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Between complexity and unfamiliarity: preferences for soil-based ecosystem services

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Abstract

Soils provide multiple benefits for human well-being, which are largely invisible to most beneficiaries. Here, we present the results of a discrete choice experiment into the preferences of Germans for soil-based ecosystem services. To tackle complexity and unfamiliarity of soils, we express soil-based ecosystem service attributes relative to the site-specific potential of soils to provide them. We investigate how knowledge about soils, awareness of their contributions to human well-being and experience with droughts and floods affect the preferences. We find substantial yet heterogeneous preferences for soil-based ecosystem services. Only some measures of familiarity exhibit significant effects on preferences.

Keywords: Agriculture, Discrete choice experiment, Ecosystem services, Nonmarket valuation, Stated preferences, Soil functions, Willingness to pay

JEL classification: Q15, Q24, Q51, Q57

1 Introduction

Agricultural soil-based ecosystem services are challenging as a valuation object. Soils are a highly complex and multifunctional resource (Vogel et al., 2018). In addition to providing obvious private benefits, including biomass production and yield stability (Droste et al., 2020), soils also contribute to multiple public benefits such as climate regulation, clean drinking water, drought protection, flood protection, and biodiversity (Dominati et al., 2010; Pascual et al., 2015). Laypeople are generally neither well aware of their complexity nor of the trade-offs involved in sustainable soil management (Schröder et al., 2020; Schulte et al., 2019). This lack of familiarity and experience is likely to impede the formation of preferences for soil-based ecosystem services (Czajkowski et al., 2015; Lienhoop and Völker, 2016), making their elicitation challenging as compared to more familiar and "visible" ecosystem services (e.g.

Huber and Finger, 2020). Another important factor is the extraordinarily high spatial heterogeneity of soils (even at small scales, such as one arable field), which implies that soil in different locations can have very different characteristics, including their potential to provide soil-based ecosystem services (Vogel et al., 2019).

The majority of existing stated preference valuation studies of soils had a rather narrow focus with respect to soil-based ecosystem services (Bartkowski et al., 2020), particularly on climate regulation (Glenk and Colombo, 2011; Rodríguez-Entrena et al., 2012) and erosion control (Almansa et al., 2012; Colombo et al., 2006, 2005). Recent exceptions are Dimal and Jetten (2020), who included three soil-based ecosystem services (water storage capacity, erosion and sediment yield control, carbon sequestration capacity) in their discrete choice experiment, and Eusse-Villa et al. (2021) and Franceschinis et al. (2022), who incorporated four soil-based ecosystem services (carbon sequestration, earthworm density, rainfall water infiltration, nitrogen in groundwater) in theirs.

In this context, the contribution of the study presented in this article is twofold. First, it provides much needed insights into public preferences for multiple agricultural soil-based ecosystem services. Second, methodologically, we offer an alternative approach to dealing with soils' spatial heterogeneity, their complexity and respondents' unfamiliarity with this multidimensional public good. In our discrete choice experiment study, we build upon related work in soil science by Vogel et al. (2019) and express soil-based ecosystem service attributes relative to the site-specific potential of soils to provide them (for other index-based attribute approaches, see Johnston et al., 2011; Meyerhoff et al., 2015). We also investigate whether and how self-assessed knowledge about and previous consideration of soils' contributions to human well-being as well as experience-based salience of relevant events (droughts and floods) affect preferences for soil-based ecosystem services. To address these questions, we report on the results of an online discrete choice experiment conducted 2021 across Germany on a sample of 1500 respondents.

2 Methods

2.1 Study region

The focus of the study was on mineral soils in arable land in Germany. We excluded permanent grassland soils due to their substantially different characteristics, protection status and the opportunity costs associated with their protection (Schmitt et al., 2021). For similar reasons, we also excluded organic soils[1] (including peatlands), which have a low share in arable land and whose protection is favoured by a widespread political and societal consensus (Wüstemann et al., 2017). According to the Federal Statistical Office (destatis), 50.7 % of the area of Germany is used for agriculture, around two-thirds of which are classified as arable land. Even for mineral arable soils, the heterogeneity in terms of biogeochemical characteristics and the associated site-specific potential to provide soil-based ecosystem services is quite high (Vogel et al., 2019).

The current state of agricultural soil protection in Germany is deficient (Bartkowski et al., 2021). Soil organic carbon content, a common indicator of soil health, is expected to continue declining due to agricultural management and climate change (Riggers et al., 2021). Overall, the pressure on agricultural soil resources in Germany is high due to tillage practices, field traffic-related compaction, unbalanced nutrient inputs, short crop rotations and pollution (e.g. pesticides); in the absence of a substantial policy shift this will likely remain so (Techen and Helming, 2017).

2.2 Discrete choice experiments

In order to properly take into account the multifunctionality of soils and the trade-offs among soil-based ecosystem services, we conducted a discrete choice experiment. Discrete choice experiments are a survey-based approach in which respondents are asked to indicate their preferences for hypothetical scenarios, in this case soil management scenarios and associated different levels of soil-based ecosystem services. Each scenario is described by attributes (ecosystem services) and attribute levels (varying intensity of ecosystem service provision), following Lancasterian consumer theory (Lancaster, 1966). The attribute levels vary between the options. Normally, one of the attributes is a monetary one that attaches a price to each alternative option. This monetary attribute plays a central role in the analysis of respondents' marginal willingness to pay (WTP) for the other attributes (Hensher et al., 2005; Louviere et al., 2000). The econometric modelling of choice experiments results is based on Random Utility Theory (Marschak, 1960; McFadden, 1974). Details of the study design and econometric approach of this study are described further below.

