

Options	A	B	Status quo
Situation in 5 years			
Yearly cost	Tax + 5 €	Tax + 60 €	Tax + 0 €
Your choice	○	○	○

2.2.3 Econometric background

The econometric analysis of choice experiments is based on random utility theory (McFadden, 1973; Manski, 1977), which posits that the indirect utility an individual n obtains from choosing an alternative i, U_{ni}, is made of both an observed component V_{ni} and a random (unobserved) component ε_{ni}, such that $U_{ni} = V_{ni} + \varepsilon_{ni}$. Individual n then chooses alternative i over all other alternatives j if and only if $U_{ni} > U_{nj}\ \forall j \neq i$. Because we do not observe ε_{ni}, this component is assumed to be random. The probability that individual n chooses alternative i can be expressed as

$$(1) \qquad P_{ni} = Prob(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj})\ \forall j \neq i$$

Different assumptions regarding the distribution of the random component translate into different discrete choice models and estimating procedures. Furthermore, the observed utility component includes individual and alternative-specific characteristics that influence the indirect utility through a vector of parameters to be estimated. These parameters are either assumed to be fixed or random (i.e., varying in the population according to a certain distribution). The latter assumption is the one we retain because it allows for taste heterogeneity (see Train, 2009, for an enlightening review).

We thus present results obtained with a random parameter logit (RPL) model. This model allows for preference heterogeneity, flexible substitution patterns between alternatives, and dynamic correlation among unobserved factors. As shown by McFadden and Train (2000), this model can approximate any random utility model arbitrarily closely.[11]

We follow the literature and choose a standard linear specification for the deterministic part V_{ni} of the utility function. The utility V_{ni} is derived from the levels of the K attributes of the alternative i, denoted by $\mathbf{X}_i = (x_{i1}, \ldots, x_{ik}, \ldots, x_{iK})$. In our case, $K = 6$ with five spatial attributes (5 areas) and one monetary attribute (tax). In addition, V_{ni} depends on a set of A economic and attitudinal characteristics (socioeconomic variables) that characterize the respondent, denoted by $\mathbf{Z}_n = (z_{n1}, \ldots, z_{na}, \ldots, z_{nA})$.

We also introduce an alternative-specific constant (ASC) to value the preference for the *status quo*. We define the dummy variable ASC, which takes the value one in the *status quo* alternative and zero otherwise. A statistically significant positive coefficient η associated with the ASC dummy variable (see equation (2) below) indicates a preference for the *status quo* alternative.

[11] The RPL model further relaxes the IIA assumption (independence of irrelevant alternatives) (McFadden and Train, 2000).

The model is thus specified so that the utility of individual n in alternative i is a linear function of the attributes levels $\mathbf{X}_i$, the socioeconomic characteristics $\mathbf{Z}_n$, and the alternative specific constant (ASC) for the *status quo*:

$$U_{ni} = \left(\eta + \mathbf{Z}_n \boldsymbol{\alpha}^{ASC}\right) ASC + \mathbf{X}_i(\boldsymbol{\beta_n} + \boldsymbol{\alpha}\mathbf{Z}_n^\top) + \varepsilon_{ni}. \tag{2}$$

The vector $\boldsymbol{\alpha}^{ASC} = (\alpha_1^{ASC}, \ldots, \alpha_A^{ASC})^\top$ measures the effect of the socioeconomic characteristics on the *status quo* utility. The matrix $\boldsymbol{\alpha}$ of size (K, A) is composed of coefficients α_{ka}, capturing the cross-effect of socioeconomic characteristic a on attribute k. The coefficients quantifying the influence of the K attributes on utility are given by the column vector of coefficients $\boldsymbol{\beta_n} = (\beta_{n1}, \ldots, \beta_{nK})^\top$, which are specific to each respondent n.

Once coefficients are estimated, WTP can be determined by estimating the marginal rate of substitution between each non-monetary attribute and the monetary attribute (Louviere et al., 2000). The marginal utility of income is represented by the monetary attribute coefficient, β_{cost}. The WTP_k^l associated with attribute k and level l is $WTP_k^l = -\frac{\beta_k^l}{\beta_{cost}}$. This corresponds to the WTP to move from the *status quo* level of attribute k to level l. As commonly assumed in the literature (Hensher and Greene, 2003), the coefficient associated with the monetary attribute (β_{cost}) is considered to be constant. The other RPL parameters (random parameters β_k^l) are assumed to be normally distributed (500 Halton draws). We use the mixlogit Stata command (Hole, 2007b) and estimate WTP by bootstrap (Hole, 2007a). We take into account the panel structure of the data to estimate standard errors because each individual responds to 8 choice sets.

2.3 Sample data and descriptive statistics

2.3.1 Data collection

We conducted interviews with 540 respondents. We met with individuals on-site in the park (302 respondents) from July to August in 2016 and 2017 and collected responses online from August 2016 to July 2017 (238 respondents). For the on-site interviews, respondents were selected at the four cardinal points of the park, taking care to ensure that the sample was spatially calibrated. For the online interviews, a survey was implemented following advertisements in the local newspapers. We were careful to deliver identical information through both interview modes.[12]

The survey was organized into four parts. First, there was a 4-minute video presentation displaying general information about the study area, the primrose

[12] Previous works find that mixed-mode surveys are an efficient and satisfactory way to increase the sample size and representativeness of a survey (Dillman et al., 2009; de Leeuw and Hox, 2011; Nielsen, 2011; Van der Heide et al., 2008).

willow invasion and its impacts, and a detailed explanation of the choice sets with an emphasis on how colors translated into actual invasion densities (the script of this presentation is provided in the Appendix in section C)[13]. Second, there was a set of preliminary questions (e.g., reasons for visiting the park, frequency of the visits, awareness of the invasion). Third, there were the DCE choice sets. Fourth, there was a set of final questions on the socioeconomic characteristics of the respondents, their degree of understanding, their satisfaction regarding the survey, and the rationale for their choices if the *status quo* was chosen in all choice sets (to distinguish protest answers and zero-value answers). Overall, the survey required approximately 15 minutes to complete.

