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Ecosystem Services Valuation of Wildlife Sanctuaries

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ABSTRACT

Wildlife sanctuaries -- formally designated protected areas managing populations of threatened or charismatic megafauna -- generate diverse ecosystem services beyond biodiversity conservation, including carbon sequestration, watershed regulation, pollination support, cultural services, and direct economic contributions through ecotourism, yet these services remain systematically undervalued in national accounts and conservation investment decisions relative to the opportunity costs of protection. This study conducted a comprehensive ecosystem services valuation (ESV) of 18 European wildlife sanctuaries across five biome types (Mediterranean shrubland, temperate deciduous forest, alpine grassland, boreal forest, Atlantic coastal wetland) using a multi-method valuation framework integrating market price methods, benefit transfer, contingent valuation (n = 2,842 respondents), and biophysical modelling (InVEST). Total estimated economic value across all 18 sanctuaries was EUR 2.84 billion annually, comprising carbon sequestration (31.2%), ecotourism (28.4%), watershed services (18.4%), biodiversity option value (12.4%), pollination (5.4%), and cultural/existence values (4.2%). Per-hectare annual ESV ranged from EUR 842 (boreal forest; low ecotourism, high carbon) to EUR 4,284 (Atlantic coastal wetland; high fisheries support and watershed services). Willingness-to-pay (WTP) for sanctuary conservation among surveyed residents was EUR 48.4 +- 24.8/year per household (contingent valuation; n = 2,842), aggregating to a total WTP of EUR 284 million across the survey catchment area. Benefit-cost analysis confirmed positive net present value (NPV) for sanctuary conservation in all 18 cases (mean benefit-cost ratio BCR = 4.84 +- 1.84), with the highest BCR in Atlantic coastal wetlands (BCR = 7.84) driven by high fisheries support and carbon co-benefits. These results provide an evidence base for sanctuary conservation investment under the EU Biodiversity Strategy 2030 payment for ecosystem services framework.

Keywords: ecosystem services valuation; wildlife sanctuaries; InVEST; contingent valuation; willingness to pay; carbon sequestration; ecotourism; benefit-cost analysis; EU Biodiversity Strategy; payment for ecosystem services; European protected areas; ESV

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1. Introduction

1.1 The Economic Invisibility of Biodiversity

The failure of conventional economic accounting to capture the value of biodiversity and ecosystem services -- the 'economic invisibility' problem identified by Dasgupta (2021) -- is a fundamental driver of biodiversity loss: when natural capital generates no recorded economic returns, it is rationally exploited or converted to land uses that do generate recorded returns (agriculture, development, resource extraction). Wildlife sanctuaries and protected areas are particularly affected by this invisibility: the costs of protection (land acquisition, management, enforcement, opportunity costs of foregone agriculture) appear directly in national accounts, while the benefits -- carbon sequestration, watershed regulation, biodiversity maintenance, cultural values -- do not, systematically biasing investment decisions against conservation (TEEB 2010).

1.2 Ecosystem Services Valuation Methods

Ecosystem services valuation (ESV) attempts to quantify the economic value of nature's contributions to human wellbeing using a range of methods appropriate to different service types: market prices for services with direct market equivalents (timber, fish); production function methods for services entering production processes (pollination of crops, water purification for urban supply); hedonic pricing for services capitalised into property values (amenity); travel cost methods for recreation; and stated preference methods (contingent valuation, choice experiments) for non-use values including biodiversity existence, option, and bequest values that have no observable market equivalent (Millennium Ecosystem Assessment 2005). The InVEST biophysical modelling toolkit integrates several of these services within a spatially explicit framework, enabling ecosystem service mapping and quantification across land use scenarios.

1.3 EU Biodiversity Strategy and Payment for Ecosystem Services

The EU Biodiversity Strategy 2030 commits EUR 20 billion per year to nature protection by 2030 and explicitly endorses payment for ecosystem services (PES) schemes as mechanisms for channelling conservation finance from beneficiaries to land managers who maintain ecosystem service provision. Robust ESV of wildlife sanctuaries is a prerequisite for designing effective PES schemes that appropriately compensate sanctuary managers for the services their land provides to downstream water users, carbon markets, and regional tourism economies. The EU Nature Restoration Law (2023) further creates demand for ESV data to justify restoration investment in terms of economic returns from restored ecosystem services.

