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Soukaina Anougmar

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Economics of pollination in drylands: Farmers' and consumers' perspectives in a middle-income country

Présentée par Soukaina ANOUGMAR

Le 16 Décembre 2021

**Sous la direction de
Jean-Michel Salles
et
Nicola Gallai**

Devant le jury composé de

Michael Christie, Professor of Environmental and Ecological Economics, Aberystwyth Business School

Arnaud Reynaud, Directeur de recherche INRAE, Directeur TSE-R

Nicholas Hanley, Professor of Environmental and One Health Economics, University of Glasgow

Lauriane Mouysset, Chargée de recherche CNRS, UMR CIREN

Sophie Thoyer, Cheffe de Département adjointe EcoSocio INRAE, UMR CEE-M

Stefanie Christmann, Senior Scientist, ICARDA Morocco

Nicola Gallai, Maître de conférence en sciences économiques, ENSFEA de Toulouse

Jean Michel Salles, Directeur de recherche CNRS, UMR CEE-M

Rapporteur

Rapporteur

Examineur

Examineur

Examineur

Guest

Supervisor

Supervisor



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*Dedicated to my parents, Najat
and Es-Seddik Anougmar.*

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LONG ABSTRACT

Pollinating insects represent an essential factor for the production of $\frac{3}{4}$ of major food crops and thus are very important to food security. These species are necessary ecological agents for natural ecosystems, which provide many ecosystem services (ES) to societies. Pollinators are facing severe declines worldwide, primarily because of human practices and climate change (CC). Pollinator decline can impact farmers' and consumers' welfare worldwide. Yet, this decline will have heavier impacts on farmers and consumers in dry low- and middle-income countries (LIC and MIC) than those in high-income countries (HIC). In these countries, farmers are increasingly using pollinator-dependent crops because they provide a better income per surface and water unit. Thus, the decline of pollinators will severely impact their income and livelihoods. In many dry LIC and MIC, consumers are exposed to nutritional insufficiencies. Therefore, pollinator decline will have strong effects on their food security. Additionally, both farmers and consumers in LIC and MIC use ES derived from insect pollination as an additional source of income.

Worldwide, efforts for the protection of insect pollination are still insufficient. The protection of these species from human practices should be based on changes in human behavior. These changes can also mitigate the impact of CC on pollinators. Over the last decade, many HIC have engaged in national and regional strategies to protect pollinators. Yet, in many cases, interventions within these strategies were deemed inefficient because they fail to account for individuals' preferences which can be a good determinant of behavioral change. In LIC and MIC in the drylands, efforts for the protection of pollinators are almost inexistent. Governments in these countries still need to acknowledge insect pollination as a threatened ecosystem service that highly contributes to farmers' and consumers' economic welfare. The economic assessment of the contribution of insect pollination to the well-being of farmers and consumers can serve as an additional argument to support the protection of pollinators in these countries. The design of efficient strategies for these countries requires the analysis of preferences of both farmers and consumers for the benefits of insect pollination. We conduct a double discrete choice experiment (DCE) to a) analyze farmers' and consumers' preferences for the benefits of insect pollination, b) assess values they derive from these species, and c) use the DCE results to suggest policy recommendations for the protection of insect pollinators in dry LIC and MIC. To achieve these objectives, we chose Morocco as our benchmark site. Morocco is a dry MIC

where pollinators are threatened severely by farming and consumption practices and CC. Another important aim of this Ph.D. thesis is to study the impact of aridity on farmers' and consumers' economic preferences to help mitigate the impacts of CC on these species using behavioral change strategies. In dry LIC and MIC, aridity can be an essential factor influencing economic preferences, and the increase in aridity levels can be an indicator of CC. Therefore, the survey takes place in 5 bioclimatic regions with varying levels of aridity within the Moroccan territory with 492 farmers and 481 consumers.

We find that both farmers and consumers highly value the benefits they derive from insect pollination. We demonstrate that aridity strongly affects farmers' and consumers' preferences for the benefits of insect pollination. Farmers' and consumers' willingness to pay (WTP) is positively related to the aridity level. Farmers' and consumers' living in regions with high aridity levels expressed a high WTP for protecting the benefits of insect pollination. We anticipate an increase in the value that farmers and consumers attribute to the benefits of pollinators following an increase in aridity levels due to CC. We show that some categories of farmers and consumers are more likely than others to engage in pro-pollinator behaviors, highlighting the importance of using targeted interventions to achieve behavioral changes. Therefore, we can build on these results to make targeted policy recommendations to achieve behavioral changes in favor of insect pollination for both farmers and consumers.

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LIST OF ACRONYMS

AI: Aridity index

AIC: Akaike information criterion

ASC: Alternative specific constant

BIC: Bayesian information criterion

CA: Conjoint analysis

CAIC: Consistent Akaike information criterion

CBD: Convention on biological diversity

CLM: Conditional logit model

CVM: Contingent valuation method

DC: Dichotomous choice

DCE: Discrete choice experiment

ES: Ecosystem Services

EU: European union

EV1: Extreme value distribution

FAO: Food and agriculture organization

FAP: Farming with alternative pollinators

INRA: Institut National de Recherche Agricole

IPBES: Intergovernmental platform on biodiversity and ecosystem services

IPCC: Intergovernmental Panel on Climate Change

IPI: International pollinator initiative

LCM: Latent class model

GMNL: Generalized multinomial logit

HIC: High Income Country

HPM: Hedonic prices model

LIC: Low income country

MEA: Millennium ecosystem assessment

MIC: Middle income country

MLM: Mixed logit model

MOA: Ministry of agriculture

NLM: Nested logit model
NOAA: National oceanic and atmospheric administration
OE: Open-ended
ONCA: Office National de Conseil Agricole
P: Precipitation
PC: Payment card
PET: Potential evapotranspiration
RPM: Random Parameter Model
RUM: Random utility models
SPM: Stated preferences methods
TCM: Travel cost method
TEEB: The economics of ecosystems and biodiversity
UN: United Nations
UNEP: UN environment program
WTA: Willingness to accept
WTP: Willingness To Pay
WTR: Willingness to receive
WTV: Willingness to volunteer
WTW: Willingness to work

INTRODUCTION

Biodiversity supports a range of ecosystems services (ES) which are essential for human existence and good quality of life (IPBES, 2019a). These services refer to the benefits people derive from ecosystems (De Groot *et al.*, 2002; MEA, 2005). The MEA (2005) classified ES into provisioning services (e.g., food, fiber, genetic resource), regulating services (e.g., climate regulation, water regulation, pollination), cultural services (e.g., aesthetic values, recreation, spiritual values), and supporting services (e.g., nutrient cycling, soil formation). ES are threatened in many parts of the world mainly because of economic and demographic growths, land-use change, and CC (MEA, 2005; TEEB, 2010).

In drylands, economies and people's livelihoods are highly vulnerable to the loss of ES (MEA, 2005; CBD, 2010). Drylands are land areas that receive relatively low overall amounts of precipitation in rainfall or snow. These lands are defined based on their aridity index (AI). AI refers to the ratio between average annual precipitation and total annual potential evapotranspiration. Based on AI, drylands can be subdivided into hyper-arid deserts (<0.5 AI), arid lands (0.05–0.20 AI), semi-arid lands (0.20–0.50 AI), and dry sub-humid lands (0.50–0.65 AI) (UNEP, 1993). Drylands cover approximately 40% of the world's land area and support two billion people, 90% of whom live in LIC and MIC (UN, 2011). In these countries, ES help populations generate additional income and mitigate the impacts of drought and extreme weather conditions on their well-being (IPBES-IPCC, 2021). Thus, the loss of ES will presumably have more rapid and severe impacts on populations in dry LIC and MIC (MEA, 2005; CBD, 2010). The conservation of biodiversity in these countries should be a priority (Ashworth *et al.*, 2009; Davies *et al.*, 2012).

Understanding and valuing the benefits that vulnerable populations derive from ES can help develop policies to conserve biodiversity and support people's livelihoods in dry LIC and MIC (Christie *et al.*, 2012). Therefore, economic valuation of ES might be used as an important tool to account for biodiversity in private and public decision-making processes and guide the development of conservation policies that protect biodiversity and alleviate poverty (Section 1.1) (CBD, 2010; TEEB, 2010, 2011a, 2011b). Over the past few decades, environmental and ecological economists have developed various methods to assess values that people derive from ES (Section 1.3). These methods can be categorized into "Non-demand

curve approaches" and "Demand curve approaches". Non-demand curve approaches are based on the assumption that people endure costs to replace ES or to avoid damages caused by their loss; the most used non-demand curve method for environmental valuation is the replacement cost method (RCM) (Damigos, 2006; IPBES, 2016). These approaches were mainly criticized for being based on market prices and costs (IPBES, 2016) which usually fail to represent the true value of environmental assets and services (Hanley *et al.*, 2007). Thus, economists have developed a range of techniques, so-called "Demand curve approaches," to value nonmarket environmental amenities (Carson, 2000). These approaches are based on individual economic preferences, which refer to individual differences in people's tendencies to take risks, delay outcomes, and act pro-socially (DellaVigna, 2018). In demand curve approaches, preferences can be indirectly elicited from people's observed behavior toward some marketed goods connected to the environmental asset/service of interest (revealed preferences). Economic preferences can also be expressed for the environmental asset/service itself using stated preferences approaches, contingent valuation method (CVM) and discrete choice modeling (DCM). The use of revealed and stated preference approaches depends on the environmental asset or service of interest. Revealed preferences approaches are not theoretically applicable to all ES contrarily to stated preferences approaches (Hanley *et al.*, 2007). Not many valuations of biodiversity and ES have been conducted in LIC and MIC (van Beukering *et al.*, 2007; Ninan and Kontoleon, 2016; Tibesigwa *et al.*, 2020; Barbier *et al.*, 2021). The limited financial means of governments (May, 1998) and their lack of technical capacity to conduct complex valuation studies (Christie, 2012; Christie *et al.*, 2012) explain the shortage in biodiversity assessments in LIC and MIC.

Insect pollination is an important regulation ecosystem service threatened worldwide because of the severe declines facing insect pollinators (section2). These declines are either driven by anthropogenic practices or/and CC (Potts *et al.*, 2010). Though clear evidence of insect pollinator decline has not been established in most LIC and MIC, the threats to pollinators are real. Indicators such as biodiversity loss (IPBES, 2019) and the decline of vertebrate pollinators (Rasmont *et al.*, 2015) show the severe threats facing pollinators in these parts of the world. Archer *et al.* (2014) linked the lack of evidence on pollinator decline in LIC and MIC to the shortage of documentation and studies on pollination in these countries.

Insect pollination is a vital ecological process to human well-being (IPBES, 2016). People's utility function for insect pollination is based on the benefits they derive from pollinators (Hanley *et al.*, 2015). There is, however, a difference in the benefits that farmers and consumers derive from insect pollination. For farmers, insect pollination is a mandatory production factor for pollinator-dependent crops, representing more than $\frac{3}{4}$ of major food crops (Klein *et al.*, 2007). It enhances the quality and quantity of yields of these crops and hence farmers' income (Garibaldi *et al.*, 2014; Christmann *et al.* 2021b). Insect pollination plays a key role in food security (Anderson and Vasiliev, 2021). It is also important for maintaining biodiversity and other ES from which consumers derive multiple benefits (Allen-Wardell *et al.*, 1998; IPBES, 2016).

The economic contribution of pollinators to crop production, food security, and human well-being was highlighted by many studies. However, these studies were mostly based in developed countries (Mwebaze *et al.*, 2010; Steward *et al.*, 2014; Breeze *et al.*, 2015; Breeze *et al.*, 2016; Mwebaze *et al.*, 2018). In dry LIC and MIC, especially those located in Africa and West Asia, economies and people's livelihoods are highly vulnerable to insect pollinator decline because of their growing dependence on these species (Potts *et al.*, 2016; Silva *et al.*, 2021). In these countries, because of dry climates, farmers are constantly switching to pollinator-dependent crops because they require less water compared to non-pollinator-dependent crops and provide higher income per surface unit (Ashworth *et al.*, 2009; Christmann, 2020a). Pollinator decline will, thus, impact the subsistence of farmers within these countries, especially smallholders, who rely directly on pollinators for the production of commodity crops (Cely-Santos and Lu, 2019). LIC and MIC gather more than 2 billion smallholder farmers, representing 83% of the world's agricultural population (Steward *et al.*, 2014). Most smallholders in these countries practice traditional family agriculture based on diversified cropping systems (Cely-Santos and Lu, 2019). Therefore, they will likely be the first to endure the impacts of pollinator decline. Pollinator-dependent crops supply major micronutrients to consumers (Smith *et al.*, 2015). Pollinator decline could, thus, lead to micronutrient deficiencies which would result in severe impacts on the human health and well-being of populations worldwide (Smith *et al.*, 2015; IPBES, 2016). These deficiencies will presumably have a higher impact on populations in LIC and MIC, which already suffer food and nutrient shortages because of demographic growth and global changes (Gilland, 2002 ; Eilers *et al.*, 2011), especially in drylands (UN, 2011). Supplementation of the essential micronutrients could be an alternative to avoid deficiencies in some countries (e.g., US and China). However, in dry LIC and MIC, where micronutrient

deficiency diseases are more likely to happen (Chaplin-Kramer *et al.*, 2014; IPCC, 2020), supplementation is not an option because of the limited access in these countries to such commodities (Cely-Santos and Lu, 2019). For many poor, vulnerable populations in dry LIC and MIC, ES depending on insect pollination, also represent an additional source of income (Allen-Wardell *et al.*, 1998; MEA, 2005; IPCC, 2020).

Despite the significant contribution of insect pollinators to farmers' and consumers' livelihoods, subsistence, and well-being, the conservation of pollinators in LIC and MIC in drylands is still overlooked by decision-makers (Cely-Santos and Lu, 2019; Christmann, 2019b). Most of the current strategies and initiatives are in HIC (FAO, 2021). These strategies focus mostly on incentives (subsidies, donations, etc.) (Christmann, 2019b). However, governments in LIC and MIC cannot afford this type of intervention (Whittington, 1998; Christie *et al.*, 2012; Christmann *et al.*, 2021b). The protection of insect pollinators in these countries requires, thus, the design of self-sustaining cost-effective conservation strategies that fit the particular context of these nations (Christmann, 2019b). As mentioned earlier, endangering behaviors related to the different human practices and the progression of aridity are the main drivers of pollinator decline in dry LIC and MIC. Thus, these conservation strategies should trigger changes in the behavior of both farmers and consumers and mitigate the impacts of aridity on these species.

Achieving pro-environmental behavior can help protect pollinators from endangering anthropogenic practices (Amel *et al.*, 2017; Byerly *et al.*, 2018; Marselle *et al.*, 2020) and mitigate the impacts of climate change (Corral-Verdugo *et al.*, 2020). Pro-environmental behavior requires an understanding of determinants and/or barriers of this behavior (Steg and Vlek, 2009; Byerly *et al.*, 2018; Nisa *et al.*, 2019). Many studies argued that economic preferences could partly drive human behavior. In the past, economic preferences were used to predict a wide range of behaviors, for instance, risk-taking (Dohmen *et al.*, 2011), health outcomes (Anderson and Mellor, 2008) and altruism and charitable giving (DellaVigna *et al.*, 2012). Lades *et al.* (2021) attested that analyzing people's economic preferences for environmental assets/services helps identify determinants and/or barriers to pro-environmental behavior. Therefore, in this context, understanding economic preferences for the benefits of insect pollination might help design behavioral change strategies to protect insect pollination from endangering behaviors and mitigate the impacts of climate change and the progression of aridity on these species. According to the IPCC (2014) report, the different climate ranges in drylands (hyper-arid, arid, semi-arid, and dry sub-humid) will undergo a major shift because of CC. The latter can be an important factor influencing people's preferences for ES and

biodiversity (Shoyama *et al.*, 2013; Khanal *et al.*, 2018). Thus, in this context, it is convenient to analyze farmers' and consumers' preferences for the benefits of insect pollination in different bioclimatic regions in dry LIC and MIC. Accounting for heterogeneity based on aridity levels in farmers' and consumers' preferences will help predict the impact of CC on the value that farmers and consumers attribute to the benefits of insect pollination. Other factors (observed and non-observed) can also influence farmers' and consumers' preferences for the benefits of insect pollination. Consequently, it is important to further explore the heterogeneity in farmers' and consumers' preferences for the benefits of insect pollination to help set a base for conservation and mitigation strategies for protecting insect pollinators in dry LIC and MIC in the dryland.

The objectives of this Ph.D. thesis are, thus, to a) analyze farmers' and consumers' preferences for the benefits of insect pollination, and b) assess the value they express for their protection, using a DCE, to help design conservation/mitigation strategies for the protection of insect pollinators in LIC and MIC in the dryland. In the past, only one study in the UK analyzed people's preferences for the benefits of insect pollination using a DCE (Breeze *et al.*, 2015). This study was conducted in a HIC, did not distinguish between production and consumption patterns related to the services derived from insect pollination, and did not consider climate as an influential factor. Therefore, the transfer of results, in this case, is almost impossible.

The research questions of this Ph.D. thesis are:

- What is the economic value of insect pollination in dry LIC and MIC, and what are its determinants?
- How do aridity and CC affect farmers' preferences for the benefits of insect pollination in dry LIC and MIC?
- How do aridity and CC affect consumers' preferences for the benefits of insect pollination in dry LIC and MIC?
- How does the heterogeneity in preferences of farmers and consumers for insect pollination affect the design of conservation policies in dry LIC and MIC?
- What kind of pollinator conservation measures can be used in dry LIC and MIC?

For this study, we chose Morocco as a benchmark site to represent dry LIC and MIC. Morocco is a dry MIC where pollinators are threatened severely by agricultural intensification and increasing aridity levels. It has been listed as very vulnerable to pollinator decline (Potts *et al.*,

2016). The Moroccan climate gradually goes from a dry sub-humid in the north of the country to a hyper-arid in the south (Trabucco and Zomer, 2019).

The first chapter is devoted to a literature review on environmental valuation and a contextual setting on pollination and insect pollinators and their protection. In the first section of this chapter, we explain the importance of environmental valuation to the conservation of biodiversity and ES. Then we present the different approaches and tools used to value the different components of biodiversity and ES in the past with a special focus on the approach we used in this Ph.D. thesis, the DCE. The second section of this chapter is dedicated to contextual information about pollination, insect pollinators, and a literature review on economic assessments conducted in the past on pollination and pollinators. The last section of this chapter represents a state of the art of past and current pollinator conservation strategies and initiatives worldwide.

The second chapter deals with the economic value of insect pollination for farmers and the impact of aridity and climate change on farmers' sensitivity to pollinator decline. In this chapter we conduct a DCE with 492 farmers in 5 different dry bioclimatic regions within the Moroccan territory. We explore farmers' preferences for insect pollination, examine the impact of aridity on their preferences and the value they attribute to its benefits. We also simulate the impact of CC on farmers' WTP to protect the benefits of insect pollination.

In the third chapter, we use a different design of the DCE with 481 consumers in the same bioclimatic regions. We explore consumers' preferences for the benefits of insect pollination and assess their stated WTP for the protection of these benefits. We assess the potential impact of the level of aridity on consumers' preferences and on the value they attribute to pollinator services. We also predict the impact of the potential shifts in the level of aridity on consumers' WTP.

In the fourth chapter we use the bioeconomic approach (Gallai *et al.*, 2009) to estimate use values of insect pollination and discuss results regarding findings of the second and third chapters.

The fifth chapter highlights the importance of protecting wild pollinators as a public good to help convince policymakers to protect these species and makes concrete policy recommendations for the protection of insect pollinators in dry LIC and MIC. In this chapter,

we use data from both DCE designs with consumers and farmers to analyze unobserved heterogeneity in preferences and define classes within farmers and consumers to help set more targeted policies for the protection of insect pollination.

In the sixth chapter, we put forward a cost-effective self-sustaining approach, Farming with Alternative Pollinators (FAP), providing a method-inherent incentive to motivate farmers to protect pollinators without external rewards. In this chapter, we test the economic profitability of FAP and simulate its capacity to enhance food security and protect natural landscapes in dry LIC and MIC.

Finally, a general summary will resume the findings of this Ph.D. thesis, and supplementary material such as explanatory sheets used for the DCE designs and the questionnaire, etc., will be provided in the appendix section.

**CHAPTER 1 - ENVIRONMENTAL VALUATION AND INSECT
POLLINATION**

1. Valuing ES: Important definitions, conceptual framework, and methods

1.1. Environmental valuation and the conservation of ES

Biodiversity is vital for human existence and good quality of life (Carrus *et al.*, 2015; Sandifer *et al.*, 2015; Bawa *et al.*, 2021). However, it is deteriorating worldwide (IPBES, 2019a). Effective biodiversity conservation requires including its different components in decision-making processes (Rands *et al.*, 2010). As a public asset, biodiversity is the basis for multiple non-rival and non-excludable benefits to humans (Starrett, 2003; Deke, 2008). A monetary measurement of the actual value of these benefits to human well-being is necessary to include biodiversity in decision-making properly (CBD, 2010; TEEB, 2010, 2011a, 2011b). However, markets usually fail to capture the actual value of environmental benefits with a non-rival and non-excludable nature (Costanza *et al.*, 2014). In this case, economic valuation can be an excellent alternative to provide a monetary measurement for environmental public goods and services. This measurement enables and eases the inclusion of costs and benefits of biodiversity into decision-making processes for resource production and consumption (Rands *et al.*, 2010). Economic valuation of environmental assets can, thus, be used to advocate the protection of biodiversity for policymakers (van Beukering *et al.*, 2007). If the costs and benefits of biodiversity are not explicitly included in decision-making, policies will not generate the optimal level of benefits for society (van Beukering *et al.*, 2007). Economic valuation of biodiversity can also justify investments in ecosystem management which can help avoid future restoration costs and enables comparisons of economic welfare between decisions and policies related to biodiversity (Balmford *et al.*, 2002).

Economic valuation of biodiversity is often based on an ecosystem service approach (DEFRA, 2015). This approach is based on biodiversity supporting various ecosystem functions that provide many services to humans. Multiple definitions and classifications were given to ES. The most widely accepted definition of ES is the benefits that humans derive from ecosystems (De Groot *et al.*, 2002; MEA, 2005), either directly or indirectly to improve their quality of life/well-being (TEEB, 2010; Díaz *et al.*, 2015). ES can be classified into provisioning services (e.g., food, fiber, genetic resource), regulating services (e.g., climate regulation, water regulation, pollination), cultural services (e.g., aesthetic values, recreation, spiritual values), and supporting services (e.g., nutrient cycling, soil formation) ((MEA, 2005).

Accounting for ES in cost-benefit analysis and decision-making processes involves summing up all the reasons why ecosystems contribute to social well-being. These reasons can be represented by a number of values that individuals derive from ecosystems. The Total Economic Value (TEV) is an approach that can be used to assess the different values (benefits) derived from ecosystem functions. The TEV of an ecosystem function gathers use, non-values and the option value. Over the years, many methods have been used to assess the different components of the TEV of ecosystem functions.

1.2. The Total Economic Value

The correct monetary measure of the change in social well-being resulting from a difference in the quality or the availability of an environmental asset is based on its TEV (Damigos, 2006). The TEV of an environmental good or service is composed of its direct use values, indirect use values, the option value, and non-use values (existence and bequest values). Direct use values are related to the direct use of the resource (such as the consumption of provisioning and cultural services). Indirect use values are associated with benefits that individuals experience indirectly or as a consequence of the primary function of a given resource (through the contribution of biodiversity to the maintenance of regulation services). The notion of the option value, introduced by Weisbrod (1964), is defined as the price that individuals are willing to pay to conserve an element in view of its possible use in the future. This value displays the characteristics of a risk aversion premium. It refers to all use values (both direct and indirect) that can be realized in the future. The definition of the option value is limited to uncertain benefits; thus, already-ascertained benefits simply postponed for future use are not considered. For non-use values, Krutilla (1967) shed light on their presence, particularly the existence value. The latter refers to the satisfaction an individual gets from knowing that an environmental asset will be preserved (a site, animal species), independently of any personal present or future use. Madariaga and McConnel (1987) associate with existence value any non-use value, or even some types of use-value like “vicarious consumptions” (e.g., viewing videos or TV programs about tropical wildlife or the forest in general). Bequest values, which refer to the satisfaction that individuals derive from knowing that a resource will be preserved for use by successive generations, and altruism values are also non-use values. One of the limits of the TEV approach is that it encompasses values that might overlap. However, the overestimation resulting from the aggregation of all value types will not be too severe in most cases (Torrás, 2000).

1.3. Environmental valuation: Concepts and methods

There are two types of approaches used for environmental valuation: “Non-demand curve” and “Demand curve” approaches (Damigos, 2006; IPBES, 2016). Non-demand curve approaches are mainly based on market prices. The most notorious non-demand curve method used for environmental valuation is the Replacement Cost Method (RCM) (Bojo, 1996 ; Hougner *et al.*, 2006; Notaro and Paletto, 2012; Jackson *et al.*, 2014; Zhao *et al.*, 2021). It relies on finding the cost of replacing a damaged or lost asset and using this cost as a partial proxy or measure of the asset’s value. RCM considers the cost incurred by replacing ES with artificial substitutes. Other non-demand curve methods such as “Damage Avoided Cost Method” (Barth and Döll, 2016; Pascal *et al.*, 2016) and “Productivity Change Cost method” (Balana *et al.*, 2012) are also used for environmental valuation.

One of the main limitations of market price-based approaches is that they do not generate welfare-consistent measures and may reflect only a part of the TEV (IPBES, 2016). Most assets and services derived from biodiversity are not exchanged on the market, and even if they are, market prices usually do not reflect their actual values (Hanley *et al.*, 2007). Thus, economists have developed some techniques, gathered under “Demand curve approaches,” to value nonmarket environmental amenities (Carson, 2000). These techniques are either based on people’s observed behavior (revealed or indirect preferences) toward some marketed goods connected to the environmental amenity of interest or stated preferences expressed for the environmental asset or service to be assessed.

1.3.1. Revealed preferences approaches

Revealed preference methods utilize existing market or experimental data on marketed goods/services to estimate non-marketed goods and services derived from biodiversity and ES (Hanley *et al.*, 2007). The main revealed preferences techniques used repeatedly in literature are the “Travel Cost Method” and “Hedonic prices.”

