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High Public Good Values for Ecosystem Service Attributes of on-farm Quinoa Diversity Conservation in Peru

Adam G. Drucker[1] · Willy Pradel[2] · Craig Scott[3] · Sarah Elmes[3] · Kleny G. Arpazi Valero[4] · Kerstin K. Zander[5]

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Abstract

Agrobiodiversity is associated with a range of important but poorly quantified public good ecosystem services, the conservation of which requires public support. With a view to determining the general public's willingness to pay (WTP) for such conservation, we organised interviews with 491 adult Peruvian residents in three regions a stated preference choice experiment (CE) to elicit the value they place on crop genetic resources conservation, using quinoa cultivation as a case study. Responses revealed strong support for the conservation of quinoa diversity particularly when conservation was framed in terms of conserving national cultural identity or food security. Respondents were willing to make a one-off donation of US$31.79 to an in situ on-farm quinoa crop diversity conservation programme, placing the highest values on programme attributes related to securing bequest/existence and option values, followed closely by stable landscape conservation. WTP was higher when the public was reminded that conservation also contributed to national cultural identify or food security. A conservative aggregation of the WTP estimates to the population of the three regions results in an estimated total WTP for quinoa conservation of US$24.18 m and a benefit-cost ratio of 1.22. Findings demonstrate the significant and frequently ignored social welfare benefits associated with non-market agrobiodiversity-related public good ecosystem services, in this case equivalent to just over a quarter of market production values. Such information can be used to design and prioritise quinoa genetic diversity conservation programmes with an emphasis on such attributes.

Keywords Agrobiodiversity conservation · Choice experiment · Ecosystem services · Stated preference · Willingness to pay (WTP) · Quinoa · Peru

Introduction

An unprecedented, accelerating, and irreversible loss of agrobiodiversity[1] is occurring at ecosystem, species, and genetic levels throughout the world (FAO, 2015, 2019), even though the existence of such diversity is the basis for sustainable agriculture, food and nutrition security, ecosystem health, and adaptation to climate change (Hajjar et al., 2008; Bellon et al., 2020; Tesfaye & Tirivayi, 2020). Unlike wild diversity, agrobiodiversity is the result of thousands of years of interaction between humans and their environment, with its continued existence dependent on the maintenance of such public good "evosystem" (i.e., evolutionary process-related) services (Faith et al., 2010).

Since many of the world's agrobiodiversity hotspots are in developing countries, society is presented with the fundamental conundrum of how to safeguard the biodiversity maintained in the fields of the rural poor while at the same time meeting their development needs and rights. Farmers' decisions tend to be based on how personally 'profitable'

✉ Kerstin K. Zander
kerstin.zander@cdu.edu.au

1 Bioversity International, Via di San Domenico 1, 00153 Rome, Italy

2 International Potato Center (CIP), Lima, Peru

3 University of San Francisco, San Francisco, CA, USA

4 Regional Agrarian Administration (DRA), Regional Government of Puno, Puno, Peru

5 Northern Institute, Charles Darwin University, Darwin, Australia

[1] Biodiversity for food and agriculture or "agrobiodiversity" is a subcategory of biodiversity that corresponds to "the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels that sustain the ecosystem structures, functions and processes in and around production systems, and that provide food and non-food agricultural products" (FAO, 2019).

crop varieties or livestock breeds are (Bellon et al., 2020) not only in terms of providing a provisioning service but also as a means of mitigating risks and stabilising both yields and incomes (Di Falco & Chavas, 2009; Poudel & Johnsen, 2009; Kassie et al., 2017; Kremen & Merenleder, 2018; Tesfaye & Tirivayi, 2020; Maligalig et al., 2021). By contrast, the public good values associated with the maintenance of such agrobiodiversity do not necessarily feature in farmer's crop diversity maintenance decisions (Narloch et al., 2011). Global market integration, land use change, and migration also contribute to changing farmers' maintenance of crop diversity (Zimmerer & de Haan, 2017; Goldberg et al., 2021).

Failures in existing policies and markets that favour high-input, high-output "improved" varieties and breeds further impact farmers' changing practices and agrobiodiversity loss (Smale et al., 2004; Pascual & Perrings, 2007; Narloch et al., 2013) by driving out traditional varieties, whose range of non-market values are not reflected in their price (Bellon et al., 2020). In addition to environmental benefits, for example related to climate change adaptation, these include their role in maintaining cultural traditions (including food culture), local identities, and traditional knowledge (Smale et al., 2004; Nautiyal et al., 2008; George & Christopher, 2020). The existence of such non-market values leads to an under-provision of genetic diversity at national and global levels, while those farmers maintaining agrobiodiversity in their fields are often left uncompensated for their opportunity costs of providing a public good ecosystem service.