2.2.1 Attribute selection

Due to the pandemic-related restrictions at the time of our study, it was not possible to conduct focus groups to inform the attribute selection, as is usually suggested in stated preference guidelines (Johnston et al., 2017). Given this, the attributes were selected based on literature

[1] According to the European Commission, organic soils are defined as soils with more than 20% carbon content in dry weight (EC, 2021).

and expert opinion. The starting point were the five main soil functions (Helming et al., 2018; Vogel et al., 2018): biomass production, nutrient cycling, water storage, carbon storage and habitat for biodiversity. A large number of ecosystem services can be linked to these soil functions, and an even larger number is affected by soil management (Bartkowski et al., 2020; Paul et al., 2021). Therefore, we decided to focus on ecosystem services that (i) could be directly linked to soil functions, (ii) are likely to be relevant for large parts of the German population, (iii) can be defined and measured in a clear and understandable way. Biomass production was excluded as a private good; habitat for biodiversity was excluded due to the large challenges associated with its definition and measurement (Vogel et al., 2019; see also Bartkowski, 2017; Pascual et al., 2015). Based on iterative consultations with soil scientists from the BonaRes project, in which the study was embedded, the following ecosystem services were identified as suitable attributes for the discrete choice experiment: climate regulation, flood protection, drought protection, and provision of clean drinking water. Figure 1 shows a diagram that was used to explain these ecosystem services to the survey respondents.

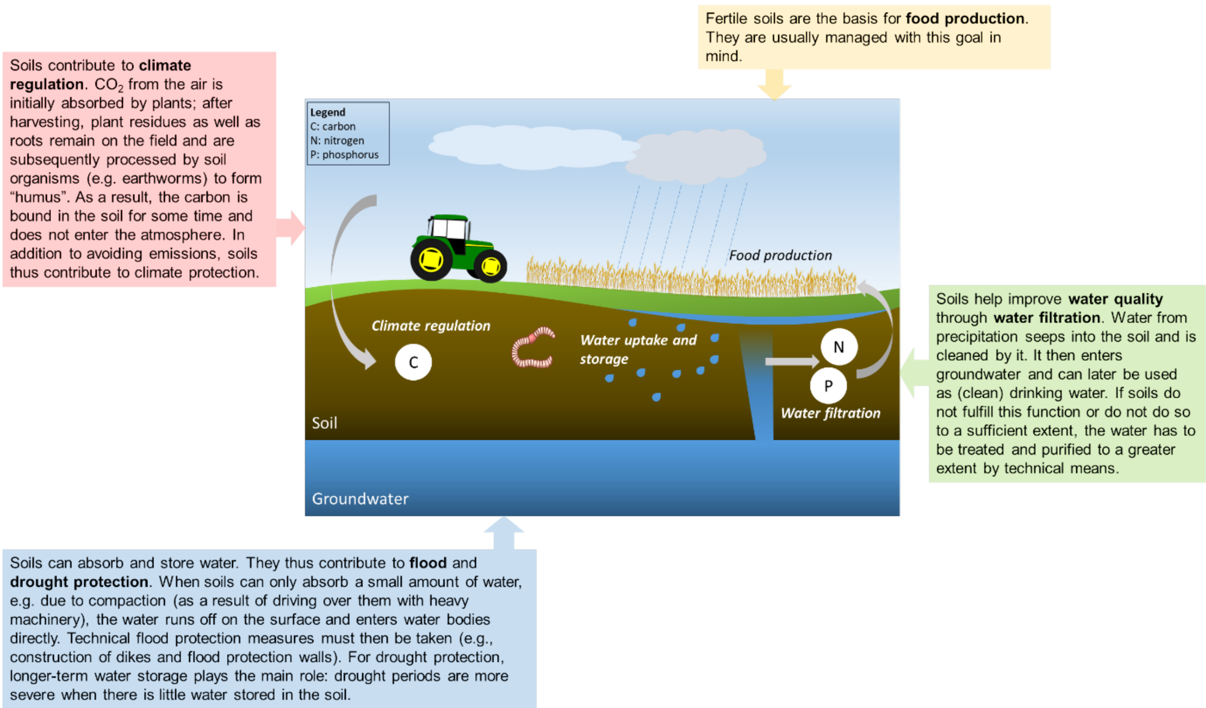

Figure 1 Description of soil-based ecosystem services as used in the survey

Following similar studies conducted in Germany (Lienhoop and Völker, 2016; Rajmis et al., 2009; Schaak and Musshoff, 2020), an increase in annual household expenditures due to taxes needed to finance additional agri-environmental payment schemes as well as due to increases in food prices was used as payment vehicle.

2.2.2 Attribute levels and the definition of the status quo

In order to account for the spatial heterogeneity of soils and the likely unfamiliarity of respondents with agricultural soils, the attribute levels were expressed in relative terms – how much of a given ecosystem service is provided compared to the maximum site-specific potential provision possible (given optimal management). This approach is inspired by the biophysical soil function evaluation approach suggested by Vogel et al. (2019). Unfortunately, currently no spatially explicit data on the status quo provision of soil functions/soil-based ecosystem services is available. Because of this, it was not possible to generate status quo values for each respondent's location. We therefore defined the attributes for a "representative" German agricultural soil. In order to allow survey respondents to develop concrete preferences for changes in the ecosystem services described in such a way, we provided information about the maximum potential for such a representative German agricultural soil in the questionnaire (Table 1).

Table 1 Explanations of maximum potential for each soil-based ecosystem service for a representative German soil

Attribute	**Maximum potential**	**Explanation and sources**
Climate regulation	0.5 Mg C ha^{-1} yr^{-1}, i.e. equivalent of a weekly car drive of 250 km	Mean C sequestration rates of cover crops and optimal crop rotations OR organic farming OR agroforestry (Wiesmeier et al., 2020), combined with mean CO2 emissions of new cars in Germany in 2019 (http://co2cars.apps.eea.europa.eu/)
Flood protection	Infiltration of more than half of an extreme rain event	Infiltration rates on arable land (experiment in Mulde/Saxony) from Wahren et al. (2009) at 33–60% (high to low pre-event soil moisture) given a 45 mm 2 h^{-1} (1 in 25 years) rainfall event
Drought protection	Temporary storage of half of typical annual precipitation	Assuming field capacity of 25% in a 1.5 m soil profile (Ulrich Weller, personal communication) and mean yearly precipitation (1991–2020) in Germany of 791 mm (DWD, 2021)
Clean drinking water	10% reductions in nutrient load with appropriate soil management	4–10% reductions in N, P, NO_3-N and sediment load achievable through changes in tillage and crop rotations for Schleswig-Holstein (Lam et al., 2011)