1.3.1.1. Travel Cost Method (TCM)

Outdoor recreational resource valuation is one of the most prolific areas of TCM applications (Smith and Kaoru, 1990; Shrestha *et al.*, 2002; Zhang *et al.*, 2015; Bertram and Larondelle, 2017; Kipperberg *et al.*, 2019). In TCM, the travel costs of an individual to a specific recreational site (such as public forests, national parks, etc.) depend on multiple variables: the

costs of driving, entrance fees to the site, and potentially the opportunity costs of the time spent traveling to the site.

$$y_i = f(tc_{ij}, tc_{is}, z_i)$$

The number of visits (y_i) is, therefore, a function of travel costs to site j (tc_{ij}), but also costs of travel to other substitute sites (tc_{is}), and individual characteristics of respondent i (z_i).

The basic assumption of the TCM is that the value of a specific site increases with increasing distance. Hence, the further away people live from the site to be valued, the higher the travel costs, and the higher the “price” of the visit. But the further away people live from the site, the greater the probability that a substitute site is available near their home. Substitute sites tend to reduce the value of the actual site (Willis *et al.*, 2012).

There are multiple forms of TCM. The original Zonal Travel Cost Model (ZTCM) was developed by Wood and Trice (1958) and Clawson (1959). It evaluates the recreational benefit in a particular area (zone) by multiplying the average cost of a visit to that area by the total number of visits. One of the limits of ZTCM is that it does not consider the different characteristics of individual visitors, which most likely affect travel expenditure. In more recent literature, the primarily used travel cost models are those based on the number of trips to a site (Christie *et al.*, 2006) and random utility travel cost models, which consider environmental attributes of the sites (Hanley *et al.*, 2002).

One of the main criticisms of TCM is that it only considers use-values related to recreational use and neglects non-use values, the option value, and other use values (Freeman, 2003). Thus, in the case of a complete absence of visits to a site, the marginal utility of the site would be zero. The TCM also assumes that the demand for visiting a specific site for recreational purposes is independent of the demand for other leisure activities or alternative marketed non-leisure goods (Hanley and Barbier, 2009).

1.3.1.2. Hedonic prices

The theoretical framework of the Hedonic Price Model (HPM) was first defined by Rosen (1974) based on Lancaster consumer theory (Lancaster, 1966). This framework assumes that the price of a property can be decomposed into a set of implicit individual or hedonic prices of the composing characteristics (utility bearing attributes) of the property (e.g., yard space,

location, etc.). HPM estimates the implicit marginal price of the attributes of a property by estimating the relationship between these attributes and the property's sale price or assessed value (Freeman, 2003). HPM can therefore be used to understand the relationship between nature and housing markets and hence estimate the value of the environment to landowners and planners (Mei *et al.*, 2018).

In the hedonic price model, the basic assumption is that the house buyer is paying for the unit and the environmental services and goods surrounding the house. Those services and goods are considered in terms of the value they add to housing prices. Usually, hedonic price studies focus on the values of single-family residential homes but may also utilize lease values for commercial or residential rental units (Sander and Haight, 2012).

HPM has been used in environmental studies to measure the value of nonmarket components of housing prices (Garrod and Willis, 1992; Sander *et al.*, 2010; Stetler *et al.*, 2010; Gopalakrishnan *et al.*, 2011; Sander and Haight, 2012; Liu *et al.*, 2020b).

Economic theory suggests that house sale prices can be estimated as a function of vectors of structural characteristics, S , neighborhood attributes, N , and environmental attributes, E (Freeman, 2003). Thus, the hedonic price model for houses takes the form:

$$\text{House Sale Price} = f(S; N; E)$$

Consumers making a house purchase decision are assumed to maximize their utility, U , from the purchase of a home given the attributes of homes for sale and their budget constraint, Y :

$$\left[\begin{array}{l} \text{Max } U = f(S; N; E) \\ \text{subject to:} \\ Y = \text{House Sale Price} + a \end{array} \right.$$

Where "a" is disposable income spent on all other goods.

The main criticism of the HPM focuses on the extent to which hedonic prices can be assumed to reflect a household's marginal WTP for a particular level of an environmental attribute (Garrod and Willis, 1992). Hedonic prices only reflect households' marginal WTP for one specific attribute if the measured level of this attribute can be perceived by the consuming household (Harris, 1981). In some cases, respondents do not have complete information on the

attribute to be assessed (ex: air pollution, radiation, and water pollution). Therefore, their marginal WTP might not be accurate.

1.3.2. Stated preferences methods

Stated Preference Methods (SPM) are survey-based methodologies that measure the value of changes in environmental goods/ services, especially those which cannot be traded on the market (Hanley *et al.*, 2007). They are based on creating a hypothetical market that defines the good/service to be assessed, the institutional context in which it would be provided, and how it could be financed (Hanley *et al.*, 2001). In SPM, people's preferences for a specific environmental good or service are used to estimate their WTP (Or Willingness To Receive (WTR)) to maintain or acquire the good or service (Bateman *et al.*, 2002). The conceptual framework of SPM lies in the neo-classical theory, precisely in welfare economics. This framework assumes that respondents are rational utility maximizers who optimize their utility by expressing their preferences (Train, 2003). Over the years, two stated preferences techniques have been used to value multiple environmental goods and services worldwide, the CVM and the DCM.

1.3.2.1. Contingent valuation method

CVM is one of the most popular valuation techniques for environmental goods and services (e.g. (Bernath and Roschewitz, 2008; Ojea and Loureiro, 2010; Brander and Koetse, 2011; Landry *et al.*, 2020)). It involves an implicit trade-off between personal income and environmental quality (Mitchell and Carson, 1989; Lo and Jim, 2015). In CVM surveys, individuals are asked to state the maximum amount of money they are willing to pay to prevent the adverse environmental change (or the minimum amount they would accept as compensation to suffer a change they could avoid). The primary data elicitation techniques in CVM are:

- Open-ended WTP data

In Open-Ended (OE) elicitation format, the respondent is asked to state their WTP by asking "How much are you willing to pay?" Hence, the respondent is free to express any amount they desire (Brookshire *et al.*, 1983). In OE, WTP is directly elicited. Yet, it is mentally demanding for respondents to state a specific WTP, which usually results in underestimates or non-responses (Loomis, 1990).

- Dichotomous choice or closed-ended WTP data

In the Dichotomous Choice (DC) elicitation format, respondents are asked to state their WTP through the question “Are you willing to pay £X?” with the bid level X being systematically varied across the sample (Bishop and Heberlein, 1979). Contrarily to OE questions, in DC, fewer mental demands are placed on the respondent, resulting in a lower proportion of non-response. DC provides a question format compatible with market settings; the price is stated, and the individual engages in “price-taking” behavior of buying or not buying at that price (Loomis, 1990).

The use of DC increased, especially after receiving the endorsement of the national oceanic and atmospheric administration (NOAA) panel in 1993 (Arrow *et al.*, 1993).

One critical problem with DC is the issue of “yeah saying.” Results of DC seemed to be significantly higher than OE questions due to “yeah saying” (Hanley *et al.*, 2001). Another problem is that WTP needs to be inferred (Loomis, 1990).

- Iterative bidding

In iterative bidding, the interviewer indicates a starting WTP bid level which may be fixed across the sample or varied systematically. The respondent is then asked if they are willing to pay this amount. If they respond positively, then the bid level increases, while if they respond negatively, the bid level decreases, and the WTP question is asked again (Randall *et al.*, 1974). Iterative bidding aims to create conditions of choice that approximate those that subjects experience in markets. The repetition gives the respondent a new opportunity to “research his preferences.” However, the iterative bidding proved to be impractical in mail surveys (Loomis, 1990).

The Standard Tobit model is commonly used to analyze CVM data. In the Tobit model, zero and positive values represent a unique choice model. The latent variable (price) is allowed in principle to take negative values. However, the negative values are not observed because of censoring at zero. Some studies also use mixture or spike models to analyze CVM data (Strazzera *et al.*, 2003). In those models, the probability of obtaining a zero value is estimated independently of the valuation function referring to individuals with positive WTP.

CVM has been criticized because of the large proportion of respondents providing protest zeros. Those respondents oppose the logic of the economic theory (Jorgensen and Syme, 2000; Lo and Jim, 2015). There are two categories of protest responses (Strazzera *et al.*, 2003):

- Respondents who disagree with the method used for preference elicitation;
- Respondents who are concerned about the fairness of the requested payment.

The zero responses driven by the respondent's economic constraints or failures to derive utility from protecting the environmental goods or services (Respondents who are truly averse or indifferent to the good or service of interest) specified in the CVM scenarios are classified as 'true zero' bids and not protests. Thus, censoring and excluding protest responses from the analysis avoids conceptual inconsistencies and underestimating aggregate WTP estimates. To identify true protest responses, respondents who state a zero bid are asked to indicate subjacent reasons (e.g. "it is unfair for me to pay," "the government should use taxes money to pay for it," "I do not want to put a dollar value on protecting plants and animals," "Not enough information is given," "I object to the way the question is asked," "the money collected won't make a difference," "I do not have faith in the authority," and "others should pay," etc.). Despite the efforts made to improve the outcome of CVM by removing protest zeros, the divide between true and protest expressions is still indistinct because respondents who are willing to pay also hold some degree of protest beliefs (Meyerhoff and Liebe, 2006).

1.3.2.2. Discrete Choice Modeling

1.3.2.2.1. Definition

DCM is also a survey-based technique that can be used to assess all values derived from environmental goods and services. Its emergence was inspired by the conjoint analysis (CA) used in marketing since the 1950s. CA predicts consumer preferences for different designs and compositions of products based on their different characteristics. In the characteristics theory of value, consumers' utilities for a good/service can be disaggregated into utilities for the different features defining this good/service (Lancaster, 1966). In DCM, respondents are presented with various hypothetical situations, called choice sets, and are asked to sequence them, rate them, or choose their most preferred. Each choice set gathers at least two different alternatives describing different levels of the good/service of interest. Alternatives are based on predefined attributes characterizing the good/service and their respective levels (Hanley *et al.*, 2001). The introduction of a payment mechanism as one of the attributes of the good/service

helps to obtain a welfare measure of the level of utility procured by the different alternatives and hence provides the possibility to empirically determine the economic dimension of discrete choices faced by individuals by estimating their WTP (McFadden, 1973).

1.3.2.2.2. Econometrics of DCM

In DCM, the indirect utility function for each respondent can be decomposed into two parts. We consider U_{nsj} , the utility that a decision-maker n in a choice situation s will derive from consuming or possessing alternative j . Hence, U_{nsj} may be decomposed into two separate components, an observed or modeled component, V_{nsj} , and a residual unobserved and unmodeled component, ε_{nsj} , such that:

$$U_{nsj} = V_{nsj} + \varepsilon_{nsj}$$

The observed or deterministic component of utility V_{nsj} , is defined as a function of k variables, X_{nsjk} , with associated preference weights, β , such that:

$$V_{nsj} = f(X_{nsjk}, \beta, \sigma)$$

Where X_{nsjk} is a vector of k attributes describing alternative j and covariates describing either the decision-maker (e.g., age, income) or some aspect related to the decision context. β is a vector of parameters to be estimated. Those parameters represent the weights that decision-makers attach to each attribute. σ is a scalar representing a positive scale parameter that links V_{nsj} to ε_{nsj} . σ serves to scale the utility of each alternative. The observable component of utility is assumed to be a linear relationship of observed attribute levels, X .

$$U_{nsj} = \sigma_n \sum_{k=1}^K \beta_{nk} x_{nsjk} + \varepsilon_{nsj}$$

Where β_{nk} are called parameters, coefficients, marginal utilities, taste weights, etc. Those parameters are alternative-specific estimates. However, the analyst might make them generic across alternatives under given circumstances. In practice, the utility specification does not allow different respondents to have different marginal utilities for each attribute. It is not feasible to estimate individual-specific parameter weights. Thus, it is common to estimate parameter weights for the population that vary randomly around a mean, such that:

$$\beta_{nk} = \bar{\beta}_k + \eta_k z_{nk}$$

$\bar{\beta}_k$ represents the mean of the distribution of marginal utilities held by the sampled population, η_k represents a deviation or spread of preferences among sampled respondents around the mean marginal utility, and z_{nk} describes random draws taken from a pre-specified distribution for

each respondent n and attribute k . To model choices, it is mandatory to make some assumptions about the unobserved components of utility. The most common assumption is that for each alternative, j , ε_{nsj} , will be randomly distributed with some density, $f(\varepsilon_{nsj})$, over decision-makers, n , and choice situations, s . This assumption enables making some probabilistic statements about choices made by decision-makers. Hence, the probability that respondent n in choice situation s will select alternative j is given as the probability that outcome j will have the maximum utility. The likelihood that the differences in the random terms, $\varepsilon_{nsi} - \varepsilon_{nsj}$ will be less than the differences in the observed components of utility, $V_{nsi} - V_{nsj}$.

$$\begin{aligned} P_{nsj} &= \text{Prob}(U_{nsj} > U_{nsi}, \forall i \neq j) \\ &= \text{Prob}(V_{nsj} + \varepsilon_{nsj} > V_{nsi} + \varepsilon_{nsi}, \forall i \neq j) \\ P_{nsj} &= \text{Prob}(\varepsilon_{nsj} - \varepsilon_{nsi} > V_{nsi} - V_{nsj}, \forall i \neq j) \end{aligned}$$

Assumptions about the specific density specification adopted for the unobserved effects, ε_{nsj} will lead to different econometric models.

In each choice set ($j \geq 2$), a baseline alternative is usually included to ensure that DCM estimates are consistent with welfare-maximizing behavior. This baseline alternative can take two forms, “status quo” and “opt out” situations (Adamowicz and Boxall, 2001). Both forms ensure that respondents are given the possibility not to enter the market (or consume) if not willing to. Otherwise, they will be forced to choose and state alternatives as being “preferred” even though they do not provide additional utility (Johnston *et al.*, 2017). In the case of a no-choice alternative, the alternative labeled “opt out” won’t have any attribute levels. However, the absence of attributes does not mean that the decision-maker is indifferent to that alternative (e.g., if alternatives correspond to three romantic comedy movies, then staying at home and not attending any of them might be the most preferred option); This alternative remains an option with some level of utility (Hensher *et al.*, 2015).

The inclusion of interaction terms within the utility function of discrete choice models is a commonly used transformation (Boxall and Macnab, 2000). Interaction terms correspond to the multiplication of two or more variables, such as $X_{nsjk} X_{nsjl}$. The variables may represent attributes, covariates, or combinations of both. Parameters associated with a single variable are often called “main effects” and those associated with an interaction term are usually named “interaction effects.”

Two forms of heterogeneity can be explored within DCM models (Adamowicz and Boxall, 2001): Heterogeneity in tastes (the β vector) and Heterogeneity in scale (the σ parameter). The first requires relaxing the assumption of the same indirect utility function for each individual. The second involves identifying individual characteristics that explain the noise or error variance surrounding the estimation of the indirect utility function. For many years, the parameters were assumed to be fixed over respondents, implying that all decision-makers share the same marginal utility. The inclusion of an interaction term relaxes this assumption (Boxall and Macnab, 2000). Also, many types of discrete choice models, such as the probit model, the mixed multinomial logit model, and the latent class model, allow for heterogeneity in the tastes exhibited by different decision makers within decision-makers. These models enable parameters to be distributed over respondents such that β_k is now represented as β_{kn} .

1.3.2.2.3. Stages of DCM

The application of the discrete choice modeling goes through a number of stages (Adamowicz *et al.*, 1998; Hanley *et al.*, 2001), which are: Selection of attributes and assignment of levels, choice of experimental design, construction of choice sets, and measurement of preferences (see table for more information about the stages of the choice modeling).

⇒ Selection of attributes and assignment of levels

The selection of attributes and their levels is one of the most determinant stages in DCM. Attributes and their levels should clearly describe the change in the good/service of interest to get accurate WTP estimates. Usually, scientific literature and interviews with experts produce a range of potential attributes and levels characterizing the good/service to be assessed. Nonetheless, the selection of attributes needs to be based on the target population's perceptions, ideas, and impressions. Therefore, experts often recommend holding focus groups with representative individuals of the targeted population(s) before final selection. Focus groups often advise on (i) the attributes to be considered and if any crucial attributes were left out; (ii) how to illustrate and describe attributes in an understandable way; (iii) how to approach the topic to create interest; and (iv) difficulties that could occur during the survey.

⇒ Choice experimental design and construction of choice sets

Statistical design theory combines the attributes and their levels into different alternative scenarios or profiles, so-called choice sets, to be presented to respondents. In these choice sets, visual features and illustrations are also provided to ease the choice process. Alternatives within

each choice set should reveal the implicit trade-offs participants make while choosing the alternative that provides the highest utility for them to achieve a statistically accurate measure of their preferences. Thus, they should be selected carefully.

Multiple design types can be used for the experimental design of choice sets in DCM. **Full factorial design** generates all possible choice situations (all possible combinations of attributes and their levels). This design enables the estimation of all possible effects (main and interaction effects). However, the use of a large number of choice sets in a study can be impractical. Thus, most experts rely on **fractional factorial designs**, which refer to a range of designs that select a subset of choice situations from the full factorial design. Some fractional factorial designs randomly select choice situations from the full factorial. However, this is not statistically accurate. Other fractional factorial designs select choice situations in a structured manner. **Orthogonal designs** are the most known fractional factorial designs. They aim to minimize the correlation between the attribute levels in the choice alternatives. These orthogonal designs have limitations, however. They cannot prevent choice situations in which a specific alternative is less preferred than the others. Thus, more recently, multiple experts have suggested another type of fractional factorial design, called **efficient design**. The latter maximizes the information from each choice alternative and finds statistically efficient designs in terms of predicted standard errors of the parameter estimates. The main limitation of efficient designs is the availability of prior parameter estimates; The stability of the design of the choice situation relies on the accuracy of the chosen priors. These priors can be found in the literature; otherwise, they can be extracted from pilot studies. In the case of the absence of priors in literature and the possibility to conduct pilot studies, **Bayesian efficient design** can be an option. In this type of design, prior parameters are not assumed to be fixed but are considered random parameters.

Despite the use of experimental designs that reduce the number of choice situations in DCM, their number can still be high in some cases. Therefore, the creation of blocks can further reduce the number of choice sets for respondents. The generated experimental design gathers many choice sets, it may be divided into blocks, and each participant is only faced with one block. Blocks are partitions, usually the same size, of choice situations within the same experimental design. In practice, respondents are randomly assigned to a block instead of answering the entire design (Reed Johnson et al., 2013).

⇒ Measurement of preferences and estimation procedure

The survey and estimation procedures to measure individual preferences depend on the form administered of DCM: ratings, rankings, or choices.

1.3.2.2.4. Forms of DCM

The DCM can take four forms: DCE, contingent ranking, contingent rating, and paired comparisons. These techniques differ in the quality of information they generate, their degree of complexity, and their ability to produce consistent welfare WTP estimates.

⇒ DCE

The DCE approach was initially developed by Louviere and Hensher (1982). In a choice experiment, respondents are presented with a number of choice sets and asked to choose their most preferred alternative within each choice set (Louviere *et al.*, 2000). The variation of levels of the different attributes within alternatives in the DCE framework delivers more information on trade-offs between the drivers of choice than the other stated preference methods. Therefore, it enables the estimation of the marginal rates of substitution between different attributes. Hence, when one attribute is expressed in monetary terms, these marginal substitution rates can be interpreted as the WTA or WTP for changes in the attributes' values. The DCE is widely used in environmental assessments (Juutinen *et al.*, 2011; Zander *et al.*, 2013a; Nordén *et al.*, 2017; Chèze *et al.*, 2020).

Random Utility Models (RUM) (Thurstone, 1927) are used to analyze the DCE data. These models are derived under the assumption that unobserved effects are drawn from an extreme value distribution (EV1). RUM were used in the earliest development and remain the basic framework of choice. The main RUM used in the choice experiment are conditional logit model (CLM) (Luce, 1959; McFadden, 1973), nested logit model (NLM) (Williams, 1977; Daly and Zachary, 1978), random parameters logit model (RPL) (Train, 2009), generalized multinomial logit (GMNL) (Train, 2009; Fiebig *et al.*, 2010) and the latent class model (LCM) (Greene and Hensher, 2013).

CLM is applied if selections obey the Independence from Irrelevant Alternatives (IAA) assumption. This assumption can be tested using a procedure suggested by (Hausman and McFadden, 1984).

The CLM is the basic model used in DCE studies, and it provides a good starting point for the analysis. CLM assumes that the parameters are constant among all respondents. Consequently, it is suitable for the assessment of the average preferences (Train, 2009).

The concern with the limitation of the IIA condition led to the development of the NLM. The latter recognizes that the variance associated with the unobserved influences in the random component is likely to be different across the set of alternatives in a choice set but possibly similar for subsets of alternatives. NLM accounts for scale heterogeneity, and it is typically set up with a hierarchical tree-like structure linking alternatives that share common scale or error variances.

RPL assumes that at least some of the parameters are random, following certain probability distribution. These random parameter distributions are assumed to be continuous over the sampled population. The RPL model allows for unobservable heterogeneity in preferences (taste heterogeneity) by assuming that each member in the sample has a different set of utility parameters. It can be estimated by specifying the utility parameters in preference space or WTP space. In preference space, WTP can be derived for non-price attributes by taking the negative of the ratios of the non-price attributes coefficients and the price coefficient. In WTP space models, the utility is reparametrized; consequently, the attribute coefficients can be directly construed as marginal WTP (Cameron and James, 1987; Scarpa and Willis, 2010). Many studies showed that models estimated in WTP space offer more reasonable and reliable WTP estimates compared to WTP estimates derived from models in preference space (Balcombe *et al.*, 2009; Thiene and Scarpa, 2009). However, other studies report a drop in model fit when the estimations are made in WTP space instead of preference space (Sonnier *et al.*, 2007; Bazzani *et al.*, 2018).

LCM is a popular alternative to the RPL in which the continuous distribution is replaced with a discrete distribution in which preference heterogeneity is captured by the membership of distinct classes of utility description. The LCM takes two forms; fixed LCM and random parameter LCM. The fixed LCM model assumes homogeneity within each class despite the observed interactions with contextual effects. The random parameter LCM, which is a natural extension of the fixed-parameter LCM, allows for another layer of preference heterogeneity within each class.

⇒ **Contingent ranking**

In contingent ranking, respondents are presented with choice sets and are asked to rank a set of alternatives within each choice set. It can be perceived as a series of choice experiments (Chapman and Staelin, 1982). Respondents are firstly asked to identify their most preferred option within the choice set. Then, after removing that option, they are asked to choose their most preferred option within the remaining choice set and so on. Therefore, contingent ranking provides more statistical information than choice experiments, which results in tighter confidence intervals around the parameter estimates. One fundamental limitation of the contingent ranking approach is the cognitive difficulty of ranking choices with many attributes and levels. Studies proved choices to be inconsistent across ranks (Ben-Akiva *et al.*, 1991). Many studies in the environmental field used contingent ranking (Garrod and Willis, 1997; Foster and Mourato, 2000; Speelman *et al.*, 2010) and some studies also compared contingent ranking with other stated preferences methods (e.g. (Bateman *et al.*, 2006).

⇒ **Contingent rating**

In contingent rating, respondents are asked to rate individually a number of scenarios. In this approach, no direct comparison of choices is needed. Hence, there is no formal theoretical link between the expressed ratings and economic choices. The contingent rating approach is not very popular among environmental economists (Gruchy *et al.*, 2012; Khanal *et al.*, 2017). The main reason behind this lack of popularity is the strong assumptions to transform ratings into utilities. Consequently, contingent rating exercises do not provide welfare-consistent value estimates.

⇒ **Paired comparisons**

In paired comparison, also known as graded or rated pairs approach, respondents are presented with a set of two alternatives and are asked to choose their preferred alternative and to express the strength of their preferences in a numeric or semantic scale (Lockwood, 1998; Brown *et al.*, 2002).

1.4. Conclusion

Stated preference surveys have been utilized to assess many ES in the past (Christie *et al.*, 2007; Zander and Straton, 2010; Dias and Belcher, 2015; Khan and Zhao, 2019). Most of these assessments were made for tangible services with distinct end products directly consumed (e.g.,

water quality). However, regulating services that enhance the production of other products, such as pollination, are less often assessed mainly because of the public's difficulty in attributing a value to them (Breeze *et al.*, 2015). The limited information available to respondents on such ES can make eliciting their value challenging (Christie and Gibbons, 2011). The complex nature of these services may increase the likelihood of respondents not fully considering all the information presented when expressing their preferences, which usually results in bias estimates (Meyhoff and Liebe, 2009). Yet, if carefully developed, stated preference studies can be used successfully to value these ES (Breeze *et al.*, 2015). DCM might have some advantages over CVM, especially in the case of complex ES (Hanley *et al.*, 2001; Breeze *et al.*, 2015). DCM provides a more detailed description of the attribute trade-offs that individuals are willing to make (Boxall *et al.*, 1996; Adamowicz *et al.*, 1998).

2. Insect pollination: a threatened ecosystem service

2.1. Introduction: Important definitions

Pollination is an essential ecological process for the reproduction and persistence of most flowering plants (Klein *et al.*, 2007; Ollerton *et al.*, 2011). It refers to the transfer of pollen between the male and female parts of flowers (i.e., the transfer of pollen from an anther to a stigma). Following pollination, pollen grains germinate on the stigma, and the resulting pollen tubes grow through the tissues of the stigma to the ovule (Krichevsky *et al.*, 2007). Then, the ovule develops into the seed and the ovary into the fruit (Dresselhaus and Franklin-Tong, 2013; IPBES, 2016).

Pollination is fundamental for the sexual union of male and female gametes; however, by itself, it does not ensure this union (Dresselhaus and Franklin-Tong, 2013). The compatibility between gametes is also crucial for a successful sexual union (Wang *et al.*, 2017; Cerovic *et al.*, 2020). Pollination can occur within or between plants to enable sexual fertilization (self and cross-pollination) (Papadakis *et al.*, 2009; Hu *et al.*, 2019). Self-pollination on a self-infertile plant, for instance, occurs often but does not result in a seed set. Self and cross-pollination are not exclusive; some plants have mixed pollination systems (IPBES, 2016).

Four common mating systems apply to flowering plants (IPBES, 2016):

- Autogamy, when pollen moves within the same flower;
- Geitonogamy, when the pollen moves between different flowers of the same plant;

- Obligate Xenogamy, which necessitates the fertilization of the plant by pollen from a genetically different individual (e.g., for apples and pears);
- Facultative Xenogamy, geitonogamy, and autogamy together (Mixed mating systems) occur to various degrees and may differ among cultivars and varieties.

