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Valuing drought impact mitigation on ecosystem services in a Mediterranean country

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ABSTRACT

Drought is a complex natural hazard increasing in frequency, duration, and severity worldwide. Although droughts cause both market and non-market impacts, the latter suffers from a dearth of economic studies quantifying their magnitude. In this paper, we investigated how droughts affect selected ecosystem services expected to result in welfare losses in Spain. This study is aimed at quantifying and simulating societal losses given the expected potential increase in drought severity in the coming decades. We estimated a Discrete Choice Latent Class Model by which we distinguished three broad classes of individuals. The common behavior across all classes is that people consistently choose to avoid the negative effects of droughts. However, there are substantial differences among the three classes; while class 1 chooses options regardless of cost, even when selecting the most expensive ones, the other two classes account for the size of the payment. Moreover, health and water use restrictions have been decisive factors in individuals' choices. We have also observed that the perception of climate change is related to individual decisions. We quantified the enormous damage drought causes to societal well-being. Policymakers should take this information into account when addressing the increasing likelihood of extreme weather events.

1. Introduction

Drought is a complex natural hazard affecting different socioeconomic sectors and environmental systems (Vogt et al., 2021), showing an increase in frequency, duration, and severity worldwide (Seneviratne et al., 2021). Projections of 1.5 °C global warming would mean that more than 75 countries will be completely affected by an increase in drought risk, and an additional 0.5 °C warming would result in another 17 countries suffering from these conditions (Gu et al., 2019). Worryingly, individual prospective evaluations of drought are strongly based on the past, which can create a wrong perception of the future real impacts, possibly greater than expected (Shao and Kam, 2020). Moreover, populations that are frequently exposed to droughts can become complacent, which might hinder the progress of adaptive strategies. This complacency can be attributed to several interrelated factors, including the reliance on short-term coping mechanisms rather than long-term adaptive strategies, as well as the psychological impacts of repeated exposure to drought conditions. The psychological impact of repeated drought exposure can lead to a normalization of drought conditions, fostering complacency among affected populations. Nguimalet (2018), notes that communities in Kenya and the Central African Republic are often unprepared for droughts due to chronic material shortages,

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suggesting a level of resignation to their circumstances that can stifle innovation in adaptive strategies. The tendency to underestimate the severity of drought impacts can further exacerbate this complacency, as communities may fail to recognize the need for more robust planning and risk management strategies (Wilhite et al., 2000). In addition, the lack of structured adaptation strategies can lead to a cycle of vulnerability. For example, the impacts of drought in Maharashtra, India, are indicative of broader trends, where communities adopt limited adaptation measures that do not sufficiently mitigate the long-term effects of drought (Udmale et al., 2014). This pattern is echoed in the work of Kattumuri et al. (2015) who argue that rural households often struggle to cope with increasing climate variability, highlighting the urgent need for improved understanding and implementation of effective adaptation strategies. Drought also makes people who are already vulnerable due to poverty, inequality, and marginalization, more susceptible. For example, in rural India, Sam et al. (2017) and Sam et al. (2020) found that citizens saw drought as a natural cause with humans exerting a limited influence on its occurrence. They considered the government should be responsible for the losses, providing the necessary assistance.

Droughts have a wide range of impacts in the areas where they occur and can also affect regions that are not directly experiencing them (CSIC, 2023) and have deferred serious effects over time (Muñoz et al., 2023; Fernández et al., 2023). One of the most worrying ways in which drought will reveal itself is in the agricultural sector because of a lack of soil moisture given lower-than-usual precipitations and enhanced evaporative demand and evapotranspiration (Rossi and Niemeyer, 2010; Vicente-Serrano et al., 2020). This, in turn, will affect both crop and pasture production. Meanwhile, the reduction in hydrological resources will affect water supplies such as stream flow, reservoir storage, wetlands, groundwater, snow melt, etc. (Hasan et al., 2019). This lack of provisions will directly affect irrigation, which again will have a direct impact on crop and pasture production (Vicente-Serrano et al., 2021), but it will also affect tourism and recreational activities, public utilities, horticulture and landscaping services, and other water-dependent industries (Bachmair et al., 2016; Bachmair et al., 2015). All of these impacts arising from a direct reduction in rainfall or water provisions are what can be called direct economic impacts (Ding et al., 2011). These include business interruptions in directly affected sectors and consequent unemployment. From these direct impacts will then arise the indirect or induced economic impacts, derived from the interactions between the different industries and sectors that operate and are linked in a complex economic system. Drought will even be priced into a firm's cost of raising equity capital because the market immediately introduces the drought conditions into their financing costs. Huynh et al. (2020) found that investors require a higher rate of returns on firms affected by droughts.

For many of these impacts (both direct and induced) there is a market, and they can be monetized to compare the different affected sectors. This is also why they are the most common impacts studied, with more straightforward approaches for economic valuation. But there is another source of impacts that is harder to directly reveal: non-market or non-monetary impacts. These can be both social and environmental and might become severe but often go unquantified given their more intangible nature and not having a market to price them (Hanley and Barbier, 2009). Drought negatively affects ecosystem services provided by the natural environment, and thus, the economic value of the natural capital. From an environmental standpoint, the non-market consequences of drought are many: herbivorous insect and pathogen outbreaks in forests (Sangüesa-Barreda et al., 2015; Bao et al., 2020), a decline in water quality downstream and increased salinity (Christian-Smith et al., 2011), increases tree mortality (Allen et al., 2010), reductions in pollinators, and risk of fires (Turco et al., 2017), all of them affecting the provision of ecosystem services. Likewise, Harding et al. (1995) modeled the environmental consequences of water management decisions under drought conditions by using a game theory model and appointed to net economic losses for wetlands, riparian areas, and national wildlife refuges.