The diversity of benefits results in a complex set of incentives that affect smallholder farmer preferences, which, particularly in in the Global South, result in the cultivation of multiple crop species in integrated farming systems, maintaining *de facto* crop diversity. Nonetheless, there is no guarantee that they will maintain socially desirable levels of diversity. Markets alone cannot be expected to reward farmers adequately for managing socially desirable levels of agrobiodiversity (Narloch et al., 2011; Drucker & Appels, 2016). Instead, complementary incentives mechanisms need to be established that reward those farmers who maintain agrobiodiversity and related ecosystem services for the public good. To justify the funding of such interventions with public money it is important to understand the values that a society places on the provision of these non-market ecosystem services (Ojea & Loureiro, 2007; Kreye et al., 2016; Zander et al., 2013). Over recent years a body of work has emerged that specifically seeks to develop and provide market-based incentives for the conservation of agrobiodiversity, such as payments for agrobiodiversity conservation services (PACS). These schemes can potentially be implemented at modest cost and designed in ways that are socially equitable (Narloch et al., 2011, 2013; Wainwright et al., 2019; Drucker & Ramirez, 2020; Drucker et al., 2023). However, scaling-up these largely project-related PACS interventions to effectively secure national and global public goods requires government support facilitated through information regarding which ecosystem services the public value most and hence which types of conservation programme attributes to prioritise in order to maximise social welfare.

It is in this context that we conducted our case-study in Peru, a megadiverse country in which there is no systematic long-term agricultural policy funding mechanism for agrobiodiversity conservation. Our aims are to assess: (1) the public's preference for ecosystem services arising from the in situ on-farm conservation of quinoa; (2) preference variation among different stakeholders; (3) preference variation under different information and motivation framing regarding a potential conservation programme; and (4) the degree to which the public's willingness to pay (WTP) for conservation is sufficient to cover the estimated costs of implementing such a diversity conservation programme. We used a total economic value (TEV) framework and conducted a choice experiment (CE) - a multi-attribute preference assessment method - with members of the Peruvian public in selected locations. The TEV framework provides a structure through which different types of benefits to society, both direct and indirect, can be aggregated to construct a comprehensive valuation. Under the framework, any public good or service may consist of both use (direct, indirect, and option) and non-use (existence, altruistic, and bequest) values (OECD, 2006). We subsequently used the CE results to inform recommendations regarding a conservation programme design that reflects the public's preferences for different types of agrobiodiversity-related ecosystem services.

Under similar circumstances, stated preference methods have been widely used to elicit the value that the public places on different attributes of biodiversity, including in the specific case of agrobiodiversity (e.g., Krishna et al., 2010; Pallante et al., 2016; Botelho et al., 2018; Häfner et al., 2018). A number of these studies have also explicitly sought to demonstrate the existence of positive benefit-cost ratios, to guide the design of biodiversity policies and as a means of justifying existing or increased conservation funding (e.g., Zander et al., 2013; Martin-Collado et al., 2014; Tyack & Ščasný, 2018; Drucker & Ramirez, 2020).

Methods

Research Context

Peru is one of 17 megadiverse countries (OECD/ECLAC, 2017) and a centre of origin for crops important to the livelihoods of the poor, such as maize, potato, and quinoa, many of which are also of global importance. It has 184 species and hundreds of varieties of domesticated native plants, of which many species/varieties are considered "severely threatened" (FAO, 2015). There are over 5700 accessions of quinoa (*Chenopodium quinoa Willd*) conserved in seven gene banks that have been characterised into 24 races (Tapia & Fries, 2007; Tapia et al., 2014), constituting thousands of varieties. Many of these are at risk of disappearing (Kost, 2016) in large part as the national and international market is concentrated around only 15–20 mostly white varieties out of an approximate total of 3000 (Rojas et al., 2009). The resulting genetic erosion threatens Peru's food and nutritional security, the sustainability of its high-altitude production systems, and its ability to adapt to future climate change along with emerging pests and diseases.

Furthermore, quinoa plays an important role in many Andean cultural traditions (Rojas et al., 2009) and its high profile in Peru in general makes it an ideal crop around which to explore its many non-market public good ecosystem service values and the general public's willingness to support its in situ on-farm conservation. Estimating the potential magnitude of such support and devising mechanisms to capture such values is critical given that poverty rates in the arid Andean rural highlands can reach over 50% (INEI, 2020).

Choice Experiment Design

In a CE, respondents are presented with a series of choice tasks, known as choice sets, each containing a finite number of alternatives that describe the hypothetical environmental good or policy outcome in question (Hanley et al., 2001). CEs have been used extensively to evaluate farmer participation in schemes providing ecosystem services (e.g., biodiversity conservation: Sardaro et al., 2016; carbon sequestration: Aslam et al., 2017) or to gauge their preferences for crop traits improving livelihoods (e.g., Kassie et al., 2017; Maligalig et al., 2021); as well as to determine consumer/general public willingness to pay for ecosystem goods and services (Zander et al., 2013; Martin-Collado et al., 2014, Blare et al., 2019; Müller et al., 2020).