Not all flowering plants require pollination to produce seeds for their reproduction (IPBES, 2016); e.g., agamospermy (where flowers make seeds without the involvement of nuclei from pollen, e.g., some cereals) and parthenocarpy (where flowers set seedless fruits without pollination or fecundation, e.g., banana).

2.2. Insect pollinators

Depending on the vector that transfers the pollen, pollination can take multiple forms: self-pollination, water pollination, wind pollination, and animal pollination. Animal pollination vectors or pollinators represent a diverse group of animals dominated by insects (bees, some species of flies, wasps, butterflies, moths, beetles, weevils, thrips, ants, and midges) (IPBES, 2016; Robert, 2016).

Bees are the most known insect pollinators since more than 90 percent of the leading global crop are visited by bees (Kleijn *et al.*, 2015). A few species of bees are managed, such as the western honey bee (*Apis mellifera*) and eastern honey bee (*Apis cerana*), some bumblebees, some stingless bees, and a few solitary bees. However, most of the world's 20,077 known bee species are wild (IPBES, 2016). Other non-bee insects such as flies, butterflies, moths, and beetles (Garibaldi *et al.*, 2013) and animals such as bats, birds, primates, marsupials, rodents, and reptiles can also ensure pollination (Willmer, 2011).

Pollinator species often complement each other (Blüthgen and Klein, 2011; Garibaldi *et al.*, 2013; Venjakob *et al.*, 2016). Hoehn *et al.* (2008) and Brittain *et al.* (2013) observed spatial complementarity of pollinators. They argue that, depending on climatic conditions (e.g., wind), pollinators operate at different height levels; therefore, the diversity of pollinators is a critical factor to good pollination. Pollinators have different temporal activities; consequently, they complement each other in time (Klein *et al.*, 2009).

Pollinators also differ in their abilities to access flowers (Fontaine *et al.*, 2006). Floral morphological barriers might, in some cases, make it difficult for some species of pollinators

to access the male and female parts of the flower (Stang *et al.*, 2009; Lázaro *et al.*, 2013). In strawberry, for instance, it has been shown that large bees pollinate the pistils at the tip of the flower, and the smaller bees pollinate the pistils at the base of the flower leading to well-shaped fruits (Chagnon *et al.*, 1993).

2.3. Pollinators decline

2.3.1. Evidence of the decline

The use of pollinator-dependent crops is increasing worldwide (Aizen and Harder, 2009; Potts *et al.*, 2016). Nonetheless, yields of these crops are decreasing and becoming less stable compared to non-pollinator-dependent crops (IPBES, 2016). The decline of pollinators is one of the main reasons behind this shortage and lack of stability of yields (e.g. (Bacci *et al.*, 2006; Pereira *et al.*, 2017)). Evidence on this decline has been found in many parts of the world (MEA, 2005; Ricketts *et al.*, 2008; Potts *et al.*, 2010; IPBES, 2016; Robert, 2016; Hallmann *et al.*, 2017; Hallmann *et al.*, 2021; Aizen *et al.*, 2019). The decline of wild plants can also be used as an indicator of pollinator decline (Pauw and Hawkins, 2011; Burkle *et al.*, 2013; Mathiasson and Rehan, 2020). In the Netherlands and the UK, evidence showed that declines in native plants translate to parallel declines in their pollinators (Biesmeijer *et al.*, 2006). The most significant declines occur for species that depend on plants with decreasing abundance and limited distribution (Scheper *et al.*, 2014). Decline has also affected managed pollinators; severe declines in managed honey bee stocks have been registered in the USA (Van Engelsdorp *et al.*, 2008) and Europe (Potts *et al.*, 2015).

2.3.2. Causes of the decline

The main drivers of pollinator decline are anthropogenic practices, climate change, pathogens, and invasive alien species (Potts *et al.*, 2010; Dore *et al.*, 2021). These drivers are impacting pollinators habitats, their health and their foraging and nesting resources.

- Human practices

Land-use change, the increasing use of agrochemicals, agricultural intensification, industrialization, and other human practices threaten pollinators worldwide (Potts *et al.*, 2010;

IPBES, 2016; Díaz et al., 2019; LeBuhn and Vargas Luna, 2021; Millard et al., 2021). These practices often modify nesting and foraging sites of pollinators and destroy their natural habitats, which leads to smaller population sizes and a decrease in the diversity of pollinator communities (Potts et al., 2010; Kennedy et al., 2013; Goulson, 2014; Hallmann et al., 2014; Goulson et al., 2015; Requier et al., 2015).

- Climate change

Climate change is also one of the main drivers of pollinator decline (Potts *et al.*, 2010; Vasiliev and Greenwood, 2021). Changes in climatic conditions and extreme weather events result in changes in pollinator temporal activities, genetics, phenology, habitat, and overall distribution (Schweiger *et al.*, 2008; Giannini *et al.*, 2012; Kerr *et al.*, 2015a; Elias *et al.*, 2017; Martinet *et al.*, 2020; Kuppler *et al.*, 2021). These changes also affect their plant-pollinator networks (Memmott *et al.*, 2007; Hegland *et al.*, 2009; Polce *et al.*, 2014; Miller-Struttman *et al.*, 2015). Some species, such as some butterflies, have adapted their ranges, abundance, and seasonal activities following the observed global changes. However, climate change is considered to be detrimental to most pollinators (IPBES, 2016).

- Parasites pathogens and invasive alien species

A broad range of parasites and pathogens (e.g., Varroa mites) attacking bee colonies and transmitting emerging and re-emerging diseases have severely affected colonies in many parts of the world (Sammataro *et al.*, 2000; Oldroyd, 2007; Van Engelsdorp *et al.*, 2008; Goulson *et al.*, 2015; GÓMez-Moracho *et al.*, 2017). Parasites and pathogens are mainly an issue for managed pollinators. However, many studies showed that they could be transmitted to native pollinators (Durrer and Schmid-Hempel, 1994; Kojima *et al.*, 2011; Furst *et al.*, 2014; Graystock *et al.*, 2016; Manley *et al.*, 2020).

The competition on floral and nesting resources could also be threatening native pollinators (Goulson, 2003; Paini, 2004; Herbertsson et al., 2016). Over the last few decades, the number of colonies of managed pollinators has increased, despite diseases and pathogens. This increase elevates the competition between managed and wild pollinators on nesting and foraging

resources, likely affecting the abundance and diversity of wild pollinators (Herbertsson et al., 2016; Torné-Noguera et al., 2016).

The rising existence of managed pollinators in ecosystems could also affect native pollinators by changing plant community composition (IPBES, 2016; Agüero et al., 2020). Managed pollinators prefer exotic plants (Goodell, 2008; Agüero et al., 2020; Urbanowicz et al., 2020). These foraging preferences can help spread invasive plants and reduce the population of native plants and consequently disrupt plant-pollinator networks (Lopezaraiza-Mikel *et al.*, 2007; Morón *et al.*, 2009; Herron-Sweet *et al.*, 2016; Mallinger *et al.*, 2017). Furthermore, commercial management, mass breeding, transport, and trade in pollinators outside their original territories have resulted in new invasions, more transmission of pathogens and parasites, and regional extinctions of native pollinator species (IPBES, 2016).

2.4. Importance of insect pollination

Insect pollination is a vital regulation ecosystem service, and it contributes to human well-being by maintaining ecosystems and food security and supporting the economy and livelihoods.

- Maintenance of ecosystems

Pollinators services contribute to gene flow, the restoration of ecosystems and play a crucial role in the stability and functioning of many terrestrial food webs (Ollerton, 2017); More than 87% of the world's flowering wild plants depend, at least in part, on insect pollination for their sexual reproduction (Ollerton *et al.*, 2011). These plants provide a wide range of resources such as food and shelter for many other invertebrates, mammals, birds, etc. (IPBES, 2016).

- Food security

Pollinators also contribute to food security and overall human well-being (Steward *et al.*, 2014; Potts *et al.*, 2016; Klein *et al.*, 2018; Anderson and Vasiliev, 2021); 76% of the world's leading crops, which are used directly for human consumption, rely upon varying extents on insect pollination (Klein *et al.*, 2007). Pollinators affect the quantity and quality of pollinator-dependent crops (Garibaldi *et al.*, 2013; Garibaldi *et al.*, 2014; Hünicken *et al.*, 2021). These crops supply significant proportions of micronutrients in global human diets (Smith *et al.*, 2015)

and contribute to the production of medicines, biofuels, fibers, construction materials, musical instruments, arts and crafts (IPBES, 2016).

- Economy and people's livelihoods:

The total economic value of insect pollination to agricultural production for human consumption worldwide was estimated to be 153 billion euros for 2005 (Gallai et al., 2009). This value represented 9.5% of the value of the world agricultural production used for human food in 2005. The estimated welfare loss resulting from productivity shocks due to a pollinator crisis was more significant in Western Africa, Eastern Asia, and Northern America (Gallai et al., 2009). Western Africa is exceptionally vulnerable to this welfare loss (Bauer and Sue Wing, 2016).

Pollinator-dependent crops generate higher income per surface unit compared to non-pollinator-dependent crops and require less water (Ashworth *et al.*, 2009; Christmann, 2020a). Therefore, many smallholders are increasingly using these crops to enhance their livelihoods, especially in LIC and MIC in drylands (Cely-Santos and Lu, 2019). In 2000, smallholders contributed to 16% of the global farmland area and 83% of the global agricultural population (Cely-Santos and Lu, 2019). Therefore the contribution of pollinators to smallholder households is significant (Steward *et al.*, 2014).

Pollinators contribute to the maintenance of the biodiversity of wild plants (IPBES, 2016). These plants produce nutritious, marketable, and valuable food and non-food products, which represent an essential source of income for vulnerable populations in many parts of the world (Pradhan, 2020; Leakey *et al.*, 2021).

2.5. The economics of pollination services

Throughout the years, many approaches have been used to estimate the economic value of pollination services. These approaches fall into two main categories: a) approaches based on direct market price and used to value of marketed benefits of pollination; replacement cost method is the most popular for valuing pollination service in this category, and b) approaches based on consumers' preferences and used to estimate the value of non-marketed benefits of

pollination. we can identify two approaches: revealed preferences based on consumers' behavior and stated preferences based on consumers' statements and choices.

2.5.1. Replacement cost method

The principle of the replacement cost method is to estimate the cost of using an alternative technology or organism to achieve the function of the valued good or service. In the case of pollination, the alternatives commonly used are hand pollination, dusting pollen, and managed pollinator. The price of managed pollinators is usually used to value native pollinators (Sandhu *et al.*, 2008; Winfree *et al.*, 2011; Hoshide *et al.*, 2018), and for honey bees, hand pollination and dusting pollen are the most used alternatives (Allsopp *et al.*, 2008; Partap and Ya, 2012). The main limitation of the replacement cost approach is that it is not practical nor cost-effective for specific crops (Gallai *et al.*, 2016).

2.5.2. Aggregate price

Another market price-based approach is the aggregate crop price. This method measures the total market price of animal pollinated crop production. The basic assumption behind this approach, for which it has been criticized, is that the production of animal pollinated crops will stop in the case of a complete loss of animal pollination (see (Costanza. *et al.*, 1997)).

2.5.3. Surplus valuation methods

Surplus valuation methods are welfare valuation methods that use supply and demand curves for a given product to estimate the impacts of changes in production on the economic welfare of producers and consumers. In the case of pollination service, surplus methods are used to estimate the effect that a shift in supply resulting from a change in pollination services has on prices and upon economic welfare via consumer and producer surplus (see (Southwick. E.E and Southwick. L, 1992; Kevan and Phillips, 2001; Gordon. J and Davis. L, 2003; Gallai *et al.*, 2009; Bauer and Sue Wing, 2016)). The surplus methods have been criticized for their data requirements, and they rely on the estimation of crop prices elasticities that require long-term data, which is usually hard to find (Gallai *et al.*, 2016).

2.5.4. Production function models

Production function models define the effect of a quantity of an input on the quantity of an output produced in relation to all other inputs used. In the case of pollination, two types of

production function methods have been used to assess the economic impact of pollination service, namely yield analysis and dependence ratios.

⇒ **Yield analysis**

It measures the market price of an additional crop production that results from pollination service (see (Garratt *et al.*, 2014; Klatt *et al.*, 2014; Pérez-Méndez *et al.*, 2020)). The main criticism for this production function method is that it does not have a standardized methodology within economic valuation literature. Thus, this method does not consider the marginal effects of other inputs and other ES on crop productivity, resulting in an overestimation of the benefits of pollination service (Gallai *et al.*, 2016).

⇒ **Dependence ratios methods also called the bio-economic approach**

Gallai *et al.* (2009) is the most known study to have used the bioeconomic approach to assess the consequences of pollinator's decline worldwide by measuring, firstly, the contribution of insect pollination to the world agricultural output economic value and secondly, the vulnerability of world agriculture in the face of pollinator decline.

The dependence ratio approach is based on the following hypothesis “the economic impact of pollinators on agricultural output is measurable through the use of dependence ratios quantifying the impact of a lack of insect pollinators on crop production value.” Hence, the total economic value of insect pollination to agriculture (IPEV) was calculated, using worldwide data from the FAO database, as follows:

$$\text{IPEV} = \sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix} \times D_i)$$

The variables used for each crop i , where $i \in [1;I]$, in each world region x , where $x \in [1;X]$, where the quantity produced (Q_{ix}), the quantity consumed (C_{ix}), the dependence ratio of the crop i on insect pollinators (D_i) and the price of crop i per unit produced in region x (P_{ix}). The dependence ratios show the level of dependence of crops on insect pollination (Klein *et al.*, 2007). The dependency of crops varies from 0 (none) to 90% (essential). The ratio of vulnerability (RV) for the world outcome used for human consumption was estimated using the following formula:

$$RV = \frac{IPEV}{EV} = \frac{\sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix} \times D_i)}{\sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix})} (\%)$$

To get a better understanding of the meaning of vulnerability, the authors of this study introduced an economic measure of this vulnerability in terms of consumer surplus.

The main conclusion drawn from Gallai *et al.* (2009) is that the total economic value of pollination for crop pollination worldwide was estimated to be €153 billion, representing 9.5% of the value of the world agricultural production used for human consumption in 2005. And in terms of welfare, the consumer surplus loss amounted to between €190 and €310 billion based upon average price elasticities of -1.5 to -0.8 , respectively.

This study has a number of limitations. Firstly, it neglects non-consumption agricultural production, livestock production, and natural vegetation. Secondly, using the bio-economic approach on a large scale requires a large set of data, which leads to data uncertainties. And finally, in terms of welfare, the assumption of an average sensitivity of prices to quantity shortage for surplus calculations affects the quality of calculations.

Despite its limitations, many other authors have used the dependence ratios approach to assess the economic value of insect pollination for agricultural production for human consumption on different scales, namely (Lautenbach. S *et al.*, 2012; Leonhardt *et al.*, 2013; Shammout *et al.*, 2014; Breeze *et al.*, 2016; Mulatu, 2019; Borges *et al.*, 2020).

2.5.5. Stated preference methods

Stated preferences use surveys to elicit respondent WTP for ecosystem goods and services that cannot be traded on existing markets, hence, the need to create hypothetical ones. In the case of pollination, contrarily to other valuation methods that value pollination benefits to markets, stated preference methods are potentially used to value the existence of pollinators and their non-marketed benefits (Gallai *et al.*, 2016). Both CVM and DCM have been used, in the past, to value pollination services.

2.5.5.1. Contingent valuation method

Not many studies have used CVM to assess the economic value of pollination (Mwebaze *et al.*, 2010; Diffendorfer *et al.*, 2014; Mwebaze *et al.*, 2018). Mwebaze *et al.* (2010) evaluated “how much public support there would be in preventing further decline to maintain the current number of bee colonies in the UK.” In this study, the elicitation format used was open-ended questions. Results showed that the mean WTP to support the bee protection policy was £1.37/week/household, equivalent to £1.77 billion per year for the 24.9 million households in the UK. The limitations of this study are mainly linked to the difficulty of separating use values from non-use values of honey bees. Diffendorfer *et al.* (2014) performed a CVM study of monarchs to understand the potential for such approaches to fund monarch conservation in the US. The survey indicated that US households valued monarchs as a one-time payment of \$4.78–\$6.64 billion. Mwebaze *et al.* (2018) used CVM to value “how much public support there would be in preventing further decline to maintain the current number of bees by estimating the WTP for a theoretical bee protection policy in the UK.” The payment card (PC) was the elicitation technique used to extract preferences, and the payment vehicle used was an income tax and presented as a weekly/annual increase. The conclusion drawn from the CVM is that the public has positive valuation preferences for the protection of bees. The findings of this study amount the mean WTP to support the bee protection policy to £43 per household per year in the UK. And, as with Mwebaze *et al.* (2010), the main limitation is the difficulty to separate use-value from non-use value and the possibility that subjects may overstate use-values. To that, we can add the survey’s small sample size, which does not entirely capture the profile of the UK population and the hypothetical bias in CVM responses.

2.5.5.2. Discrete choice modeling

The only study we could find in the literature using a DCE to value pollination service is Breeze *et al.* (2015). The latter performed a DCE to examine the UK public’s WTP to conserve the benefits of insect pollinators to maintain local agricultural production and the aesthetic benefits of diverse wildflower assemblages. Breeze *et al.* (2015) used the following attributes: “UK grown fruit and vegetables available in local shops compared to now,” “Variety of wildflowers in local green spaces compared to now,” “Possible future increase in Monthly taxation.” For non-monetary attributes, levels were specified identically as changes in current levels compared to now from no change to –30% in a linear incremental scale (same as now, 10%, 20%, 30%). For the monetary attribute, nine levels were determined (£0*, £0.5, £1, £1.5, £2, £2.5, £3, £3.5,

£4). The Bayesian mixed logit with two contrasting controls for attribute non-attendance, exclusion, and shrinkage was used to analyze the survey data statically. The findings of this study estimated the value of pollination service to £25.5–£12.6/person in the UK. They also showed that respondents tend to avoid the status quo scenario of pollinator and pollination service losses and are willing to pay accordingly. This study has a number of limitations, mainly the small sample, and a number of economic and ecological knowledge gaps :

- An unknown proportion of quantities of products are used in processing rather than sold fresh. Thus, it is impossible to estimate the proportion of UK products for domestic consumption accurately.
- The relative importance of produce origin compared to price or quality remains unquantified. Consequently, it is impossible to assess the impacts of other trade-offs resulting from a loss of pollination service.
- The relationships between pollinator abundance and diversity have not been similarly generalized.
- There has not been an assessment of how many UK plant species benefit from pollination services. Consequently, it is not possible to accurately define how wild plant communities will react to a loss of pollinators.

2.6. Conservation of pollination services:

The increasing dependence on pollinator worldwide and the worrying declines facing these species has fueled fears of a global pollinator crisis (Steffan-Dewenter et al., 2005). Following the establishment of the International Pollinators Initiative coordinated by the Food and Agriculture Organization of the United Nations (FAO) in 2002, interests in the protection of insect pollinators have increased worldwide. This initiative provided initial guidance on the necessary measures for the conservation of these species through interventions in 6 thematic areas (FAO, 2014): (i) Making of pollinator-friendly pesticides policies, (ii) Conservation and enhancement of pollinator habitats, (iii) Use of valuation, incentives and payments for ES, (iv) Participation, knowledge-sharing and empowerment of rural and indigenous people and local communities, (v) Supporting collaborative research and outreach and (vi) Raising public awareness and knowledge sharing.

Other initiatives, namely the MEA and the Intergovernmental Science-Policy Platform on Biodiversity and ES (IPBES), also provided an insight into the importance of the conservation

of insect pollinators. The MEA brought to light the term “Ecosystem services” and classified pollination as one that needs protection (MEA, 2005) and the IPBES, which was established in 2012 to undertake different assessments to encourage and guide the process of policymaking for the protection and conservation of ES, also provided recommendations for the protection of pollinators in their assessment on pollinators, pollination, and food production (IPBES, 2016).

Many studies also emphasized the importance of insect pollination and made further recommendations for specific policy targets to address the pollinator crisis (Dicks *et al.*, 2016a; Dicks *et al.*, 2016b; Christmann, 2019b; Porto *et al.*, 2020). More recently, research focused more on the importance of promoting ecological intensification as a solution to protect pollinators (Garibaldi *et al.*, 2019; Gemmill-Herren *et al.*, 2021).

In the light of the increasing number of publications of the insect pollinator and the need for their conservation (Porto *et al.*, 2020), many countries launched conservation strategies (Appendix 1); In France, Switzerland, Ethiopia, Colombia, and Sri Lanka, for instance, strategies focus primarily on scientific research and, in the Netherlands for example, conservation measures focus on awareness-raising by citizen science. Worldwide, governments have also engaged in initiatives for the protection of these species over the last decade, namely the “International Pollinator Initiative and the Plan of Action 2000-2015” and the “International Pollinators Initiative 2018-2030” by the CBD, the “EU pollinator initiative” in Europe, “Promote pollinators, the coalition of the willing on pollinators,” and “the North American Pollinator Initiative”. Other initiatives such as the “African Pollinator Initiative” are existent but not operative.

Nonetheless, these efforts are still insufficient; Hall and Steiner (2019) stated that pollinator conservation policies and actions in the US failed to address policy targets proposed by biologists and, in the EU, Marselle *et al.* (2020) pointed out that policies focus primarily on education and environmental restructuring interventions, whereas, other important types of intervention such as coercion, restriction, and incentivization are, either, completely absent or under-used. Importantly, almost half of the existent pollinator conservation actions failed to identify the intervention target. According to Gemmill-Herren *et al.* (2021), there is still a divide between science, knowledge, and policy, despite the advancement that the scientific study of pollination and ecosystems services has known over the last twenty years. Besides, most of the existent conservation strategies take place in HIC.

2.7. Conclusion

Insect pollination is an important production factor of 76% of major food crops and is essential to food security. It is also a vital ecological process for natural ecosystems, which provide a number of ES to societies. Yet, insect pollinators are declining worldwide mainly because of human practices and CC. In the past, some assessments of the economic contribution of insect pollination to social welfare were conducted to guide the conservation of these species. However, efforts for conservation are still inefficient, not sufficiently targeted, and mainly focused on HIC.

Disclaimer

This PhD thesis is organized in articles, therefore, redundancies might occur between the different chapters. I apologize to the readers for this inconvenience.

**CHAPTER 2 - DOES ARIDITY INCREASE FARMERS' SENSITIVITY
TO POLLINATOR DECLINE? AN ANALYSIS IN FIVE
CONTRASTING DRY REGIONS**

Abstract

Insect pollinators, which represent an important factor in the production of many crops, face worrying declines in many parts of the world. Farmers in drylands in LIC and MIC are particularly vulnerable to pollinator decline because of their growing dependency on insect pollination. Agricultural intensification and the increase in aridity levels are two main factors endangering pollinators in these countries. Actions for the protection of pollinators need to mitigate the impacts of aridity on these species and change threatening farming behaviors. People's economic preferences can partly drive human behavior. Therefore, analyzing farmers' preferences for the benefits of insect pollination in different aridity levels might help design successful conservation strategies. In this study, we conduct a DCE with farmers in a dry MIC, Morocco, to a) explore their preferences for insect pollination and b) examine the impact of aridity on their preferences and the value they attribute to its benefits. The survey took place in 5 different dry bioclimatic regions within the Moroccan territory, dry sub-humid, semi-arid(irrigation-based), semi-arid(rainfall-dependent), arid, and hyper-arid, with a total of 492 farmers. Our findings show that farmers have a high WTP for the protection of insect pollination benefits and that the contribution of pollinators to the quality of fruits and vegetables is the most valued benefit. The study demonstrates that aridity strongly affects farmers' preferences and that farmers' WTP increases at high levels of aridity. It also shows that the value that farmers attribute to the benefits of pollinators might increase as a result of climate change.

Keywords: Insect pollinator, Farmers' preferences, Aridity, Human behavior

1. Introduction

Insect pollination is an essential input for producing more than 3/4 of the world's major food crops (Klein *et al.*, 2007). Yet, agricultural practices are some of the main factors driving pollinator decline worldwide (Potts *et al.*, 2016). Farmers in dry LIC and MIC are constantly shifting to pollinator-dependent crops (Potts *et al.*, 2016), mainly because they provide higher incomes per surface and water units (Ashworth *et al.*, 2009; Christmann, 2020a). Therefore, the decline of insect pollinators in these countries will heavily impact farmers' subsistence and well-being, especially smallholders (Cely-Santos and Lu, 2019). LIC and MIC gather more than 2 billion smallholders, representing 83% of the world's agricultural population (Steward *et al.*, 2014). Most of these smallholders are located in drylands (UN, 2011) and practice traditional family agriculture based on diversified cropping systems (Cely-Santos and Lu, 2019). Thus, there is an urgent need to protect insect pollinators in dry LIC and MIC. Most of the existing strategy models for the protection of insect pollinators for farmers are based on incentives such as rewarding schemes which can only be affordable in HIC (Batary *et al.*, 2015; EU, 2020; FAO, 2021); these rewarding schemes have been heavily criticized by the EU for not being sufficiently targeted and efficient (EU, 2020).

Many studies argue that conservation strategies for the protection of insect pollination from anthropogenic practices should be based on changes in human behavior (Amel *et al.*, 2017; Byerly *et al.*, 2018; Marselle *et al.*, 2020). In this context, changes in farming practices can help target farmers' detrimental behaviors that endanger these species (Christmann and Aw-Hassan, 2012; Quiroga *et al.*, 2015). People's economic preferences partly derive the human behavior (Amoah and Addoah, 2021; Lades *et al.*, 2021); therefore, analyzing farmers' preferences for the benefits of insect pollination and assessing the value they attribute to these benefits might help design successful behavioral change strategies for the protection of these species in dry LIC and MIC (Hall and Martins, 2020b; Marselle *et al.*, 2020).

Another main driver of pollinator decline is CC (Potts *et al.*, 2016). According to the IPCC report (2014), many dry LIC and MIC are expected to experience significant shifts in climate due to the progression of aridity. Achieving pro-environmental behavior in these countries might also help mitigate the impacts of CC on pollinators (Corral-Verdugo *et al.*, 2020). Therefore, understanding farmers' economic preferences for the benefits of insect pollination

might help design behavioral change strategies that can also mitigate the impacts of climate change and the progression of aridity on these species.