Before starting the video presentation, respondents were asked whether they lived in the subregion where the park is located. Respondents living in the area surrounding the park (i.e., subregion of *Loire-Atlantique*) were told that the primrose willow would be managed with a budget financed through an increase in residential and labor taxes. People living outside this area were informed that controlling the invasion would increase the tourist tax.[14] In both cases, the payment mode was very similar as it was an increase in a tax rate. The choice of the mode of payment was discussed in focus groups and seemed the most adequate for our case study.

During the choice experiment itself, each individual was presented with the 8 choice sets obtained from the experimental design (see sub-section 2.2.2).

Among the 540 respondents, 124 were excluded for not having answered all the choice sets. Of the remaining 416 respondents, 26 were excluded due to "protest answers", and 5 others due to lack of understanding. Respondents identified as providing "protest answers" are those who, while answering the *status quo* in all choice sets, explained their unwillingness to reveal their true preferences with specific reasons (e.g., it is not their responsibility to pay, anger against politics, anger against polluters, ...). Those answering the *status quo* in all choice sets but explaining this choice with reasons that show a real zero-WTP (e.g., no interest in preserving this zone) were left in the sample. We identified a lack of understanding based on an open-ended question that asked respondents who stated they were not satisfied with their answers to explain why. We excluded respondents who declared that they had difficulties understanding the study.

Some respondents completed the survey much faster than others (less than 2 minutes), which could indicate they did not reveal their true preference. Our re-

[13]Note that we were careful to emphasize the consequentiality of our study - that is the fact that respondents believe there is a nonzero probability that their answers actually influence decisions, which improves their incentives to answer truthfully (Johnston et al., 2017) - by specifying that the results would be communicated to the park managers to build their future management strategy.

[14]This tax is to be paid by clients at check-out in a hotel, in a campsite, etc. It is not generally included in the reservation quote but is announced in the terms.

sults remain unchanged when we exclude the top quartile of the speed-distribution, and we decided to retain these respondents in our preferred sample. Moreover, we tested the interaction of the decision time with the evaluation of the attributes, showing that decision time does not significantly affect respondents' valuation of attributes. Robustness checks were also done when removing 19 respondents who said that the explanations given at the beginning of the survey were not fully clear to them. Because removing these respondents did not impact the results of the model, we kept them in the sample.

The final sample used for data analysis comprised 385 respondents (272 face-to-face and 113 web respondents) and 9,240 observations (8 choice sets times 3 alternative options per choice set times 385 individuals).

2.3.2 Descriptive statistics

Tables 1 and 2 summarize the variability in respondents' general socioeconomic characteristics and their use of, and acquaintance with, the regional park and the marsh in particular. Variables used in the parametric regression are also introduced.

Table 1: Summary statistics

Variable	#Obs	Mean	SD	Min	Max
Do you live in *Loire-Atlantique*? (*LiveInTheRegion*: 1=Yes; 0=No)	385	0.69	0.46	0	1
Have you visited the park before? (*VisitBefore*: 1=Yes; 0=No)	374	0.83	0.37	0	1
I have visited the park before:					
because I live in the park (*LiveInThePark*: 1=Yes; 0=No)	385	0.37	0.48	0	1
because I work in the park (*Work*: 1=Yes; 0=No)	385	0.15	0.36	0	1
for hiking (*Hike*: 1=Yes; 0=No)	385	0.45	0.50	0	1
for boat rides (*Boat*: 1=Yes; 0=No)	385	0.27	0.45	0	1
for hunting (*Hunt*: 1=Yes; 0=No)	385	0.06	0.23	0	1
for fishing (*Fish*: 1=Yes; 0=No)	385	0.14	0.34	0	1
Did you know before that the primrose willow was an invasive alien species? (*KnowInvasive*: 1=Yes; 0=No)	385	0.65	0.48	0	1
Household size? (*Householdsize*)	361	2.4	1.2	0	7
Age (*Age*)	365	51.22	16.19	16	85
Do you visit the park at least once a year? (*HowOften*: 1=Yes; 0=No)	385	0.68	0.47	0	1

Table 2: Summary statistics (continued)

Variable	Freq.	%	Cumul.
How often do you visit the park? (*323 non-missing responses*)			
1=At least once a week	119	36.84	36.84
2=Every month	46	14.24	51.08
3=At least once a year	94	29.10	80.19
4=Less than once a year	62	19.20	99.38
5=Never	2	0.62	100.00
Household yearly income (*302 non-missing responses*)			
1=Less than 15,000 €	48	15.89	15.89
2=Between 15,001 and 25,000 €	98	32.45	48.34
3=Between 25,001 and 45000 €	113	37.42	85.76
4=More than 45,001 €	43	14.24	100.00
Education			
0=Strictly less than high school + 2 years	201	52.21	52.21
1=High school + 2 years or more	184	47.79	100.00
Gender (*374 non-missing responses*)			
0=Male	229	61.23	61.23
1=Female	145	38.77	100.00

Note that 69% of the interviewed population lives in the *Loire-Atlantique* subregion, and 83% had visited the park before. Only 65% of respondents were aware of the primrose willow invasion even though more than 80% of respondents visit the park at least once a year.

Tables 3 and 4 compare some socioeconomic characteristics of the sample respondents (as defined in Tables 1 and 2) with the French population and the population that lives in the subregion of *Loire-Atlantique*.[15]

Table 3: Representativeness of the sample with respect to socioeconomic characteristics

	Our sample	France[a]		*Loire-Atlantique*[b]	
	Mean	Mean	p-value[c]	Mean	p-value[c]
Household size	2.4	2.2	0.000	2.2	0.000
Age	51	49	0.009	48	0.000
Higher education	47.8%	30%	0.000	31.8%	0.000
Gender (% of female)	38.8%	48.9%	0.000	51.5%	0.000

[a] Data from INSEE (2017, 2018), the French national statistics institute.
[b] Data from INSEE (2017), the French national statistics institute.
[c] Significance of one-sample t-tests: test of equality of our sample's mean to mean at French and *Loire-Atlantique* levels.

[15] As almost 70% of our sample are respondents from *Loire-Atlantique*, we compare our sample not only with the whole French population but also with the population living in this region.