The scarce literature quantifying non-market impacts of droughts is probably because of the valuation complexity of the former, which in turn can make the assessment process costlier and time-consuming. Furthermore, many of those studies do not quantify these costs; they only make a qualitative assessment of the process that takes place. Fleming et al. (2023) underscore the lack of comprehensive studies on the socio-economic impacts of drought, emphasizing the need for a deeper understanding of its economic implications. Economic valuation methods can assess non-market impacts of drought, directly revealing information that would otherwise be hard to access, such as mental health information on a localized area. One common approach for valuing non-market impacts is through Stated Preference methods (Johnston et al., 2017) such as the Discrete Choice Experiments (DCE). In the following years, droughts will be even more recurrent in some countries. Thus, quantifying the implied losses in welfare might reveal the unequal distribution of effects on the population and the immediate need for action. Other authors determined the willingness to pay to avoid drought-related water restrictions for households and businesses (Hensher et al., 2006); the value placed by a mountain community on human ecosystem services (Andreopoulos et al., 2015); the farmers' preferences for different attributes of a sand storage dam project (Nthambi et al., 2021); or the preferences of small-scale farmers for mitigation measures related to water and soil conservation (Agúndez et al., 2022). The objective of this study is to estimate the effect of drought on human welfare. Human welfare is a multifaceted concept that includes how the mentioned impacts on health, biodiversity, vegetation integrity, and water availability, affect individuals and, by aggregation, threaten the well-being of communities dependent on these ecosystem services. For this purpose, we have selected, four elements that may be affected at different levels by droughts: changes in natural landscapes, impacts on health, impacts on biodiversity, and restrictions on the use of water. These elements are, to some extent, susceptible to improvement or adaptation in a horizon of increased frequency of droughts in some parts of the world.

2. Material and methods

2.1. Study area

Our case study broadly refers to the effects of droughts in Spain, particularly significant given that approximately 75% of the country's land area is classified as arid, semi-arid, or sub-humid. In these regions, drought events tend to have more severe and far-reaching consequences, amplifying the importance of understanding and mitigating their effects. The impacts on vegetation changes focus on the forest surrounding areas of the upper Aragón River basin (2181 km^2) (Fig. 1). This area is in the North of Spain in Spanish Pyrenees and covers 28 municipalities with 19892 inhabitants of which 9810 are women and the population over 65 years old is around 21.5% (INE, 2022). Aragon River flows from north to south with limestone, shale, and clay formations. The streamflow generated in the basin reaches the Yesa reservoir at the outlet of the study area, with a capacity of 447 hm^3, built-in 1960 to supply water for irrigating 110.000 ha through the Bardenas Canal (López-Moreno et al., 2004) one of the most arid areas in Spain. The selection of this medium-sized mountain basin (Upper Aragón River catchment) is a reference to provide representative data. This basin was chosen for its ecological relevance and its ability to illustrate changes in ecosystems vulnerable to drought. Like the rest of Spain and other Mediterranean countries, this mountain area is undergoing significant land-use changes associated with population decline, leading to increased vegetation, which, together with climate evolution, is causing a substantial decrease in runoff generation (García-ruiz et al., 2011).

Climatologically, the basin receives an annual rainfall total exceeding 1500 mm in the northernmost sector, declining to 800 mm in the Inner Depression. In Bardenas the annual precipitation barely