Climate can be a key factor influencing people's preferences for ES (Shoyama *et al.*, 2013; Khanal *et al.*, 2018). Dry LIC and MIC gather a number of climate ranges on their territories; thus, analyzing farmers' preferences for the benefits of insect pollination in different bioclimatic regions within these countries can help to account for the heterogeneity in preferences of farmers for the benefits of insect pollination, due to varying levels of aridity, and also predict the impact of CC on the value they attribute to these benefits following the future expected shifts in aridity levels. Accounting for heterogeneity in preferences of farmers and the effect of CC on the value they attribute to the benefits of insect pollination will help set more targeted behavioral change and CC mitigation strategies for the protection of these species in LIC and MIC in the dryland.

Stated preferences (SPs) approaches can be used to elicit and analyze farmers' preferences. The framework of SPs assumes that respondents are rational utility maximizers who optimize their utility by expressing their preferences (Train, 2003). The utility function of farmers for insect pollination is based on the benefits they derive from the diversity and abundance of pollinators for their production. However, farmers might find it difficult to express their preferences in this case, mainly because of the nature of the benefits they derive from insect pollination for their production. As a production factor, insect pollination contributes to the diversity, quality, and quantity of yields of pollinator-dependent crops (Klein *et al.*, 2007; Garratt *et al.*, 2014; Saez *et al.*, 2020). This contribution can easily be confounded with the contribution of other production factors such as climate, fertilizers, etc., if the process of pollination and pollinators are not known. Limited information of farmers on insect pollinators and their benefits can lead to biased results of SPs. The accurate elicitation of preferences for the benefits of insect pollination will, thus, require a certain level of knowledge of farmers about pollinator services.

Sufficient knowledge of farmers about insect pollination is not the only requirement for an accurate elicitation of their preferences. An adjustment of SPs approaches to the context of LIC and MIC is also needed. Most guidelines for SPs approaches were designed and tested in HIC. Christie *et al.* (2012) pointed out the challenges of using SPs approaches in LIC and MIC. In subsistence economies, the choice of an adequate payment mechanism can be a significant

issue; asking farmers to express their WTP for insect pollination benefits in money or taxes, for instance, might bias the results of the used SP approach. Money might not be the most common measure of wealth for farmers, and hence asking farmers to express a monetary WTP would result in comprehension burdens. Besides, most farmers in LIC and MIC do not pay taxes and usually have trouble trusting the government to deliver policies (McCauley and Mendes, 2006). In these cases, the risk of farmers using simplifying decision mechanisms while expressing their preferences is relatively high (Meyerhoff and Liebe, 2009).

Many studies addressed the issue of the payment mechanism in LIC and MIC by suggesting the use of other measures of wealth which might be more significant to farmers, such as the number of bags of rice (Rowcroft *et al.*, 2004) or through the use of labor-based payment mechanisms (Khanal *et al.*, 2018; Hagedoorn *et al.*, 2020); Rai *et al.* (2015) and Tadesse *et al.* (2017) show that farmers in LIC and MIC prefer to express their demand for ES by offering their time instead of making monetary payments. Such payment mechanisms will help accurately elicit farmers' preferences; however, the value they attribute to the service of interest might be valid only within a particular context, making the transfer of value almost impossible (Christie *et al.*, 2012).

In this paper, we use a DCE to analyze farmers' preferences for the benefits of insect pollinators in dry LIC and MIC and assess the value they are willing to pay to secure these benefits while trying to overcome the mentioned challenges related to the elicitation of farmers' preferences in LIC and MIC. We also analyze farmers' preferences for benefits of insect pollinators and assess the value they attribute to these benefits in five different dry bioclimatic regions which varying levels of aridity. This analysis will provide decision-makers with the necessary information to design targeted efficient behavioral change and CC mitigation strategies to protect insect pollinators in these nations. To represent dry LIC and MIC, we chose Morocco as our benchmark site.

Section 2 is devoted to the context and area of the study in which we explain pollination, its importance, and threats facing insect pollinators in dry LIC and MIC. We then proceed to further clarify why we chose Morocco as our benchmark site. Section 3 deals the methodological framework of the DCE, in which we introduce and explain our choice of attributes and levels as well as the sampling technique. Section 4 covers results organized in 5

subsections. In the first subsection, we describe the different characteristics of the sample and assess the level of knowledge of farmers about insect pollination. In the second, we explore farmers' preferences for the benefits of insect pollination. In the third, we identify the impact of the different bioclimatic regions on farmers' preferences. In the fourth, we assess the stated WTP of farmers to protect the benefits of insect pollination and inspect the impact of the level of aridity on this value. In the final subsection, we measure the extent of the effects of the potential shifts in the level of aridity resulting from CC on farmers' WTP. Results are then discussed in the light of literature in section 5, and their relevance for policy design is presented in conclusion.

2. Context and area of the study

Pollination is an essential ecological process for the reproduction of flowering plants in cultivated crops and wild plant communities (Klein *et al.*, 2007; Ollerton *et al.*, 2011). It refers to the transfer of pollen from the male (anther) to the female (stigma) parts of flowers, which represents a crucial step in producing fruits and seeds. There are different forms of pollination depending on the vector that carries the pollen, namely self-pollination, water pollination, wind pollination, and animal-mediated pollination (IPBES, 2016).

Pollinating insects are diverse and include hundreds of thousands of bees, flies, butterflies, moths, beetles, etc. Over the years, farmers have learned to manage some of these insects, namely, the western honey bee, the eastern honey bee, some bumblebees, some stingless bees, and a few solitary bees, to respond to the growing agricultural demand for pollination (Aizen and Harder, 2009; IPBES, 2016). Nonetheless, managed pollinators can only supplement pollination services of wild insects and not substitute them (Garibaldi *et al.*, 2013).

Insect pollinator populations are experiencing worrying declines in many parts of the world (Potts *et al.*, 2010; IPBES, 2016; Hallmann *et al.*, 2017; Hallmann *et al.*, 2021). Evidence of the decline has been found in the USA, the EU and the UK (Biesmeijer *et al.*, 2006; Van Engelsdorp *et al.*, 2008; Scheper *et al.*, 2014; Potts *et al.*, 2015; Robert, 2016; Powney *et al.*, 2019). In most LIC and MIC, evidence of this decline has not been found yet, because of the shortage of documentation and lack of studies on pollination and pollinators (Archer *et al.*, 2014). The decline of plants often translates to insect pollinator loss; therefore, the significant losses of plant biodiversity in these parts of the world can inform on the state of insect pollinators (Pauw and Hawkins, 2011; Burkle *et al.*, 2013).

Agricultural intensification and CC are two main factors driving pollinator decline (Potts *et al.*, 2016). The intensive use of agrochemicals, monoculture, tillage and mowing can affect pollinators health and result in habitat destruction and damage their nesting and food resources (Gill *et al.*, 2012; Burkle *et al.*, 2013; Goulson, 2014; Hallmann *et al.*, 2014; Goulson *et al.*, 2015; Requier *et al.*, 2015). Besides, changes in ecosystems and extreme climatic conditions, due to CC, induce changes in pollinator temporal activities, genetics, phenology, etc., impact their habitat and overall distribution and affect their plant-pollinator interactions (Memmott *et al.*, 2007; Schweiger *et al.*, 2008; Hegland *et al.*, 2009; Giannini *et al.*, 2012; Polce *et al.*, 2014; Kerr *et al.*, 2015a; Miller-Struttmann *et al.*, 2015 ; Elias *et al.*, 2017; Martinet *et al.*, 2020; Kuppler *et al.*, 2021)

Agroecosystems in dry LIC and MIC are highly vulnerable to pollinator decline, especially in Africa and West Asia (Gallai *et al.*, 2009; Potts *et al.*, 2016; Aizen *et al.*, 2019). This vulnerability results from their growing dependence on pollinator-dependent crops (Potts *et al.*, 2016). In these countries, farmers, primarily smallholders, use diversified cropping systems as a risk premium to face climatic hazards (Ashworth *et al.*, 2009; Christmann, 2020a). Therefore, the decline of insect pollinators will increase farmers' vulnerability to CC and affect their livelihoods.

Morocco is a MIC where pollinators are threatened severely by both agricultural intensification and the progression of aridity. The Moroccan climate is expected to experience, by the end of the century, significant shifts due to an increase in aridity levels (Schilling *et al.*, 2012; IPCC, 2014) and in 2008, the Moroccan government launched a large agricultural intensification strategy following the “Plan Maroc Vert” (Harbouze *et al.*, 2019); as a result, Morocco has been registered among the countries with the highest levels of agrochemical use (FAO, 2018).

The country has been listed as very vulnerable to pollinator decline (Potts *et al.*, 2016). So far, there has been no forward evidence on pollinator decline in Morocco, except for vertebrate pollinators (Rasmont *et al.*, 2015b). Lhomme *et al.* (2020) prepared the first baseline for bee monitoring in the country; however, the research is still in its early stages, and no conclusions can be made. Nonetheless, the major losses in plant biodiversity in Morocco bring forward the severe threats facing pollinating insects (Rankou *et al.*, 2015; Lala *et al.*, 2017; IPBES, 2019a).

These threats are likely to impact Moroccan agroecosystems highly dependent on insect pollination. According to the Ministry of Agriculture, 22% of the country's agricultural production is pollinator-dependent (MOA, 2017b) and agricultural exports are dominated by pollinator-dependent products (MOA, 2017a). The agricultural sector has a major influence on the Moroccan GDP (Harbouze *et al.*, 2019) In 2017, it accounted for 13% of the total GDP and 11,6% of the total exports of the country. This sector remains the primary source of employment (MOA, 2017a). The decline of pollinators can, therefore, have severe impacts on the economy of the country, and farmers would be the first to undergo these impacts. The protection of insect pollination in Morocco and other LIC and MIC in the same situation is, therefore, of great importance for farmers' subsistence and economic growth. Pollinator-dependent crops are more labor-intensive than e.g. cereals, therefore pollinator protection is an issue of social stability in Morocco.

3. Methodology

3.1. DCE: Theoretical framework

The DCE is a stated preference technique used to model preferences for ES and estimate their economic values (Hanley *et al.*, 2001; Hanley *et al.*, 2015). In DCE surveys, ES are defined by a number of attributes (or characteristics) and their levels. The mixture of these attributes and levels generates different situations or choice sets. Each choice set is composed of 2 to 3 alternatives describing hypothetical changes in the ES to be assessed. Respondents are then asked to choose their most preferred alternative within each choice set. By including a payment mechanism as one of the attributes of the ES, WTP can be inferred from people's choices.

The DCE approach was initially developed by Louviere and Hensher (1982). Its conceptual framework is rooted in the characteristics demand theory (Lancaster, 1966) and the random utility theory (McFadden, 1973). This framework is based on the assumption that the utility people derive from a situation can be defined by a set of characteristics. Consequently, respondents' utilities for goods or services can be disaggregated into utilities for composing characteristics of those goods or services.

We consider U_{nsj} , the utility that a decision-maker n in a choice situation s will derive from consuming or possessing alternative j . Hence, U_{nsj} may be decomposed into two separate

components, an observed or modeled component, V_{nsj} , and a residual unobserved and unmodeled component, ε_{nsj} , such that:

$$U_{nsj} = V_{nsj} + \varepsilon_{nsj}$$

The observed or deterministic component of utility V_{nsj} is defined as a function of k variables, X_{nsjk} , with associated preference weights, β , such that:

$$V_{nsj} = f(X_{nsjk}, \beta, \sigma)$$

X_{nsjk} is a vector of k attributes describing alternative j and/or covariates describing either the decision-maker or some aspect of the decision context. β is a vector of parameters to be estimated. σ is a scalar representing a positive scale parameter that links V_{nsj} to ε_{nsj} . σ serves to scale the utility of each alternative.

The observable utility component is assumed to be a linear relationship of observed attribute levels, X . β_{nk} represents marginal utilities.

$$U_{nsj} = \sigma_n \sum_{k=1}^K \beta_{nk} X_{nsjk} + \varepsilon_{nsj}$$

To model choices, it is mandatory to make a number of assumptions about the unobserved components of utility. The most common assumption is that for each alternative, j , ε_{nsj} , will be randomly distributed with some density, $f(\varepsilon_{nsj})$, over decision-makers, n , and choice situations, s . This assumption enables making some probabilistic statements about the choices made by decision-makers. Hence, the probability that respondent n in choice situation s will select the alternative j is given as the probability that outcome j will have the maximum utility. The likelihood that the differences in the random terms, $\varepsilon_{nsi} - \varepsilon_{nsj}$ will be less than the differences in the observed components of utility, $V_{nsi} - V_{nsj}$.

$$P_{nsj} = \text{Prob}(U_{nsj} > U_{nsi}, \forall i \neq j)$$

$$P_{nsj} = \text{Prob}(V_{nsj} + \varepsilon_{nsj} > V_{nsi} + \varepsilon_{nsi}, \forall i \neq j)$$

$$P_{nsj} = \text{Prob}(\varepsilon_{nsj} - \varepsilon_{nsi} > V_{nsi} - V_{nsj}, \forall i \neq j)$$

A baseline alternative is usually included in each choice set ($j \geq 2$ alternatives) to interpret results in standard welfare economic terms. This baseline alternative can take two forms: the status quo and opt-out option (Adamowicz and Boxall, 2001)

3.2. DCE: Definition and levels of attributes

Our selection of attributes to characterize insect pollination for this DCE was based on three steps:

- First step: literature review

The accurate selection of the non-payment attributes for this DCE should be based on the utility farmers derive from insect pollination. In the literature, we did not find any elicitation of farmers' preferences for insect pollination. Therefore, in this step, we focused our review on the benefits that farmers derive from pollinators. These benefits represent the different economic values (TEV) that insect pollination provides to farmers. Insect pollination contributes to farmers' well-being by supporting diversified crops production on the farm and guaranteeing good quality and high quantity of yields (Klein et al., 2007; Garratt et al., 2014; Saez et al., 2020). Thus, the attributes selected in this step are:

- "Diversity of agricultural production on the farm," which refers to the possibility of producing all crops (pollinator dependent and independent crops) or only pollinator independent crops during an agricultural campaign,
- "Quantity of fruits and vegetables produced on the farm," which refers to contribution of pollinators to the number of tons of pollinator dependent crops harvested in an agricultural campaign,
- "Quality of fruits and vegetables produced on the farm" refers to contribution of pollinators to the caliber, taste, smell and shape (presence or absence of deformations) of pollinator dependent crops.

For the payment mechanism, we based our review on measures of wealth and suggestions from previous DCE designs to value different components of biodiversity in LIC and MIC. A labor-based mechanism seemed to be the best fit for Morocco (Gibson *et al.*, 2015; Rai *et al.*, 2015; Tadesse *et al.*, 2017). However, because of farmers' difficulty to believe that the government will use the outcome of their work to deliver successful policies. The willingness to volunteer (WTV) can be a good alternative to a labor-based mechanism. The payment mechanism we suggested in this step is "the number of volunteering days per year in an association for the protection of pollinators and their natural habitats"; WTV has proven to be useful to value ES in a HIC (Ando *et al.*, 2020), however, in literature we couldn't find a study which implements this type of payment mechanism for ES in LIC and MIC. Thus, we use the second and third steps to validate our choice of payment mechanism and our choice of non-payment attributes.

- Second step: Focus group with Moroccan experts (Appendix6)

The selected attributes were discussed with a group of Moroccan experts. These experts confirmed the relevance of the selected attributes. They considered that the attribute "Diversity of agricultural production on the farm" could be a convenient proxy of the ecological function

of insect pollination (Ollerton *et al.*, 2011) in agroecosystems. Therefore, this attribute might be linked to indirect use values of insect pollination. During discussions on farmers' perceptions of the diversity of production, experts also mentioned that farmers always link diverse agricultural landscapes to the existence and diversity of pollinators (e.g., bees and butterflies). Hence, this attribute might represent existence values of insect pollination as well. The importance of the attributes "Quantity of fruits and vegetables produced on the farm" and "Quality of fruits and vegetables produced on the farm" for the subsistence of farmers was highlighted by experts. Thus, we linked these two attributes to the direct use values in the TEV of insect pollination for farmers. The attributes "Quantity of fruits and vegetables produced on the farm" and "Quality of fruits and vegetables produced on the farm" also represent indirect use values insect pollinators provide to farmers; for instance, the diversity and abundance of pollinators help with pest control (Christmann *et al.*, 2017; Christmann *et al.*, 2021a).

- Third and final step: Focus groups with farmers

The outcome of the first two steps was confirmed by two focus groups with Moroccan farmers. We also learned that when farmers express their interest in the conservation of the different benefits of insect pollination, they implicitly link this conservation to the well-being of future generations. Thus, we can connect these attributes to use values of insect pollination and bequest values. The option value can also be captured by these attributes; farmers implicitly wish to have the option to use the benefits represented by the attributes in the future. For the payment mechanism, farmers indicated that the WTV might not be adapted to farmers with higher wages. Consequently, we suggested an equivalent alternative in cash to include all categories of farmers in the DCE. This alternative, confirmed by both focus groups, corresponds to the "1/3 of what the farmer gains daily". The WTP in volunteering days can, therefore, be converted into the monetary form according to the following formula:

$$WTP = \text{Volunteering days} * 1/3 \text{ of the average daily individual income}$$

This monetary alternative for the WTV does not only help to include all categories of farmers but also eases the process of value transfer for other countries in the same situation. Volunteering, as explained to farmers, can take multiple forms, for instance, seeding strips of marketable habitat enhancement plants and the creation of nesting and water support sites for pollinators out of low-cost local materials and waste products near and on farms which will protect the diversity of pollinators and attract more of them on the farm and hence enhance

pollination (Christmann and Aw-Hassan, 2012; Christmann *et al.*, 2021b). The levels attested by farmers in the two focus groups are "high" and "low (reference)" for the first three attributes and "12, 24, 36, and 48 days per year " for the payment mechanism (table1).

To lower the bias related to the comprehension burdens of the attributes if farmers are not fully aware of the contribution of insect pollination to their production, we firstly prepared a short explanatory paragraph about the context of the study, which was read to all interviewed farmers before the survey. This paragraph defines insect pollination and explains its benefits to farmers and the drivers of pollinator decline (Appendix2). Secondly, during the survey, questions linking the chosen attributes to insect pollination were asked to farmers to mentally prepare them for the choice cards. Before proceeding with the choices, farmers were given explanatory sheets of the attributes (Appendix3), where we clearly state that their choices should be based on the contribution of insect pollination to the different attributes. In these sheets, images were used to illustrate the different attributes and their levels. Thirdly, we chose to conduct a face-to-face survey to ensure that farmers understood the attributes and how they can be influenced by insect pollination (The prepared sheets of the attributes were explained before moving to choice cards). And finally, we added a follow-up question to the choice cards to check if farmers considered the contribution of insect pollination while making their choices (more than 90% of them responded positively).

Table 1: The attributes and the levels used for the DCE and their correspondent component of the TEV of pollination

Attributes	Components of the TEV	Levels
<i>1st attribute</i> - Diversity of agricultural production on your farm	<i>Indirect use value</i> <i>Existence value</i> <i>Bequest value</i> <i>Option value</i>	High
		Low (reference)
<i>2nd attribute</i> - Variety of fruits and vegetables produced on your farm	<i>Direct use value</i> <i>Bequest value</i> <i>Option value</i>	High
		Low (reference)
<i>3rd attribute</i> - Quality of fruits and vegetables produced on your farm	<i>Direct use value</i> <i>Bequest value</i> <i>Option value</i>	High
		Low (reference)

<i>Payment mechanism per year per farmer-</i> Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the farmer earns daily)		12, 24, 36, and 48 days per year
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3.3. DCE: Experimental design

The full-factorial design produces 32 choice sets. This number was reduced to 8 choice sets in one block, using an efficient design on the *Ngene* software. Preliminary choice sets were first produced using multinomial logit and standard priors. These choice sets were tested in a pilot study with 20 Moroccan farmers to ensure the relevance of the chosen attributes and their levels before generating the final choice sets. The collected data was analyzed, and results helped define new priors to refine the final design generated using a mixed logit model (MLM). The survey was conducted with 492 farmers (Appendix7), sampled in five bioclimatic regions, generating 11808 observations.

Each choice set includes two alternatives and an opt-out option (or no-choice situation) (figure1). The no-choice situation is a blank option devoid of any attribute levels. This option was included in the DCE to not force participants to choose if they do not express a preference towards the first two alternatives in a choice card. In the literature, most DCE designs on ES use the status quo instead of the opt-out option. The definition of a status quo for an ecosystem service requires a deep knowledge of the current situation of the service of interest. Nonetheless, in the case of insect pollination, especially in Morocco, this situation remains poorly known.







	Alternative1 <i>High diversity :</i>	Alternative2 <i>Low diversity :</i>	Opt out
Diversity of agricultural production on the farm			
Quantity of agricultural production of fruits and vegetables on the farm	<i>Low quantity :</i> 	<i>High quantity :</i> 	
Quality of agricultural production of fruits and vegetables on the farm	<i>High quality :</i> 	<i>Low quality :</i> 	
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or eq:1/3 of what the farmer gains daily)	12	48	
Your choice			

Figure 1: Example of a choice set used in the DCE

3.4. DCE: Sampling

The survey was conducted in 5 bioclimatic regions in Morocco: Tanger-Tétouan-Elhouceima, Fès-Meknès, Casablanca-Settat, Draa-Tafilalet and Laayoun-Sakia-El Hamra (see figure 2).



Figure 2: Map of the administrative regions in Morocco

The choice of these regions was mostly based on their climate range. In dry areas, the evolution of aridity is an important indicator of CC (Dong *et al.*, 2012; Asadi Zarch *et al.*, 2017). The change in aridity levels can be measured through aridity index (AI), defined as the ratio of the annual precipitation (P) to Potential Evapotranspiration (PET) (UNEP, 1993). This index recognizes significant decreasing trends resulting from CC in arid and semi-arid climates (Huo *et al.*, 2013).

Table 2 summarizes the average AI of the 5 chosen bioclimatic regions. The level of aridity becomes higher, and the AI index becomes lower from north to south of Morocco. We represent all five climate ranges present in dry LIC and MIC in our selection of the five regions.

Table 2: AI of the regions chosen for the study of Morocco

Regions	AI	Climate range
Tanger-Tétouan-El Houceima (TTH)	0.553	Dry sub-humid
Fès-Meknès (FM)	0.456	Semi-arid (irrigation-based)
Casablanca-Settat (CS)	0.32	Semi-arid (rainfall based)
Draa-Tafilalet (DT)	0.098	Arid
Laayoun-Sakia-El Hamra (LSH)	0.027	Hyper-arid

Source: (Trabucco and Zomer, 2019)

Farmers interviewed per climate range were randomly selected from lists provided by the “Office National de Conseil Agricole (ONCA),” the governmental institution for agricultural development in Morocco. The data collected was analyzed using a MLM in both preferences space (Train, 2009) and WTP space (Train and Weeks, 2004). Effect coding was used for the first two alternatives in each choice set, and the opt-out option was coded 0.

4. Results

4.1. The sample

Table 3 shows the characteristics of the sample randomly chosen for this study. The majority of respondents are males (93%) aged between 30 and 60 years old (76%), mostly married and having kids (88%). 14% of our sample did not receive a formal education, 39% did not go beyond primary school, 37% are smallholder farmers (0 to 5 ha), and 43% depend entirely on rainfall. The level of knowledge about pollination and the risks pollinators face is high (more

than 80%). The best-known pollination vector is the honey bee; however, the difference between native and managed pollinators is less known.

Table 3: Respondents' characteristics

Descriptors	Shares
Gender	<ul style="list-style-type: none"> ⇒ F: 7% ⇒ M: 93%
Age	<ul style="list-style-type: none"> ⇒ 42% between 45& 60 years ⇒ 34% between 30 & 44 years ⇒ 16% between 60 & 75 years
Personal situation	88% married
Children	88% have Children
Education	<ul style="list-style-type: none"> ⇒ 26% have an elementary education ⇒ 17% have secondary education ⇒ 17% have a college education ⇒ 14% have no formal education ⇒ 13% have preschool education ⇒ 12% have a high school education
Agricultural Revenue/year	<ul style="list-style-type: none"> ⇒ 20% make more than 15760 € ⇒ 19% between 4503 & 6754 € ⇒ 17% between 2251 & 4503 € ⇒ 14% between 6754 & 9006 € ⇒ 10% less than 2251 € ⇒ 9% between 9006 & 11257 € ⇒ 7% between 11257 & 13508 € ⇒ 3% between 13508 & 15760 €
Farm size	<ul style="list-style-type: none"> ⇒ 29% from 0 to 3 ha ⇒ 19% from 3 to 5 ha ⇒ 24% from 5 to 10 ha ⇒ 14% from 10 to 20 ha ⇒ 14% from 20 to plus 200

Irrigation	<p>⇒ 43% is not irrigated</p> <p>⇒ 29% is irrigated</p> <p>⇒ and the rest is half irrigated half not irrigated</p>
Pollination knowledge	86% know the process of pollination
Pollination vector knowledge	85% know at least one pollination vector
Knowledge of the difference between wild and managed pollinators	60% know the difference between wild and managed pollinators
Knowledge concerning threats to pollinators	86% know that pollinators are endangered
Level of aridity	<p>⇒ Dry sub-humid: 19,72 %</p> <p>⇒ Semi-arid (with irrigation): 20,13%</p> <p>⇒ Semi-arid (rainfall): 19,72%</p> <p>⇒ Arid :20,11%</p> <p>⇒ Hyper-arid: 20,33%</p>
Level of crop dependence on pollinators	37% produce crops that depend on pollinators

4.2. Hierarchy and heterogeneity of preferences

In the first column of table 4, results of the mixed logit in preferences space estimations show that taste parameters of “Diversity of production,” “Quantity of produced fruits and vegetables,” and “Quality of produced fruits and vegetables” are significant and positive. The taste parameter of the payment mechanism is significant and has the correct specification. The “Quality of produced fruits and vegetables” seems to have a significant effect on farmers’ choices. The alternative specific constant (ASC), which was included in the model to capture the opt-out option, is significant and positive. Results for the ASC show that respondents prefer the first two alternatives and strongly reject the opt-out option. Results of the mixed logit also show significant standard deviation of the mean taste parameters for all attributes, including the payment mechanism.