Table 4: Representativeness of the sample with respect to occupation

	Our sample	France[a]		*Loire-Atlantique*[b]	
	%	%	p-value[c]	%	p-value[c]
Farmer	3.8%	0.8%	0.000	0.7%	0.000
Craftsman, shopkeeper, business owner	12.6%	3.4%	0.000	3.3%	0.000
White collar professions	19%	9.6%	0.000	10.1%	0.000
Middle-level occupation	8.6%	13.8%	0.002	16.1%	0.000
Employee	17.7%	15.3%	0.315	15.9%	0.505
Worker	6.4%	11.8%	0.001	12.7%	0.000
Retiree	26.3%	32.5%	0.003	26.3%	0.706
Other without professional activity	5.6%	12.8%	0.000	14.8%	0.000

[a] Data from INSEE (2017, 2018), the French national statistics institute.
[b] Data from INSEE (2017), the French national statistics institute.
[c] Significance of one-sample proportion tests: test of equality of our sample's proportion to proportion at French and *Loire-Atlantique* levels

Our sample differs from the French population except for the proportion of employees and the *Loire-Atlantique* population except for the proportion of employees and retirees. In terms of magnitude, our sample shows a slight over-representation of males and high levels of education (typical of online surveys). Regarding occupation, we observe an over-representation of farmers, craftsmen/shopkeepers, and white-collar workers and an under-representation of middle-level professions and workers.

3 Results

Table 5 presents parameter estimates of the random parameter logit (RPL) models with the ASC. As explained in section 2.2.3, the ASC parameter can be interpreted as the respondents' variation in utility due to staying in the *status quo.* A negative coefficient parameter estimate associated with the *status quo* means respondents reject the no-policy option.

Three models are estimated. The first model does not include interaction variables (Model 1 in Table 5). The second model includes interactions with variables that account for the residential location of the respondents (Model 2 in Table 5, see subsection 3.2). The third model takes into account respondents' socioeconomic characteristics and stated recreational and professional use of the park (Table A1 in the Appendix, see subsection 3.3).

Table 5: Random Parameter Logit: attributes only (Model 1) and interactions with location of respondents (Model 2)

	Model 1		Model 2					
			Live in the Park		Live in the subregion		Log(Distance to Park)	
	Param. Coeff. (SE)	SD Coeff. (SE)	Param. Coeff. (SE)	SD Coeff. (SE)	Param. Coeff. (SE)	SD Coeff. (SE)	Param. Coeff. (SE)	SD Coeff. (SE)
ASC	-3.403***	5.325***	-3.794***	5.318***	-3.445***	5.276***	-4.148	5.111***
	(0.005)	(0.055)	(0.539)	(0.564)	(0.846)	(0.485)	(2.593)	(0.565)
x *Local*			0.969		-0.071		0.042	
			(0.680)		(0.903)		(0.229)	
area 1								
Medium	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Low	0.687***	0.916***	0.784***	0.913***	0.605***	0.884***	0.671	0.829***
	(0.096)	(0.127)	(0.123)	(0.127)	(0.165)	(0.126)	(0.603)	(0.145)
x *Local*			-0.079		0.132		0.006	
			(0.188)		(0.192)		(0.058)	
area 2								
High	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Medium	1.029***	0.009	0.981***	0.017	0.648***	0.032	2.325**	0.003
	(0.136)	(0.127)	(0.160)	(0.187)	(0.202)	(0.191)	(0.725)	(0.235)
x *Local*			0.052		0.522**		-0.118*	
			(0.212)		(0.221)		(0.068)	
Low	2.093***	0.552***	2.048***	0.561***	1.810***	0.529***	3.217***	0.490**
	(0.170)	(0.136)	(0.188)	(0.137)	(0.221)	(0.142)	(0.717)	(0.152)
x *Local*			0.093		0.384*		-0.099	
			(0.208)		(0.216)		(0.066)	
area 3								
High	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Medium	1.738***	0.054	1.580***	0.059	1.520***	0.008	2.395***	0.007
	(0.104)	(0.128)	(0.118)	(0.127)	(0.153)	(0.128)	(0.555)	(0.141)
x *Local*			0.439**		0.299*		-0.070	
			(0.170)		(0.169)		(0.052)	
Low	2.722***	1.058***	2.405***	1.044***	2.413***	1.003***	4.382***	0.895***
	(0.176)	(0.138)	(0.195)	(0.138)	(0.245)	(0.138)	(0.820)	(0.152)
x *Local*			0.930***		0.438*		-0.172**	
			(0.257)		(0.255)		(0.077)	
area 4								
Medium	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Low	0.665***	0.128	0.642***	1.044	0.492***	0.091	1.167*	0.319
	(0.092)	(0.345)	(0.115)	(0.138)	(0.153)	(0.487)	(0.587)	(0.295)
x *Local*			0.038		0.230		-0.041	
			(0.168)		(0.176)		(0.056)	
area 5								
Medium	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Low	0.332***	0.253	0.385***	0.254	0.396***	0.194	0.359	0.162
	(0.087)	(0.173)	(0.100)	(0.176)	(0.127)	(0.219)	(0.437)	(0.239)
x *Local*			-0.180		-0.088		0.002	
			(0.142)		(0.134)		(0.041)	
Tax	-0.062***		-0.063***		-0.062***		-0.064***	
	(0.005)		(0.005)		(0.005)		(0.006)	
Log L	-2238.3***		-2229.4***		-2232.2***		-1,784.8***	
AIC[a]	4510.553		4507.034		4514.205		3619.633	
BIC[a]	4631.785		4685.317		4692.487		3792.255	
#Obs.	9,240		9,240		9,240		7,368	
#Ind.	385		385		385		307	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; [a]: Akaike's Information Criterion and Bayesian Information Criterion;

3.1 Model without interactions

In the RPL model without interactions (Model 1 in Table 5), the estimated parameters are statistically significant and consistent with what we expected. Several standard deviation parameter estimates are also significant, hinting at preference heterogeneity among the respondents for the *status quo* and areas 1, 2, and 3. The ASC is significantly negative, indicating that respondents have, on average, a disutility associated with the *status quo* and favor implementing management strategies against the primrose willow invasion. However, the large and significant standard deviation parameter for the ASC indicates heterogeneity of preferences regarding the *status quo*: some respondents are strongly willing to pay to manage the invasion, whereas others are indifferent or unwilling to pay to improve the *status quo*.