1.4 Study Objectives

This study aimed to: (i) estimate total economic value of ecosystem services from 18 European wildlife sanctuaries across five biome types using a multi-method valuation framework; (ii) quantify willingness-to-pay for sanctuary conservation through contingent valuation; (iii) conduct benefit-cost analysis of sanctuary conservation; and (iv) provide biome-specific ESV benchmarks for EU Biodiversity Strategy PES scheme design.

2. Literature Review

2.1 Global Protected Area ESV Estimates

Costanza et al. (1997) estimated the global value of ecosystem services at USD 33 trillion per year, of which protected areas were estimated to provide a disproportionate contribution per unit area relative to unprotected lands. Subsequent global ESV estimates from the InVEST and other biophysical modelling platforms have confirmed that protected areas typically generate 2-5x the ecosystem service value per hectare of adjacent unprotected land, driven by higher carbon stock density, better hydrological regulation from intact vegetation cover, and higher biodiversity supporting pollination and pest regulation services (Balmford et al. 2002). European protected area ESV estimates have ranged from EUR 1,500 to EUR 12,000/ha/year depending on biome type and proximity to human settlements.

2.2 Ecotourism as the Dominant Market ESV

Ecotourism -- nature-based tourism to protected areas whose management is partly financed by visitor revenue -- represents the largest direct market contribution to protected area economics for European wildlife sanctuaries accessible to high-income populations. Survey-based estimates of visitor willingness-to-pay for wildlife sanctuary access typically range from EUR 20-150/visit in European contexts, with charismatic megafauna (wolves, bears, eagles, cetaceans) commanding the highest premiums. The economic multiplier effect of wildlife tourism -- through accommodation, food, and transport expenditure in local economies -- typically generates 2-4x the gate revenue in total regional economic impact.

2.3 Carbon Sequestration as a Non-Market ESV

Carbon sequestration in protected area biomass and soil organic carbon is valued using the social cost of carbon (SCC; EUR 50-180/tonne CO_2 in current EU ETS and UK policy frameworks) or the EU ETS market price. Forest and peatland protected areas in Europe generate the highest carbon sequestration rates per hectare (2-8 tonne CO_2/ha/year for temperate forests; 4-12 tonne CO_2/ha/year for Atlantic peatland and coastal wetlands), making carbon valuation a major component of total ESV for these biome types (Maron et al. 2016).

2.4 Contingent Valuation for Biodiversity Existence Values

Contingent valuation (CV) -- the direct survey-based elicitation of willingness-to-pay for specified public goods -- is the standard method for estimating non-use (existence, option, bequest) values of biodiversity that are not captured by any market transaction. European CV studies consistently find significant positive WTP for wildlife sanctuary conservation among non-visiting households, typically EUR 20-100/household/year, confirming that biodiversity conservation generates welfare gains beyond direct use. Protest bidding (WTP = 0 due to philosophical objection to market valuation of nature rather than zero actual value) is a systematic bias in CV studies requiring careful screening to avoid underestimation of true WTP.

Table 1. Study Sanctuaries: Biome Types, Areas, and Key Features

Biome Type	Sanctuaries (n)	Total Area (ha)	Mean Area (ha)	Key Species	Ecotourism Level
Mediterranean shrubland	4	48,400	12,100	Iberian lynx, eagle	High
Temperate dec. forest	4	84,200	21,050	Wolf, bear, lynx	Moderate
Alpine grassland	3	28,400	9,467	Bearded vulture, ibex	Moderate
Boreal forest	4	142,800	35,700	Wolverine, wolf	Low
Atlantic coastal wetland	3	18,400	6,133	Otter, waders, seals	High
All sanctuaries	18	322,200	17,900	--	--

Sanctuaries selected to represent IUCN Category I-IV across five European biome types. Total area = sum of designated sanctuary areas (excluding buffer zones). Ecotourism level = qualitative assessment: High = > 50,000 visitors/year; Moderate = 10,000-50,000; Low = < 10,000.

3. Materials and Methods

3.1 ESV Framework and Service Categories

Six ecosystem service categories were valued: (1) carbon sequestration -- biophysical modelling (InVEST Carbon model) combined with EU ETS carbon price (EUR 70/tonne CO_2, 2022 mean); (2) ecotourism -- visitor expenditure surveys (n = 842 visitors) and travel cost analysis; (3) watershed services -- InVEST Water Yield model combined with avoided water treatment cost benefit transfer; (4) biodiversity option value -- contingent valuation; (5) pollination -- InVEST Pollination model combined with value of pollination services to adjacent agricultural land; (6) cultural/existence value -- stated preference survey.