Table 4: Results of mixed logit estimation in preference space without and with interactions

	MLM	MLM with interactions
Main coefficients		
ASC	7.69***	8.50***
	(0.32)	(0.40)
Diversity of production	0.34***	0.38***
	(0.04)	(0.14)
Quantity produced of fruits and vegetables	0.35***	0.39***
	(0.04)	(0.14)
Quality of produced fruits and vegetables	0.76***	0.31
	(0.07)	(0.25)
Number of volunteering days	-1.00***	-1.49***
	(0.08)	(0.46)
Observed heterogeneity		
Diversity of production * Gender		-0.03
		(0.15)
Quantity produced of fruits and vegetables* Gender		-0.01
		(0.15)
Quality of produced fruits and vegetables* Gender		-0.15
		(0.21)
Quality of produced fruits and vegetables* Aridity level		0.18***
		(0.04)
Number of volunteering days or equivalent * Gender		-0.04
		(0.26)
Number of volunteering days or equivalent * Age		0.18*
		(0.09)

Number of volunteering days or equivalent *		-0.19*
Irrigation		(0.10)
Number of volunteering days or equivalent *		0.12**
Aridity level		(0.06)
Standard deviation		
Diversity of production	0.27***	0.18***
	(0.06)	(0.06)
Quantity produced of fruits and vegetables	0.17***	0.24*
	(0.05)	(0.09)
Quality of produced fruits and vegetables	1.05***	1.03***
	(0.07)	(0.07)
Number of volunteering days or equivalent	1.63***	1.50***
	(0.12)	(0.09)
Observations	11808	11808
N_clust	492	492
AIC	4425.16	4303.98
BIC	4491.55	4377.75

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

We added interactions to the MLM estimation to explore the heterogeneity in farmers' preferences (significant standard deviation of the mean taste parameters of the attributes). Separately, we crossed the variables "gender", "age", "education", "personal situation", "income", "farm size", "irrigation", "honey production", "knowledge of pollinators", "level of aridity" and "level of dependency on the production on insect pollination" with the different attributes in distinct mixed logit estimations. Our choice of these variables was based on a literature review of the personal characteristics affecting economic preferences for ES and variables affecting the production function of farmers. The mixed logit with interactions estimation in table 4 incorporates only the significant interactions when crossed separately.

Results of the mixed logit in preference space with interactions show that farmers' preferences are not affected by any personal characteristics except "age". Older farmers appear to be more sensitive to the payment mechanism. However, the variable "level of aridity", a climate range indicator, shows significance when crossed with the attribute "Quality of the produced fruits and vegetables" and, too, with the payment mechanism. The variable irrigation, which is also a climate range indicator, shows significance, as well, when crossed with the payment mechanism. Thus, in climates where the level of aridity is high, farmers are more sensitive to both the "Quality of produced fruits and vegetables" and the payment mechanism and vice versa. Besides, farmers in irrigated perimeters are less sensitive to the payment mechanism, and those with rainfall-dependent farms are more sensitive to it.

The added interactions explained only a part of the heterogeneity in farmers preferences for the different attributes, which implies that the source of this heterogeneity is not entirely driven by the variables studied. Nonetheless, interactions showed the important effect of aridity on farmers' preferences.

4.3. Effects of the level of aridity on farmers preferences

The analysis of farmers' preferences shows strong effects of the level of aridity. Thus, to further explore these effects, we analyzed data per climatic range using a MLM in preference space (table 5).

Table 5: Estimation of the mixed logit in preference space per climatic range

	MLM in Dry-Sub- Humid climate	MLM in Semi- Arid (Irrigation based) climate	MLM in Semi-Arid (Rainfall dependent) climate	MLM in Arid climate	MLM in Hyper - Arid climate
Main coefficients					
ASC	8.40 ^{***}	8.61 ^{***}	7.87 ^{***}	8.74 ^{***}	11.48 ^{***}
	(1.18)	(1.49)	(1.91)	(1.67)	(2.39)
Diversity of production	0.07	0.45 ^{***}	0.37 ^{***}	0.57 ^{***}	0.34 ^{***}

	(0.08)	(0.10)	(0.10)	(0.15)	(0.06)
Quantity produced of fruits and vegetables	0.18 ^{***}	0.48 ^{***}	0.44 ^{***}	0.52 ^{***}	0.29 ^{***}
	(0.03)	(0.09)	(0.08)	(0.12)	(0.06)
Quality of produced fruits and vegetables	0.21	0.93 ^{***}	0.42 ^{***}	1.25 ^{***}	1.25 ^{***}
	(0.17)	(0.18)	(0.15)	(0.22)	(0.25)
Number of volunteering days	-1.77 ^{***}	-1.14 ^{***}	-1.18 ^{**}	-1.77 ^{***}	-0.56 ^{***}
	(0.49)	(0.27)	(0.49)	(0.56)	(0.17)
Standard deviation					
Diversity of production	0.23 ^{**}	0.24 [*]	0.09	0.34 ^{***}	0.02
	(0.12)	(0.14)	(0.10)	(0.12)	(0.04)
Quantity produced of fruits and vegetables	0.05	0.24 [*]	0.30 ^{**}	0.71 ^{***}	0.00
	(0.06)	(0.13)	(0.15)	(0.16)	(0.04)
Quality of produced fruits and vegetables	1.15 ^{***}	1.06 ^{***}	0.57 ^{***}	1.26 ^{***}	1.55 ^{***}
	(0.19)	(0.17)	(0.17)	(0.21)	(0.24)
Number of volunteering days	2.67 ^{***}	1.52 ^{***}	1.78	2.11 ^{***}	1.06 ^{***}
	(0.68)	(0.28)	(1.21)	(0.74)	(0.16)
Observations	2325	2373	2325	2373	2400
N_clust	97.00	99.00	97.00	99.00	100.00
AIC	957.87	844.82	900.13	862.81	715.12
BIC	1009.64	896.77	951.90	914.76	767.17

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Farmers' preferences differ between climatic ranges; for instance, in the arid and hyper-arid climates, farmers strongly prefer the "Quality of produced fruits and vegetables" compared to farmers from the other climatic ranges. In the dry sub-humid climate, mean taste parameters of

the "Diversity of production" and "Quality of produced fruits and vegetables on the farm" are not significant. The standard deviation around the mean taste parameter of the attribute "Quality of produced fruits and vegetables" and "Number of volunteering days" is significant for all climate ranges.

4.4. WTP analysis

In order to estimate the economic value of the benefits of insect pollination for farmers, we calculated, in table 6, the WTP stated by Moroccan farmers to protect the benefits of insect pollination using a mixed logit in WTP space model for the full dataset. In the same table, we also estimated the WTP per climate range, using the same statistical model, to capture the effects of aridity on the value of the benefits of insect pollination. In the mixed logit in WTP space, the coefficient on the payment variable is assumed to be lognormally distributed; therefore, it should be multiplied by -1 ("negative number of volunteering days") before entering the model (Train and Weeks, 2004).

Table 6: Estimation of the mixed logit in WTP space for the full dataset and per climatic range

	MLM in WTP space					
	Full dataset	Dry Sub-Humid	Semi-Arid (Irrigation based)	Semi-Arid (Rainfall dependent)	Arid	Hyper - Arid
Main coefficients						
ASC	134.14***	94.57***	199.46*	93.41***	71.63***	398.80
	(23.63)	(23.27)	(114.29)	(16.38)	(9.81)	(267.88)
Diversity of production	3.77***	4.14***	4.35***	5.79***	4.82***	6.44***
	(0.53)	(0.82)	(0.54)	(1.42)	(1.38)	(2.27)
Quantity produced of fruits and vegetables	2.81***	1.81**	2.27**	6.90***	4.87***	4.96**
	(0.62)	(0.90)	(0.92)	(1.95)	(1.81)	(2.39)

Quality of produced fruits and vegetables	10.68 ^{***}	3.01	9.42 ^{***}	5.67 ^{***}	11.71 ^{***}	25.46 ^{***}
	(1.43)	(3.01)	(0.88)	(1.72)	(2.54)	(8.89)
Negative number of volunteering days	-3.25 ^{***}	-3.54 ^{***}	-3.27 ^{***}	-3.28 ^{***}	-2.96 ^{***}	-3.72 ^{***}
	(0.13)	(0.25)	(0.50)	(0.17)	(0.14)	(0.34)
Standard deviation						
Diversity of production	0.40	0.42	0.76 [*]	0.26	2.56	2.12
	(0.40)	(0.53)	(0.45)	(2.35)	(2.33)	(1.51)
Quantity produced of fruits and vegetables	0.61	1.07	0.07	2.75	3.45	2.34
	(0.61)	(1.24)	(0.89)	(3.22)	(2.20)	(1.57)
Quality of produced fruits and vegetables	13.07 ^{***}	8.86 ^{***}	-13.13 ^{***}	0.00	12.04 ^{***}	27.22 ^{***}
	(1.48)	(3.32)	(1.72)	(1.47)	(2.41)	(8.46)
Negative number of volunteering days	0.95 ^{***}	0.77 [*]	1.75 ^{***}	0.06	0.41	0.41
	(0.16)	(0.46)	(0.52)	(0.48)	(0.26)	(0.31)
Observations	11808	2325	2373	2325	2373	2400
N_clust	492	97.00	99.00	97.00	99.00	100.00
AIC	5386.98	1296.47	1012.66	1186.62	1095.10	914.29
BIC	5453.37	1348.23	1064.61	1238.38	1147.05	966.34

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The attribute “Quality of produced fruits and vegetables” is the most valued attribute, and the “Quantity of produced fruits and vegetables” is the least valued attribute for the full dataset.

The farmers in the different climate ranges value the attributes characterizing insect pollination differently. For instance, the “Quality of produced fruits and vegetables” becomes highly valued when we shift from climate ranges with low levels of aridity to climate ranges with high levels of aridity.

Based on the values presented in table 8, we calculate the WTP of farmers for the full dataset and per climatic range (sum of estimations in WTP space for the different attributes). Table 7 displays WTP estimations for the full dataset and per climate range. The payment mechanism we used translates to two forms: the number of volunteering days and the equivalent in Euros. We used the average personal income (of the sample), for the full dataset and per climatic range, to transform WTP from the volunteering days' format to the monetary format.

Table 7: The WTP in euros for the full dataset and per climate range

Climate ranges	Number of volunteering days per year	The average income per year	WTP per farmer per year
Full dataset	17,27	11 061 €	177 €
Dry Sub-Humid	8,96	8 129 €	67 €
Semi-Arid (Irrigation based)	16,05	11 897 €	177 €
Semi-Arid (Rainfall dependent)	18,35	10 511 €	179 €
Arid	21,4	12 730,26 €	252€
Hyper -Arid	36,86	12 180 €	416€

Results of the full dataset analysis show that the WTP for the protection of insect pollination equals 177 € per year per farmer and that the value stated by farmers differs between climate ranges when analyzed separately. The higher the level of aridity, the higher is the willingness to contribute to pollinator protection.

4.5. The impact of the shift in the level of aridity on farmers WTP

As a result of CC, the aridity level is expected to shift in Morocco (IPCC, 2014). The impact of the shift of aridity between the different climate ranges on farmers WTP for the protection of insect pollination benefits can be estimated as follows (table 8):

Table 8: The impact of the shifts in aridity level on farmers WTP

Shifts between climate ranges	Impact on farmers' WTP/year
From Sub-humid to semi-arid	+110 €
From semi-arid to arid	+76 €
From arid to hyper-arid	+165 €

The shift in the level of aridity increases farmers' WTP for the protection of the benefits of insect pollination. Therefore, CC appears to increase the value farmers attribute to insect pollination in dry areas, such as Morocco.

5. Discussion

This study substantiates the importance that farmers in aridity-prone climates place on the benefits of insect pollination. Interviewed farmers stated a higher WTP to protect the benefits derived from pollinators than a similar study valuing insect pollination in the UK by Breeze *et al.* (2015). Many factors can explain the difference in WTP estimates between the two studies. First, the payment mechanisms employed in both studies are different: taxes vs. volunteering work. Unlike the willingness to volunteer, which is well accepted by populations in LIC and MIC to express their demand for ES (Tadesse *et al.*, 2017), people in HIC do not always welcome green taxes (Carattini *et al.*, 2019). Our choice to not specify the volunteering period can also be a factor explaining the resulting high WTP estimates. During interviews, farmers indicated that their choice of scenarios is valid outside of their hectic periods (harvesting, tillage, etc.). This choice was thoroughly discussed concerning the opportunity cost of farmers and the value of the WTP estimates in the focus groups held before the survey. However, since volunteering to protect pollinators can be beneficial to pollinators throughout the year, the period was not specified. Second, the survey design and the targeted population; farmers, targeted in our case, and consumers, targeted by Breeze *et al.* (2015), derive different benefits from insect pollination. Therefore the attributes chosen to represent these benefits in both studies are dissimilar. And finally, the number of observations and the survey method; the sample selected for this study is almost twice the one selected in Breeze *et al.* (2015). Besides, face-to-face interviews and postal-based surveys usually result in different estimates. Our results also bring forward climate as a significant potential factor explaining this difference. Morocco has an aridity-prone climate, whereas the UK shows no signs of aridity. The impact of aridity on farmers' preferences is apparent in the spatial distribution of the WTP they express.

The trend in figure 3 displays a link between the WTP stated by farmers and the aridity level of the region they live in. In regions with low aridity levels, farmers are willing to pay less to protect insect pollination services than farmers living in areas with high aridity levels. This result was unexpected given that the contribution of insect pollination to agricultural production is higher in region where the levels of aridity is low (Gallai *et al.*, 2009). It might be explained by the limited extent of pollinator services and thus the need to fully maintain these services, which can be expressed through their high WTP. It could also be linked to the place attachment and the sense of place of farmers in aridity-prone climates. This sense may influence people's motivations and hence their preferences and WTP. A similar study by García-Llorente *et al.* (2012) showed that populations' level of support of biodiversity conservation in Mediterranean semi-arid climates can be affected by their geographical position. García-Llorente *et al.* (2012) demonstrated that the great sense of belonging and the urge to protect semi-arid landscapes could explain the high WTP of respondents to conserve these areas.

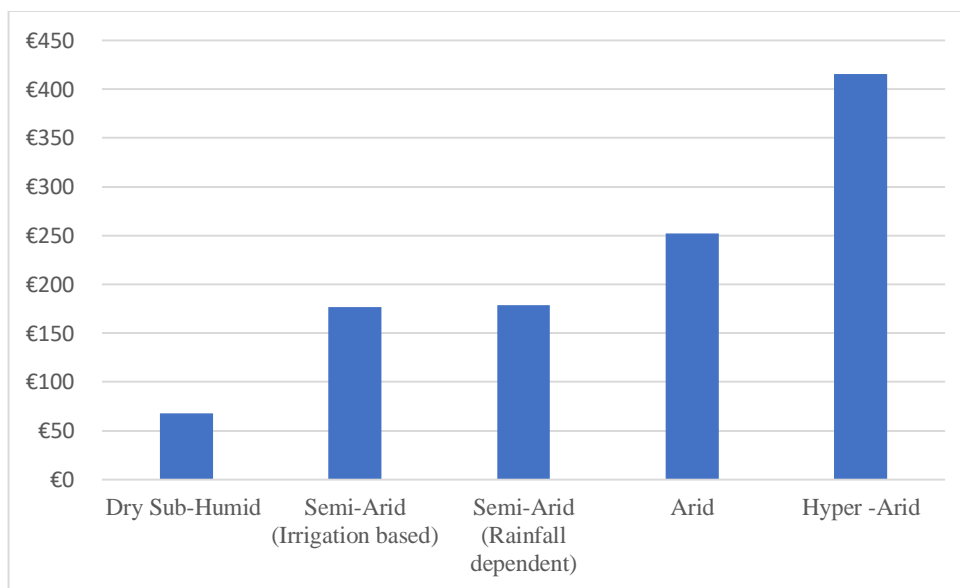


Figure 3: Moroccan farmers' WTP to maintain pollination service per climate range

The trend displayed in figure 3 might help to speculate the evolution of the value of insect pollination in the course of increasing aridity due to CC in many dry LIC and MIC around the world. The predicted shifts in the levels of aridity all over the world by the end of the century (IPCC, 2014) could impact farmers' preferences and hence gradually increase their WTP. Thus, farmers' WTP can be perceived as a precautionary attitude towards future risks of a complete loss of pollinator services. However, the occurrence of this precautionary attitude might be

triggered when a threshold is reached. The effects of the pollinator decline on yields might not be noticeable until a certain level is reached. Starting from this level, farmers will, allegedly, begin to notice a decrease in profit due to lower crop quality, quantity, etc. In this case, WTP estimates may represent an insurance premium for farmers to avoid a further decrease in pollination services as the level of aridity becomes higher. Therefore, farmers pay to have an option to benefit from pollinator services in the future, which represents an option value of pollinators. A similar conclusion was drawn by Andreopoulos *et al.* (2015) regarding the impact of CC on the economic value of ES. Their study shows an increase in WTP for adaptation strategies due to the increasing risk of CC. These two conclusions tend to strengthen the legitimacy of actions and policies in favor of the conservation of insect pollination.

Our study demonstrates as well that preferences for the different benefits of insect pollination vary across the sample. However, the general tendency indicates that the “Quality of the produced fruits and vegetables” is the most appreciated benefit of insect pollination. This tendency arises from market constraints imposed by consumers’ preference for higher-quality products. García-Llorente *et al.* (2012) showed that, in the semi-arid Mediterranean region, respondents always express a strong preference for the visual quality of ES.

The inclusion of an “opt-out” or “no-choice” in DCE was recommended by many authors to reduce forced choice among participants. These options add realism to the choices presented to participants, which is important for welfare-consistent estimation of DCE. Restricting the choice to be between potentially unrealistic alternatives raises concerns of external validity (Lancsar and Louviere, 2008; Louviere and Lancsar, 2009; Johnston *et al.*, 2017; Campbell and Erdem, 2019). However, in our case, this option was strongly rejected by farmers. This result may be an additional indicator of farmers’ good understanding of the issues and the positive attitude of the farmers towards pollination and pollinators, and their willingness to engage in actions for the protection of pollination services. Nonetheless, the absence of significant income effects on the payment mechanism suggests that the opportunity costs of volunteering work did not disincentive payments enough for farmers to prefer the no-choice option in which there is no form of payment.

6. Conclusion: Relevance to policy design

The main objective of this study is to highlight the impact of aridity levels on farmers’ preferences for the protection of the benefits of insect pollination. In this context, results show

that preferences for insect pollination services are significantly impacted by aridity. Hence, future mitigation strategies in Morocco to protect pollinators should be adapted to preferences within each climate range.

By now, also in HIC, pollinator protection remains limited; there is a clear "gap" between recognizing the importance of pollinators and protecting them in place (Potts *et al.*, 2016). The initiatives of the European Union (EU) for the protection of wild pollinators, for example, were deemed inadequate and ineffective (EU, 2020). Marselle *et al.* (2020) criticized European protection policies for not sufficiently targeting human behavior. Here we show that preferences can change significantly even within one country. The impact of the level of aridity on farmers' preferences could be a particularity of Morocco and other aridity-prone climates or LIC and MIC. In any case, it raises questions about global guidelines for policies (Dicks *et al.*, 2016a; Christmann, 2019b; Gemmill-Herren *et al.*, 2021). Thus, we suggest participatory development of strategy and action plans based on nationally assessed awareness and priorities.

CC can accelerate pollinator decline, and simultaneously pollinator decline exacerbates negative effects of CC; the spiral of first environmental and later economic degradation is fueled by the coincidence of both (Christmann, 2019a). However, potential conflicts between the conservation of insect pollination and CC mitigation and adaptation policies could make the creation of conservation policies a challenging process (CBD, 2009). Thus, the shaping of pollination conservation and CC mitigation and adaptation strategies should be multidimensional (Gemmill-Herren *et al.*, 2021). In this study, we consider the issue of pollinator conservation from a producer's supply perspective; nonetheless, the perception of consumers in a demand perspective is equally important since consumer behavior drastically impacts pollinators and their habitats and influences farmers' preferences. Besides, multiple approaches should be administered in data collection to capture as much information as possible. Our study is based on individual surveys; however, it might also be informative to base further assessments on shared pluralistic protocols such as the Deliberative Monetary Approach (DMA) (Kenter *et al.*, 2016). These protocols involve more stakeholders, and hence, complement DCE results and support shaping more efficient policies (Kieslich and Salles, 2021).

This study was initially set to assist in shaping pollinator protection policies in dry climate LIC and MIC. However, this could have relevance for HIC also suffering from aridity in many parts of the world. The share of drylands in the world, according to the UN (2011), surpasses 40%; agroecosystems in the US, for instance, have been identified as very vulnerable to pollinator decline, mainly because of drought and CC (Reilly *et al.*, 2020; Hung *et al.*, 2021; Jordan *et al.*, 2021).

**CHAPTER 3 - THE IMPACT OF THE INCREASE IN ARIDITY
LEVELS ON THE ECONOMIC VALUE OF INSECT POLLINATION IN
DRY CLIMATES: CONSUMERS' PERSPECTIVE**

Chapter 3 is considered for a publication in Ecological Economics (Article in review)

Abstract

Pollinating insects are vital for food security and maintaining natural ecosystems. It is well established that these species are facing severe declines worldwide. In dry LIC and MIC, consumers are highly vulnerable to pollinator decline. Human behaviors and the increase in aridity due to CC are the main potential drivers of this decline in these countries. The protection of pollinators, thus, requires behavioral change strategies that can also mitigate the effect of the increase in aridity levels on these species. In this study, we target consumer behavior, often neglected in the course of pollinator protection despite being of great importance. Economic preferences partly drive human behavior. Thus, to help protect pollinators in dry LIC and MIC, we conduct a DCE to a) explore consumers' preferences for the benefits of insect pollination and assess their WTP for the protection of these benefits, b) explore the potential impact of the current level of aridity on their preferences and WTP estimates and c) identify the impact of the potential shifts in the level of aridity, due to CC, on consumers' WTP. To represent dry LIC and MIC, we chose Morocco, a dry MIC, as our study area. The survey was conducted with 481 consumers living in five bioclimatic regions with varying degrees of aridity. Results show that consumers in the dry LIC and MIC have a high WTP to protect insect pollination. We demonstrate that consumers' preferences for insect pollination change considerably between different aridity ranges and that their WTP increases as the level of aridity goes higher. We also highlight the potential increase in the WTP estimates following the shifts in aridity levels due to CC.

Keywords: Insect pollination, Level of aridity, Consumers' preferences, Choice experiment.

1. Introduction

Insect pollination is an important regulating service which plays a significant role in food security (Anderson and Vasiliev, 2021). It also supports biodiversity and a wide range of ES from which populations derive multiple benefits (Allen-Wardell *et al.*, 1998; IPBES, 2016). Worldwide, pollinating insects face severe declines mainly because of human activities and CC (Potts *et al.*, 2010). Evidence of this decline was found in many parts of the world, namely in the UK, USA, EU, etc. (Biesmeijer *et al.*, 2006; Van Engelsdorp *et al.*, 2008; Potts *et al.*, 2010; Scheper *et al.*, 2014; Potts *et al.*, 2015; Robert, 2016; Hallmann *et al.*, 2017; Powney *et al.*, 2019; Hallmann *et al.*, 2021; Zattara and Aizen, 2021).

Drylands cover a significant proportion of the world's land area (40%) and support 2 billion people, 90% of whom live in LIC and MIC (UN, 2011). In most of these countries, clear evidence of insect pollinator decline has not been established yet (Archer *et al.*, 2014). Nonetheless, indicators such as biodiversity loss (IPBES, 2019) and the decline of vertebrate pollinators (Rasmont *et al.*, 2015) can inform on the severe threats facing pollinators in these parts of the world.

Consumption behavior is responsible for some of the main drivers of pollinator decline (Landscape alteration, pollution, etc.) (Potts *et al.*, 2010). Yet, pollinator decline will have a major impact on the social welfare of consumers, especially in dry LIC and MIC (Christmann, 2019a; Christmann, 2020). Pollinator-dependent crops supply major proportions of micronutrients in global human diets (Smith *et al.*, 2015). Thus, pollinator decline could result in major micronutrient deficiencies worldwide (Smith *et al.*, 2015; IPBES, 2016). In many dry LIC and MIC, populations already suffer important food and nutrient shortages (Gilland, 2002; Eilers *et al.*, 2011) and cannot afford supplementation (Chaplin-Kramer *et al.*, 2014; Cely-Santos and Lu, 2019; IPCC, 2020). Thus, the impact of pollinator decline on their welfare will be higher. Vulnerable populations in these countries also rely on provisioning and cultural ES, supported by pollinators, to generate additional income (Allen-Wardell *et al.*, 1998; MEA, 2005; IPCC, 2020) and mitigate the impacts of drought and extreme weather conditions on their well-being (IPBES-IPCC, 2021).

Protection strategies, e.g., the “EU pollinator initiative” (EU, 2020), focus more on farmers than on consumers despite the efforts motivated by the 12th Sustainable Development Goal to ensure

sustainable consumption and production behaviors. Consumer behavior can be of great importance to pollinator protection (Amel *et al.*, 2017; Anderson *et al.*, 2020). The change of consumer behavior can, in addition to creating pollinator-friendly environments in residential areas (Amel *et al.*, 2017; Byerly *et al.*, 2018; Marselle *et al.*, 2020) and mitigating the impact of the increase in aridity on these species (Corral-Verdugo *et al.*, 2020), alter the demand function in the agricultural and industrial sectors, heavily endangering pollinators. Shifts to organic and sustainable labeled food, for instance, can significantly reduce the use of agrochemicals which endangers pollinators severely (Forister *et al.*, 2019). Recently, a few stewardships started operations, namely, “Bee Better Certified” (<https://beebettercertified.org>) in the USA and the French label “Certified Bee Friendly” (<http://www.certifiedbeefriendly.org>).

Achieving pro-pollinator behavior requires understanding its determinants and/or barriers (Steg and Vlek, 2009; Byerly *et al.*, 2018; Nisa *et al.*, 2019). Investigations of this level for consumers necessitate an analysis of their preferences for the values they derive from insect pollination and an economic assessment of these values in LIC and MIC. In the past, economic preferences were used as determinants of a wide range of behaviors, for instance, risk-taking (Dohmen *et al.*, 2011), health outcomes and altruism (Anderson and Mellor, 2008), charitable giving (DellaVigna *et al.*, 2012) and also environmental behavior (Lades *et al.*, 2021). Thus, in this study, we use the DCE to elicit and analyze consumers’ economic preferences for the benefits they derive from insect pollination and assess the values they attribute to these benefits. However, the correct elicitation of preferences will require a moderate to a high level of awareness of consumers about the threats facing pollinators and the benefits of insect pollination to their welfare (Quiroga *et al.*, 2015). Thus, we also investigate the level of knowledge of consumers about insect pollination. To represent MIC and LIC, we chose a MIC with important agricultural sector and different levels of aridity, Morocco.