Unsurprisingly, the parameter associated with the monetary attribute is negative: respondents' utility decreases as the tax increases, all else being equal. Parameters are significant and positive for the five areas, meaning that lowering the level of invasion increases respondents' utility for all five areas. However, comparing the same improvement with respect to invasion prevalence in different areas shows that respondents value some areas more. For instance, improving area 1's level of invasion from *Medium* invasion levels (Yellow) to *Low* invasion levels (Green) increases respondent's utility twice as much as the same improvement in area 5 (parameters 0.687 and 0.332, respectively). These results strongly suggest spatially differentiated preferences.

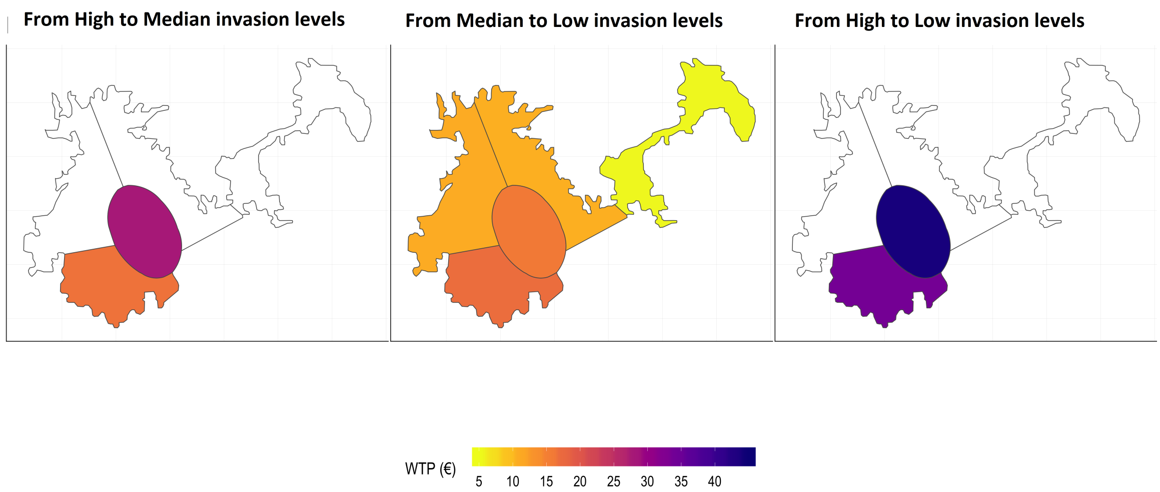
Table 6 presents the WTP derived from the estimates of the RPL without interactions, with confidence intervals computed by bootstrap (Hole, 2007a). As noted earlier, there is significant spatial heterogeneity in preferences. Focusing first on invasion level improvements from *Medium* to *Low* levels of invasion, the WTP is three times higher for areas 2 and 3 than area 5. On average, respondents are willing to pay approximately 5 € to maintain the primrose willow at a *Low* invasion level in area 5. They are willing to pay twice as much for the same objective in areas 1 and 4 (around 10 €) and three times as much in areas 2 and 3 (around 15 €). This heterogeneity of WTPs supports the hypothesis that central and southern areas are more valued, possibly because they are more frequented and important to support the economic and recreational activities of the park. Another explanation is that the central and southern areas (areas 2 and 3) are historically the first areas invaded. The invasion then spread to areas 1 and 4 and finally reached area 5. The central and southern areas are also the only ones likely to reach a *High* invasion levels in five years if no controls are put in place. As *High* invasion levels have critical impacts on use and non-use values, avoiding these impacts may explain the preference for invasion control in these two areas. Figure 4 shows the extent of WTP estimates in the different areas.

Table 6: Willingness to pay (€) and bootstrapped confidence intervals from the RPL without interactions (Model 1 in Table 5)

	WTP for improving the invasion level		
	from *High* to *Medium*	from *Medium* to *Low*	from *High* to *Low*
area 1		11.09 [8.30, 13.87]	
area 2	16.60 [12.69, 21.12]	17.16^a	33.76 [30.10, 38.48]
area 3	28.03 [23.12, 32.98]	15.86^a	43.89 [37.11, 50.02]
area 4		10.72 [8.04, 13.30]	
area 5		5.35 [3.68, 7.46]	

Note: (a) Difference between WTP for improvement from *High* level of invasion to *Low* level of invasion and WTP for improvement from *High* level of invasion to *Medium* level of invasion.

Figure 4: Average WTP for primrose willow management in different areas



As expected, the transition from *High* to *Low* invasion levels is always more valued than a transition from *High* to *Medium* invasion levels. Interestingly, the WTP to avoid *High* invasion levels is much higher for area 3 than it is for area 2. Respondents are reluctant to let the primrose willow reach critical levels, especially in area 3. This may be because area 3 is home to one of the park's major tourist villages, Saint-Joachim, which is the center of economic and recreational activities in the marsh. This village is home to the park office, multiple rowboat departures, and thatched buildings, typical of the historic houses of the marsh. The remainder of the data analysis focuses on explaining spatial heterogeneity by exploring the impact of respondents' residential location (section 3.2) and their socioeconomic characteristics and recreational/professional use of the marshland (section 3.3).

3.2 Heterogeneity analysis: residential location

To explore the role of the respondents' residential location on their spatial preferences, we interact each area (spatial attribute) with three spatial variables: (1) whether the respondent lives in the park, (2) whether the respondent lives in the subregion of *Loire-Atlantique*, and (3) how far from the park the respondent lives[16]. These three variables are used as proxies for being a local resident or not (this is why they are associated with the term *Local* in the first column of Table 5). The estimation results are provided on the right side of Table 5 (Model 2), and the WTP for areas in which the coefficient on the interaction variable is significant is presented in Table A2, Appendix B.

The principal impact of living in the park on WTP is for area 3. For this area, local residents are willing to pay 30 to 40% more to increase the control of the primrose willow (see Table A2).