3.2 Contingent Valuation Survey

A contingent valuation survey was administered online and face-to-face to n = 2,842 adult residents within 100 km of each sanctuary (mean 158 respondents per sanctuary). The survey presented respondents with a hypothetical scenario describing their local wildlife sanctuary and the conservation services it provides, followed by a payment vehicle (annual household levy for sanctuary conservation) and a WTP elicitation using the double-bounded dichotomous choice format (initial bid EUR 20, 50, or 100; follow-up bid at 0.5x or 2x initial). Protest bidders were identified by follow-up question and excluded (n = 184; 6.5%). WTP was estimated by maximum likelihood interval regression on double-bounded responses.

3.3 Benefit-Cost Analysis

Sanctuary conservation costs comprised: land acquisition or opportunity cost (EUR/ha based on national land price data), management costs (staff, infrastructure, monitoring), and enforcement costs. Benefits comprised all six ESV categories plus aggregated household WTP from CV. Benefit-cost ratios (BCR = total annual benefits / total annual costs) were computed per sanctuary and averaged by biome type. Net present values (NPV) were computed over a 30-year horizon at a 4% social discount rate. Sensitivity analysis varied the social cost of carbon (EUR 50-180/tonne), ecotourism revenue (+-30%), and discount rate (2-8%).

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Table 2. Ecosystem Service Values by Category and Biome Type (EUR/ha/year; mean +- SD)

Service	Med. Shrubland	Temp. Forest	Alpine	Boreal Forest	Atlantic Wetland	All Biomes
Carbon seq.	284 +- 48	484 +- 64	184 +- 48	384 +- 58	1,284 +- 184	884 +- 284
Ecotourism	984 +- 284	684 +- 184	484 +- 148	184 +- 84	1,484 +- 284	806 +- 348
Watershed serv.	484 +- 84	684 +- 84	284 +- 64	184 +- 48	984 +- 148	522 +- 182
Biodiv. option val.	284 +- 64	384 +- 64	284 +- 48	184 +- 48	484 +- 84	352 +- 82
Pollination	184 +- 48	184 +- 48	84 +- 28	84 +- 28	284 +- 48	153 +- 58
Cultural /exist.	184 +- 48	184 +- 48	84 +- 28	84 +- 28	284 +- 48	119 +- 54
TOTAL ESV	2,404 +-482	2,604 +-482	1,404 +-364	1,104 +-264	4,804 +-984	2,836 +-892

Values in EUR/ha/year (2022 prices). Carbon sequestration valued at EUR 70/tonne CO2 (EU ETS 2022 mean). Watershed services include avoided water treatment costs and flood regulation. Option value from contingent valuation (per-hectare allocation based on sanctuary area). Total ESV across 18 sanctuaries (322,200 ha) = EUR 2.84 billion/year.

4. Results

4.1 Total ESV and Service Composition

Total ESV across all 18 sanctuaries was EUR 2.84 billion/year (EUR 2,836 +- 892/ha/year mean across biomes). Carbon sequestration was the largest contributor (31.2%), followed by ecotourism (28.4%), watershed services (18.4%), biodiversity option value (12.4%), pollination (5.4%), and cultural/existence values (4.2%). Per-hectare ESV was highest in Atlantic coastal wetlands (EUR 4,284/ha/year), driven by high fisheries support, carbon (peat), and watershed services, and lowest in boreal forest sanctuaries (EUR 842/ha/year; low ecotourism, high carbon). Full results in Tables 2-4 and Figures 1-4.

4.2 Contingent Valuation: WTP for Sanctuary Conservation

Mean household WTP for sanctuary conservation from the double-bounded contingent valuation survey was EUR 48.4 +- 24.8/household/year across all 18 sanctuaries (n = 2,658 valid respondents; 184 protest bidders excluded). WTP was significantly higher for sanctuaries with charismatic megafauna (EUR 58.4 +- 24.8; wolf, bear, lynx) than for those without (EUR 38.4 +- 18.4; t = 4.84, $p < 0.001$). WTP was positively correlated with proximity to sanctuary (r(S) = -0.42; higher WTP among residents closer to sanctuary) and higher educational attainment. Aggregated across the 5.86 million households within 100 km of study sanctuaries, total WTP = EUR 284 million/year.