The status quo was defined based on expert opinion of soil scientists from the BonaRes project: for a representative German agricultural soil, it was set at 50% for climate regulation, 70% for each flood protection and drought protection, and 30% for clean drinking water. Based on these values, a set of evenly distributed levels for the other alternatives were defined (Table 2).[2] The attribute levels for the price attribute were defined based on similar studies conducted in Germany (Lienhoop and Völker, 2016; Meyerhoff et al., 2015; Wätzold et al., 2008). To support the interpretation of the relative values of attribute levels, we used pictograms (see example choice card in Figure 2).

Table 2 Attribute levels

Attribute	SQ level	Levels
Climate regulation	50%	75%, 100%
Flood protection	70%	80%, 90%, 100%
Drought protection	70%	80%, 90%, 100%
Clean drinking water	30%	50%, 75%, 100%
Increase in household expenditure per year	0€	25€, 50€, 75€, 100€, 125€, 150€

Figure 2 Example of a choice card as used in the online survey

[2] Given the status quo level for clean drinking water, perfectly even distribution of levels including 100% was not possible.

2.2.3 Experimental design

The experimental design was generated with the help of the Ngene software, version 1.2.1 (Rose et al., 2018). Given the large number of attribute combinations (a full factorial would have consisted of 324 distinct alternatives), we generated a Bayesian D-efficient design (Scarpa and Rose, 2008) with eight two-alternative choice sets per respondent (the status quo option was added to each choice set afterwards). For the pretest (see section 2.2.3 below), minimal priors close to zero were set for all coefficients to create eight two-alternative choice sets, and a modified Fedorov algorithm (Cook and Nachtrheim, 1980) was used. For the main survey, we used coefficient estimates from the pretest as priors.[3] To increase the efficiency of the design in the main survey, we generated 30 blocks, which were randomly assigned to respondents. To each block, a constant choice set was added to allow for validation of simulation results, which resulted in nine choice sets per individual in the final design (the constant choice set was selected from the pretest design). For the main design, the modified Fedorov algorithm was used as well.

2.2.4 Pretest

The pretest was conducted in June 2021 on a non-representative sample of 50 respondents. The pretest had two main purposes: (i) to test the comprehensiveness, complexity and comprehensibility of the survey (measured by means of an open question at the end); and (ii) to provide priors to be used in generation of the experimental design for the main study. Based on the positive responses in the open question, no substantial changes to the survey were necessary.

2.2.5 Econometric modelling

In line with basic Random Utility Theory (McFadden, 1974), we assume that respondent *n* in our choice experiment selects alternative *i* from choice set *S* if and only if she derives a higher utility from the chosen alternative than from the other alternatives in the choice set (*j*):

$$U_{ni} > U_{nj}, \forall j \neq i \text{ and } i, j \in S$$

with

$$U_{ni} = V_{ni} + e_{ni} = \beta_n x_{ni} + e_{ni}$$

[3] All data including questionnaire instruments are available from the BonaRes repository: https://doi.org/10.20387/bonares-77fb-p034; code and pretest data are available at https://github.com/BartoszBartk/soil-ce.

where V is the observable utility component, e is the unobservable random utility component, x is the vector of observed characteristics of the alternative (attributes), β is the vector of attribute coefficients. Furthermore, we assume that the coefficients of the ecosystem services attributes vary across individuals and can be explained by co-variates:

$$\beta_{nk} = \beta_k + \pi_k z_n + \sigma_k \varepsilon_{kn}$$

where β_{nk} is the individual-specific coefficient of attribute k for individual n, β_k is the constant part of the coefficient, π_k is the vector of coefficients of individual characteristics z_n, σ_k is the constant component of the error term, while ε_{kn} is its individual-specific component. We assume normal distribution of the random parameters for all ecosystem services attributes and a lognormal distribution for the (negative of the) price parameter.

Based on this, we estimated three mixed logit models (McFadden and Train, 2000), all based on maximum likelihood simulation with 1000 Sobol draws – one without, one with interactions between the random parameters and selected individual-specific variables (related to experience and familiarity with the ecosystem services), as well as one with interactions between the alternative-specific constant of the status-quo alternative and another set of individual-specific (mainly socio-demographic) variables. To derive marginal willingness to pay (WTP) estimates, we additionally estimated the simple mixed logit model without interactions in WTP space (Scarpa et al., 2008).

All analyses were conducted in the statistical programming language R, version 4.0.5 (R Core Team, 2020), using the package 'apollo' (Hess and Palma, 2019) as well as 'ggplot2' (Wickham, 2016) and 'HH' (Heiberger, 2020) for graphics.

2.3 Survey administration and sample

The survey was implemented online by a subcontracted company, Innofact AG (https://innofact-marktforschung.de/), using an existing internet panel. In addition to the choice experiment itself, the survey included a battery of auxiliary questions designed to better understand the respondents' choices. The full questionnaire can be found in the BonaRes Repository. In this article, we focus on questions related to the respondents' experience with the analyzed soil-based ecosystem services. Variables included in the analyses are presented in Table 3.