The alternatives presented in a CE vary in regard to the levels associated with each of the attributes and respondents are usually asked to choose their most preferred alternatives. By making this choice, respondents trade-off the attributes and the associated costs that come with the chosen alternative. A key component of the experiment is the definition of attributes used in the choice experimental design (Johnston et al., 2017). The attributes and levels for this study drew on Zander et al. (2013) and Martin-Collado et al. (2014) and were adapted to the Peruvian crop genetic resource context in consultation with Peruvian genetic resources and agricultural experts. Each attribute represents a component of the TEV so that the sum of the separate attribute values may be used as a proxy for the TEV of the public good ecosystem service associated with the maintenance of quinoa diversity in farmers' fields. The four attributes included Andean landscape conservation (includes ecological processes and aesthetics), insuring against the risk of agricultural production loss in the context of broader food security issues, quinoa diversity conservation and the maintenance of traditional knowledge and cultural practices – the latter including aspects of food culture (see Table 1).

As a monetary value, which is required for the calculation of welfare estimates based on WTP, we selected a one-off donation (in New Peruvian Soles) to a diversity conservation programme for the crop in question. The use of one-off payment vehicles described as donations are common when evaluating environmental goods and services through respondents' stated preferences (e.g., Veríssimo et al., 2009; Kragt & Bennett, 2011). Although one-off payments have been criticised for not being incentive compatible (Johnston et al., 2017), we opted against the use of a non-voluntary tax contribution vehicle as many respondents may fall outside the tax net. Nor did we select a repetitive payments vehicle as we did not want to make assumptions about how long payments are needed to successfully conserve crop varieties, which could potentially require support in perpetuity. The one-off payment vehicle also helps to simplify respondent understanding of the total cost of the CE alternatives.

We used a generic design such that each choice set consisted of three alternatives from which respondents were asked to select their most preferred. One of the alternatives was always described as the status-quo (SQ), while two others represented different scenarios under a quinoa crop diversity conservation programme. The SQ alternative did not involve a personal cost for respondents and can be interpreted as leaving things to business-as-usual and a consequent continuing erosion of quinoa diversity. The other two scenarios involved a one-off contribution towards a conservation programme and would result in benefits associated with an increase in such diversity (or at least avoiding any further decline). Given the number of attributes and their levels (Table 1), there would have been too many possible combinations ($3^3*2^1*7^1=378$) to use all of them in the survey and hence we designed a choice experiment that only included a fraction of these combinations. The use of qualitative levels for two of the attributes (Conservation of Andean Landscape - Improve, Stable, Decrease; and Risk of Agricultural Production Loss - High, Medium, Low), as in other studies (Zander et al., 2013; Martin-Collado et al., 2014) was necessary due to the challenges of articulating potential impacts in quantitative terms with regard to such multidimensional concepts as landscapes and food security. The design was pre-tested before the main survey started.

Table 1 Attributes and levels used in choice experiment

	Attribute	Attribute Levels*	Attribute Description	TEV Component
	Conservation of Andean Landscape	Improve Stable **Decrease**	Maintaining different varieties of quinoa can be important for landscape maintenance. The absence of biodiversity can negatively impact ecological processes and aesthetic values.	Indirect Use: Landscape
	Risk of Production Loss	**High** Medium Low	A lack of biodiversity increases the vulnerability of crops to extreme events such as hail, wildlife, diseases, etc. This can negatively impact regional food security. Funding would increase incentives to plant more native varieties on farms to offset cost of lower market returns.	Indirect Use: Option (insurance)
	Conservation of Diversity (% of Existing Quinoa Varieties Existing in 50 Years)	90% 50% **10%**	Market pressures for certain types of quinoa have increased the risk of extinction for other varieties with lower market values. Funding would provide access to seeds, seed exchange programs, and gene bank storage. Maintaining at least a "safe" minimum population of quinoa varieties in their traditional environment will greatly reduce the possibility that they might one day no longer be available to future generations.	Non-Use: Bequest/ Existence
	Maintenance of Traditional Knowledge and Cultural Practices	Yes **No**	Biodiversity is an important cultural asset. Different varieties of quinoa are often associated with local cultural events and special food products. For example, the misa quinoa variety is used for "Pago a La Tierra" [Payment to (Mother)Earth] ceremonies.	Indirect Use: Cultural
$	Program Cost (Soles)	**0**/2/5/10/25/50/100	Each program has an implementation cost. This is expressed in terms of the value of a one-off individual donation.	

* SQ Level in Bold

Table 2 Sample description (N = 491)

Characteristic	Sample Statistics	National Statistics (Peru, 2017 Census)*
Female (%)	48%	51%
Average age (SD)	39.4 (13.8)	32
Location (%)		N/A
Puno	41	N/A
Cusco	18	N/A
Lima	41	
Education (coded 1 to 3)		> 15 years old
Primary education (1)	2%	18%
Secondary education (2)	22%	45%
Technical post-secondary (3)	31%	14%
University (4)	44%	20%
Income (US$/month) (coded from 1 to 6)		
0–121 (1)	16%	
122–258 (2)	23%	Puno: US$ 182
259–606 (3)	42%	Cusco: US$ 233
607–1515 (4)	15%	(Metropolitan)
1516–3030 (5)	2%	Lima: US$ 374[a]
>3030 (6)	0%	