Hence, a respondent living in the park is willing to pay 53 € $(38.22 + 14.78)$ for the prevalence of invasion in area 3 to decrease from a *High* invasion level to a *Low* invasion level. The average respondent is willing to pay 38 € for the same improvement (see Table A2 in the Appendix). When comparing the preferences of individuals who live inside and outside of the *Loire-Atlantique* subregion, results are similar and indicate a preference of individuals living in the subregion to control the invasion in areas 2 and 3. The WTP estimates for area 2 are 20% to 80% greater for the subregion residents compared with the mean respondent and about 20% greater for area 3 (see Table A2 in the Appendix).

Finally, we construct a third variable indicating the log of the distance from the centroid of the park to the centroid of the ZIP code of respondents' residences.

[16]We use a log specification for the distance to the park. There is little theoretical guidance regarding the specification of the distance variables (Concu, 2007), and we empirically explored several. The log specification was found as best performing in terms of AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion).

The city of *Saint-Joachim* is coded as the center of the park[17]. Goodness of fit parameters show that the model using this third proxy is the best-fitting model (smaller AIC and BIC). The model differs from the two previous models in that space is modeled as a continuous variable. In this third case, the *Local* variable measures the distance to the park, and the estimated parameters are negative. This means that the further away the respondents live from the park, the lower their WTP.

The respondents' place of residence still plays an important role in the assessment of areas 2 and 3, especially for improvements from a *High* to *Medium* level of invasion in area 2 and for improvements from a *High* to *Low* level of invasion in area 3. Consistent with the literature on distance decay and as mentioned previously, we find that the further away from the park respondents live, the less they value management. On average, for a 1% increase in distance to the park, respondents are willing to pay about 1.92 € less for moderate improvements in area 2 (*High* to *Medium* invasion levels) and about 2.72 € less for large improvements of area 3 (*High* to *Low* invasion levels) (see Table A2 in the appendix).

Moreover, contrary to the two previous models in which all the estimated parameters were significant, the model with the continuous distance variable shows that the parameters for areas 1 and 5 as well as the *ASC* are not significant. The contrasting results obtained when comparing the three models with three different distance indicators can be explained by the discrete versus continuous treatments of distance. This reflects complex relationships between respondents' residential location and their preferences, which can be explained by boundary effects (living inside versus outside the park or the subregion) and distance effects (living closer to or further away from the center of the park).

Taken together, interactions with the three different variables describing residential location indicate that local residents are globally willing to pay more than "outsiders" to improve the invasion situation, but mostly in area 3. These results can indicate that residents are probably more use-value oriented than non-residents, this preference for area 3 being justified by the fact that this area is home to *Saint Joachim*, a typical Brieron village and the center of the regional park's recreational activities. Distance is also an important variable in confirming the specific status of areas 2 and 3 and, in particular, the priority given to area 3 by respondents living close to the park.

[17] For the 307 individuals whose responses are used for the last column of model 2 in Table 5, the mean distance to the park is about 111.1 km (SD: 189.27). The first quartile is 7.4 km, the median is 18.3 km, and the third quartile is 132.5 km.

3.3 Heterogeneity analysis: respondents' characteristics and use of the park

In a third specification, we examine the interactions of the main parameters with various socioeconomic characteristics (age, gender, income, education) and variables associated with the activities that respondents typically engage in within the park (hiking, hunting, fishing, rowboat rides or work). These variables (*Age*, *Gender*, *Income*, *Education*, *HowOften*, *Hike*, *Hunt*, *Fish*, *Boat*, *Work*) are defined and described in Tables 1 and 2. In the interest of space, the detailed results from this enlarged model are shown in Appendix A, Table A1, where only significant estimated interaction parameters are reported.

Supporting the arguments that women may be more motivated by public good issues than men (e.g. Bruner et al., 2017), we observe that women are, on average, more averse to the *status quo* than men (i.e., more willing to implement management of the invasion), although this result is not confirmed in area 1.

Regarding the overall preference for preserving areas 2 and 3, two major results show up. The first is that working in the park is a key factor explaining preferences for preserving these areas. We speculate that, just like respondents living in the park, respondents working there are better aware of the importance of these areas for recreational and economic activities.

A second result is that preferences for invasion management in area 3 are stronger among respondents who visit the park often. Like residents of the park and people working in the park, respondents who come often prefer area 3, which may be explained by the fact that they are aware of the specificity and emblematic characteristics of this area. Parameter estimates also show that respondents who hike in the park value more area 2 than the average. Interestingly, these same respondents give area 3 a lower than average value, which is consistent with the fact that the main hiking trail circles the park and does not cross area 3.

4 Discussion and conclusion

As noted in the Summary for Decision Makers of the IPBES Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019), inclusive governance through the development and implementation of invasive alien species management with relevant stakeholders is essential to achieving sustainability goals. Assessing public preferences for invasive species management, including prioritizing sites, is a prerequisite for this goal. In this study, we develop an original discrete choice experiment to evaluate the spatial preferences of individuals regarding the management of an invasive alien species. The originality of the method is twofold: (1) it relies on a representation of different management options in the form of stylized geographical maps to assess respondents' preferences for the management of an invasion on different invaded sites, and (2) it incorporates distance decay modeling to estimate the influence of respondents' location on their preferences.

We assess public preferences for primrose willow management in the Brière Regional Park in France and obtain three main results relevant to decision making. The first result is strong spatial heterogeneity in preferences with, on average, areas in which respondents are willing to pay two to three times more than in other areas. We find that respondents are willing to pay annually from 5 € for the lowest-valued area to 17 € for the highest-valued area to reduce the invasive alien species from a medium to a low invasion level; they are willing to pay 17 € for the lowest-valued area and 28 € for the highest-valued area annually to reduce the invasive alien species from a high to a medium invasion level. We show that these preferences for spatially targeted management are highly significant among park residents and/or regular visitors and less so among respondents who live far away, favoring a more homogeneous management across space. The main implication of this result is that monitoring efforts should be targeted foremost in the central and southwest areas of the marshland at the expense of the other areas, particularly the eastern area. This is especially true when the preferences considered, and thus the stakeholders deemed relevant, are residents and regular park users who have unambiguous preferences for targeting control efforts in those areas and in the central area of the marshland in particular.