Table 3 Description of variables used in the analysis

Variable	Description	Coding
age	Respondents' age	Continuous
gender	Respondents' gender	0 = male 1 = female 2 = diverse
abi	Highest educational attainment	binary 0 = below Abitur 1 = Abitur or higher
income	Monthly net household income (calculated based on a 7-category scale)	Continuous
member	Membership in environmental association	0 = no 1 = yes
donation	Donations to environmental associations/organizations in last 12 months	0 = no 1 = yes
urban	Urban/rural residence based on postcode	0 = rural 1 = urban
no_ag	Neither respondent nor a family member active in farming or livestock husbandry	0 = no 1 = yes
awareness	Frequency of thinking about the importance of soils for own well-being	5-point scale 5 = very often 4 = rather often 3 = sometimes 2 = rather seldom 1 = not at all
knowledge	Self-assessed knowledge about condition of soils in respondent's region	5-point scale 5 = no knowledge 4 = little knowledge 3 = average knowledge 2 = much knowledge 1 = expert knowledge
exp_drought	Respondent, family or friends directly affected by drought	4-point scale 3 = within last 5 years 2 = within last 6–10 years 1 = longer ago than 10 years 0 = never
exp_flood	Respondent, family or friends directly affected by flood	4-point scale 3 = within last 5 years 2 = within last 6–10 years 1 = longer ago than 10 years 0 = never

The target sample of the survey was 1500 respondents from across Germany. Representativeness quotas were required for gender, age, education and location of residence (at federal states, i.e. NUTS2 level as well as in urban and rural areas; identified via postal codes).

3 Results

The main study was conducted in late June and early July 2021 on a representative sample of 1500 respondents. 19 respondents were excluded as protest votes. To be interpreted as protest votes, three criteria needed to be fulfilled: (i) status quo alternative chosen in all nine choice sets; (ii) response time for each choice set (except the first) below the lowest median response time for any choice set (10 s); (iii) "Very high" choice experiment decision influence score for at least one among five questions related to the payment scenario (Items 1–5, Q10 in questionnaire). The final sample analysed here was therefore 1481 respondents.

3.1 Descriptive statistics

Table 4 provides the summary statistics of the sample.

Table 4 Basic sample characterizing statistics

Variable	Sample
Age	
Mean	44.6
Median	46.0
Gender	
Female	732 (49%)
Male	744 (50%)
Diverse	5 (0%)
Residence	
Urban	1210 (82%)
Rural	271 (18%)
Education	
Below Abitur	966 (65%)
Abitur or equivalent	308 (21%)
Higher education	207 (14%)
Household monthly income	
Below 1000€	165 (11%)
1000–1500€	196 (13%)
1500–2000€	210 (14%)
2000–2500€	227 (15%)
2500–3500€	303 (20%)
3500–5000€	263 (18%)
Above 5000€	117 (8%)
Environmental organizations	
Members	153 (10%)
Donated last 12 months	354 (24%)
Activity in agriculture (self or close others)	
Farming	173 (12%)
Animal husbandry	109 (7%)

3.2 Auxiliary questions

In order to shed light on the unfamiliarity of respondents regarding the importance of soils, we asked questions related to respondents' knowledge about and attitudes towards soils. These questions also served as preparation to the choice experiment part of the survey. Figure 3 shows the distribution of responses to scale-based questions about the awareness of soils' importance for one's own well-being (left panel) and about the self-assessed knowledge about the state of soils in one's region (right panel). The Pearson correlation between the two is 0.581, meaning that respondents who have thought about the importance of soils for their own well-being also tend to have a higher degree of knowledge about soils in their region.

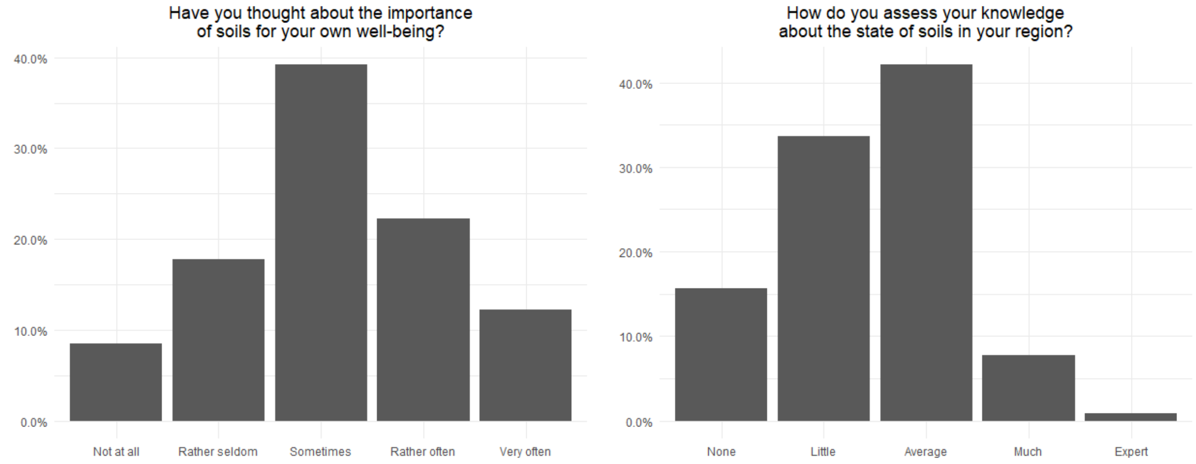

Figure 3 Awareness of importance of soils for well-being and knowledge about state of soils in the region

Furthermore, after the choice experiment, respondents were asked about their experience with floods and droughts (measured as respondents or their friends or family members being affected by either) in order to capture the influence of (the salience of) these experiences on the preferences for the respective soil-based ecosystem services (Figure 4).