Several studies highlighted the impact of CC on economic preferences for ES (Shoyama *et al.*, 2013; Khanal *et al.*, 2018). In drylands, the shift in aridity levels can be an indicator of CC; therefore, investigating the impact of aridity on consumers’ economic preferences can provide a better understanding of the determinants and barriers of pro-pollinator behavior in dry LIC and MIC. Therefore, we collect data for the DCE in 5 different bioclimatic regions with varying levels of aridity within the Moroccan territory. These bioclimatic regions were chosen to

represent the different sub-divisions of climates in drylands (UNEP, 1993). According to the IPCC (2014) report, the different climate ranges in drylands will undergo major shifts because of CC. Thus, we predict the possible impact of the increase in aridity levels, due to CC, on the contribution of insect pollination to consumers' welfare.

The context, motivations, and our choice of the area of this study are explained in the next section, and choices made for the DCE are described in the methodology section. Results are then displayed following the objectives of the study. First, we define the sample and assess the level of knowledge of consumers about pollination and pollinators. Second, we explore consumers' preferences for the numerous benefits of insect pollination and define the impact of the level of aridity on their preferences. Third, we assess the value of insect pollination for consumers, and finally, we measure the impact that the increase in the levels of aridity, as a result of CC, might have on this value. These results are discussed, and policy recommendations for decision-makers are outlined in conclusion.

2. Context and motivation

Insect pollinators are vital agents for the reproduction of 87% of flowering plants (Ollerton, 2011). Their services are mandatory to achieve food security, maintain natural balance, and enhance livelihoods (Ollerton, 2017; Chaplin-Kramer *et al.*, 2019; Reilly *et al.*, 2020). The majority of food crops (76%) are pollinator-dependent (Klein *et al.*, 2007). These crops supply major proportions of micronutrients, such as vitamin A, iron, and folate, in global human diets (Chaplin-Kramer *et al.*, 2014). Most wild plants are dependent on insect pollination for their fruit and seed set (Ollerton, 2017). These plants deliver various ES in the four MEA categories (cultural, provisioning, regulating, and supporting) (MEA, 2005) and provide a source of income for many communities (IPBES, 2016). Therefore, the decline of pollinators will have alarming impacts on food security, livelihoods, and well-being (Eilers *et al.*, 2011; Smith *et al.*, 2015; IPBES, 2016; Cely-Santos and Lu, 2019).

Climate change (CC), landscape alteration, agricultural intensification, and the spread of pathogens and alien species are the main drivers of pollinator decline (Potts *et al.*, 2010; Kojima *et al.*, 2011; Goulson *et al.*, 2015; Graystock *et al.*, 2016). These drivers affect pollinators on individual and community levels and damage their habitat and nesting resources (Potts *et al.*, 2016). In the long run, CC is expected to affect pollinators the most by inducing changes in their temporal activities, genetics, and phenology and changing the overall composition and

functioning of pollinator communities (Thomas *et al.*, 2001; Memmott *et al.*, 2007; Hegland *et al.*, 2009; Martinet *et al.*, 2020). It also causes temporal and morphological mismatches between pollinators and their natural plant partners (Polce *et al.*, 2014; Kerr *et al.*, 2015; Miller-Struttman *et al.*, 2015; Elias *et al.*, 2017; Kuppler *et al.*, 2021). Impacts of CC on ecosystems are expected to rise throughout warming and extreme weather conditions (IPCC, 2020). These impacts tend to make insect pollinators more vulnerable to other drivers of the decline (Gonzalez-Varo *et al.*, 2013).

Many scientists and organizations called for immediate pollinator conservation actions (Allen-Wardell *et al.*, 1998; FAO, 2014; Garibaldi *et al.*, 2014; IPBES, 2016) and very recently, also, addressing human behavior (Forister *et al.*, 2019; Hall and Martins, 2020; Marselle *et al.*, 2020; Kawahara *et al.*, 2021). The design of efficient conservation strategies targeting human behavior requires an analysis of economic preferences for the benefits derived from insect pollinators and an assessment of the values associated with these benefits (TEEB, 2010 2011a; Lades *et al.*, 2021; TEEB, 2011b). A relevant economic evaluation of insect pollination should consider its TEV (use-values, non-use values, and option value) (Perman *et al.*, 2011; Mwebaze *et al.*, 2018). In literature, most assessments focus on use values of insect pollination, mainly related to marketable benefits of insect pollination (Burgett *et al.*, 2004; Allsopp *et al.*, 2008; Gallai *et al.*, 2009). Nonetheless, few studies used stated preferences approaches to capture other values of insect pollination (Mwebaze *et al.*, 2010; Breeze *et al.*, 2015; Mwebaze *et al.*, 2018). In this study, we use a DCE to explore preferences for the benefits of insect pollination from consumers' perspectives and assess the values consumers associate with these benefits in Morocco.

Like most dry LIC and MIC, Morocco is an aridity-prone country identified as highly vulnerable to pollinator decline (Gallai *et al.*, 2009; Potts *et al.*, 2016). Besides agricultural intensification (Harbouze *et al.*, 2019), industrialization and landscape alteration (HCP, 2005), CC is also a factor endangering pollinators in Morocco (Rasmont *et al.*, 2015). This factor can quickly become the first driver of pollinator decline in Morocco and many other dry LIC and MIC because of the growing risk of aridity and desertification (Schilling *et al.*, 2012; IPCC, 2014). Therefore, it is important to protect pollinators in dry LIC and MIC to avoid potential ecological catastrophes triggered by their loss (Lever *et al.*, 2014; Christmann, 2019a).

In aridity-prone climates, aridity index (AI) is a key indicator of CC (Dong *et al.*, 2012; Asadi Zarch *et al.*, 2017). This index, defined as the ratio of the annual precipitation (P) and Potential EvapoTranspiration (PET), measures the change in aridity levels (UNEP, 1993). Based on the AI, Trabucco and Zomer (2019) were able to identify all climate ranges of dry LIC and MIC within the Moroccan territory, dry sub-humid, semi-arid (irrigation-based), semi-arid (rainfall dependent), arid and hyper-arid. This particularity is behind our choice of Morocco as a benchmark site for this study. In the last few years, the AI has shown shrinking tendencies in dry climates with high aridity levels in many parts of the world (Huo *et al.*, 2013). By the end of this century, all climate ranges in dry LIC and MIC will undergo significant changes due to the progression of aridity (IPCC, 2014). Following these changes, pollinators could face severe threats in the future.

3. Methodology

3.1. Definition of DCE

The DCE is an SP technique used for modeling preferences for ES and the estimation of their economic values (Hanley *et al.*, 2001; Hanley *et al.*, 2015). This approach was initially developed by Louviere and Hensher (1982). The conceptual framework of DCE lies in the characteristics demand theory (Lancaster, 1966) and the random utility theory (McFadden, 1973). It is based on the assumption that the utility people derive from ES can be decomposed into a sum of utilities of the various benefits of these ES. Each benefit can be defined by one or multiple characteristics or attributes. Thus, in DCE surveys, ES are characterized by a number of attributes and their respective levels. The mixture of these attributes and levels produces different situations describing hypothetical changes in the service to be assessed. These situations are presented within choice sets in which respondents are eager to make a choice. By including a payment mechanism as one of the attributes of the service, WTP can be inferred from people's choices.

3.2. Selection of the attributes and levels

Selecting appropriate attributes and their levels to characterize ES is usually complicated (Hanley *et al.*, 2001). We base the selection of attributes and levels to represent insect pollination to consumers, in this DCE, on three steps:

- Step on: Literature revue:

We establish our selection of appropriate non-payment attributes to represent the benefits of pollinators to consumers based on the utility they derive from insect pollination. The diversity and abundance of pollinating insects in nature are two major factors influencing the diversity and density of the vegetation cover, and hence, affecting the aesthetics of the landscape (Ollerton *et al.*, 2011; Breeze *et al.*, 2015). Pollinators are also essential production factors affecting the diversity, quantity, and quality of fruits, vegetables, and other pollinator-dependent crops, which are mandatory for food security (Klein *et al.*, 2007; Garratt *et al.*, 2014; Saez *et al.*, 2020). These benefits correspond to use values, non-use values, and the option value in the TEV of insect pollination (Table 8).

No prior studies used the DCE to assess the TEV of insect pollination in LIC and MIC. The only study using a DCE was conducted in the UK and used tax payment as the payment mechanism (Breeze *et al.*, 2015). However, this form of payment is not accepted by populations in LIC and MIC, along with other types of monetary payments (Christie *et al.*, 2012). Thus, we based our literature review on forms of payments that are more likely to be accepted in LIC and MIC. Many studies suggested the use of labor-based payment mechanisms in LIC and MIC (Rai *et al.*, 2015; Tadesse *et al.*, 2017; Khanal *et al.*, 2018; Hagedoorn *et al.*, 2020). A study by Ando *et al.* (2020) tested a new payment mechanism in the form of volunteering which might also be convenient for populations in LIC and MIC.

- Step two: focus group with experts (Appendix 6)

In this step, we held a focus group with Moroccan experts who, based on our literature review, suggested three attributes to characterize the benefits derived from insect pollination from a consumer perspective (table 8):

- The “Aesthetics of the landscape in your region” is defined by two criteria, the diversity of plant cover, which refers to forests, wildlands, green spaces, flowers, etc. and the density of plant cover, which corresponds to the degree of coverage of the soil with plants;

- The “Variety of fruits and vegetables available on the market in your region,” which represents the number of species and varieties of pollinator-dependent crops available on the market;
- The “Quality of fruits and vegetables available on the market in your region” refers to the quality of pollinator-dependent, characterized by caliber, taste, smell, color, and shape.

The focus group agreed on the non-relevance of including an attribute to represent the benefits of insect pollination to the quantity of fruits and vegetables since there has not been a shortage in supply, quantity-wise, on the Moroccan markets for years. This attribute may be very important as pollinator decline could entail reduced supply of pollinator-dependent crops, and hence, higher food prices. Thus, we insisted on this attribute in the next step of choosing attributes.

Based on experts’ perceptions towards the different attributes, we confirmed that the selected attributes represent use values of insect pollination and implicitly portray some non-use values and option value. The “Aesthetics of the landscape in your region” captures existence values of insect pollinators and all the selected attributes portray bequest values of insect pollination. Consumers usually associate the beauty of nature with the existence of insects (bees, butterflies, etc.). Besides, when consumers express their will to protect all the benefits of insect pollinators, they also wish to have the option to use them in the future and conserve them for future generations. Therefore, adding attributes to represent non-use values and the option value will cause major overlaps and create comprehension burdens for respondents. For the payment mechanism, experts agreed that consumers would relate better to the willingness to volunteer.

- Step three: focus groups with consumers

In the third step, we held a focus group with Moroccan consumers who concurred with the choice of attributes made in the previous steps. As suspected by experts, the attribute representing the benefits of insect pollination to the quantity of pollinator dependent crops was completely ignored by consumers; thus, we chose not to include it in the DCE. The perceptions of consumers of the attributes confirmed our assumptions about non-use values and the option value. The willingness to volunteer, as experts suspected, was the most accepted form of payment by consumers. Therefore, we suggested a willingness to volunteer (WTV) in the form

of “the number of volunteering days per month in an association for the protection of pollinators and their natural habitats.” Nonetheless, to respond to some concerns about this form not being adapted to all categories of consumers (those with higher wages), we suggested adding an equivalent form of payment in cash to the existing volunteering-based payment mechanism, which was also confirmed by participants within the focus group. This alternative corresponds to “the 1/3 of what the consumer gains daily”. The WTP in volunteering days can, therefore, be converted into the monetary form according to the following formula:

$$WTP = Vol\ days * 1/3\ of\ the\ average\ daily\ individual\ income$$

As explained to consumers, volunteering can take multiple forms, for instance, the creation of nesting and water support sites for pollinators out of low-cost local materials and waste products in natural areas. The levels of all the attributes, also presented in table 8, were suggested following the literature review and confirmed by both focus groups of experts and consumers.

Table 8: The attributes and the levels used for the DCE and their correspondent component of the TEV of pollination

Attributes for consumers	Levels	Components of TEV
<i>1st attribute</i> - Aesthetics of the landscape in your region	Good	<i>Indirect use values</i> <i>Bequest value</i> <i>Existence values</i> <i>Option value</i>
	Bad (reference)	
<i>2nd attribute</i> - Variety of fruits and vegetables available on the market in your region	High	<i>Indirect use values</i> <i>Bequest value</i> <i>Option value</i>
	Low (reference)	
<i>3rd attribute</i> - Quality of fruits and vegetables available on the market in your region	High	<i>Indirect use values</i> <i>Bequest values</i> <i>Option value</i>
	Low (reference)	

<i>Payment mechanism per month per consumer-</i> Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	One day, two days, three days, four days	
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3.3. Experimental design

To produce the choice sets, an efficient design was administered on the software Ngene. The design generates eight choice sets in one block. A multinomial logit model and standard priors were used to produce initial choice sets. These choice sets were tested with 20 Moroccan consumers. The collected data was analyzed, and results were used to define new priors to refine the design for the final choice sets, which were generated using a mixed logit model (MLM). Each choice set includes two alternatives and an opt-out option (see figure 4). The survey was conducted face to face with 481 consumers (Appendix 8), generating 11544 observations in total.







	Scenario 1	Scenario 2	Opt out
1st attribute - Aesthetics of the landscape in your region	Good 	Good 	
2nd attribute - Variety of fruits and vegetables available on the markets in your region	High 	Low 	
3rd attribute- Quality of fruits and vegetables available on the markets in your region	High 	Low 	
Monetary attribute per month per consumer- Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (eq to 1/3 to what you make on normal day of work)	3 days	2 days	
Your choice			

Figure 4: Example of a choice set used in the DCE

The 5 bioclimatic regions chosen for the DCE are: Tanger-Tétouan-Elhouceima, Fès-Meknès, Casablanca-Settat, Draa-Tafilalet and Laayoun-Sakia-El Hamra (Figure 5). The choice of these regions was based on their level of aridity. The level of aridity increases as we shift from north to south of Morocco.

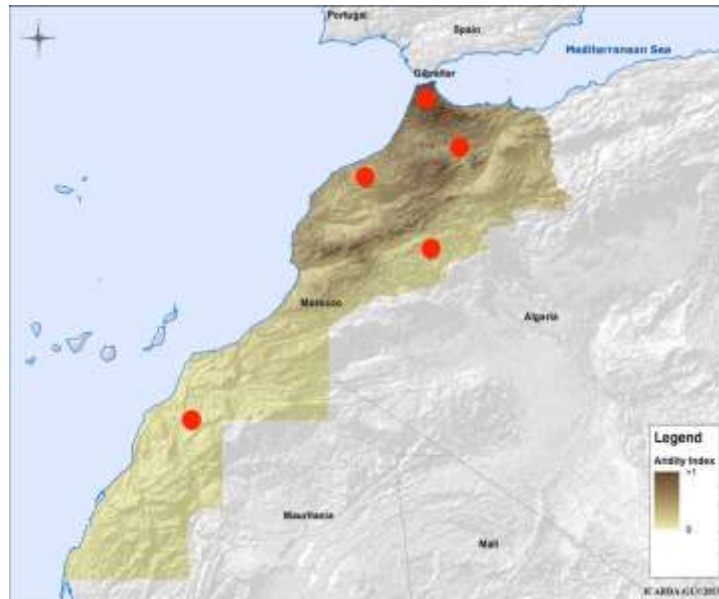


Figure 5: Map illustrating the graduation of the levels of aridity in Morocco and the five bioclimatic regions chosen for the study

To gain a good representation of our targeted population, we identified all gathering points of the different categories of adult consumers, depending on the region and the type of the territory (rural, urban, semi-urban), mainly local markets, supermarkets, restaurants, coffee shops, and tea parties. We randomly approached people and interviewed those who agreed to the interview. Before proceeding with the questions, we read a short explanatory paragraph to the respondents about the context of the study. Each questionnaire took between 20min and an hour, depending on the interviewees. The data collected was analyzed on Stata using a MLM in both preferences space (Train, 2009) and WTP space (Train and Weeks, 2004). Effect coding was used for the first two alternatives in each choice set, and the opt-out option was coded 0.

Stated preferences methods put an important comprehension burden on respondents, especially given the complexity of pollination (ecological process) (Breeze *et al.*, 2015) and the context of the study (LIC and MIC) (Christie *et al.*, 2012). Thus, in addition to assessing consumers' level of knowledge about insect pollination, we established a number of measures to control the bias coming from this comprehension burden. We firstly prepared a short explanatory paragraph about the context of the study, which was read to all interviewed farmers prior to the survey. This paragraph defines insect pollination and explains its benefits to consumers and the drivers of pollinator decline (Appendix4). Secondly, during the survey, questions linking the chosen attributes to insect pollination were asked farmers to mentally prepare them for the

choice cards. Before proceeding with the choices, consumers were given explanatory sheets of the attributes (Appendix5). And finally, we added a follow-up question to the choice cards to check if farmers took into consideration the contribution of insect pollination while making their choices (more than 90% of them responded positively). The face-to-face survey also helped with controlling the bias in this case.

4. Results

The different climate ranges are almost equally represented in the sample, with a small under-representation of the semi-arid (irrigation-based) and a narrow over-representation of arid and hyper-arid climates. The majority of respondents live in urban and suburban areas, the share of male respondents is higher (72%), and almost half the sample has a college education. The level of knowledge of pollination and its vectors is high (81%), and the knowledge of the difference between wild and managed pollinators is moderate (54%) (Table 9).

Table 9: Respondents' characteristics

Descriptors	Shares
Type of territory	⇒ 44% live in the urban areas ⇒ 37% live in suburban areas ⇒ 18% live in rural areas
Gender	⇒ F: 28% ⇒ M: 72%
Age	⇒ 45% between 30 & 44 years ⇒ 29% between 45 & 60 years ⇒ 20% between 18 & 29 years ⇒ 6% between 60 & 75 years
Personal situation	⇒ 65% married ⇒ 29% single ⇒ 4% divorced ⇒ 2% widow
Children	63% have children
Education	⇒ 49% have a college education

	<ul style="list-style-type: none"> ⇒ 15% have a high school education ⇒ 13% have secondary education ⇒ 12% have elementary education 4% have no education ⇒ 7% have preschool education ⇒ 4% have no formal education
Employment sector	<ul style="list-style-type: none"> ⇒ 49% services sector ⇒ 24% energy, industry ⇒ 20% agribusiness ⇒ 1% environment ⇒ 6% other sectors
Revenue/year	<ul style="list-style-type: none"> ⇒ 15% less than 2251 € ⇒ 22% between 2251 & 4503 € ⇒ 19% between 4503 & 6754 € ⇒ 15% between 6754 & 9006 € ⇒ 11% between 9006 & 11257 € ⇒ 9% between 11257 & 13508 € ⇒ 6% between 13508 & 15760 € ⇒ 4% make more than 15760 € ⇒ 3% between 13508 & 15760 €
Partner revenue per year	<ul style="list-style-type: none"> ⇒ 67% does not work ⇒ 3% less than 2251 € ⇒ 7% between 2251 & 4503 € ⇒ 6% between 4503 & 6754 € ⇒ 8% between 6754 & 9006 € ⇒ 4% between 9006 & 11257 € ⇒ 5% between 11257 & 13508 € ⇒ 2% between 13508 & 15760 € ⇒ 2% make more than 15760
Pollination knowledge	81% know the process of pollination
Pollination vector knowledge	76% know at least one pollination vector

Knowledge of the difference between wild and managed pollinators	54% know the difference between wild and managed pollinators
Level of aridity	⇒ Dry sub-humid: 20 % ⇒ Semi-arid (with irrigation): 18% ⇒ Semi-arid (rainfall): 20% ⇒ Arid:21% ⇒ Hyper-arid: 21%

Results of the mixed logit in preferences space (table 10) show that taste parameters of “Aesthetics of the landscape in your region,” “Variety of fruits and vegetables in local markets,” and “Quality of fruits and vegetables in local markets” are significant and positive. The taste parameters of the “Aesthetics of the landscape in your region,” and “Quality of fruits and vegetables in local markets” are almost equal.

The coefficient of the payment mechanism is significant and negative. The alternative specific constant (ASC) in the model, which captures the opt-out option, demonstrates that respondents strongly prefer the first two alternatives to the opt-out option.

Table 10: Results of mixed logit estimation in preference space without and with interactions

	MLM	MLM with interactions
Main coefficients		
ASC	8.44 ^{***}	9.16 ^{***}
	(1.12)	(0.82)
Aesthetics of the landscape in your region	0.51 ^{***}	0.52 ^{***}
	(0.06)	(0.16)
Variety of fruits and vegetables in local markets	0.22 ^{***}	0.14 ^{**}
	(0.04)	(0.06)
Quality of fruits and vegetables in local markets	0.45 ^{***}	0.27 ^{**}
	(0.07)	(0.11)

Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> : 1/3 of what the consumer gains daily)	-0.70 ^{***}	-1.14 ^{***}
	(0.27)	(0.31)
Observed heterogeneity		
Aesthetics of the landscape * Level of aridity		-0.07 ^{**}
		(0.03)
Variety of fruits and vegetables* Level of aridity		0.04 [*]
		(0.02)
Quality of fruits and vegetables* Level of aridity		0.09 ^{***}
		(0.03)
Number of volunteering days * Level of aridity		0.40 ^{***}
		(0.10)
Number of volunteering days * Personal situation		-0.97 ^{***}
		(0.37)
Aesthetics of the landscape * Education		0.09
		(0.06)
Standard deviation		
Aesthetics of the landscape in your region	0.80 ^{***}	0.78 ^{***}
	(0.08)	(0.09)
Variety of fruits and vegetables in local markets	0.24 ^{**}	0.20
	(0.11)	(0.18)
Quality of fruits and vegetables in local markets	0.99 ^{***}	0.94 ^{***}
	(0.08)	(0.09)
Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	3.06 ^{***}	2.87 ^{***}
	(0.51)	(1.05)
Observations	11544	11544
N_clust	481.00	481.00
ll	-2333.22	-2329.82
AIC	4684.43	4679.65

BIC	4750.62	4753.19
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Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Given the high standard deviation of the mean taste parameters of the MLM estimation, we explore consumers' heterogeneity in preferences by adding interaction terms to the MLM. First, we crossed the different attributes with the personal characteristics of respondents, displayed in table 9, separately. Then, only significant interactions (when analyzed separately) were added to the mixed logit estimation in table 10 (second column). Results show that consumers' preferences are not affected by their personal characteristics except their "family situation" and the "level of aridity" on the territory they live in.

The variable "personal situation" is significant only when crossed with the payment mechanism (entered as a dummy, married and not married); people who are not married are more sensitive to the payment mechanism. However, the variable "level of aridity" impacts preferences for all the attributes. Consumers in climates with high levels of aridity are more sensitive to the attributes "Variety of fruits and vegetables," "Quality of fruits and vegetables," and "Number of volunteering days per month" but are less sensitive to the attribute "Aesthetics of the landscape." Thus, to further study these effects, we analyzed data per climatic range using a MLM in preference space (table 11).

Table 11: Estimation of the mixed logit in preference space per climatic range

	MLM in Dry-Sub- Humid climate	MLM in Semi- Arid (Irrigation based) climate	MLM in Semi-Arid (Rainfall dependent) climate	MLM in Arid climate	MLM in Hyper - Arid climate
Main coefficients					
ASC	8.14 ^{***}	11.66 ^{***}	15.10 ^{**}	14.12 ^{***}	18.84 ^{***}
	(1.66)	(1.67)	(6.65)	(4.63)	(5.74)
Aesthetics of the landscape in your region	0.71 ^{***}	0.70 ^{***}	1.13 ^{***}	0.58 ^{***}	0.81 ^{***}
	(0.19)	(0.17)	(0.29)	(0.13)	(0.14)

Variety of fruits and vegetables in local markets	0.24**	0.19*	0.15	0.49***	0.34***
	(0.10)	(0.11)	(0.12)	(0.10)	(0.09)
Quality of fruits and vegetables in local markets	0.33*	0.41***	0.62**	1.61***	0.73***
	(0.19)	(0.13)	(0.31)	(0.20)	(0.17)
Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	-1.45***	-3.19***	-0.98*	-0.53**	-0.68**
	(0.54)	(0.61)	(0.51)	(0.23)	(0.31)
Standard deviation					
Aesthetics of the landscape in your region	0.70***	1.10***	1.38***	0.56***	0.80***
	(0.16)	(0.22)	(0.36)	(0.16)	(0.19)
Variety of fruits and vegetables in local markets	0.33**	0.61***	0.49*	0.31*	0.59***
	(0.16)	(0.19)	(0.25)	(0.16)	(0.17)
Quality of fruits and vegetables in local markets	1.00***	1.27***	0.91	1.26***	1.12***
	(0.20)	(0.27)	(0.56)	(0.27)	(0.13)
Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	3.68***	5.35***	3.09**	1.74***	2.59***
	(0.80)	(0.84)	(1.26)	(0.58)	(0.56)

Observations	2328	2136	2280	2400	2400
N_Clust	97	89	95	100	100
AIC	1040.20	877.87	825.16	761.62	874.12
BIC	1091.97	928.87	876.74	813.67	926.17

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Consumers' preferences vary across the different climate ranges. The likelihood of choosing the opt-out option decreases as the level of aridity becomes higher. The taste parameter of the "Aesthetics of the landscape" is particularly high in the semi-arid (rainfall-dependent) climate, and the taste parameter of the "Quality of fruits and vegetables" is exceptionally high in arid climates.

The WTP of consumers is estimated using a Mixed logit in the WTP space model. Table 12 shows WTP estimates for the full dataset and per climate range to capture the effect of aridity on the value of the benefits of insect pollination.