The second result is that WTP varies significantly across respondents according to their living locations and activities. The WTP of residents and regular users of the park is much higher than non-residents and occasional users. This result implies that the former are more concerned, which makes them legitimate and relevant stakeholders.

Finally, a third result concerns the monetary envelope allocated annually to management. Assuming that each tax household pays the minimum average WTP obtained in our study (5 €), this envelope amounts to about 283,000 € if the tax households are those of the residents of the park and 623,000 € if the tax households are those of the Saint-Nazaire metropolis. These amounts, which we estimate assuming the lowest WTP obtained in our study, are more than twice the average budget currently allocated in the first case and more than five times in the second. The main implication of this result is that it suggests an increase in management budgets or, at least, the organization of an audit to better survey the willingness to pay of taxpayers.

This work opens multiple research perspectives. The main one is to couple the analysis of relevant stakeholders' preferences with a joint analysis of the spatial heterogeneity of management costs and the spatial dynamics of the invasion. We showed in the study an unambiguous preference for invasion control in the central and southwestern areas of the marshland. But what if management is particularly costly in these areas, or if limiting the dynamics of spread requires management in other areas? Accounting for the spatial heterogeneity of management costs and the spatial dynamics of the invasion may counterbalance the results of our analysis, justifying a prioritization strategy that considers all three ingredients simultaneously.

Fundings

Financial support from INRA-ONEMA/AFB Convention 2016-2019 and ANR Green-Econ (ANR-16-CE03-0005) is acknowledged.

Acknowledgements

We kindly thank the Editor and the two anonymous reviewers of this manuscript. The article greatly benefited from helpful and detailed comments by Jean-Patrice Damien, David Finnof, Maxime Hourdé, Maureen Page, Alban Thomas, the seminar audiences of CEE-M 2019 (Montpellier, FR) BIO-ECON 2018 (Cambridge, UK), the JRSS 2018 (Nantes, France) and WONV 2017 (Leeds, UK). We are grateful to Lisa Chesnerie, Orianne Cormier, Annie Hofstetter, Maxime Hourdé, Jean-Marc Rousselle and Michael Tropé for their technical assistance. Finally, we would like to thank the Brière park management office for their hospitality and the time they gave us in this study.

Ethics declarations

The authors have no potential conflict of interest concerning the present study.

References

Adamowicz, W., Louviere, J., and Williams, M. Combining revealed and stated preference methods for valuing environmental amenities. Journal of Environmental Economics and Management, 26(3):271–292, 1994.

Adams, D. C., Bwenge, A. N., Lee, D. J., Larkin, S. L., and Alavalapati, J. R. Public preferences for controlling upland invasive plants in state parks: Application of a choice model. Forest Policy and Economics, 13(6):465 – 472, 2011.

Bliemer, M. C. and Rose, J. M. Serial Choice Conjoint Analysis for Estimating Discrete Choice Models. In Hess, S. and Daly, A., editors, Choice Modelling: The State-of-the-art and the State-of-practice, pages 137–161. Emerald Group Publishing Limited, jan 2010. ISBN 978-1-84950-773-8, 978-1-84950-772-1/.

Bliemer, M. C. and Rose, J. M. Experimental design influences on stated choice outputs: An empirical study in air travel choice. Transportation Research Part A: Policy and Practice, 45(1):63–79, 2011.

Bradshaw, C., Leroy, B., and Bellard, C. Massive yet grossly underestimated global costs of invasive insects. Nat Commun, 7(12989), 2016.

Brouwer, R., Martin-Ortega, J., and Berbel, J. Spatial preference heterogeneity: a choice experiment. Land Economics, 86(3):552–568, 2010.

Bruner, D. M., D'Attoma, J., and Steinmo, S. The role of gender in the provision of public goods through tax compliance. Journal of Behavioral and Experimental Economics, 71:45–55, 2017.

Burnett, K. M., Kaiser, B. A., and Roumasset, J. A. Invasive species control over space and time: Miconia calvescens on oahu, hawaii. Journal of Agricultural and Applied Economics, 39(s1):125–132, 2007.

Büyüktahtakin, İ. E. and Haight, R. G. A review of operations research models in invasive species management: state of the art, challenges, and future directions. Annals of Operations Research, 271(2):357–403, 2018.

Chakir, R., David, M., Gozlan, E., and Sangare, A. Valuing the impacts of an invasive biological control agent: A choice experiment on the asian ladybird in france. Journal of Agricultural Economics, 67(3):619–638, 2016.

ChoiceMetrics. Ngene 1.2 user manual and reference guide. ChoiceMetrics, January, 2018.

Concu, G. B. Investigating distance effects on environmental values: a choice modelling approach. Australian Journal of Agricultural and Resource Economics, 51 (2):175–194, 2007.

de Leeuw, E. and Hox, J. Internet surveys as part of a mixed mode design. In Das, M., Ester, P., and Kaczmirek, L., editors, Social and behavioral research and the Internet: Advances in applied methods and new research strategies. Routledge, Taylor and Francis Group, New York, 2011.

Diagne, C., Leroy, B., and Gozlan, R. Invacost, a public database of the economic costs of biological invasions worldwide. Sci Data, 7(277), 2020.

Dillman, D. A., Phelps, G., Tortora, R., Swift, K., Kohrell, J., Berck, J., and Messer, B. L. Response rate and measurement differences in mixed-mode surveys using mail, telephone, interactive voice response (ivr) and the internet. Social Science Research, 38(1):1–18, 2009.

Epanchin-Niell, R. S. Economics of invasive species policy and management. Biological Invasions, 19(11):3333–3354, 2017.

Epanchin-Niell, R. S. and Wilen, J. E. Optimal spatial control of biological invasions. Journal of Environmental Economics and Management, 63(2):260–270, 2012.

Epanchin-Niell, R. S., Haight, R. G., Berec, L., Kean, J. M., and Liebhold, A. M. Optimal surveillance and eradication of invasive species in heterogeneous landscapes. Ecology Letters, 15(8):803–812, 2012.

François II, D. d. B. Lettre patente du duc François II de Bretagne, datant du 8 Août 1461 [Letter], original copy of the 6 of may 1656, 1461.