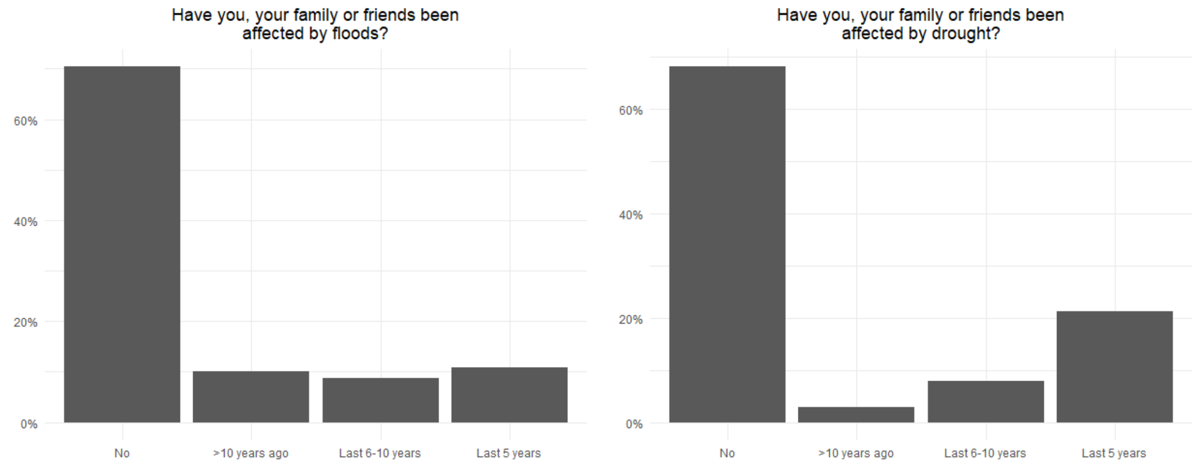

Figure 4 Experience with floods and drought

Note that the study was conducted following three consecutive heavy drought years in Germany (2018, 2019, 2020) (de Brito et al., 2020), but shortly before a series of extreme-rainfall related floods in western and southern Germany in late July 2021. For both floods and drought, about 2/3 of all respondents did not report having been affected directly (themselves or family or friends). However, ca. 45 % of the sample have been affected by at least one of both; 17 % have been affected by both flood and drought. The correlation between the two experience variables is 0.296, suggesting an intermediate level of "double exposure" to these extreme weather events (Ward et al., 2020).

Lastly, to activate respondents' thinking about the importance of soil-based ecosystem services (i) against other ecosystem services provided by agricultural landscapes, (ii) for society, (iii) and for themselves, respondents were asked before the choice experiment to indicate their preferences on a five-point scale. The results can be seen in Figures 5 and 6.