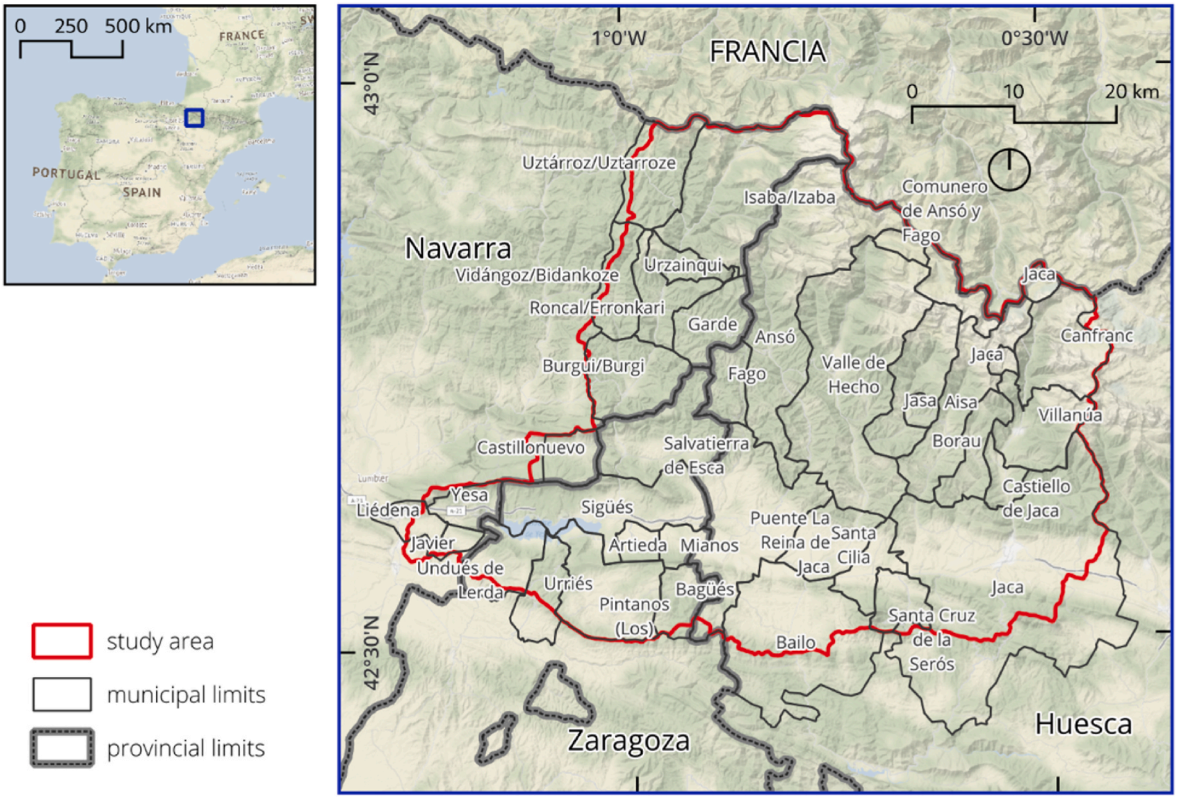

Fig. 1. Study area Upper Aragón River catchment.

exceeds 400 mm. Apart from summertime, rainfall is distributed all over the year, albeit with higher intensities during spring and autumn. The mean annual air temperature is 10 °C. Snow cover appears in the period from December to April, especially at sites located above 1500 m.a.s.l (López-Moreno and García Ruiz, 2004; López-Moreno et al., 2020). Long-term annual mean runoff is 915 hm3, with a peak occurring mainly during springtime. Runoff has exhibited a marked decline in the last decades associated with changes in precipitation and evaporative demand, but mostly to the increase of vegetation linked to agricultural abandonment in the headwaters during the 20th century (Bruno et al., 2021). Hydrological projections point toward an intensification of the decreasing streamflow in the next decades (López-Moreno et al., 2014). This corresponds to the annual peak of rainfall and melting of the snowpack. This area has been taken as the reference area to simulate the impacts of droughts in mountain areas. Changes in the vegetation due to decreasing rainfall changes have been simulated, specifically the species *Abies Alba* and *Fagus Sylvatica* (1250–1650 m.a.s.l) in the subalpine mixed forest belt.

2.2. Study design

The systems affected by droughts considered in this study are a selection related to the provision of ecosystem services identified in previous literature and through *focus groups*. All of these services lack market prices and should be highlighted in public policy making, since they may impact the social welfare. To develop welfare-improving and potentially increasing drought adapting policies, discrete choice experiments (DCE) are a good analytical option (Johnston et al., 2017). DCEs are based on stated individual preferences, that is, what people say they would do, which are applied to elicit a valuation of changes in health, landscape (vegetation), biodiversity, and water quality. The DCE and the rest of the data necessary for the valuation were collected through a survey (n = 521) randomly conducted in Spain during April and May 2022. The final sample for analysis has a slightly higher number of men (55%). Fifty-nine percent of our sample had more than a high school education, 49 years of age on average, almost 49% were employed, of which 13% were manual or primary sector workers, and 15% were unskilled. Twenty-six percent live in towns with less than 5000 inhabitants, and 39% in large cities with more than 100,000 inhabitants.

The use of DCE to estimate the impacts of droughts on individual welfare implies describing them in terms of changes in their provision and selecting a plausible range of variation. The variability of the potential impacts is then categorized into some levels, and are offered in impact/level combinations to individuals for their choice (Table 1). The selection of impacts and range of variation is set following the iterative review of literature, the consultation with experts, and the test in focus groups (Mariel et al., 2021). In the previous months (February and

Table 1
Attributes and levels selected for the discrete choice experiments.

Attribute	Name in tables	Range of variation in the study
Changes in natural landscapes	Area	Decrease in the woodland (*Abies Alba* and *Fagus Sylvatica*) in 5%, and 10%[a] or, alternatively, no change.
Impacts on health	Health	Number of persons affected in respiratory incidences: 3 in 10, 7 in 10[a], or no change.
Impacts on biodiversity	Biodiversity	Increase in the probability of disappearance number of threatened species in 4 and 12[a] species, or no change.
Water use:	- Water restrictions - Not suitable for drinking - Water safe	The levels considered were: water restrictions for certain uses (car washing, pools, etc.)[a], water not available for drinking, or water safe for drinking and cooking.
Cost of remediation	Cost	Increase in the price of the shopping basket and the price of supplies (energy, tap water): 0[a], 5, 10, 15, 20, 25, 30 euros.

[a] Levels describing the "No intervention"/Status Quo alternative.

March 2022), we held three focus groups of around 8 individuals where each attribute was exhaustively described and all the questions included were discussed. Focus groups were organized for pretesting, by inviting members of the general public from places such as neighborhood associations, public schools, and senior centers. On the other hand, pre-testing assures that the scenarios for the valuation of the changes provoked by droughts are well understood and credible. A series of pilot surveys usually do pre-testing. In this project, we first ran a short personal series of interviews and, on a second round, we collected 30 complete responses from a selected panel (pilot). These attributes together with predictors enter into the regression model to explain choices. After intense screening, we selected Climate Change (CC) at present (CCatpresent) as the predictor for those who feel that (CC) is already visible. Other attitudinal nor socio-economic variables were found significant.

We want to increase response efficiency by reducing the measurement error derived from responses due to lack of attention or other sources (Johnson et al., 2013), and therefore we need to design the experiment considering the dimensionality of the choice experiment. In other words, we want to minimize uncertainty (Mariel et al., 2021), which increases efficiency. The most commonly used efficiency measure is D-efficiency, and the criterion we have pursued here is the lowest D-error. The alternatives are compared to minimize the standard errors and the degree of correlation between parameters (Mariel et al., 2021). We used Ngene (ChoiceMetrics, 2018) for this design and the D-error for 36 choice cards was 0.002481. The resulting choice sets are represented in choice cards. Those cards (see an example in Fig. 2) are the central part of the valuation questionnaire.