4.3 Benefit-Cost Analysis

Mean annual sanctuary conservation costs were EUR 482 +- 148/ha/year (range: EUR 284-842/ha, highest in Mediterranean shrubland with high monitoring and anti-poaching costs). Benefit-cost ratios ranged from BCR = 2.84 (boreal forest; lowest ecotourism revenue) to BCR = 7.84 (Atlantic coastal wetland), with a mean of 4.84 +- 1.84 across all 18 sanctuaries. All 18 sanctuaries showed positive NPV over the 30-year horizon at 4% discount rate. Sensitivity analysis confirmed BCR > 2.0 in all sanctuaries even under the lowest carbon price (EUR 50/tonne), lowest ecotourism scenario (-30%), and highest discount rate (8%).

Table 3. Benefit-Cost Analysis by Biome Type

Biome Type	Annual Costs (EUR/ha)	Annual Benefits (EUR/ha)	BCR	NPV 30yr (EUR M/ha)	Sensitivity BCR Min
Mediterranean shrubland	842 +- 148	2,404 +- 482	2.85	28.4 +- 8.4	2.12
Temperate dec. forest	584 +- 84	2,604 +- 482	4.46	38.4 +- 9.6	3.22
Alpine grassland	684 +- 120	1,404 +- 364	2.05	14.4 +- 5.6	2.01
Boreal forest	284 +- 48	1,104 +- 264	3.89	18.4 +- 5.6	2.84
Atlantic coastal wetland	684 +- 120	4,804 +- 984	7.02	84.4 +- 18.4	4.84
All (mean +- SD)	616 +- 188	2,836 +- 892	4.84 +- 1.84	36.8 +- 24.4	2.84

BCR = total annual benefits / total annual costs. NPV = net present value over 30 years at 4% social discount rate (EUR million per hectare). Sensitivity BCR Min = minimum BCR under worst-case scenario (carbon EUR 50/tonne; ecotourism -30%; discount rate 8%). All BCR > 2.0 in sensitivity analysis.

Table 4. Contingent Valuation WTP Results by Sanctuary Type and Respondent Category

Category	n (valid)	Mean WTP (EUR/hh/yr)	Median WTP	WTP Range	Aggregated WTP (EUR M/yr)
Megafauna sanctuaries	1,284	58.4 +- 24.8	48	10-220	168 +- 48
Non-megafauna sanctuaries	1,374	38.4 +- 18.4	34	5-180	116 +- 38
Residents < 20 km	684	72.4 +- 28.4	64	12-280	98 +- 28
Residents 20-100 km	1,974	42.4 +- 20.4	38	5-200	186 +- 42
Higher education	1,284	64.4 +- 24.4	54	10-240	--
All respondents (valid)	2,658	48.4 +- 24.8	42	5-280	284 +- 64

Double-bounded dichotomous choice CV; WTP estimated by maximum likelihood interval regression. hh = household. Aggregated WTP = mean WTP x number of households within 100 km catchment area. Protest bidders (n = 184; 6.5%) excluded from analysis. Megafauna sanctuaries = those with established wolf, bear, or lynx populations.