Glenk, K., Johnston, R. J., Meyerhoff, J., and Sagebiel, J. Spatial Dimensions of Stated Preference Valuation in Environmental and Resource Economics: Methods, Trends and Challenges. Environmental and Resource Economics, 75(2): 215–242, 2020.

Greiner, R., Bliemer, M., and Ballweg, J. Design considerations of a choice experiment to estimate likely participation by north australian pastoralists in contractual biodiversity conservation. Journal of Choice Modelling, 10:34–45, 2014.

Hanley, N., Wright, R., and Koop, G. Modelling recreation demand using choice experiments: Climbing in scotland. Environmental and Resource Economics, 22 (3):449–466, 2002.

Hensher, D. A. and Greene, W. H. The Mixed Logit model: The state of practice. Transportation, 30(2):133–176, 2003.

Hole, A. R. A comparison of approaches to estimating confidence intervals for willingness to pay measures. Health Economics, 16(8):827–840, 2007a.

Hole, A. R. Fitting mixed logit models by using maximum simulated likelihood. The Stata Journal, 7(3):388–401, 2007b.

Hoyos, D. The state of the art of environmental valuation with discrete choice experiments. Ecological Economics, 69(8):1595 – 1603, 2010.

IPBES. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany, 2019.

Japelj, A., Kus Veenvliet, J., Malovrh, J., and et al. Public preferences for the management of different invasive alien forest taxa. Biol Invasions, 21:3349–3382, 2019.

Jardine, S. L. and Sanchirico, J. N. Estimating the cost of invasive species control. Journal of Environmental Economics and Management, 87(C):242–257, 2018.

Johnston, R., Boyle, K., Adamowicz, W., Bennett, J., Brouwer, R., Cameron, T., Hanemann, M., Hanley, N., Ryan, M., Scarpa, R., Tourangeau, R., and Vossler, C. Contemporary guidance for stated preference studies. Journal of the Association of Environmental and Resource Economists, 4(2):319–405, 2017.

Johnston, R. J., Swallow, S. K., and Bauer, D. M. Spatial factors and stated preference values for public goods: Considerations for rural land use. Land Economics, 78(4):481–500, 2002.

Louviere, J., Hensher, D., and Swait, J. Stated choice methods : analysis and applications. Cambridge University Press, 2000.

Manski, C. F. The structure of random utility models. Theory and Decision, 8(3): 229–254, 1977.

Martin-Ortega, J., Brouwer, R., Ojea, E., and Berbel, J. Benefit transfer and spatial heterogeneity of preferences for water quality improvements. Journal of Environmental Management, 106(15):22–29, 2012.

McFadden, D. Conditional logit analysis of qualitative choice behaviour. In Zarembka, P., editor, Frontiers in Econometrics, chapter 4, pages 105–142. Academic Press New York, New York, NY, USA, 1973.

McFadden, D. and Train, K. E. Mixed MNL models for discrete response. Journal of applied Econometrics, 15(5):447–470, 2000.

McGeoch, M. A., Genovesi, P., Bellingham, P. J., Costello, M. J., McGrannachan, C., and Sheppard, A. Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biological Invasions, 18(2):299–314, 2016.

Nielsen, J. Use of the internet for willingness-to-pay surveys. a comparison of face-to-face and web-based interviews. Resource and Energy Economics, 33(1): 119–129, 2011.

Paini, D. R., Sheppard, A. W., Cook, D. C., De Barro, P. J., Worner, S. P., and Thomas, M. B. Global threat to agriculture from invasive species. Proceedings of the National Academy of Sciences, 113(27):7575–7579, 2016.

Potapov, A. B. and Lewis, M. A. Allee Effect and Control of Lake System Invasion. Bulletin of Mathematical Biology, 70(5):1371–1397, 2008.

Rolfe, J. and Windle, J. Public preferences for controlling an invasive species in public and private spaces. Land Use Policy, 41:1 – 10, 2014.

Scalera, R. How much is Europe spending on invasive alien species? Biological Invasions, 12(1):173–177, jan 2010.

Sheremet, O., Healey, J. R., Quine, C. P., and Hanley, N. Public preferences and willingness to pay for forest disease control in the uk. Journal of Agricultural Economics, 68(3):781–800, 2017.

Street, D. J., Burgess, L., and Louviere, J. J. Quick and easy choice sets: Constructing optimal and nearly optimal stated choice experiments. International Journal of Research in Marketing, 22(4):459–470, 2005.

Subroy, V., Rogers, A. A., and Kragt, M. E. To bait or not to bait: A discrete choice experiment on public preferences for native wildlife and conservation management in western australia. Ecological Economics, 147:114 – 122, 2018.

Train, K. E. Discrete choice methods with simulation. Cambridge University Press, 2009.

Van der Heide, C. M., Van den Bergh, J. C., Van Ierland, E. C., and Nunes, P. Economic valuation of habitat defragmentation: A study of the veluwe, the netherlands. Ecological Economics, 67(2):205–216, 2008.

Appendix

A Impact of respondents' activities

Table A1: Random parameter logit with interactions with respondents' characteristics and activities

	Parameter coefficient (SE)	SD coefficient (SE)
ASC	-3.368*	4.773***
	(1.984)	(0.513)
x *Gender*	-1.694**	
	(0.834)	
area 1: Green	2.051***	0.856***
	(0.564)	(0.155)
x *Gender*	-0.419*	
	(0.232)	
x *Age*	-0.013*	
	(0.007)	
x *Education*	-0.410*	
	(0.245)	
x *Hike*	0.552**	
	(0.234)	
area 2: *Medium*	0.233	0.004
	(0.680)	(0.180)
x *Fish*	-0.802*	
	(0.413)	
x *Hike*	0.952***	
	(0.277)	
area 2: Green	1.134*	0.503***
	(0.651)	(0.177)
x *Hike*	0.449*	
	(0.266)	
x *Work*	0.622*	
	(0.357)	
area 3: *Medium*	1.095**	0.044
	(0.493)	(0.155)
x *Education*	0.474**	
	(0.221)	
x *HowOften*	0.718***	
	(0.218)	
x *Work*	0.498*	
	(0.284)	
area 3: Green	1.596**	1.106***
	(0.741)	(0.165)
x *HowOften*	1.389***	
	(0.335)	
x *Hike*	-0.792**	
	(0.317)	
x *Work*	0.741*	
	(0.420)	
area 4: Green	0.349	0.047
	(0.516)	(0.284)
area 5: Green	-0.607	0.143
	(0.374)	(0.214)
x *Income*	0.000**	
	(0.000)	
x *Hike*	0.355**	
	(0.162)	
x *Work*	0.684***	
	(0.223)	
Tax	-0.070***	
	(0.006)	
Log L	-1673.8***	
#Obs.	7,104	
#Ind.	296	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Only significant interaction effects are reported.