Table 12: Estimation of the mixed logit in WTP space for the full dataset and per climatic range

	MLM in WTP space					
	Full dataset	Dry Sub-Humid	Semi-Arid (Irrigation based)	Semi-Arid (Rainfall dependent)	Arid	Hyper - Arid
Main coefficients						
ASC	9.35***	5.99***	10.98**	9.74***	12.74***	19.06**
	(1.27)	(0.90)	(4.59)	(1.88)	(3.02)	(8.27)
Aesthetics of the landscape in your region	1.12***	0.83***	0.73***	1.31***	0.60***	1.54**
	(0.21)	(0.27)	(0.28)	(0.47)	(0.21)	(0.75)

Variety of fruits and vegetables in local markets	0.44 ^{***}	0.39 ^{**}	0.11	0.23 ^{**}	0.43 ^{***}	0.59 [*]
	(0.10)	(0.16)	(0.18)	(0.10)	(0.15)	(0.31)
Quality of fruits and vegetables in local markets	1.27 ^{***}	0.57 ^{**}	0.56 ^{***}	0.63 ^{***}	1.87 ^{***}	0.98 ^{**}
	(0.22)	(0.24)	(0.19)	(0.22)	(0.47)	(0.48)
Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> : 1/3 of what the consumer gains daily)	-0.83 ^{***}	-0.83 ^{***}	-0.70 ^{***}	-0.72 ^{**}	-0.69 ^{***}	-1.01 ^{**}
	(0.17)	(0.29)	(0.27)	(0.30)	(0.26)	(0.45)
Standard deviation						
Aesthetics of the landscape in your region	0.58 ^{***}	0.92 ^{***}	0.61 ^{**}	0.76 [*]	0.22	0.70
	(0.18)	(0.34)	(0.26)	(0.40)	(0.15)	(0.67)
Variety of fruits and vegetables in local markets	0.11	0.05	0.05	0.12	0.05	0.12
	(0.09)	(0.14)	(0.12)	(0.10)	(0.09)	(0.18)
Quality of fruits and vegetables in local markets	2.36 ^{***}	1.44 ^{***}	2.32 ^{***}	0.79 ^{***}	0.93 ^{***}	2.90 ^{**}
	(0.38)	(0.43)	(0.44)	(0.23)	(0.29)	(1.34)
Number of volunteering days per month in an association for the protection of pollinators and their natural habitats	0.54 ^{***}	0.48 ^{**}	1.37 ^{**}	0.34	-0.04	-0.09

(or <i>eq</i> :1/3 of what the consumer gains daily)						
	(0.14)	(0.19)	(0.65)	(0.23)	(0.15)	(0.21)
Observations	11544	2328	2136	2280	2400	2400
N_Clust	481	97	89	95	100	100
AIC	5329.71	1351.72	1037.32	1070.55	926.17	957.18
BIC	5395.89	1403.50	1088.32	1122.13	978.22	1009.23

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

For the full dataset, the attributes “Aesthetics of the landscape in your region” and “Quality of fruits and vegetables in local markets” are almost equally valued by consumers. This tendency does not apply to all climate ranges; for instance, in the arid climate, the “Quality of fruits and vegetables in local markets” is by far the most valued. The “Variety of fruits and vegetables in local markets” is the least valued attribute on average and within all climate ranges.

In Table 13, we calculated, based on the values presented in table 12, the WTP for the full dataset and per climate range in volunteering days (sum of values estimated for each attribute). The transformation from the WTV to the WTP in monetary form was based on the equivalent form of the payment mechanism (1/3 of what the consumer gains daily); for each day of volunteering, we counted 1/3 of the average daily income of our sample for the full dataset and per climate range.

Table 13: The WTP/year stated by consumers for the full dataset and the dataset of each climate range

Climate ranges	Average WTP in volunteering days	WTP/cons
Dry sub-humid	21.39	154.65 €
Semi-arid (irrigation-based)	16.78	98.98 €
Semi-arid (rainfall dependent)	26.08	158.95 €

Arid	34.86	213.21 €
Hyper-arid	37.33	239.32 €
Full Dataset	34.07	216.61 €

The WTP for the protection of insect pollination equals 216,61 € per year per consumer. The WTP stated by consumers differs significantly between climate ranges. On average, the WTP increases as the level of aridity becomes higher. This trend does not apply to the semi-arid irrigation-based climate range. The slight over-representation of the arid and hyper-arid climate ranges and the under-representation of the semi-arid irrigation-based could have influenced this result.

As a result of CC, the aridity level will experience significant changes in many regions of the world (IPCC, 2014). In Morocco, the impact of these changes on WTP to protect insect pollination benefits is estimated in table 14 (estimation is based on the difference in values in table 13).

Table 14: The impact of the shift in the level of aridity on consumers' WTP

Shifts between climate ranges	Impact on consumers' WTP/ year
From Sub-humid to semi-arid	+4.3 €
From semi-arid to arid	+54.26 €
From arid to hyper-arid	+26.11 €

The shift in the level of aridity increases the average WTP stated by consumers. The transition from semi-arid to arid climate appears to affect consumers' WTP the most.

5. Discussion

The high WTP stated by consumers demonstrates the importance they place on the benefits of insect pollination in LIC and MIC. In contrast, a similar study valuing insect pollination in the UK (Breeze *et al.*, 2015) reported considerably lower WTP. The difference between these findings might be explained by several factors, including the administrated payment mechanisms (volunteering-based payment vs. tax payment) and the context of the countries (MIC v.s HIC). Yet, García-Llorente *et al.* (2012) show that, despite these differences, respondents express high WTP to support the conservation of regulating and cultural ES in the

Mediterranean semi-arid climates. Thus, climate can be an important factor explaining this difference. Unlike the UK, Spain and Morocco have large drylands.

For the full dataset, the “Aesthetics of the landscape” and “Quality of Fruits and Vegetables” are almost equally valued. This result was not unexpected since assessments of ES in the literature show that people tend to prefer the conservation of landscapes and the quality of natural resources. Alcon *et al.* (2020) showed in their assessment of the benefits of intercropping that people express a strong social preference towards the beauty of the landscape in the Mediterranean semi-arid lands, and Birol *et al.* (2010) demonstrated in their valuation of water resources that residents in water-scarce regions tend to prefer the conservation of the quality of water compared to other characteristics of water resources (e.g., the quantity of water).

Concerning the components of the TEV, our study shows that values placed on the quality of fruits and vegetables and those placed on the aesthetics of landscapes are almost equal. This result highlights the significant contribution of non-marketable benefits of insect pollination, often neglected by decision-makers, to consumers’ welfare. Marre *et al.* (2015) found that the share of non-use values comprise between 25% and 40% (minimum) of the mean WTP of populations for ecosystem conservation. Zander *et al.* (2013) conducted a similar study to assess the TEV of endangered livestock breeds in Italy and found high bequest and existence values of these breeds. Therefore, future assessments should focus on all components of the total economic value and not only use values to guarantee a fair representation of insect pollination in cost-benefit analysis for private and public decision-making.

Our study highlights the effect of the level of aridity on consumers’ preferences. Aridity impacts respondents’ preferences for the opt-out option or the “no-choice” option, which was included in the DCE to ensure that consumers were not forced to make a choice that includes some level of payment. On average, consumers reject the opt-out option, which was also the case in Breeze *et al.* (2015). Nonetheless, the analysis per climate range shows that the likelihood of choosing the opt-out option decreases as the level of aridity increases. One reason might be that in areas with high levels of aridity, respondents are more pressured to choose an alternative that guarantees a certain utility despite the payment, which suggests that the need for the services of insect pollination increases as the level of aridity becomes higher.

The trend involving the “Aesthetics of the landscape” and “Quality of Fruits and Vegetables” does not apply to all climate ranges, suggesting that aridity impacts consumers’ preferences for the different attributes chosen to represent insect pollination. In arid climates, for instance, the quality of fruits and vegetables is by far the most valued attribute. The presence of oases, which are a particularity of arid landscapes, can be a factor explaining this tendency. Respondents in arid regions visit these oases regularly, and hence they do not express a need for the “Aesthetics of the landscape.” Nonetheless, oases do not affect their consumers’ preferences for the “Quality of Fruits & Vegetables” because the quality of fruits and vegetables produced in oases usually does not meet consumer expectations; hence, consumers express their need for it through their high WTP.

The impact of aridity on consumers’ preferences for pollinator services is also reflected in their WTP to protect the benefits derived from insect pollination. Our study shows that consumers’ WTP increases as the level of aridity becomes higher. This result, combined with the finding of Breeze *et al.* (2015) and García-Llorente *et al.* (2012), questions the representativeness of average values and global trends used for policymaking. Preferences and stated WTP can vary considerably within the same country because of aridity and maybe other factors. Hence, conservation strategies should be targeted and adapted to the different populations and their environment to ensure their efficiency, especially if based on behavioral changes, which are mandatory in the case of pollinator protection (IPBES, 2016; Marselle *et al.*, 2020).

CC is expected to generate future shifts in the levels of aridity in many LIC and MIC in the dryland (IPCC, 2014). Our study shows that these shifts will potentially result in changes in consumers’ preferences and increase their WTP to protect the benefits they derive from insect pollination. This result confirms Andreopoulos *et al.* (2015); they examined the impacts of CC on the economic value of ES and came to the conclusion that the WTP of respondents for adaptation strategies increases due to the increasing risk of CC. Our findings insinuate that CC increases the need for the benefits of insect pollination, which suggests that the benefits of insect pollination help mitigate the implications of CC on consumers. Several studies link the conservation of insect pollination and the importance of cross-pollination for higher genetic diversity of plants to CC adaptation (Christmann and Aw-Hassan, 2012; Christmann, 2019a;

Christmann, 2020). Therefore, the contribution of pollinating insects to CC adaptation and mitigation might be bigger than expected.

The impact of the transition from one level of aridity to another on consumers' WTP varies significantly. This difference could be linked to the extent of the benefits derived from insect pollination for consumers in each climate range; when insect pollination starts providing fewer services to consumers in nature, they start expressing their need for them. The transition from semi-arid to arid, for instance, has a higher impact on consumers' WTP compared to the transition from dry sub-humid to arid. The difference in services between dry sub-humid and semi-arid is probably less visible from consumers' perspectives, and farmers might be best placed to notice the change.

Results of the region with irrigation-based agriculture in a semi-arid climate do not apply to most of the trends in this paper. The region "Fès-Meknes" chosen to represent this range produces an important share of fruits and vegetables of the total production of Morocco, as the irrigation compensates aridity effects.

6. Conclusion

Our study highlights the understanding and sensitivity that consumers living in a dry MIC express towards the threats facing insect pollination. It shows that consumers' preferences for the benefits they derive from pollinators could be affected by climate variability. These findings converge with a similar study conducted on farmers (Chapter 2, article in review), which confirms the link between climate and peoples' perceptions and understandings of pollination services. In literature, this link has not been established yet for other ES, except Andreopoulos *et al.* (2015), who showed that peoples' preferences for ES change due to the increasing risk of CC.

Decision-makers in Morocco and other dry LIC and MIC should consider the impact of the level of aridity on consumers' preferences for ES when designing policies for the conservation of ES, in this case, pollination. Nonetheless, in other contexts, the source of the heterogeneity in consumers' preferences might be linked to other factors. Therefore, in general, the shaping of conservation strategies for ES should be based on more targeted local studies to uncover any source of heterogeneity, even within the same country. The use of standard information for

policy design leads to inefficient strategies, e.g., rewarding schemes for farmers in the EU (EU, 2020).

Our results suggest that consumers need the benefits of insect pollination and maybe other ES to help mitigate CC implications. Consequently, policies for the protection of pollinators should go hand in hand with mitigation and adaptation strategies for CC. Thus, shaping multidimensional policies focusing on pollinator protection and CC mitigation and adaptation might be more efficient.

Lately, multiple proposals have called for the conservation of ES, in this case, pollination, by triggering changes in human behavior (Forister *et al.*, 2019; Hall and Martins, 2020; Marselle *et al.*, 2020; Kawahara *et al.*, 2021). Nonetheless, inducing these changes is not always straightforward, especially in HIC. The identification of classes within the targeted population (e.g., consumers in different bioclimatic regions) can help ease the process of inducing the change. The analysis of the TEV of insect pollination in this study shows that consumers value both marketable and non-marketable components; however, the values attributed for each component vary across climate ranges. Consequently, it might be advantageous to base the promotion of behavioral changes to protect pollinators among consumers on TEV components with a special focus on the most valued component within each climate range. This classification of preferences is based on climate, which we chose based on heterogeneity analysis in the MLM; nevertheless, other factors might enable the identification of further classifications.

Indeed, this study was first set for LIC and MIC dry countries, but our results could also be relevant for HIC despite differences in consumers' habits. Many dry HIC have also been identified as vulnerable to pollinator loss, such as the USA (Reilly *et al.*, 2020). Actions for protecting pollinating insects remain limited (Potts *et al.*, 2016), especially from consumers' perspectives, even in HIC. Therefore, our findings might set a base for further studies in these countries to protect pollinators.

**CHAPTER 4 - APPENDIX CHAPTER : APPLICATION OF THE
BIOECONOMIC APPROACH**

1. Context

The conservation of ES requires an accurate economic assessment of their contribution to human well-being (Heal, 1999; TEEB, 2010, 2010 2011a, 2011b). This contribution can be represented by a number of values that individuals derive from ES. The TEV is an approach that can be used to assess these values (section 1.2). The TEV of an ES is comprised of use-values (direct and indirect), non-values, and the option value. Over the years, many methods have been used to assess the different components of the TEV of ES (section 1.3).

In the case of insect pollination, many assessments have been conducted in the past (section 2.5). Gallai *et al.* (2009) is one of the most known studies to have assessed the value of insect pollination worldwide. This study used a bioeconomic approach to measure the contribution of insect pollination to world agricultural production for human consumption and the vulnerability of world agriculture to pollinator decline. It is based on the assumption that the economic impact of pollinators on the agricultural output is measurable through the use of dependence ratios quantifying the effects of the loss of insect pollinators on the value of crop production (section 2.5.4). These dependence ratios reflect the level of dependence of crops on insect pollination (Klein *et al.*, 2007). Following this study in 2009, many other authors used the bioeconomic approach to assess the economic value of insect pollination for agricultural production for human consumption on different scales (Brading *et al.*, 2009; Lautenbach. S *et al.*, 2012; Leonhardt *et al.*, 2013; Shammout *et al.*, 2014; Breeze *et al.*, 2016; Mulatu, 2019; Borges *et al.*, 2020; Sabbahi, 2021).

Within the TEV of insect pollination, the bioeconomic approach only measures marketed indirect use-values for farmers and partly for consumers (IPBES, 2016); Gallai *et al.* (2009) also attempted to calculate the consequent surplus loss in a pollinator-free market using different price elasticities. Therefore, assessments using this approach underestimate the contribution of insect pollination to human well-being. In the second and third chapters, we use a DCE (section 1.3.2.2) to estimate the TEV of insect pollination based on the WTP stated by both farmers and consumers in a dry MIC, Morocco. Assessments in these chapters emphasize, in addition, to use values of insect pollination, non-marketed indirect use-values, non-use values, and the option value. Thus, to further highlight the importance of these values to farmers' and consumers' welfare, we use the bioeconomic approach to assess the value of insect

pollination to agricultural production for human consumption for Morocco and discuss results regarding findings of the second and third chapters.

In the methodology section, we describe the formulas of the bioeconomic approach and explain the data used for the estimation. The results and discussion section is organized into three subsections. The first subsection is dedicated to the value of insect pollination between 2009 and 2017 and its share in the Moroccan GDP. The second subsection is devoted to the vulnerability of agricultural production to pollinator loss, also between 2009 and 2017, and the last subsection is consecrated to the value of insect pollination and vulnerability of the agricultural output to pollinator loss in all Moroccan regions in the same period. Morocco accounts for 12 regions; five are included in the second and third chapters (figure 6).

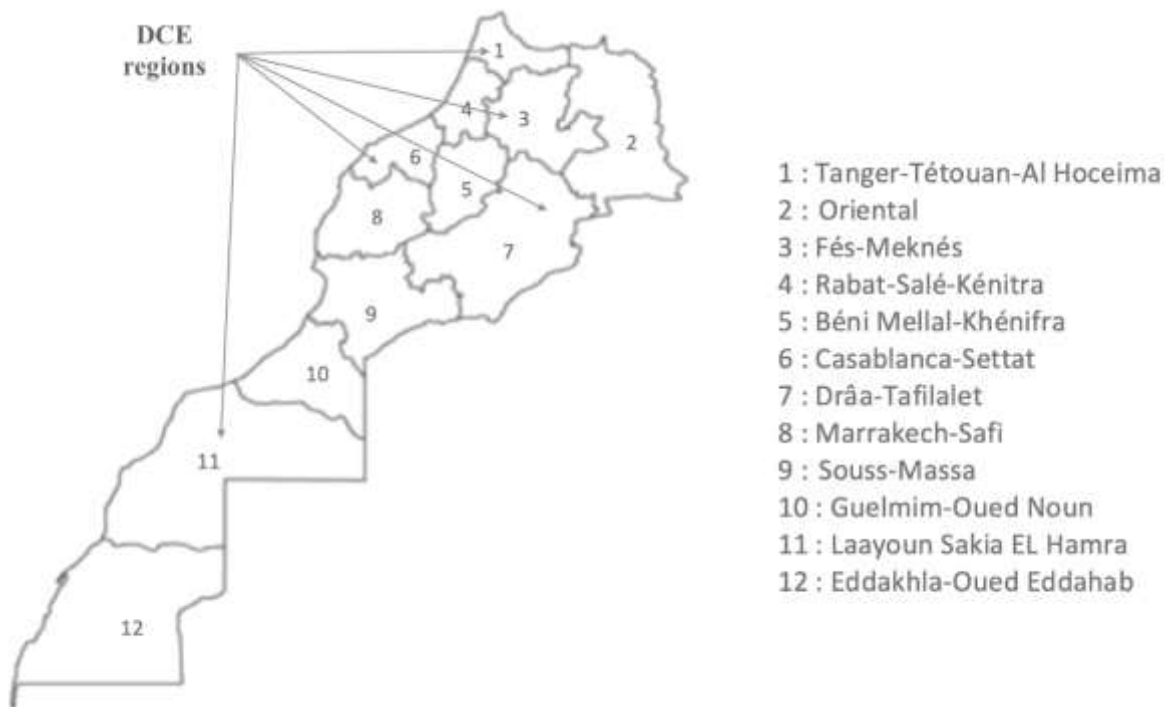


Figure 6: MAP of the Moroccan regions

2. Methodology

In Gallai *et al.* (2009), the formula used to estimate the contribution of insect pollination to agricultural production for human consumption (IPEV) is:

$$\text{IPEV} = \sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix} \times D_i)$$

For each crop i , where $i \in [1; I]$, in each world region x , where $x \in [1; X]$, where the quantity produced (Q_{ix}), the dependence ratio of the crop i on insect pollinators (D_i) and the price of crop i per unit produced in region x (P_{ix}). The ratio of vulnerability (RV) for the outcome used for human consumption is defined as follows:

$$\text{RV} = \frac{\text{IPEV}}{\text{EV}} = \frac{\sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix} \times D_i)}{\sum_{i=1}^I \sum_{x=1}^X (P_{ix} \times Q_{ix})} (\%)$$

For this study, we use two annual datasets of quantities and producer prices; from the ministry of agriculture (MOA), which we got on request, and from the FAO online database (<http://www.fao.org>). Both datasets cover the period between 2009 to 2017. The FAO dataset considers 76 crops and commodities, and the MOA dataset considers 93 crops and commodities. In the MOA dataset, quantities and prices are specified for each Moroccan administrative region. Data on dependence ratios of crops were taken from Klein *et al.* (2007). These ratios correspond to 0% when the crop shows no dependence on insect pollination, 5% in little dependence, 25% in modest dependence, 65% in high dependence, and 95% in essential dependence. We got data on the Moroccan GDP from the world bank database (<datacatalog.worldbank.org>).

3. Results and discussion

3.1. Value of insect pollination to agricultural production and its contribution to the GDP

In figure 7, we display the evolution of the value of insect pollination for crop production for human consumption between 2009 and 2017. There is a significant difference in value between the estimation based on the FAO database and the one based on the MOA database. In 2016-2017, for instance, the value of insect pollination for crop production for human consumption based on the FAO database was $1,06 \times 10^9$ € and based on the MOA database, this value was $1,85 \times 10^9$ €. Our estimation using the FAO database confirms Sabbahi (2021). On average, the

evolution of value estimated based on the FAO database between 2009 and 2017 shows a stable to a decreasing tendency, yet, the evolution of value based on the MOA database shows an increasing trend. Findings based on the MOA database confirm Potts *et al.* (2016) concerning the assumption of the growing dependence on insect pollination in dry LIC and MIC. However, findings based on the FAO database show a decrease in reliance on insect pollination in the same period. Most assessments of pollination using the bioeconomic approach rely on the FAO database. The latter, however, seems to be incomplete and does not reflect reality, especially in LIC and MIC.

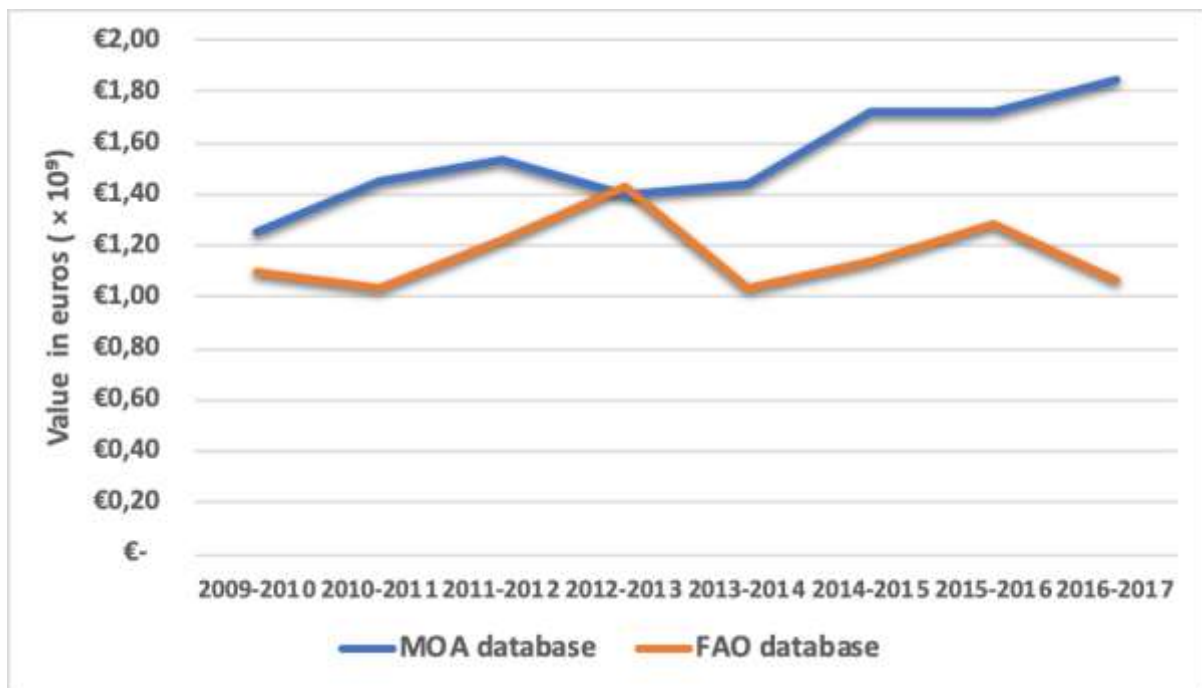


Figure 7: Economic Value of insect pollination (€) for crop production for human consumption using the FAO and the MOA database (2009-2017)

The share of the value of insect pollination to crop production for human consumption in the Moroccan GDP is portrayed in figure 8. It varies between 1,72% and 2,07% between 2009 and 2017. This share underestimates the contribution of insect pollination to the economy and people's economic welfare. In the second and third chapters, the average WTP stated by farmers and consumers for the protection of insect pollination is 177€/ year for farmers and 217€/ year for consumers. In Morocco, there are 1,8 Million farms (Akhenouch, 2017), and following the 2014 demographic census, simulations show that, in 2019, the population of adult consumers between the age of 18 and 75 will be 24 Million (www.hcp.ma). The aggregated value for Morocco is, thus, $5,45 \times 10^9$ €. This value exceeds the value estimated using the bioeconomic approach. Marre *et al.* (2015) found that the value of non-use values may comprise between 25

and 40% (minimum) of the mean WTP for ecosystem preservation. Thus, the difference (of 35%) in value between the bioeconomic approach estimates and the DCE estimates confirms that both farmers and consumers highly value insect pollination, not only for marketed indirect use-values but also other use-values non-use values, and the option value. Yet, most assessments of insect pollination are based on its marketed use-value (section 2.5). Thus, the information available to decisions makers underestimates the contribution of insect pollination to human welfare. This lack of information will impact the outcome of cost-benefit analysis for private and public decision-makers and, hence, insect pollinator protection (van Beukering *et al.*, 2007).