2.3. Model specification

The valuation of drought-related impacts on ecosystem services is based on the assumption that they can be treated as arguments of the utility function of the individuals affected by these changes (Hanemann, 1984; Johnston et al., 2017; Mariel et al., 2021). By aggregating individual responses across various groups or the whole society, we can approximate the impact of droughts on the services or the asset itself. Damages are estimated by deriving the net change in income that compensates for changes in the provision of goods and services affected by droughts. That is, the aim is to quantify the changes in welfare caused by droughts by measuring the willingness to pay (WTP) to avoid damages.

Formally, let z be a vector of market goods and q a vector of environmental services, then u the individual's direct utility function:

$$u(z,q) \tag{1}$$

The quantity of z is freely chosen given the prices ($pric$) while q is exogenously determined. When individual maximizes utility subject to income (y) this function can be formulated as the indirect utility function v:

$$v(pric, q, y) = \max_{z}\{u(z, q)|pric \bullet z \leq y\} \tag{2}$$

The expenditure function associated with the utility change can be framed as:

$$e(pric, q, u) = \min_{z} \{pric \bullet z|u(z, q) \geq u\} \tag{3}$$

which defines the minimum amount of money an individual has to spend to reach a certain level of utility given the utility function and the prices of market goods.

This indirect utility function together with the expenditure function is the theoretical framework for quantifying welfare effects for non-market goods and services (Haab and McConnell, 2002; Mariel et al., 2021) or, in other words, these two make it possible to know how individuals respond to changes in the goods and services due to a drought.

For that purpose, in the survey, individuals are presented with choice cards containing different alternatives from which they select their preferred one. The analysis is conducted using discrete choice models and the purpose is to predict the preferences from the characteristics of alternatives, from choice situations, from the attributes, and considering the varying array of respondents. We apply a latent class model (Discrete Choice Latent Class Model) with a finite mixture structure to capture preference heterogeneity. In this case, each latent class matches a segment of the population allocating the same importance to the impacts of droughts of the alternatives offered. We present in eq. (4) the basic model applied in this study, and, in Table 2 there is the notation.

$$P(y_{it} = m|z_{it}^{att} z_{it}^{pre}) = \frac{exp(\eta_{m|z_{it}})}{\sum_{m'=1}^{M} exp(\eta_{m'|z_{it}})} \tag{4}$$

Heterogeneity is explained via latent classes. In a latent class conditional model, it is assumed that individuals belong to different latent

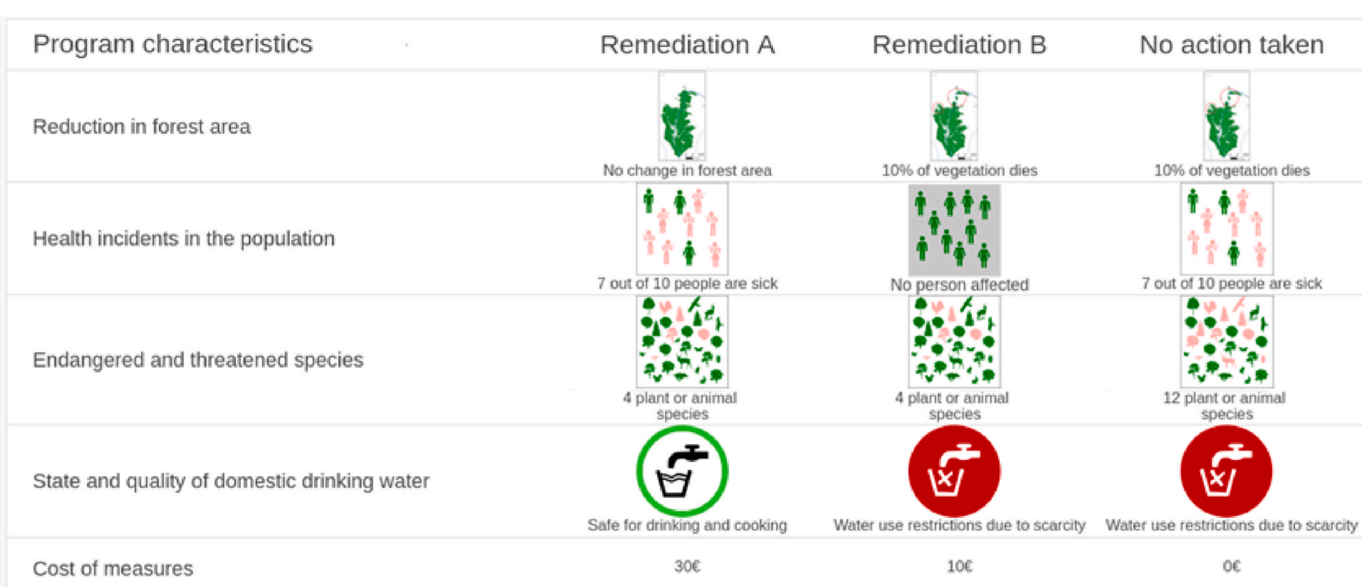

Fig. 2. Example of a Discrete Choice Experiments' card.

Table 2
Notation.