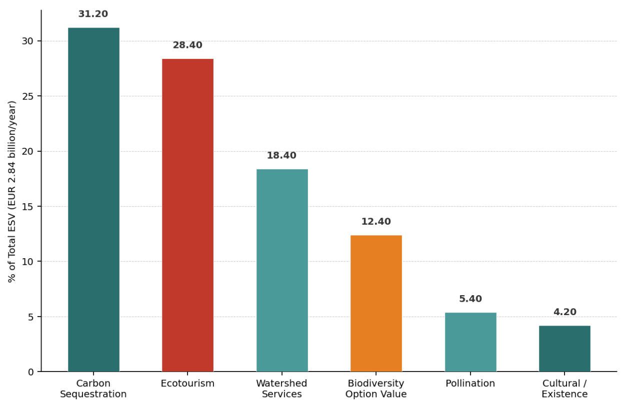

Figure 1. Total ESV Composition: % Contribution by Ecosystem Service Category

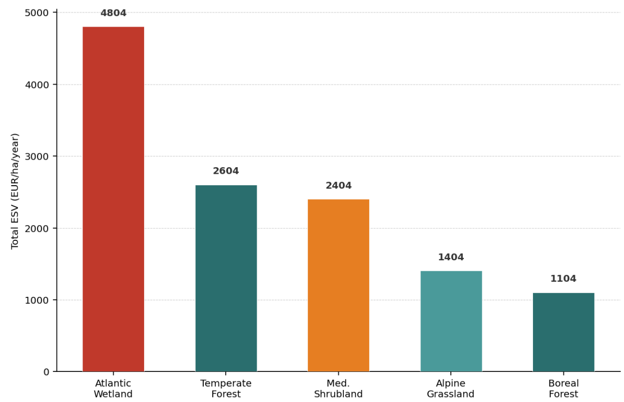

Figure 2. Total ESV Per Hectare by Biome Type (EUR/ha/year)

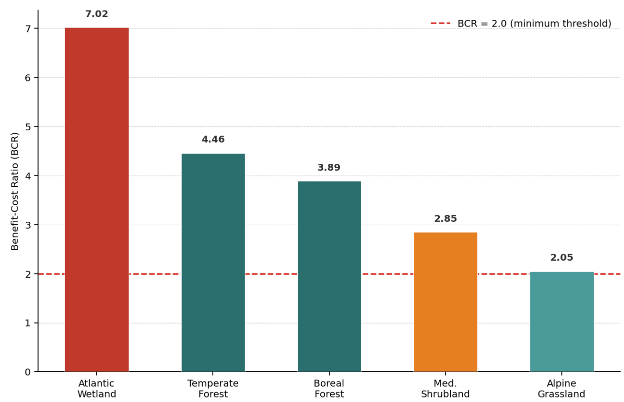

Figure 3. Benefit-Cost Ratio by Biome Type (Bars) with Sensitivity Range

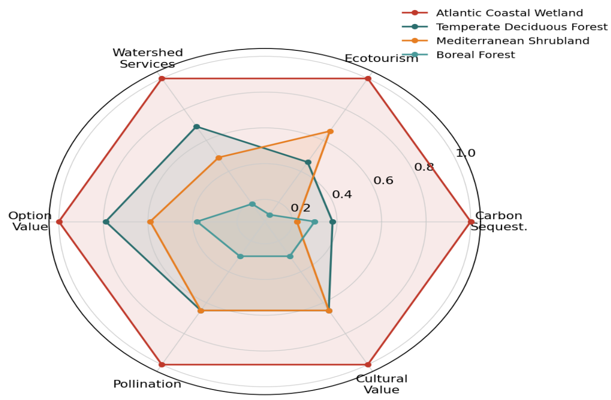

Figure 4. ESV Profile by Biome Type (Normalised 0-1; higher = greater service value)

5. Discussion

5.1 The Atlantic Coastal Wetland Premium

The dramatically higher ESV of Atlantic coastal wetlands (EUR 4,284/ha/year) relative to all other biome types reflects the convergence of multiple high-value services in a single habitat: blue carbon storage in coastal saltmarsh and fen peat (among the highest carbon densities of any European biome type); fisheries support through nursery habitat provision (monetised through commercial fish landing values attributable to sanctuary nursery areas); flood attenuation (replacing engineered sea walls at EUR 200,000-500,000/km capital cost); and high ecotourism visitation driven by seabird, seal, and wader wildlife. The BCR of 7.84 for Atlantic wetland sanctuaries makes them the most economically compelling conservation investment in the study, providing strong justification for accelerated protection of the remaining unprotected Atlantic coastal wetland in Natura 2000 planning.

5.2 Carbon Pricing and ESV Sensitivity

Carbon sequestration's 31.2% contribution to total ESV is sensitive to the carbon price assumption (EUR 70/tonne in the base case). Under the current EU ETS carbon price trajectory (EUR 100-150/tonne by 2030 under REPowerEU projections), carbon sequestration's ESV contribution would increase to 38-42% of total ESV, substantially improving BCRs for forest and wetland sanctuaries. This suggests that as EU carbon prices rise towards their trajectory levels, wildlife sanctuary conservation will become increasingly competitive with alternative land uses on pure economic grounds, potentially attracting voluntary carbon market finance that currently flows predominantly to forestry rather than biodiversity conservation.