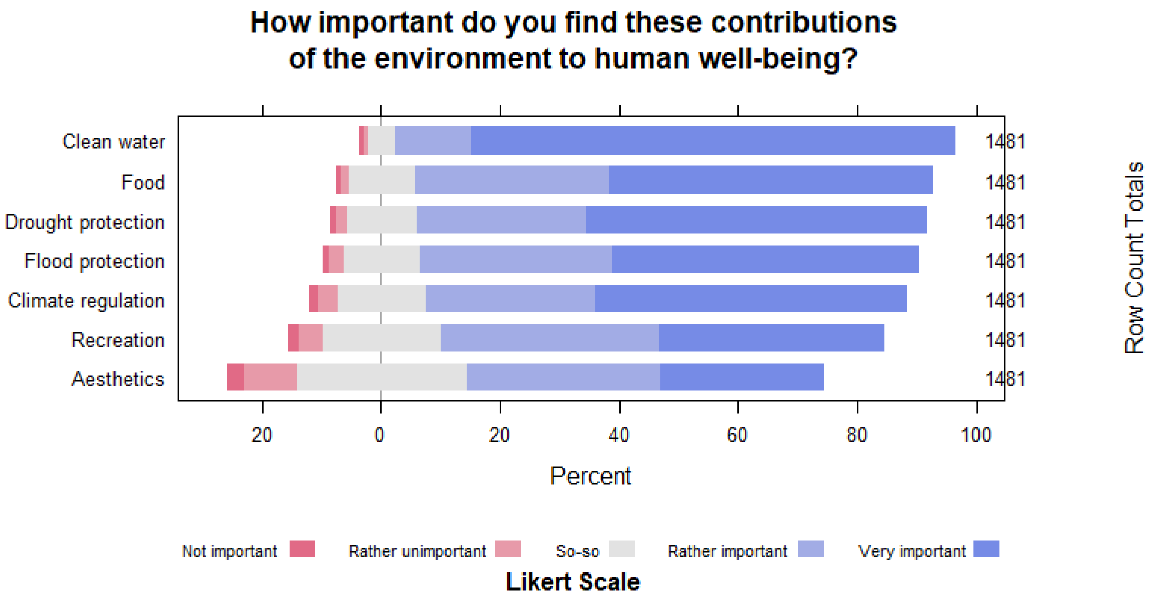

Figure 5 Importance of ecosystem services provided by agricultural landscapes

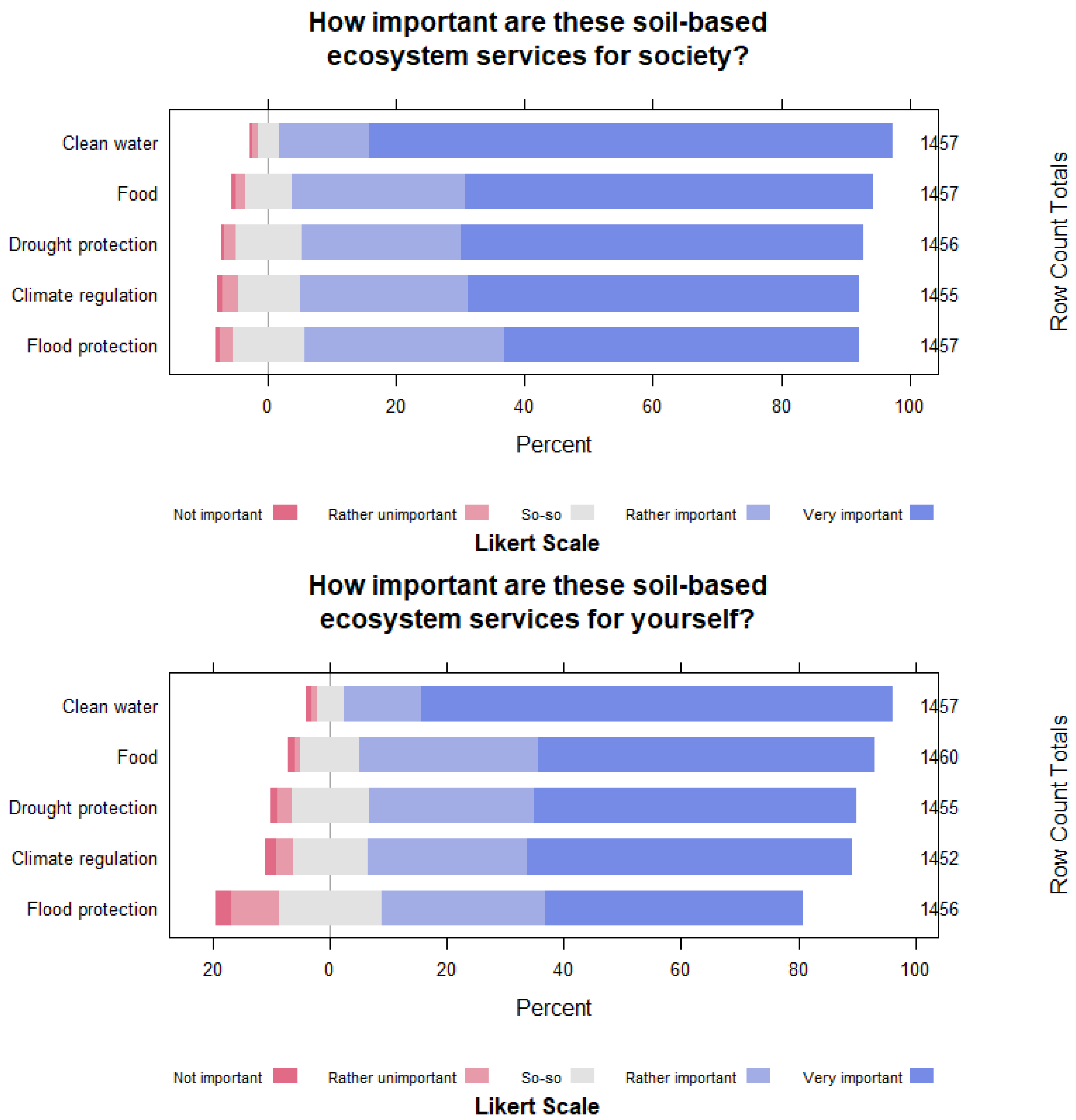

Figure 6 Perception of importance of soil-based ecosystem services in agricultural landscapes for society and for oneself

All three questions led to similar rankings of soil-based ecosystem services. The two non-soil ecosystem services in the general question (recreation and aesthetics) scored lowest. The main difference at the aggregate level is the shift in the relative ranking of climate regulation and flood protection when scored in a general framing versus when scored in the explicit context of soils. However, at the individual level, the correlation between the importance scores from the perspective of society vs. from own perspective is less strong then suggested by the aggregate scores (Table 5), which implies that many respondents perceive the importance of individual soil-based ecosystem services for themselves and for society at large differently.

Table 5 Correlation between ecosystem service importance scores for society and for oneself

Ecosystem service	Pearson correlation coefficient
Clean water	0.645
Food production	0.672
Drought protection	0.664
Flood protection	0.544
Climate regulation	0.696

Furthermore, we examined the correlation between perceived importance of soil-based ecosystem services for oneself and for society with the self-assessed knowledge about soils as well as general awareness of their importance for human well-being. In all cases, the correlation was also significantly positive, but rather weak (0.320 for knowledge and importance for society, 0.176 for knowledge and importance for oneself, 0.244 for awareness and importance for society, 0.096 for awareness and importance for oneself).

3.3 Choice modelling

The results of the estimated models can be found in Table 6. We started by estimating a simple multinomial logit model. Mixed Logit 1 includes only random attribute parameters. Mixed Logit 2 additionally includes interactions between the ecosystem services attributes and selected individual-specific variables related to respondents' experience agriculture, soils as well as with droughts and floods. Mixed Logit 3 includes interactions between the status-quo choice and a somewhat broader set of individual-specific variables. For readability, we refrain from reporting confidence intervals or the exact p-values.

Table 6 Model results

	Multinomial Logit *Coefficient (std. error)*	**Mixed Logit 1** *Coefficient (std. error)*	**Mixed Logit 2** *Coefficient (std. error)*	**Mixed Logit 3** *Coefficient (std. error)*
ASC_2	-0.020 (0.021)	0.002 (0.026)	-0.024 (0.027)	-0.000 (0.026)
ASC_3 *(SQ)*	-0.419 (0.071)***	-2.927 (0.125)***	-2.985 (0.126)***	0.647 (0.513)**
Preference parameters				
drought	0.006 (0.002)***	0.015 (0.002)***	-0.016 (0.010)	0.014 (0.002)***
flood	0.002 (0.001)+	0.010 (0.002)***	-0.004 (0.009)	0.010 (0.002)***
climate	0.009 (0.001)***	0.020 (0.001)***	-0.008 (0.007)	0.019 (0.001)***
water	0.024 (0.001)***	0.041 (0.002)***	0.014 (0.008)*	0.040 (0.002)***
price	-0.010 (0.000)***	-4.412 (0.067)***	-3.390 (0.098)***	-4.418 (0.067)***
Distributions of random parameters				
sd.drought		0.018 (0.003)***	0.022 (0.003)***	0.016 (0.003)***
sd.flood		0.010 (0.003)***	0.012 (0.003)***	0.008 (0.003)**
sd.climate		0.017 (0.002)***	0.018 (0.002)***	0.014 (0.002)***
sd.water		0.040 (0.002)***	0.047 (0.002)***	0.039 (0.002)***
sd.price		1.772 (0.081)***	0.880 (0.090)***	1.789 (0.064)***
Interactions				
drought : exp_drought			0.003 (0.002)*	
drought : awareness			0.004 (0.002)*	
drought : knowledge			-0.001 (0.003)	
drought : urban			0.002 (0.005)	
drought : no_ag			0.019 (0.005)***	
flood : exp_flood			-0.001 (0.002)	
flood : awareness			0.002 (0.002)	
flood : knowledge			0.002 (0.003)	
flood : urban			0.007 (0.005)+	