I, i	Group of cases or individuals i
T, t	Replications
	Response variable for case I and replication t. Vector notation
M, m	Alternatives presented to the individual
$z^{att}_{itmp}, z_i, z^{att}$	Attributes/characteristics of alternatives. Vector notation
$z^{att}_{itq}, z_i, z^{pre}$	Predictors/characteristics of replications. Vector notation
p, q	Indices to denote a particular attribute and predictor
P, Q	Total number of attributes and predictors
K	Total number of latent classes, latent class variable
$\eta_{m\|x,z}$	Systematic component in the utility of alternative m for case i and replication t

classes that differ concerning some or all of the β parameters (Kamakura and Russell, 1989). Since the choice probabilities depend on class membership x, the model is now:

$$P\left(y_{it}=m|x, z_{it}^{att} z_{it}^{pre}\right)=\frac{\exp\left(\eta_{m|x,z_{it}}\right)}{\sum_{m'=1}^{M}\exp\left(\eta_{m'|x,z_{it}}\right)} \tag{5}$$

The systematic component in the utility of alternative m at replication t given that case i belongs to latent class x is:

$$\eta_{m|x,z_{it}}=\beta_{xm}^{con}+\sum_{p=1}^{P}\beta_{xp}^{att}\bullet z_{imp}^{att}+\sum_{q=1}^{Q}\beta_{xmp}^{pre}\bullet z_{itq}^{pre} \tag{6}$$

where the logit regression coefficients are allowed to be class-specific (Vermunt and Magidson, 2005).

Once the model coefficients are estimated, this allows calculating the welfare measure *Willingness to Pay* (WTP), i.e. the amount of income a person is willing to pay for a certain improvement or to avoid a damage that will leave that person as before the change. WTP is defined as the marginal rate of substitution between the attribute and the price attribute in the utility function, that is,

$$WTP=-V'(att)\,/\,V'(c) \tag{7}$$

where V' is the first partial derivative of the indirect utility function, att is the attribute or characteristic of interest, and c is the cost attribute. If attributes enter linearly, the willingness to pay (WTP) is defined as:

$$WTP=\frac{-\beta_{att}}{\beta_c} \tag{8}$$

3. Results

The basic model (BM) considers the attributes and the alternative specific constant (ASC) where is referred to the choice of the status quo alternative. It is shown in the first column of Table 3. Neither ASC nor Area, are statistically significant, and the cost variable does not show the expected negative sign. These results claim for another specification. The second column of Table 3 presents a random parameter model in ASC constants (RPL-ASC). The *Akaike Information Criteria* (AIC) shows that RPL fits the data better than the BM.

On the third column, a RPL in attributes (RPL-ATTS) is shown. Even though the pseudo R2 are alike, the AIC clearly shows that RPL-ATTS represents the underlying data more accurately; that is, there is a great variability in the responses that concern health, biodiversity and water restrictions and water not suitable for drinking. The results shown in Table 3 recommend the estimation of a new model to better explain the unobserved heterogeneity. In this sense, Table 4 presents the results from a Latent Class Model (LCM).

The LCM is our best model (Table 4), since it is the one with lower Akaike Information Criteria (AIC). Pseudo R2 also increases, indicating a better fir of the data to a latent class model. The LCM distinguish 3 classes with significantly different choice patterns. Class 1, comprising 38% of survey participants, has all statistically significant variables except for water restrictions. Classes 2 (34%) and 3 (28%) show differences, mainly in the valuation of *WaterUse*; thus Class 2 places high values on good water quality while Class 3 is dissatisfied with water use restrictions but does not opt for good quality.

We expected the *Cost* attribute to be negative, indicating that individuals always prefer to pay less rather than pay more. Contrary to expectations, the *Cost* parameter is positive for Class 1. If we closely examine the profile of the *Cost* attribute choices (Table 5), we find that individuals in Class 1 often chose the most expensive options, while those in Classes 2 and 3 mostly opted for the lowest costs and even 0 cost options.

Table 3
Basic model and random parameter models in ASC and attributes.

	BM	RPL-ASC	RPL-ATTS
Area	0.017	0.022	0.030*
Health	0.136***	0.146***	0.212***
Biodiversity	0.044***	0.048***	0.075***
Water use:			
Water restrictions	−0.130	0.095	−0.420***
Not suitable for drinking	−0.390***	−0.886***	−0.150
Water safe	0.510***	0.791***	0.560***
Cost	0.021**	0.019*	0.022**
ASC	−0.130	−2.580***	−0.540***
Random parameter estimates			
ASC-rp		−2.120***	
Health-rp			0.360***
Biodiversity-rp			0.130***
Water restrictions-rp			−0.620***
Not suitable for drinking-rp			0.470**
Good quality-rp			0.150
Pseudo-R^2	0.27	0.49	0.49
AIC	4188.22	3616.80	3595.67

Statistically significant at *** 1%, ** 5% level, and * 10% level.

Table 4
Coefficients of Latent Class Random Parameter model.

	Class1	Class2	Class3	Mean (Std. Dev.)
Area	0.092***	0.177***	0.174***	0.144 (0.041)
Health	0.183***	0.604***	0.684***	0.468 (0.224)
Biodiversity	0.148***	0.274***	0.184***	0.201 (0.055)
Water use:				
Water restrictions	−0.195	−0.139	−3.241***	−1.034 (1.383)
Not suitable for drinking	−0.816***	−0.834***	1.891	−0.059 (1.222)
Water safe	1.010***	0.973***	1.350	1.093 (0.162)
Cost	0.072**	−0.122***	−0.074***	−0.036 (0.086)
CCatPresent	–	−0.23 ***	–	
Intercept	0.13	0.03	−0.16	
Pseudo R^2	0.61	0.55	0.70	0.69[i]
N (individuals)	521			
N (observations)	9378			

Statistically significant at *** 1% and ** 5% level; [i] Overall Pseudo R^2.

Table 5
Cost Profile (% of choices).