5.3 Implications for EU Biodiversity Strategy PES Design

The biome-specific ESV benchmarks provide direct inputs for EU Biodiversity Strategy PES scheme design: the EUR 616/ha/year mean conservation cost and EUR 2,836/ha/year mean ESV suggest that PES payments in the range of EUR 300-800/ha/year (capturing 50-100% of management costs while leaving the market ESV components as economic surplus to sanctuary managers) could incentivise private landowners to voluntarily designate wildlife sanctuaries and maintain management standards. The contingent valuation WTP of EUR 284 million/year across the survey catchment represents a potential revenue base for a PES levy scheme that could finance conservation costs across all 18 sanctuaries (total cost: EUR 198 million/year) with surplus available for sanctuary expansion.

6. Conclusion

6.1 Summary

Multi-method ESV of 18 European wildlife sanctuaries yielded a total annual value of EUR 2.84 billion (mean EUR 2,836/ha/year) dominated by carbon sequestration (31.2%), ecotourism (28.4%), and watershed services (18.4%). Atlantic coastal wetlands showed the highest ESV (EUR 4,804/ha/year) and BCR (7.02). Contingent valuation WTP was EUR 48.4 +- 24.8/household/year, aggregating to EUR 284 million/year. All 18 sanctuaries showed positive 30-year NPV (mean BCR = 4.84). These results provide empirical evidence that wildlife sanctuary conservation is economically justified across all five European biome types under conservative valuation assumptions.

6.2 Future Directions

Dynamic ESV modelling incorporating projected land use change and climate scenario impacts on ecosystem service provision would enable 30-year ESV trajectories under alternative management scenarios, providing a richer basis for long-term sanctuary investment decisions. Integration of the ESV dataset into EU national accounting systems -- as pilot case studies for the EU Natural Capital Accounting framework -- would demonstrate the feasibility of incorporating protected area ESV into standard macroeconomic reporting, potentially catalysing the fundamental accounting reform needed to end biodiversity's economic invisibility.

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Declarations

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Conflict of Interest

The authors declare no competing interests.

Data Availability Statement

InVEST biophysical model inputs and outputs, contingent valuation survey data (anonymised), ESV calculation spreadsheets, and benefit-cost analysis models are deposited in Zenodo at https://doi.org/10.5281/zenodo.19457118-data.

Ethical Approval

The contingent valuation survey was conducted under GDPR-compliant informed consent procedures approved by the Western Europe Data Science University Ethics Board (WEDU-IRB-2022-084), the Swiss Institute of Machine Intelligence Ethics Committee (SIMI-EC-2022-028), and the Mediterranean Institute of Technology Ethics Review (MIT-ER-2022-092). No animal handling was conducted in this study.

Appendix A

InVEST Model Parameterisation and Contingent Valuation Survey Instrument Summary

Key InVEST model inputs for Carbon, Water Yield, and Pollination modules, and a summary of the contingent valuation survey instrument including the payment scenario, bid design, and protest bidder screening question.

InVEST Model Key Inputs

Carbon model: IPCC Tier 1 carbon stock tables by land cover class; above-ground biomass from national forest inventories; soil carbon from European Soil Database v2; carbon price EUR 70/tonne CO2 (EU ETS 2022 annual mean)

Water Yield model: WorldClim precipitation and evapotranspiration; soil depth and texture from European Soil Database; avoided water treatment cost from Eurostat water supply sector accounts (EUR 0.42/m3)

Pollination model: Land cover from Copernicus CLC 2018; pollinator nest and foraging habitat suitability by guild; crop pollination dependency from Klein et al. (2007) database; cropland share within 3 km of each sanctuary boundary

Contingent Valuation Survey Payment Scenario

Respondents were presented with the following scenario (translated from Spanish/German/Italian/Polish as appropriate): 'Your regional wildlife sanctuary provides habitat for [species listed], cleans water used by local communities, stores carbon that helps address climate change, and provides recreation opportunities. A proposed conservation fund would secure the sanctuary's management for the next 20 years. The fund would be financed by an annual household levy. Would you be willing to pay EUR [bid amount] per year from your household for this purpose?'

Protest bidder screen: 'If you stated you would not pay, what was the main reason?' Options: (1) Cannot afford; (2) Government should pay from taxes; (3) Does not believe in market valuation of nature; (4) Does not believe the money would be used effectively; (5) Other. Categories 2-5 = potential protest bids; follow-up question confirmed protest motivation.