* Censos Nacionales 2017: XII de Población, VII de Vivienda y III de Comunidades Indígenas https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/libro.pdf

[a]INEI, 2017

An important issue in experimental design is the identification of efficient designs[2] capable of generating statistically significant attribute combinations associated with a given sample size (Rose & Bliemer, 2008). We generated a Bayesian efficient design (see Sándor & Wedel, 2001; Ferrini & Scarpa, 2007) of 24 choice sets blocked into three blocks using the software STATA. Each respondent was assigned one block of eight choice sets each (see Fig. S1). The design was based on prior parameter estimates that we assumed after expert consultation and literature review. Using prior parameter estimates leads to more reliable parameter estimates for a given sample size, even if the information on the parameters is scant and the priors mis-specified (Bliemer et al., 2009). While we did not know the exact values of the priors, we were quite certain about the expected signs.

Sampling and Data Collection

With a view to exploring how public willingness to support genetic resources conservation may vary among segments of rural and urban populations as they become more geographically distant from the genetic resource in question, population samples were selected across the important Andean quinoa producing regions of Puno and Cusco. These included the regional capital cities, whose populations are respectively 135,300 and 437,500 (INEI, 2017), as well as the surrounding rural areas where incomes might be expected to be even more constrained compared to those within the cities. We also conducted surveys in the national capital, Lima (population 9.17 m (INEI, 2017)), which is distant from these quinoa producing areas but with higher average incomes.

With a view to overcoming logistical and cost challenges of visiting households in Peru, we used a "second-best" convenience sampling method that involved enumerators randomly recruiting participants in central or communal areas, such as town squares, bus stations, and markets. Although convenience sampling can result in the risk of selection bias (Moore, 2001) and unbalanced samples, given the experimental design and randomised treatment we used here, we anticipated no major issues arising from demographic imbalances, and a significant overlap between the sample and the actual demographics can in fact be observed (Table 2).

Sample size calculation used a cluster sampling approach (Walker & Adam, 2011) considering District population, an expected WTP contributor's rate of 0.4 for Lima and 0.3 for the regional cities, a sample precision level between 0.1 (Lima and Puno) and 0.15 (Cusco) in a normal distribution z

[2] Efficient designs aim to ensure that the predicted standard errors of the parameter estimates are minimised (Hoyos, 2010). While there is a range of different efficiency criteria that can be used, our design aimed to minimise the D-error, the most widely used efficiency measure (Street et al., 2005).

with p-value equals to 0.95. To take into consideration population heterogeneity, we considered a population heterogeneity of 0.15 in Metropolitan Lima and 0.1 in the regional capital cities. Finally, optimal cluster size was measured based on heterogeneity of population and cost of data collection. As a result, the minimum sample size was determined to be 471 (84 in Cusco, 195 in Puno, and 192 in Lima). Interviews were conducted with 491 adult Peruvian resident respondents between July and September 2017 in Cusco (91), Puno (200) and Lima (200). The interviews were administered in Spanish (and occasionally in local languages Quechua and Aymara) by three groups of trained enumerators in their respective locations. Subjects were not compensated for their participation, eliminating any selection bias related to financial incentives. Only adults were interviewed, and consent was established before each interview.

Questionnaire

We used a three-part structured questionnaire. Respondents were first asked questions related to their familiarity with and use of different varieties of quinoa. Second, they were presented with the CE sets. In the third section, we asked for basic demographic information (gender, age, occupation, income, education, household composition, socio-economic status, and wealth).

Information was provided regarding agrobiodiversity in general. Prior to being presented with the choice sets, respondents were also reminded that achieving good conservation outcomes has a cost, that quinoa varieties are not the only crop that may require conservation funding, that there may be other good causes to support, and that their household budgets need to cover other expenses too. This so-called cheap talk script helps minimise hypothetical bias that could lead respondents to overstating their willingness-to-pay (Ladenburg & Olsen, 2014). Having provided instructions on how to interpret the choice sets and make selections, eight choice sets were then individually presented.

Information Framing

Framing is an effective way to increase awareness and potential WTP (Czajkowski & Hanley, 2009) because the value of an environmental good or service depends not only on their physical characteristics, but also on the context within which they are situated. In CE this refers to how the goods and services are described to respondents, in addition to their attributes. By providing different information to different sample treatment groups, respondents can be primed by the introduction of a stimuli before making their choices. This can trigger an emotional response, establish context, or change a subjects' frame of reference (Weingarten et al., 2016).

Numerous case studies have shown framing to increase WTP in specific contexts for both direct and non-direct use products. Banerji et al. (2016), for example, found that nutritional information significantly increased WTP for vitamin-fortified millet in India. Bergstrom et al. (1990) found that framing increased WTP for American wetlands when respondents were reminded how different programme attributes related to desirable consumption services. By contrast, Fox et al. (2002) found that Chinese consumers preferred to pay less for pork products when information about harmless irradiation was presented. These findings suggest that the effects of information framing can move WTP in both directions, depending on the person's perception of the information provided.