Cost of option in €	Class 1	Class 2	Class 3
0	8.8	**46.4**	**33.4**
5	5.5	25.2	23.1
10	7.8	13.7	16.0
15 to 20	27.2	11.4	18.6
25 to 30	**55.7**	03.4	8.9
Mean payment	21.5	5.4	8.3

A significant predictor found for the choice is the *CCatpresent*, (i.e. the perception that Climate Change can be felt at present). The negative sign (Table 3) indicates that respondents in Class 2 are less likely to opt for "doing nothing", i.e. the status quo, if they reported feeling Climate Change at present. Although Class 2 had the highest percentage (22%) of non-intervention or status quo choices, those individuals who felt that climate change was already having an impact were more likely to choose "doing something" (Option 1 or 2). Class 2 also reported a lower level of drought experience in the past compared with the other two classes (30%–37% of classes 1 and 3). In Annex 1 we present a post-hoc analysis of some descriptive statistics of individuals classified in each class regarding gender, age, experience with drought, and others.

To compare the relative importance of the attributes across classes, we re-scaled the maximum effects of the attributes within a latent class to the sum of 1. For class 1, *Cost* is the attribute that has the largest effect on choice compared to the other attributes, which sustains our hypothesis that people in this class chose the most expensive option through the choice cards (Fig. 3). For Class 2, the largest effect on choice is *Health* followed by *Cost;* while for Class 3 the largest effect is *Water Use*. In the latter two classes, individuals have taken *Cost* into account, they have chosen a balance between their preferred attributes at the lowest cost. *Area* (changes in landscape due to changes in density of woodland) is the least valued attribute for all classes.

From equation (8) we obtain an approximation of the value people place to avoid welfare losses through the willingness to pay. This individual WTP is per attribute increase/decrease (1%/category/unit) per person in Table 6. We chose not to include Class 1 WTP out of prudence, as their choices could reveal strategic behavior that would require *ad hoc* study. The WTP of estimated coefficients not statistically significant at 10% level for classes 2 and 3 are also not given.

As we can see, water use restrictions reflect individual welfare losses of €44 for 28% of the sample. The Spanish population over 18 years of age is around 83% of the total population (INE, 2022), so class 1 would count approximately 15 million individuals, class 2 with 13.5 million and class 3 with 11 million. The losses due to the impact of drought on health, on a conservative basis (Classes 2 and 3), would be in the order of EUR 169 million; and water cutoff losses around EUR 488 million.

Table 6
Willingness to pay (in €).

Attribute	Class2	Class3
Area	1.4[a]	2.4[a]
Health	4.9[a]	9.2[a]
Biodiversity	2.2[a]	2.5[a]
Water restrictions	n.s.	−43.8[a]
Not suitable for drinking	−6.8[a]	n.s.
Water safe	8.0[a]	n.s.

[a] Statistically Significant at 1% level; n.s. Not statistically significant at 10% level.

4. Discussion

There are numerous studies quantifying drought impacts on agriculture and the indirect impacts on the rest of the economy (Beillouin et al., 2020; Naumann et al., 2021; Zampieri et al., 2017). For example, Kelly and Phelps (2019) found that in regions of Australia highly dependent on agriculture, drought caused reductions in regional expenditure. Farmers were able to spend less at town businesses, which in turn reduced expenditures even more. The unemployment first felt in the agricultural sector was transferred to town businesses, people had to emigrate for work, and the value of assets such as houses decreased due to the fall in demand. Pérez and Barreiro-Hurlé (2009) studied drought impacts in the Ebro river basin, Spain. They found that Gross Value Added fell by €405 million and €77 million for agriculture and the hydroelectric sector, respectively. But people value the environment and the ecosystem services it offers, and drought poses significant threats to these provisions in some regions.

To further elaborate on why people value natural resources stemming from water availability, it is important to recognize that water is not only essential for human life and economic activities, but also plays a

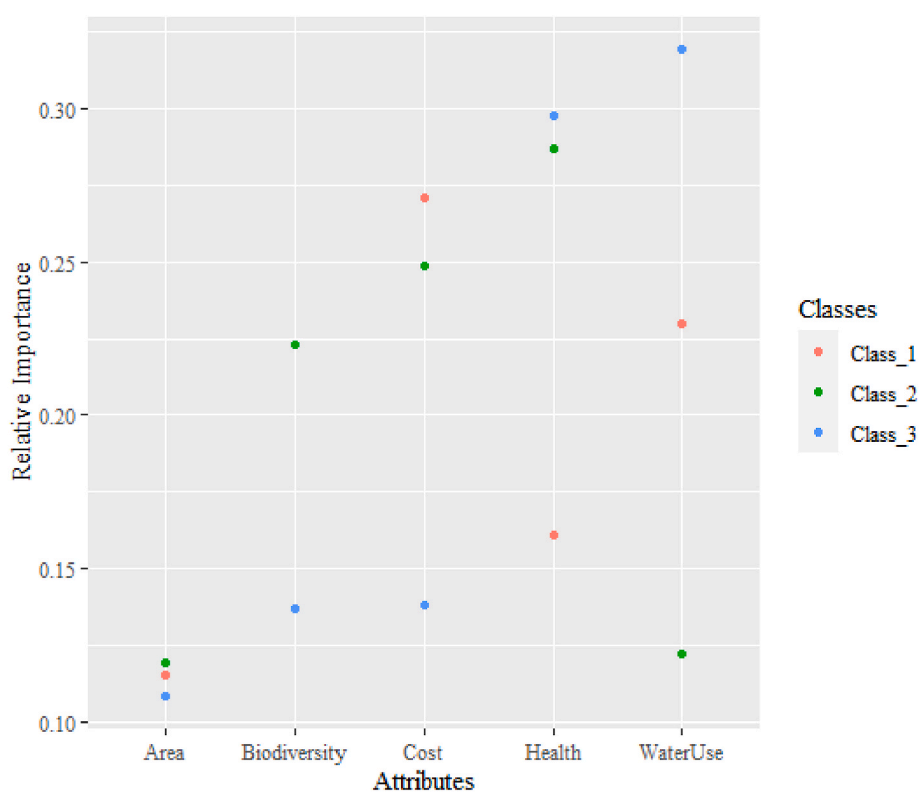

Fig. 3. Relative importance of attributes across classes (*Note that there is a graphic coincidence in Biodiversity's point for Classes 1 and 2*).