B Estimated willingness to pay for RPL models with interactions

Table A2: Estimated willingness to pay (€) and bootstrapped confidence intervals from the RPL with interactions (Model 2) in Table 5) - reported only for areas for which the parameters for the interaction variables are statistically significant

	WTP for improving the level of invasion	
	from *High* to *Medium*	from *High* to *Low*
Model 2: RPL with interaction variables: "Live in the Park"		
area 3	25.12	38.22
	$[20.12, 30.63]$	$[31.53, 46.24]$
x *Local*	6.98	14.78
	$[0.62, 12.93]$	$[4.74, 23.06]$
Model 2: RPL with interaction variables: "Live in the subregion"		
area 2	10.42	29.14
	$[2.81, 17.92]$	$[21.98, 36.78]$
x *Local*	8.40	6.18
	$[10.46, 17.46]$	$[-2.86, 15.46]$
area 3	24.46	38.85
	$[18.49, 31.01]$	$[30.61, 48.21]$
x *Local*	4.82	7.05
	$[-1.45, 11.29]$	$[-2.45, 16.65]$
Model 2: RPL with interaction variables: "Log(Distance to Park)"		
area 2	36.85	
	$[8.16, 65.53]$	
x *Local*	-1.92	
	$[-4.67, 0.83]$	
area 3		68.65
		$[41.32, 95.97]$
x *Local*		-2.72
		$[-5.62, 0.17]$

C Script of the DCE presentation

The presentation was made with the support of a PowerPoint dispaying illustrations. The presentation consisted of five main components : a description of the study, a description of the park and the invasion, a detailed presentation of the impacts of the primrose willow in the park, a description of the attributes and of the *status quo*, and the key objective of the study. The script is detailed below.

General presentation of the study

As part of a research project conducted by INRA in partnership with Onema and the Brière Regional Natural Park, you will be asked to answer a questionnaire on the management of the primrose willow invasion in the Briéron marshland. This will make it possible to set up management methods adapted to your preferences and in particular to your use of the Park. We will first introduce you to the issues related to the invasion of the marshland, then a series of questions will be asked to you. Note that your answer will be communicated to Park managers in order to design control strategies.

Description of the Park and the primrose willow invasion

The Park has an area of 55,000 ha, including 20,000 ha of wetlands (marshes, canals, etc.). 80,000 people live there and many activities are carried out in the park, such as tourism with rowboat rides and hiking and recreational activities such as waterfowl hunting or fishing. Finally, agriculture is an important economic activity in the marshland and consists mainly of cattle breeding. All these activities are threatened by the primrose willow, a water plant native from Latin America that has proliferated in the Park since the late 1990's.

On the images presented to you we observe from left to right a state of gradual flooding:

- On the left, the primrose willow starting to invade a canal.
- In the middle a canal blocked by the primrose willows, severely affecting navigability in the marsh and associated activities
- Finally, on the right, the canal and its banks are completely invaded, making it impossible to use the park for cattle breeding, hunting, fishing or tourism.
- Biodiversity is also at risk because where the primrose willow proliferates, most of the other species in the marsh disappear.

Impacts of the invasion

The invasion is located in the wetland and its contours, the primrose willow can only reproduce in very wet areas. We have divided this study area into 5 sub-areas of relatively similar size. The southeastern part of the wetland is excluded from the study because it is the subject of a salt experiment and no manual or mechanical controls will be carried out in the coming years.

Activities practiced in the five study areas are distinct:

- Tourism and in particular barge trips are practiced in the south-western area of the marsh and in the area surrounding Saint Joachim
- Fishing is practiced throughout the wetland and in particular around Saint Lyphard and Saint Joachim
- Waterfowl hunting is conducted on water bodies in the central and southern part of the marshes
- Finally, livestock farming is mainly found in the southern area of the marsh as well as in the eastern area, which is a less humid agricultural area.

Presentation of attributes and of the *status quo* situation

You can see on the left image the current invasion situation. The green color represents a low or non-existent level of flooding that does not harm users while the yellow color represents a level of fragmented invasion likely to hinder uses. Finally, the red color represents a drastic level of flooding that makes it very difficult to carry out agricultural or recreational activities . In the image on the right, you can see the so-called "*status quo*" map representing the state of invasion in 5 years if no management action is taken during this period.

Objective of the study

The objective of our study is to gather the preferences of the main users of the park of which you are a part. To do this, we will present you with a succession of choice cards representing management choices.
The choice cards look like this. Each time we have three management options that outline the state of the invasion in five years.

For local inhabitants : Each option corresponds to a management strategy and is likely to involve an additional cost added to the housing tax of the inhabitants of the 21 communes of the park.

For tourists : Each option corresponds to a management strategy and involves a cost to which park visitors are likely to contribute. The contribution could be financed in part by an increase in the tourist tax on accommodation and an increase in the rates for rowboat riding.

On the right we see the so-called *status quo* option, which describes the state of the park in 5 years if no action is taken. This option has no cost. We can note that Option A described here is a strategy to focus control efforts in the eastern part of the park. It encourages breeding and fishing activities in this area and allows a cost of 5 €, which will be added to your tax. The more ambitious Option B aims to deploy control efforts throughout the fleet. It makes it possible to maintain the state of invasion we are currently experiencing but is more expensive.

You will have to choose the option you prefer. Eight choice cards will be presented to you in succession. Each time you will have to choose 1 of the 3 management options proposed to you. The analysis of your choices will allow us to better understand your preferences and will be used to define the most appropriate management strategy for the next five years.

We thank you for your participation and start the questionnaire now with some general questions to get to know you better.