We used two different framing scenarios, one about the national identity (NI) significance of quinoa and one about food security (FS). The NI framing text contained a series of historical facts detailing quinoa's history as native to Peru and attempts by Spanish colonizers to eradicate the crop in the sixteenth century (Fig. S2). We hypothesised that this stimulus involving cultural nationalism would increase the appreciation of native crops, and hence respondents' WTP. The FS framing utilised a series of questions regarding personal food security, based on the hypothesis that heightened sensitivity to potential food shocks may increase the valuation of biodiversity and hence WTP for its conservation, given its role as an informal insurance mechanism.

The sample was split into three treatments with two groups of respondents being randomly presented with additional information about either the NI or the FS. A control group received neither of these additional information texts. All three treatment groups received basic information regarding what agrobiodiversity is, why it is important, and current status/threats.

Data Analysis

Choice experiments are based on random utility theory (Luce, 1959; McFadden, 1974) and the characteristics theory of value (Lancaster, 1966). One commonly applied method is the random parameter logit (RPL) model, which was also used here to analyse the choice data. RPL models are extensions of basic conditional logit models. Through the inclusion of random parameters, such models are less restrictive in terms of assumptions - such as the independence of irrelevant alternatives (IIA) property - and suitable to capture preference variation around the mean of the random parameters (Hensher & Greene, 2003). Being more flexible in terms of assumed distribution is useful when there is limited prior knowledge about the distribution of individual preferences. RPL models are also able to account for panel-data, such as those we obtained in this study with each respondent answering eight choice sets, allowing unobserved preference heterogeneity across individuals to be considered (see e.g., Hensher & Greene, (2003)) for detailed model specifications). All attributes were set as random parameters with a normal distribution with the exception of the cost attribute, which was restricted to a triangular distribution constrained to a non-negative range in order to avoid the possibility of negative WTP values (Hensher et al., 2015).

The RPL only captures unobserved preference heterogeneity. To better explain the source of this heterogeneity, interaction terms between relevant socio-economic variables and between the SQ alternative and these variables were also included. Such interaction terms related to location (relative to Puno), respondents' age, gender, income, and level of education (see Table 2). The variable for the framing group was interacted with the SQ alternative. We present three models, one without interaction terms (Model 1), one with interaction terms associated with the SQ alternative (Model 2), and one with interaction terms associated with the attributes (Model 3). We initially tested for all interactions, but only maintained those in the final models that were significant. We further estimated three RPL models, without interaction terms, for each of the three framing groups to gauge separate WTP estimates for these three groups in line with our aim to test if the information framing changed the amount respondents were willing to pay. For attributes with three levels (see Table 1) the reference levels were the ones of the SQ alternative. Dummy variables for the other two levels were created and included in the models so as to model the preference for the change from the SQ. All RPL models were simulated using 2000 Halton draws.

The WTP estimates from the RPL model results were also calculated using simulations. The simulated distributions were obtained by dividing draws from the distributions of the attribute coefficients by draws from the distributions of the coefficient of the monetary attribute. 10,000 Halton draws were used in these calculations. This allowed mean WTP to be identified across all respondents. The simulation-based method also provided the 2.5th percentile (lower bound) and the 97.5th percentile (upper bound) for a 95% confidence interval.

Results

Sample Description

The gender-ratio of the respondents was roughly equal (48% female) and approximated that of the whole country (Table 2). The average age was 39 (ranging between 18 and 77). More than 75% of respondents had post-secondary education, implying that they were better educated than the national average. About 39% of the sample earned less than the minimum monthly wage (US$ 258) while 65% had incomes within the average income range for Puno, Cusco, and Lima (US$183-$374/month). Respondents from Cusco had higher incomes, with 40% having at least US$607/month, compared to 5% among residents of Puno and 21% among those from Lima. Residents from Puno also had the highest share of low incomes (58% had an income of below US$259/month, compared to 23% in Cusco and 37% in Lima; (Table S1)).As per design, a third of respondents (164) received additional information about NI, a third (165) about FS, and a third (162) as a control group did not receive any of the additional information. This share was the same across all three locations. The share of women, the location, and age distributions did not significantly differ across the groups.

Choice Experiment Results

Almost 90% of the choices made resulted in a conservation programme alternative being selected over the SQ. Results of the baseline RPL model (Table 3) showed that respondents preferred all levels of the attributes associated with the conservation of quinoa attribute to that of the SQ, i.e., they disliked the implications for quinoa diversity conservation under the current situation (SQ). Respondents preferred the highest attribute level (90% of varieties) related to the existence of quinoa varieties in 50 years relative to rates of only 50%, which in turn was preferred to rates of only 10%. They also preferred the maintenance of cultural traditions over their loss. By contrast, respondents preferred only the medium attribute level associated with 'Risk of production loss' and 'Conservation of the Andean Landscape' over the highest level and the SQ level. The similar mean WTP and confidence intervals indicated that the difference between the medium and high levels of these two attributes were not statistically significant.