crucial role in providing various ecosystem services. Aquatic ecosystems offer cultural and recreational services such as fishing and aesthetic enjoyment of landscapes. Additionally, wetlands and water bodies are vital for climate regulation, water purification, and biodiversity maintenance. In the context of climate change and increasing water scarcity, people are likely becoming more aware of these multifaceted values, which may explain their willingness to pay for conservation and sustainable management of water resources.

Naumann et al. (2021) study the economic impacts of drought in Europe, reinforcing the urgent need for adaptive strategies in the face of climate change. Fleming et al. (2023) highlight the need for socio-economic studies to understand its economic implications. Our findings emphasize the importance of addressing the effects of drought on ecosystem services, balancing human needs and environmental preservation. Drought information is relevant to decision-makers at various levels, including households, public and private planners in sectors like land managers, disaster prevention, and electricity production. Drought information is provided as a public good but, as such, valuation is not straightforward, since drought affects services that are not traded in markets thus, lacking market-based revenues (Liu et al., 2020).

We investigated the extent to which droughts affect a limited number of ecosystem services which are expected to result in welfare losses. By using stated preference methods, Andreopoulos et al. (2015) compared the costs of adaptation to climate change with the willingness to pay for adaptation measures of a mountain community. Their results show a strong value in preserving ecological status. Adaptation measures to preserve ecosystem services outweighed the costs of adaptation, which implied that adaptation would be worthwhile. In summary, people value natural resources stemming from water availability. Nikouei and Brouwer (2017) measured the welfare values of sustained urban water flows for recreational and cultural amenities and found that more than ¾ of visitors were willing to pay additional taxes to preserve water flow in a natural park. Given that the river was drying out, a significant reduction in welfare was expected.

There is great variability in responses, the processes that lead respondents to these decisions, and the heuristics are quite different. Understanding this heterogeneity in effects is essential to inform policy designs tailored to different segments of the population, improving the efficacy and efficiency of interventions. To account for the variability, we might need questionnaires lasting several hours that would allow us to know the individual reality, but this is very costly in terms of time and resources and, probably, the self-selection of the participants willing to devote their time would represent a significant bias.

The differences in individual priorities regarding drought impacts can be attributed to several factors, including: previous personal experiences with droughts, which can influence risk perception; economic dependence on water-sensitive activities, such as agriculture; level of education and environmental awareness; cultural values and beliefs about nature; geographic location and exposure to different types of ecosystems; socioeconomic level, which can affect the capacity to adapt to drought impacts; age and gender, which may influence concerns about long-term impacts.

These factors may interact in complex ways to shape individual priorities, explaining the heterogeneity observed in our results.

We applied a latent class model to estimate the minimum conservative appreciable damages of droughts which may be of interest in policy making. The final goal was to quantify and simulate societal losses given the expected potential increase in the frequency of droughts in the next years (López-Moreno et al., 2014). Undertaking this task econometrically allowed us to group the assessments into clusters or classes, following a data approach that does not impose any prior classification criteria. Thus, we were able to distinguish 3 broad classes of individuals in which, although there is overlap in the direction of values, (e.g. all classes value good water quality or health protection), they do not have the same priorities over the whole sample.

It's important to recognize that while our study provides valuable insights, perceptions, and values associated with local ecosystem services can vary significantly across different geographical and cultural contexts. Factors such as local traditions, land use history, governance structures, and socioeconomic conditions can strongly influence how communities perceive and value drought impacts. To capture these local aspects in quantitative models, future research could incorporate cultural and context-specific variables, conduct comparative studies between different regions, or complement quantitative methods with qualitative approaches that capture local narratives and perspectives. This would allow for a more nuanced and contextualized understanding of behaviors and attitudes towards drought-related losses.

The common behavior of all classes is that people mainly choose to avoid the negative effects of droughts, i.e. they mainly choose the options of "doing something" versus "doing nothing" or status quo. However, there are substantial differences between the 3 classes; while class 1 chooses without considering the amount of the payment and even choosing the most expensive options, the other two classes do consider the size of the payment. The former (class 1) may be an indicator of the difficulty of choosing between such diverse impacts for some individuals, the most expensive option may be the one that offers the most, so the effort of choice is reduced. This behavior may be explained as individuals choosing regardless of the cost in the hope of obtaining improvements in other attributes. In the focus groups and follow-up questions, it was recurrent that, given the difficulty of choosing when you were not familiar with it, choosing the most expensive option was a guarantee that something would be done. That is, people want remediation actions, but they are not certain about how and what to choose. Another reason for choosing the option with the highest cost is that individuals do not consider their income restrictions, or the proposed amount is too low, so it can be overlooked. On the other hand, Johansson and Kriström (2021) adduce reasons why these responses, seemingly outside of economic theory, may make sense. They argue that it may be a manifestation that the respondent feels that he/she is already paying too much in taxes and therefore should get the best option regardless of the cost.