flood : no_ag			-0.002 (0.005)	
climate : awareness			0.003 (0.001)*	
climate : knowledge			0.001 (0.002)	
climate : urban			0.002 (0.003)	
climate : no_ag			0.017 (0.004)***	
water : awareness			0.006 (0.002)**	
water : knowledge			-0.002 (0.002)	
water : urban			-0.002 (0.004)	
water : no_ag			0.020 (0.004)***	
price : awareness			0.003 (0.001)***	
price : knowledge			0.002 (0.001)**	
price : urban			0.002 (0.002)	
price : no_ag			-0.002 (0.002)	
ASQ_3:				
:gender				-0.466 (0.179)**
:age				-0.032 (0.006)***
:urban				-0.132 (0.236)
:abi				-0.493 (0.222)*
:income				-0.000 (0.000)***
:awareness				-0.225 (0.099)*
:knowledge				-0.008 (0.119)
:no_ag				-0.512 (0.237)*
:donation				0.243 (0.249)
:member				0.023 (0.309)
N (observations)	13329	13329	13329	13329
N (respondents)	1481	1481	1481	1481
AIC	24171.0	17737.3	17531.8	17670.7
BIC	24223.5	17827.2	17786.7	17835.7
Log-likelihood	-12078.52	-8856.64	-8731.9	-8813.36
Significance codes: ‘***’: p < 0.001; ‘**’: p < 0.01; ‘*’: p < 0.05; ‘+’: p < 0.1				

The goodness-of-fit measures indicate a strong increase in the model fit between the multinomial logit and both mixed logit models, implying that there is indeed a large preference heterogeneity. Therefore, we focus on the mixed logit models in the following. Interestingly, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) are in disagreement with respect to the relative fit of the three mixed logit models. Overall, the inclusion of interactions does not seem to improve model performance substantially. In the model without interactions, all five choice experiment attributes are highly significant and have the expected signs. The same holds for their standard deviations as a measure of preference heterogeneity.

In the model with interactions with random parameters of the attributes, only the water quality and price attributes remain significant according to the usual cut-off levels. However, the standard deviations remain highly significant. As for the interactions, which explain the heterogeneity in the random parameters, only few are significant. Somewhat surprisingly, no relationship to agriculture (*no_ag*) has a positive influence on the preferences for drought protection, climate regulation and clean water provision. Living in an urban area only has a very weak effect on the preferences for flood protection. Self-assessed *awareness* of the importance of soils for human well-being has a positive interaction with the preferences for drought protection, climate regulation and clean water provision. Self-assessed *knowledge* about agricultural soils does not have a significant effect on the preferences for any of the ecosystem services. Surprisingly, experience with floods does not affect the preferences for the corresponding ecosystem service attribute, while experience with droughts does affect preferences for drought protection in the expected positive way.

The third mixed logit model, which uses interactions with individual-specific variables to explain the tendency to status-quo choices, follows the no-interactions model closely in terms of preference coefficients and their standard deviations. Regarding the factors that influence a tendency to choose the status-quo alternative, four of the included interactions have been found to be insignificant: living in an area identified as urban; self-assessed knowledge about agricultural soils in one’s region; donating to environmental organizations; and membership in an environmental organization. Conversely, the tendency to choose the status-quo alternative is significantly lower for: female repondents; older respondents; respondents with relatively higher formal education; respondents with a higher self-assessed awareness of the importance of soils for human well-being; respondents with higher incomes; and respondents with no direct relationship to agriculture.

Table 7 reports the marginal WTP estimates from the model in WTP space.

Table 7 Marginal WTP estimates for soil-based ecosystem services from mixed logit in WTP space

	Marginal WTP in € p.a. ***(std. error)***
drought	0.65 (0.10)
flood	0.58 (0.10)
climate	0.75 (0.06)
water	2.16 (0.08)

Note that the marginal WTP is per percentage point increase in the provision of a given soil-based ecosystem service relative to maximum potential provision. As such, the WTPs are directly comparable across ecosystem services. WTP is highest for increases in clean water provision and lowest for flood protection. These results imply that the household WTP for a hypothetical increase from status quo (70% realized potential for drought protection, 70% realized potential for flood protection, 50% realized potential for climate regulation and 30% realized potential for clean water) to 90% realized potential for all four soil-based ecosystem services[4] is 184.20 € per year.

4 Discussion

The main objective of the present study has been to explore the importance of ecosystem service enhancement in terms of public preferences using a choice experiment in Germany. Since soil-based ecosystem services are a particularly challenging valuation object due to their complexity, unfamiliarity and heterogeneity across scales, we further explored the influence of respondents' knowledge and experience on preferences as well as determinants of a general preference for improvements in the selected ecosystem services.

More than 70% of respondents regard the provision of soil-based ecosystem services as important for themselves or society (see Figure 5). The choice experiment underlines this finding: in around 87% of cases, respondents were willing to trade off an increase in household expenditures for increases in the provision of soil-based ecosystem services. These findings show a strong preference for (public support of) agricultural management that enhances ecosystem service provision.

Both the price attribute and the non-monetary attributes (i.e. flood, drought and climate protection and water quality) affect the choice of non-status quo management scenarios.

[4] Given trade-offs among the ecosystem services, an increase to 100 % across the board is highly unlikely.

Although all four ecosystem services have a significant influence on choice, water quality seems to be particularly relevant to respondents (see coefficient in the mixed logit results and marginal WTP estimate). This is interesting insofar as water quality improvements are actually considered the "weakest" contribution of soils to human well-being, as was also implicit in the description of soils' potential to provide the studied ecosystem services (see Table 1; note that respondents were able to see this information while working with the choice cards, by hovering over an icon). We can only speculate about this somewhat counter-intuitive result. Possible explanations include: the salience and long tradition of public debates concerning agriculture-related nitrate pollution of water bodies in Germany (Conrad, 1988); the widespread geographical relevance (compared to flood and water protection, which are relevant only in selected areas) and high "relatability" (compared especially to the more abstract climate change regulation); and the exceptionally low status quo value of this attribute and thus the largest improvement potential for water quality (compared to the other attributes). Against the last interpretation speaks the fact that 'clean water' scored highest already in the general question presented in Figure 5, which was asked before the status quo was explained. Further investigations that are beyond the scope of this article are needed, e.g. by testing whether living in areas with high nitrate loads can explain preference heterogeneity for this ecosystem service.