Location had a significant impact on whether respondents chose the SQ alternative. Respondents from Puno were more likely to choose the SQ alternative (and hence be least likely to be WTP for conservation programmes) than those from Lima and Cusco (in that order) (Model 2 in Table 3). There was no significant difference found between the WTP of urban and rural respondents, as well as the other demographic parameters tested (income, age, gender, and education). Respondents from Lima had a higher preference for most attributes, except for the medium levels 'Risk of production loss' and 'Conservation of the Andean Landscape' (Model 3 in Table 3), compared to respondents from Puno (the reference location level) Respondents from Cusco, on the other hand, were more likely to prefer a conservation programme with a medium risk of production loss than respondents from the other two locations. People from Cusco also had a higher preference for high (90%) levels of quinoa diversity still existing in 50 years compared to people

Human Ecology (2024) 52:67–79

Table 3 Results of RPL model without (Model 1) and with (Model 2) interaction terms

	Model 1			Model 2			Model 3		
	Coefficient	SE	SD	Coefficient	SE	SD	Coefficient	SE	SD
Risk of production loss: Low	0.96***	0.11	1.24***	1.11***	0.11	1.13***	0.83***	0.13	1.19***
Risk of production loss: Medium	1.01***	0.12	1.54***	1.17***	0.12	1.40***	0.70***	0.15	1.42***
Percentage of Quinoa varieties still existing in 50 years: 90%	1.01***	0.12	1.66***	1.19***	0.11	1.62***	1.21***	0.37	1.50***
Percentage of Quinoa varieties still existing in 50 years: 50%	0.68***	0.11	1.25***	0.88***	0.10	1.14***	0.33**	0.15	1.10***
Maintenance of Traditional Knowledge and Cultural Practices	0.70***	0.10	1.44***	0.83***	0.09	1.34***	-0.62*	0.37	1.28***
Conservation of the Andean Landscape: Increasing	0.86***	0.12	1.332***	0.97***	0.12	1.31***	0.63***	0.14	1.30***
Conservation of the Andean Landscape: Stable	0.94***	0.11	1.02***	1.03***	0.10	1.02***	0.89***	0.10	1.02***
One-off donation	-0.04***	0.003	0.04***	-0.03***	0.002	0.03***	– 0.03***	0.002	0.03***
SQ	-0.55***	0.12					-0.80***	0.13	
Interactions									
SQ * National Identity group				-0.50***	0.18				
SQ * Food Security group				-0.69***	0.18				
SQ * Puno				0.89***	0.16				
SQ * Cusco				-0.93***	0.25				
Lima * Low production risk							0.34*	0.17	
Lima * 90% varieties in 50 years							1.63***	0.24	
Lima * 50% varieties in 50 years							1.40***	0.20	
Lima * Maintenance of culture							0.75***	0.18	
Lima * Increasing landscape							0.35*	0.21	
Cusco * Medium production loss							0.91***	0.27	
Cusco * 90% varieties in 50 years							0.70**	0.29	
Female * 90% varieties in 50 years							-0.39*	0.21	
Female * 50% varieties in 50 years							-0.33*	0.18	
Age * 90% varieties in 50 years							-0.02**	0.007	
Education * Maintenance of culture							0.44***	0.15	
Loglikelihood	-3107.9			-3069.3			-3024.5		
Pseudo R^2	0.28			0.29			0.30		

Significance at 1% (***), 5% (**) and 10% (*) levels; SQ = Status-quo

from Puno, but less so than people from Lima, as indicated by the lower coefficient of the interaction term (1.03 for the interaction with 'Cusco' compared to a coefficient of 1.73 for 'Lima').

Of the demographic variables, gender, age, and education had minor impacts on preferences. Women were less likely to prefer a conservation programme that aims at maintaining quinoa diversity with negative coefficients for both attribute levels, 90% and 50% of quinoa varieties still existing in 50 years. The older respondents were, the less likely were they to prefer the 90% level of quinoa diversity existence in 50 years. Education was positively associated with a preference for the maintenance of traditional knowledge and cultural practices.

Framing had a significant impact on respondents' preferences for the SQ. Those who were informed about the importance of quinoa for Peru's national/cultural identity or for food security were less likely to choose the SQ over one of the two presented conservation programmes, i.e., those primed were more likely to be willing to pay something for conservation than the control group.