Droughts have also important effects on health, and can be affected in different ways such as nutrition-related effects, water-related effects, airborne and dust-related diseases, vector-borne diseases, and mental health effects, among others. One of the observed consequences is on mental health, mainly for farmers and their employees given that drought directly affects them (Edwards et al., 2015), and are positively correlated with drought intensity. Reduced life satisfaction is also a concern. Carroll et al. (2009) found that very low rainfall during spring in rural Australia affected life satisfaction by US$ 14,500. Based on the projections of increased frequency of spring droughts, they estimated a total loss of over 7$ AUS billion per year. Also, in rural Australia, drought has caused increased mental health problems for children and young people (Carnie et al., 2011). Physical health may also become affected by drought since induces the liberation of dust particles into the air which can, in turn, enter the lungs and cause internal damage. Machado-Silva et al. (2020) found that drought increased the number of respiratory disease-related hospitalizations. Our results are in line with previous research, reinforcing the idea that health effects are one of the most relevant attributes influencing social well-being.

The results of this study have significant implications for environmental management and decision-makers. They provide a monetary quantification of the 'invisible' impacts of drought on individual and collective well-being, which can help justify investments in mitigation and adaptation measures. They also reveal population priorities regarding ecosystem services, which can inform resource allocation in ecosystem management.

For landscape planning, these results suggest the importance of maintaining the integrity of ecosystems that provide highly valued services, such as water regulation and biodiversity maintenance. Environmental managers could use this information to design conservation strategies that maximize benefits for human well-being.

Decision-makers can integrate these findings into their processes in several ways: using economic value estimates to conduct more comprehensive cost-benefit analyses of water management policies; prioritizing investments in green infrastructure that improves drought resilience; designing education and awareness programs that address the concerns most valued by the population; developing adaptive management policies that consider heterogeneity in population preferences.

By considering these 'invisible effects' of drought, policymakers can develop more holistic and effective strategies for water resource management and climate change adaptation. This information should be considered in the face of a growing horizon of extreme weather events, as it provides a solid base for designing future programs to mitigate and adapt to these events given competing limited resources.

Regarding future directions of research, we have to note that the information was collected months before the drought of the year 2022 in Spain (as in the rest of Europe) became acute. The valuation, as usual, is contingent on the selected attributes for the analysis and the moment of surveying. Therefore, a current survey after the months of the current pressing drought could reveal even greater welfare losses. These attributes were revealed to be the most appreciated in focus group sessions, and our experiment was revealed to be valid for decision-making as it gives guidance on where the damage will be most appreciated in case of recurring drought. We also observed the influence of beliefs in the classification of responses. Climate change beliefs were proven to be related to responses in class 2. We expect that further research will highlight other complex influences on choice behavior too.

We have analyzed only some of the effects of drought, so our estimates of damage to the well-being can be considered very conservative. In an increasing drought scenario, the water becomes scarcer, vegetation dries up, and the landscape loses part of its biodiversity and natural landscape features. Landscapes and aesthetic beauty provide cultural ecosystem services that are important for the sustainability of the area, for the appreciation and satisfaction of the population that lives there, and also for tourists that visit the region (Soy-Massoni et al., 2016). The effects of drought on scenic beauty are identified as a relevant issue for future research. In many studies relating to scenic beauty, conservation of cultural ecosystem services, and people's preferences regarding certain landscapes, there is a tendency towards preferring more natural or, at the most, more traditional farming landscapes over modern intensive farming landscapes (Howley et al., 2012; Soy-Massoni et al., 2016). The conservation of not only natural features but simply traditional landscape features is important for visitors to the areas that have them (Van Berkel and Verburg, 2014) and is also important for the inhabitants (Alfonso et al., 2017). Changes towards more homogeneous landscapes are perceived negatively (Schirpke et al., 2013) and there is substantial support for cultural landscape conservation (Rewitzer et al., 2017).

5. Conclusions

Drought poses serious problems for several socioecological systems around the world, and it is expected an increase in frequency, duration, and severity worldwide. Droughts cause a variety of impacts, from direct impacts on economic sectors (agriculture, tourism, public utilities, and other water-dependent industries) to intangible nature impacts on the ecosystem services provided by the natural environment. This research analyzed the welfare change produced by four frequent impacts of droughts: changes in natural landscapes, impacts on health, impacts on biodiversity, and restrictions on the use of water. Results showed that health and water use restrictions have been decisive in individuals' choices and well-being. Understanding the impacts on welfare provides a solid base for designing future programs to mitigate and adapt to extreme climate events given competing limited resources.

CRediT authorship contribution statement

Begoña A. Farizo: Writing – original draft, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Miguel Sevilla-Callejo:** Software, Data curation, Formal analysis, Methodology. **Mario Soliño:** Writing – review & editing, Software, Methodology, Data curation, Resources. **Sergio M. Vicente-Serrano:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Juan I. López-Moreno:** Writing – review & editing, Project administration, Funding acquisition. **Angelina Lázaro-Alquézar:** Writing – review & editing, Resources. **Conor Murphy:** Writing – review & editing. **Sam Grainger:** Writing – review & editing. **Tobias Conradt:** Writing – review & editing, Resources. **Hongxiao Jin:** Writing – review & editing. **Boris Boincean:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Annex 1. Descriptive composition of classes in percentages

	Class 1	Class 2	Class 3
Size	37.7	34.1	28.2
Woman	37.1	32.3	30.1
Age			
18 - 32	36.1	38.4	25.6
33 - 45	35.8	33.6	30.6
46 - 53	37.9	36.6	25.5
54 - 62	41.3	29.6	29.1
63 - 90	37.1	33.0	29.9
Place of growth < 5000 inhabitants	39.7	33.6	26.6
Ever suffered drought	40.6	29.7	29.8
Never visit natural areas	29.1	42.0	28.9

Data availability

Data will be made available on request.

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