In general, participants of valuation studies often cannot be expected to have complete knowledge about the good to be valued due to unfamiliarity (Czajkowski et al., 2015). This is especially the case for complex environmental goods, such as soil-based ecosystem services. A limited amount of knowledge about complex goods can be problematic due to undervaluation of (future) benefits and may result in lower robustness of the results. This is further aggravated by the fact that respondents are usually surveyed only once and do not get time to learn, reflect and/or construct preferences throughout the survey (Burney, 2000; Lienhoop and Völker, 2016). As discussed above, in this study the issues of spatial heterogeneity of soils,[5] their complexity and respondents' unfamiliarity with their exact contributions to human well-being were addressed by the use of indices to express attribute changes. For each soil-based ecosystem services, the current or hypothetically improved provision was compared to the maximum provision potential (explained for each ecosystem service in Table 1). To ensure that the information provided was not overly complex, this difference between actual and potential provision was expressed in relative terms. This provided a middle road between difficult-to-understand quantitative indicators of ecosystem services and qualitatively expressed attributes

[5] Note that this is distinct from and only partly related to spatial heterogeneity of preferences, which we do not address in this article.

(Johnston et al., 2017). The small number of protest votes (19 out of 1500) and status-quo-choices (less than 14% of all choices) as well as the highly significant soil-based ecosystem services attribute coefficients suggest that the chosen approach was successful in reducing complexity and in easing the answering of the survey. However, the issues associated with preference formation can be addressed only limitedly in online surveys; their proper consideration would require the inclusion of a time- and cost-intensive process of deliberation (Schaafsma et al., 2018). At the same time, deliberative monetary valuation might offer a way to include soil biodiversity as a particularly challenging good (Bartkowski, 2017; Pascual et al., 2015; Paul et al., 2020).

The use of indices to express ecosystem service changes relative to their site-specific maximum provision potential may offer an opportunity to more easily combine preference information with model-based estimates of an ecosystem biophysical potential to provide ecosystem services (Kaim et al., 2021; Polasky et al., 2008). Thus, site-specific trade-offs among (soil-based) ecosystem services can be illuminated and analyzed explicitly. Ideally, this would require spatially explicit information about the current status quo provision of the ecosystem services, thus allowing to dynamically adapt the experimental design of the choice experiment survey based on a status quo that is adapted to a respondent's specific location. Unfortunately, this kind of data is not yet available for soil-based ecosystem services in Germany, so we had to use a generic "representative" status quo. Furthermore, such an approach to combine biophysical and preference information would be particularly policy-relevant if it allowed to consider the heterogeneity of preferences between different societal groups (Cavender-Bares et al., 2015), including the "supply side", i.e. farmers.

One of the more surprising findings from our choice experiment is the lack of an effect of experience (or: affectedness) with floods on the preference for the respective ecosystem service. Also, the other indirect measures of familiarity and experience had ambivalent effects. The location of residence (urban/rural) had no effect in either of the two models with interactions. Self-assessed knowledge of the soil condition in one's region did not have any effect on preferences. However, one should also note that the share of respondents who assessed their soil-related knowledge as "high" was very low (see Figure 3). Self-assessed awareness of soils' contribution to human well-being affected the probability of choosing the status-quo alternative and had some effect on preferences for the specific ecosystem services, except for flood protection. The only variable related to familiarity and experience (though indirectly) with a rather consistent effect was the lack of relationship to agriculture, which had a positive interaction with all ecosystem services attributes except for flood protection, and also significantly reduced the probability of choosing the status-quo alternative. Taken together, especially in combination with the relatively low self-assessed soil-related knowledge, these findings suggest that there is a need to further examine the heterogeneity of preferences for soil-based ecosystem services, including possibly their spatial heterogeneity and its interaction with the availability of substitutes and complements (Eusse-Villa et al., 2021; Glenk et al., 2020). Also, it would have been highly instructive to repeat the choice experiment about a month later, i.e. following the widely discussed and therefore highly salient floods in parts of Germany that occurred shortly after the present survey had been implemented. Brouwer (2006) argues that extreme events may change people’s risk perception and as a consequence willingness to pay, though he did not find evidence that occurrence of extreme events (extremely hot and dry weather) over a nine months period influences the WTP for bathing water quality (reduction of associated health risks). For our study, our expectation would be a substantial increase in the size and significance of the flood protection coefficient in the choice experiment, due to a kind of availability bias (Tversky and Kahneman, 1973).

5 Conclusions

Despite the importance of soil-based ecosystem services to human well-being, management and incentives to improve soil quality and enhance the respective services are very limited in the EU. At the same time, little knowledge is available about the demand for ecosystem services provided by soils. Against this background, discrete choice experiments are a useful tool to elicit and understand public preferences for soil-based ecosystem services. However, the valuation of complex, spatially heterogenous, unfamiliar and multifunctional natural resources poses several methodological and practical challenges as described above.

The study presented here advances the discrete choice modelling literature through our use of a novel approach to handle soils’ spatial heterogeneity, their complexity and respondents’ unfamiliarity with this multidimensional public good, namely using index-based attributes to express ecosystem service provision relative to the site-specific maximum potential. Furthermore, the results provide insights relevant from a management and policy perspective. We have shown that a majority of respondents considered the provision of soil-based ecosystem services as important for society and themselves but also that most were willing to pay for an increase in the provision of soil-based ecosystem services, especially with regard to water quality. This illustrates that a strong public support of agricultural management that enhances ecosystem service provision exists, emphasising the need to address the environmental challenge of soil degradation.

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