Respondents had the highest WTP for securing bequest/existence and option values (Table 4). They were WTP US$8.76 for the certainty of 90% of quinoa varieties continuing to exist in 50 years and US$8.73 for a medium level of risk associated with agricultural production loss, while relatively strong preferences were also expressed for low levels of risk (US$8.37). Similarly, landscape conservation values were also important and "medium" level values preferred; with respondents willing to donate US$8.15 for ensuring a stable conservation status compared to US$7.52 for improving that status conservation. WTP for maintaining

Table 4 WTP (US$) estimates from baseline RPL model (no interactions), for both priming groups (FS: food security and NI: national identity) and control group (no priming)

Attribute	WTP Pooled (95% confidence interval)	WTP NI group (95% confidence interval)	WTP FS group (95% confidence interval)	WTP control group (95% confidence interval)
1a. Risk of production loss: Low	27.6 (3.6–50.6)	32.7 (2.3–62.0)	27.6 (6.9–47.5)	22.7 (0.6–43.8)
1b. Risk of production loss: Medium	28.8 (-1.0–57.4)	35.6 (-5.0–74.6)	27.4 (8.1–45.9)	29.0 (0.6–56.2)
2a. Percentage of Quinoa varieties still existing in 50 years: 90%	28.9 (-3.2–59.7)	27.0 (-9.7–62.4)	33.9 (4.1–62.7)	24.4 (-6.5–54.0)
2b. Percentage of Quinoa varieties still existing in 50 years: 50%	19.7 (-4.5–42.9)	19.3 (-2.2–40.0)	27.7 (5.2–49.4)	14.6 (-9.3–37.7)
3a. Conservation of the Andean Landscape: Increasing	24.8 (-0.9–49.5)	27.3 (3.8–49.8)	24.9 (1.2–47.7)	19.6 (-6.9–45.1)
3b. Conservation of the Andean Landscape: Stable	26.9 (7.2–45.9)	31.5 (3.9–58.1)	25.7 (14.1–36.7)	20.8 (2.1–38.8)
4. Maintenance of Traditional Knowledge and Cultural Practices	20.3 (-7.5–47.1)	17.8 (-16.9–51.2)	22.0 (-2.5–45.5)	15.5 (-7.1–37.7)
Total (Soles) of highest WTP for each type of attribute (= 1b + 2a + 3b + 4)	**104.9**	**111.90**	**109.2**[b]	**89.7**
Total (of highest WTP attribute values[a]	**31.79**	**33.93**	**33.09**	**27.18**
Percentage change relative to control		**24.7%**	**21.7%**	
Percentage change relative to pooled sample		**6.7%**	**4.1%**	

[a]Exchange rate during the months of the survey was approximately US$ 1 = New Peruvian Soles 3.3

[b]Total includes 1a rather than 1b, as food security group WTP higher for the former than the latter

See Table S2 in Supplementary Information for the separate RPL models for each group from which these WTP were calculated

traditional knowledge and cultural practices (including food culture) was US$6.15. Respondents within the 'Food Security' framing group were willing to pay more to secure the diversity of varieties in 50 years; approximately US$10 more for 50% and US$7 more for 90% varieties to be conserved (Table 4). Respondents within the 'National Identity' group were willing to pay the most for a low and medium production risk. The control group, who were not presented with an explanation about the motivations and benefits of quinoa conservation, had the lowest WTP for every attribute level except for a medium risk of production loss.

The Total Economic Value of Quinoa

The TEV of quinoa diversity conservation can subsequently be calculated by the summing the highest WTP values of the attributes obtained from the pooled sample RPL model without interaction terms. The TEV placed by the public on the public good ecosystem services associated with a quinoa diversity conservation programme was US$31.79 if medium levels of landscape conservation (US$8.15) and risk of production loss (US$8.73) were to be achieved, and 90% of varieties secured for the next 50 years (US$8.76), while maintaining cultural practices (US$6.15). Given that there are approximately 3,380,960 households in the three studied regions in Peru (11.86 m population – with an average household size of 3.51 persons (INEI, 2017)), this amounts to a total willingness to pay for quinoa conservation of US$107.5 m (US$31.79 × 3.38 m households).

Discussion

Quinoa's Total Economic Value and Conservation Costs

Most respondents revealed strong support for conservation through their dislike of the current state of quinoa diversity conservation under the SQ. Regarding the different components of TEV, respondents had the highest WTP for securing bequest/existence and option values, followed closely by stable landscape conservation.

Regarding policy implications, as the WTP estimates were derived from a stated preference method, it should be noted that there nonetheless remains uncertainty as to whether all those respondents who said they would donate, would in fact do so in a non-hypothetical setting. How many people would pay has been shown to be context-specific (Kim et al., 2012). Meta-analyses have found that people would pay about 75%, of what they stated (Murphy et al., 2005); while Morrison (2000) and List and Gallett (2001) found that no more than 30% of those who stated that they would donate something, would in fact do so if given the opportunity. Zander et al. (2014) also used a similar weighting, which if we were to apply here to generate a conservative WTP estimate, would result in a value of US$24.18 m ((US$31.79 × 0.75 × 3.38 m x 0.3). This represents just over a quarter (25.9%) of the gross market value of Peru's annual quinoa production (US$93.4 m in 2016, according to FAOSTAT).

The existence of such significant non-market values also helps justify the implementation of an actual conservation programme, as relative to the costs (US$19.75 m for 2,700 varieties over 50 years, as estimated by Drucker & Ramirez, 2020), this results in a positive benefit-cost ratio of 1.22 (US$24.18 m/19.75 m).

Distance Decay

Previous empirical evidence has shown that the location distance of environmental goods and services has a significant effect on the utility that individuals obtain and therefore the values they assign to them (e.g., Bateman et al., 2006; Olsen et al., 2020). This phenomenon of distance decay depends on the type of ecosystem service that primarily motivates respondents (Olsen et al., 2020). For example, for recreational and other direct use values, people living close to the associated ecosystem services have been found to obtain greater benefits and also assign higher overall protection values relative to those living further away (e.g., Bateman et al., 2006; Rolfe & Windle, 2012; Khan et al., 2019). For other values, such as cultural values, the effect of location and distance has been less clear (Olsen et al., 2020).

We found that those living in the hotspot for quinoa diversity (Puno) were more likely to choose the SQ alternative (and hence be least likely to be willing to pay for conservation programmes) than those further away from Puno and closer to the consumer markets of Lima and Cusco. This result is consistent with Zander et al. (2013), who concluded that respondents who lived close to the genetic resources in question were in fact willing to contribute less to their conservation than respondents from distant cities.

In the context of Peru, this could reflect the fact that residents in Lima and Cusco have higher average disposable incomes[3]. But it could also be because those living where quinoa diversity is still locally abundant might not perceive the urgent need for conservation, thus weakening possible motivation for action (Fernández-Llamazares et al., 2016), or that such efforts would not provide them with sufficient additional non-market benefits to those already accruing to them. This suggests that when public donations are being solicited for quinoa conservation, people outside the diversity hotspot region of Puno should be a priority target group.

Age, Gender, and Education

Of the demographic parameters, gender had the largest effect in explaining attribute variation within the sample. In other contexts, women have been shown to be more likely to pay for conservation, as are younger people and those with higher incomes and levels of education (amongst others, Blare et al., 2019). Here we could not confirm this but found that women preferred to pay for the existence of quinoa variety diversity less than men (Table 3). Age was also negatively associated with paying for the future existence of varieties. Education was positively associated with a preference for the maintenance of traditional knowledge and cultural practices.

Framing Effects

The only other significant parameter was the framing group. The control group, who did not receive additional information about why quinoa conservation is so important, were willing to pay the least. This finding is in line with previous studies, showing the importance of information and knowledge in general decision-making (Banerji et al., 2016; Shreedhar & Mourato, 2019). Given the impact of framing on WTP, public-awareness campaign messages regarding quinoa diversity-related food security, national/cultural identity, and other benefits should be carefully articulated whenever soliciting donations or justifying government conservation-related tax surcharges.

While those people who received information about the national/cultural identity and food security aspects of quinoa conservation were willing to pay more for all levels of the attributes 'Conservation of Andean Landscape' and 'Risk of Production Loss', they also preferred the medium levels of landscape conservation provision and risk of production loss (Table S2). A stable condition of the Andean Landscape could be preferred because the landscape is already regarded as how it should be, and respondents do not see the need to pay for further improvement. The preference for a medium level of production loss risk could indicate that the public consider quinoa to be a widely available commodity crop in Peru and are thus unconcerned about a potential decline in production and an undersupply of it, as long as that risk is not high.

Study Limitation

It is worth noting that the convenience sampling approach we used, while resulting in significant overlap with national socio-demographics did have an over-representation of

[3] 2015 average monthly real income per capita in Puno was US$ 182, in comparison to US$ 233 in Cusco, and US$ 374 in Metropolitan Lima (INEI, 2017), based on a 2015 exchange rate of USD1 = New Peruvian Soles 3.186.

post-secondary educated respondents along with an underrepresentation of those earning less than a minimum wage. This may have resulted in an upward bias of the stated benefits (including, albeit common in stated preference studies, because of aggregating based on all households in the study regions), leading to the results needing cautious interpretation. By contrast, our conservative WTP calculations do not account for potential service purchasers from other parts of Peru and elsewhere, nor do they account for the value of the personal ecosystem service benefits that would be generated and accrue to farmers under a conservation programme. The overall impact on the estimated total benefits is therefore ambiguous.

Conclusions

Megadiverse countries such as Peru are ideally placed to implement agrobiodiversity conservation strategies while both a rich range of genetic resources and accompanying traditional knowledge still exist (unlike in the Global North. In the case of quinoa diversity, the public revealed support for conservation, having the highest willingness to pay for securing bequest/existence and option values, followed closely by stable landscape conservation. Framing had an important influence on willingness-to-pay (suggesting the importance of public-awareness campaign articulation), as did distance from the quinoa diversity hotspot of Puno (suggesting the importance of targeting people in other regions too). Aggregated total economic value across the study region was found to be equivalent to just over a quarter of the market value of annual Peruvian quinoa production. The existence of such significant non-market ecosystem service values also results in a positive benefit-cost ratio for conservation intervention, which can consequently be used as an argument to justify and inform the allocation of government funds and private donations.

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Data Availability Anonymised survey data are available from the authors upon request.

Declarations

Ethical Approval and Consent to Participate Survey participants agreed to participate in interviews.

Consent for Publication The results obtained are published with the consent of the survey participants.

Competing Interests The authors declare no competing interests.

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