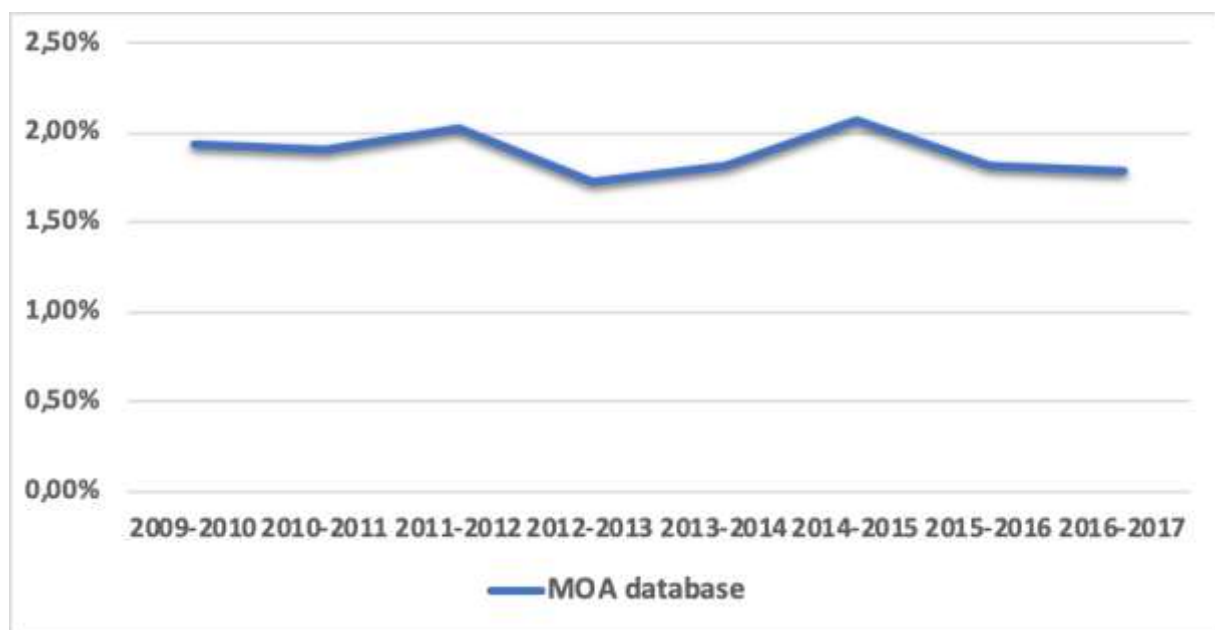


Figure 8: Contribution of insect pollination to the GDP using FAO and MOA databases

3.2. The vulnerability of crop production to pollinator loss

Figure 9 displays the vulnerability of crop production for human consumption to pollinator loss between 2009 and 2017. This vulnerability varies between 18% in 2012-2013 and 27% in 2015-2016. The agricultural sector in Morocco is highly dependent on climatic conditions (Harbouze *et al.*, 2019). The agricultural campaign was outstanding in 2012-2013 because of the increase in rainfall (an increase of 20% compared to 2011-2012). The value of agricultural production in 2012-2013 was $7,79 \times 10^9$ €, which is 14% higher than the year before. In 2015-2016 rainfall was deficient (HCP, 2018). In this year, the value of agricultural production was $6,46 \times 10^9$ € which is 19% lower than the year before. Thus, in this measure of vulnerability, the impact of the loss of insect pollination on the agricultural outcome is confounded with effects of other

contextual factors, in this case, climatic hazard. This raises questions about the representativeness and accuracy of this measure. However, in the second and third chapters, we acknowledge the impact of the climatic hazard on the value of insect pollination in dry LIC and MIC. We show that farmers' and consumers' sensitivity to pollinator decline increases in extreme climatic conditions.

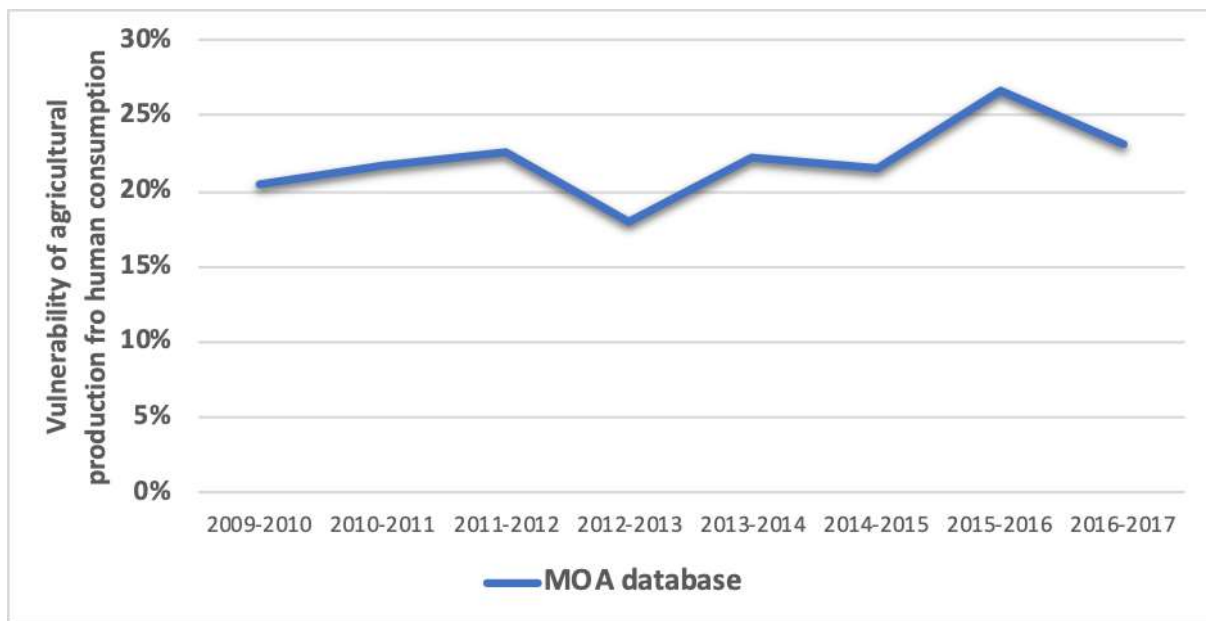


Figure 9: Evolution of the vulnerability of crop production for human consumption to pollinator loss between 2009 and 2017

3.3. Value of insect pollination in all Moroccan regions

In table 15, we display the estimation of the value of insect pollination using the bioeconomic approach for all Moroccan administrative regions based on the MOA database. In most regions, the value of insect pollination increases between 2009 and 2017. Yet, in Laayoun Sakia EL Hamra and Eddakhla-Oued Eddahab, the value of insect pollination for crop production for human consumption is null for almost the entire period. The survey in the second chapter shows that farmers in Laayoun Sakia EL Hamra usually practice subsistence agriculture and thus derive use values from insect pollination. These values are not accounted for by market mechanisms (Christie *et al.*, 2012). In the second and third chapters, we show that farmers and consumers in Laayoun Sakia EL Hamra express the highest value for insect pollination. In these chapters, we also demonstrate that TEV of insect pollination for farmers and consumers increases as the level of aridity increases. Thus, in Eddakhla-Oued Eddahab, where the level of

aridity is high (Trabucco and Zomer, 2019), the value of insect pollination for farmers and consumers is also expected to be high.

Table 15: Economic value of insect pollination (€) for crop production for human consumption of Moroccan Administrative regions using the MOA database (2009-2017)

	2009- 2010	2010- 2011	2011- 2012	2012- 2013	2013- 2014	2014- 2015	2015- 2016	2016- 2017
Béni Mellal- Khénifra	$9,57 \times 10^7$	$1,18 \times 10^8$	$1,22 \times 10^8$	$1,01 \times 10^8$	$8,61 \times 10^7$	$1,14 \times 10^8$	$1,18 \times 10^8$	$1,19 \times 10^8$
Drâa- Tafilalet	$1,30 \times 10^8$	$1,43 \times 10^8$	$1,67 \times 10^8$	$1,88 \times 10^8$	$1,84 \times 10^8$	$2,02 \times 10^8$	$1,88 \times 10^8$	$3,12 \times 10^8$
Eddakhla- Oued Eddahab	$4,93 \times 10^6$	0	0	0	0	$5,02 \times 10^6$	0	0
Fés-Meknés	$3,02 \times 10^8$	$2,85 \times 10^8$	$2,90 \times 10^8$	$3,56 \times 10^8$	$3,26 \times 10^8$	$3,99 \times 10^8$	$4,43 \times 10^8$	$5,22 \times 10^8$
Casablanca- Settat	$4,42 \times 10^7$	$4,21 \times 10^7$	$4,03 \times 10^7$	$2,64 \times 10^7$	$2,66 \times 10^7$	$4,70 \times 10^7$	$4,91 \times 10^7$	$3,87 \times 10^7$
Guelmim- Oued Noun	$4,99 \times 10^6$	$2,80 \times 10^6$	$6,05 \times 10^6$	$3,31 \times 10^6$	$6,46 \times 10^6$	$8,23 \times 10^6$	$8,41 \times 10^6$	$1,52 \times 10^7$
Laayoun Sakia EL Hamra	0	0	0	0	0	0	0	0
Marrakech- Safi	$1,87 \times 10^8$	$1,97 \times 10^8$	$2,63 \times 10^8$	$1,68 \times 10^8$	$1,78 \times 10^8$	$2,26 \times 10^8$	$1,86 \times 10^8$	$1,85 \times 10^8$
Oriental	$7,06 \times 10^7$	$7,61 \times 10^7$	$8,58 \times 10^7$	$1,04 \times 10^8$	$1,24 \times 10^8$	$1,26 \times 10^8$	$1,34 \times 10^8$	$1,08 \times 10^8$
Rabat-Salé- Kénitra	$2,06 \times 10^8$	$2,50 \times 10^8$	$2,53 \times 10^8$	$2,11 \times 10^8$	$2,83 \times 10^8$	$2,99 \times 10^8$	$3,00 \times 10^8$	$2,96 \times 10^8$
Souss- Massa	$1,26 \times 10^8$	$1,37 \times 10^8$	$1,62 \times 10^8$	$1,32 \times 10^8$	$1,15 \times 10^8$	$1,47 \times 10^8$	$2,07 \times 10^8$	$1,76 \times 10^8$
Tanger- Tétouan-Al Hoceima	$8,36 \times 10^7$	$2,00 \times 10^8$	$1,43 \times 10^8$	$1,06 \times 10^8$	$1,15 \times 10^8$	$1,47 \times 10^8$	$8,92 \times 10^7$	$7,92 \times 10^7$

In figure 10, we highlight the evolution of the value of insect pollination for crop production for human consumption between 2009 and 2017 for all Moroccan regions. The value of insect pollination for agricultural outcomes increased in three regions during this period, Fes-Meknes, Draa-Tafilalet, and Rabat-Salé-Kénitra. Yet, in the second and third chapters, we demonstrate that Fès-Meknès has the lowest value of insect pollination among the regions studied. Thus, future assessments of pollination and ES, in general, should focus more on the contribution of non-use and options values to the human welfare for better conservation. Many studies emphasized the importance of these values for the preservation of ES worldwide (e.g. (Wattage and Mardle, 2007; Dutton *et al.*, 2010; Breeze *et al.*, 2015; Marre *et al.*, 2015; Mwebaze *et al.*, 2018)).

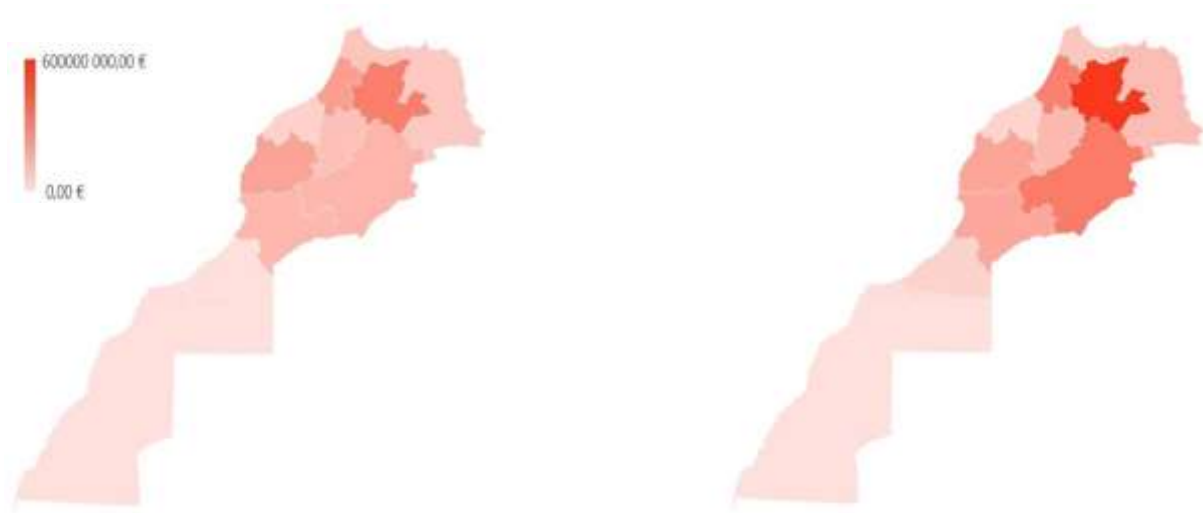


Figure 10: The value of insect pollination for agricultural production for human consumption for all Moroccan regions using the MOA database: a) in 2010-2011; b) in 2016-2017

Figure 11 represents the vulnerability of the agricultural outcome to pollinator loss in all Moroccan regions. This vulnerability is highest in Drâa-Tafilalet and Souss-Massa, and both regions have high aridity levels. In the third and fourth chapters, we also find that Drâa-Tafilalet is the region where the sensitivity of farmers and consumers is the second highest.

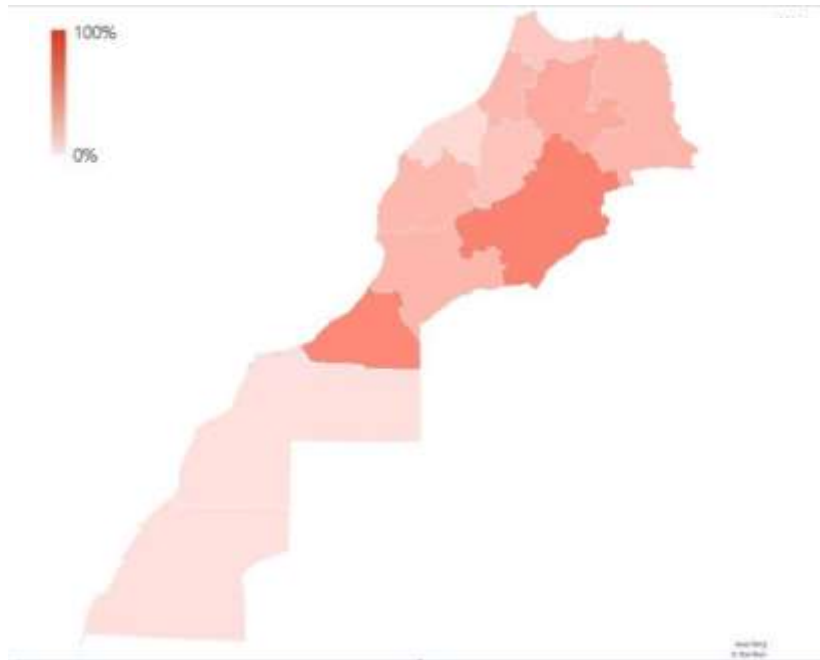


Figure 11: The Vulnerability of agricultural production for human consumption for all Moroccan regions using the MOA database (2016-2017)

4. Conclusion

The use of the FAO database for assessments does not provide accurate estimates. These estimates deliver biased information to decision-makers which impacts the conservation of pollinators, especially in LIC and MIC, where datasets seem to be incomplete.

Most assessments for insect pollination are based on use-values. These assessments underestimate the contribution of insect pollination to human welfare by almost 40%, which impacts the efforts made to protect insect pollinators.

The bioeconomic approach only considers marketed agricultural production, yet, in most LIC and MIC, farmers are primarily smallholders who practice subsistence agriculture (Cely-Santos and Lu, 2019). Therefore, this approach in LIC and MIC to estimate the value of insect pollination for agricultural production for human consumption might be less accurate than in countries with more market-oriented agriculture.

In the measure of vulnerability, the impact of the loss of insect pollination on the agricultural outcome is confounded with the effects of CC. This raises questions about the representativeness and accuracy of this measure.

**CHAPITRE 5 - CONSERVING PUBLIC GOODS: HOW DO FARMERS'
AND CONSUMERS' ECONOMIC PREFERENCES IMPACT THE
DESIGN AND IMPLEMENTATION OF POLLINATOR
CONSERVATION STRATEGIES?**

Disclaimer:

In chapter 5, we reused the datasets from both farmers' and consumers' designs. Yet, because of some convergence issues when running data with the latent class model, we downsized the sample in this chapter from 492 farmers and 481 consumers to 370 and 413. Downsizing the sample did not significantly change the random parameter models (in preferences and WTP spaces) estimates presented in the 2nd and 3rd chapters.

Abstract

Human practices are threatening wild pollinators worldwide. However, efforts for the protection of insect pollination are still insufficient. In HIC, national and regional conservation strategies and initiatives: a) are not based on accurate assessments of the benefits and costs of insect pollination to the economic welfare of societies, b) fail to account for people's perceptions and preferences for insect pollination and distinguish between farmers and consumers and c) fail to deliver outcomes at the least cost to the economy. In LIC and MIC, governments still need to acknowledge insect pollination as a threatened public good contributing to farmers' and consumers' welfare. Thus, in this study, we conduct a double DCE with consumers and farmers to a) help measure values that insect pollination delivers to social welfare, b) assess farmers' and consumer's knowledge about insect pollination, and c) analyze the heterogeneity in farmers' and consumers' preferences for the protection of insect pollination. We chose to conduct this study in Morocco, a MIC, to help convince policymakers in LIC and MIC concerning the importance of insect pollination as a public good that needs to be protected. Our findings show the high contribution of insect pollination to people's welfare in LIC and MIC. They also highlight the significant heterogeneity in farmers' and consumers' preferences towards the benefits of insect pollination. We use this result to discuss and suggest new targeted policy interventions for farmers and consumers in HIC, LIC, and MIC.

Keywords: Wild pollinators, Public good, Heterogeneity in preferences, Farmers' preferences, Consumers' preferences, Conservation strategies

1. Introduction

1.1. The conservation of pollination as a public good

Public good conservation is an increasingly important economic issue (e.g. (Hanley *et al.*, 1998; Oniki *et al.*, 2020; Zhou *et al.*, 2020; Laureti *et al.*, 2021)). An environmental asset is considered a public good if its consumption is *non-rival* and *non-excludable* (Hanley *et al.*, 1997; Deke, 2008). Biodiversity generates a range of ES, which might display the nature of public goods (Deke, 2008; Rands *et al.*, 2010). These services refer to the benefits humans derive from ecosystems (De Groot *et al.*, 2002; MEA, 2005). There are four classes of ES, provisioning services, regulating services, cultural services, and supporting services MEA (2005).

Insect pollination is a regulatory service that highly contributes to social welfare (MEA, 2005). It provides benefits associated with agricultural production and regular consumption (IPBES, 2016). Insect pollinators enhance the quality and quantity of $\frac{3}{4}$ of the world-leading food crops (Klein *et al.*, 2007; Garibaldi *et al.*, 2013; Garibaldi *et al.*, 2014; Winfree *et al.*, 2018). They also support food security (Anderson and Vasiliev, 2021) and maintain other ES from which farmers and consumers derive multiple benefits (Allen-Wardell *et al.*, 1998; Ollerton *et al.*, 2011; IPBES, 2016; Ollerton, 2017). Insect pollinators represent a diverse group of wild insects (e.g., bees, wasps, butterflies, etc.) (IPBES, 2016; Robert, 2016). Some of these insects have been domesticated over the years to ensure the function of pollination in agroecosystems and honey production (IPBES, 2016). Yet, managed species cannot ensure the process of pollination globally; they only pollinate a few flower types and cover a limited surface (Nabhan and Buchman, 1997 ; Christmann, 2019a).

Wild insect pollinators display public good properties. Farmers and consumers have free access to the benefits provided by wild insect pollinators (*non-exclusion*). However, the benefits of insect pollination would be *non-rival* only if the stock of pollinators is sufficient to ensure pollination globally; when a bee pollinates a flower or focuses on a farm, it is unavailable to others. Therefore, wild insect pollinators can be confounded with common-property resources. These resources are often overused due to their *non-exclusion* and *rivalry* traits; when a person's consumption rivals another person's consumption, and they both have free access, they will capture more benefits from the resource, which will lead to its overuse (Hanley *et al.*, 1997). Insect pollination cannot be overused because of the simple consumption of its benefits.

Yet, the stock of pollinators is diminishing because of the worrying declines facing pollinator populations worldwide (MEA, 2005; Ricketts *et al.*, 2008; Potts *et al.*, 2010; IPBES, 2016; Robert, 2016; Hallmann *et al.*, 2017; Hallmann *et al.*, 2021; Zattara and Aizen, 2021). Most of the threats endangering pollinators are led by human activities (Potts *et al.*, 2010; IPBES, 2016; Díaz *et al.*, 2019; Hallmann *et al.*, 2021; Millard *et al.*, 2021; Zattara and Aizen, 2021). Farming behavior (e.g., agricultural intensification and agrochemical use) and consumption behavior (e.g., land-use change) are the primary drivers of pollinator decline (Potts *et al.*, 2010; Goulson *et al.*, 2015; Requier *et al.*, 2015). Farmers' and consumers' behavior towards insect pollination is impacted by its non-rival and non-excludable properties; When dealing with public goods, people usually do not face the full benefits and costs of their actions which can translate to socially irresponsible behaviors towards these goods (Public good dilemma) (Starrett, 2003; van Dijk *et al.*, 2003). People also fail to account for the broader and long-term social costs and benefits of biodiversity in their decision-making process, which results in endangering behaviors towards ecosystems (Deke, 2008).

Governments usually take responsibility for the conservation of public goods (Laureti *et al.*, 2021). This conservation requires an accurate measurement of their costs and benefits to societies and human well-being (Heal, 1999). Nonetheless, to date, the contribution of most ES to social well-being is still not factored into the price of goods and services due to markets' failure to account for most costs and benefits of biodiversity (Costanza *et al.*, 2014). The assessment of values people derive from biodiversity can be very challenging, especially non-use and option values (IPBES, 2019). However, the economic valuation of ES can provide an accurate measurement of these values (CBD, 2010; TEEB, 2010, 2011a, 2011b). For insect pollination, many economic valuation methods have been used over the years in many parts of the world (IPBES, 2016). However, most of these evaluations focus on direct use values partly captured by market mechanisms; we identify three studies focused on indirect use values and non-use values of insect pollination (Mwebaze *et al.*, 2010; Breeze *et al.*, 2015; Mwebaze *et al.*, 2018). Another challenge for conserving public goods would be to elaborate socially acceptable behavioral change strategies that need to be delivered at the least cost to the economy (Moore *et al.*, 2004; Naidoo *et al.*, 2006; Liu, 2021). Governments in many countries are engaged in pollinator conservation strategies and initiatives on both national and regional levels at different extent.

1.2. The basis and focus of current pollinator-protection strategies

To avoid a future pollinator crisis (Steffan-Dewenter et al., 2005), governments in many countries are engaged in pollinator conservation strategies and initiatives on both national and regional levels. These strategies and initiatives were inspired by a number of international guidelines for the protection of insect pollinators; the first guidelines for the protection of insect pollination were provided by the “International Pollinators Initiative (IPI),” established in 2002 and coordinated by the FAO. Since then, many other initiatives have also provided insights on the necessary measures to protect these species, namely the MEA in 2005 and IPBES in 2016. These measures focus on supporting scientific research, the making of pollinator-friendly pesticides legislations, the conservation and enhancement of pollinator habitats, the use of incentives and payments for ES, and raising public awareness and knowledge sharing. Some studies also addressed the pollinator crisis and suggested policy recommendations for specific contexts (Dicks *et al.*, 2016a; Dicks *et al.*, 2016b; Christmann, 2019b; Porto *et al.*, 2020; Christmann *et al.*, 2021a). More recently, research focused more on the importance of promoting ecological intensification as a solution to protect pollinators (Garibaldi *et al.*, 2019; Gemmill-Herren *et al.*, 2021), however sustainable intensification does not automatically benefit all pollinators (Kleijn et al. 2014), because the increased land-use for agriculture (Aizen et al. 2019) threatens non-crop pollinators. To safeguard them as well, higher productivity must be harmonized with pollinator-friendly farming to reduce land-use change (Christmann et al. 2021b)

Following the IPI in 2002, many regional initiatives have emerged. The most known regional initiative is the “EU pollinator initiative” (<https://ec.europa.eu/>) in Europe. This initiative was heavily criticized for not being sufficiently targeted (EU, 2020). Interventions within this initiative focus mainly on incentives for farmers in the form of agroecological reward schemes, e.g., for seeding wild-flower strips. Another outcome of IPI is “the North American Pollinator Initiative” (<https://promotepollinators.org/>). The EU and USA invest billions of dollars in agroecological rewarding schemes (Batáry *et al.*, 2015; Dicks *et al.*, 2015). Yet, add-on incentives are one of the least effective interventions to achieve pro-environmental behavior (Byerly *et al.*, 2018; Nisa *et al.*, 2019); external compensation is not based on better understanding and intrinsic motivation (Christmann, 2020). The “African Pollinator Initiative” (<http://www.arc.agric.za/>) is also an outcome of the IPI initiative; however, it is less active.

Another “International Pollinators Initiative 2018-2030” was initiated by the CBD and charged to FAO (<https://www.cbd.int/>).

At a national level, France, Germany, Netherlands, Norway, Switzerland, the UK (Scotland, England, and Wales), Ireland, the USA, and Canada are the main countries with established strategies to protect pollinators (www.fao.org). Most of these strategies are either focused on scientific research (e.g., France, Switzerland) or raising awareness (e.g., Netherlands). The scientific research axis in these national strategies focuses primarily on taxonomy, developing and coordinating databases, and red lists on insect pollinators. However, since the main threats to insect pollinators are led by human behavior, we would expect this axis to be also devoted to research on knowledge, perceptions, and preferences for insect pollinators and their benefits from both farmers’ and consumers’ points of view. Knowledge, perceptions, and preferences can define and predict human behavior; therefore, understanding them will help design targeted interventions to achieve pro-pollinator behavior and meet acceptable environmental outcomes (Anderson and Mellor, 2008; Dohmen *et al.*, 2011; DellaVigna *et al.*, 2012; Tarakini *et al.*, 2020; Amoah and Addoah, 2021; Burns *et al.*, 2021; Gemmill-Herren *et al.*, 2021; Lades *et al.*, 2021). Marselle *et al.* (2020) stated that education interventions are the most overused interventions: 23% of current interventions for the protection of insect pollination worldwide are focused on education. Yet, according to Byerly *et al.* (2018) and Nisa *et al.* (2019), education interventions are the least effective in changing human behavior. Almost half of the European pollinator conservation actions failed to identify the intervention target (Marselle *et al.*, 2020). Hall and Steiner (2019) stated that pollinator conservation policies in the US failed to address policy targets. Thus, the lack of efficient targeting for education interventions in national strategies might explain their failure to achieve behavioral changes.

Most current pollinator conservation strategies take place in HIC (FAO, 2021). So far, Sri Lanka, Colombia, Nigeria, and Ethiopia are the only LIC and MIC that took the first steps to protect insect pollinators. Besides Ethiopia and Nigeria, Morocco and Burundi are the only countries that have joined the coalition of the willing on pollinators (<https://promotepollinators.org>). A priori, the impact of pollinator loss on consumers and farmers’ economic welfare will be higher in LIC and MIC compared to HIC, because agroecosystems in LIC and MIC are highly vulnerable to pollinator loss because of farmers’ increasing use of pollinator-dependent crops (Potts *et al.*, 2016; Silva *et al.*, 2021) and notably

for the lower-income strata reduced options for consumers to purchase pollinator-dependent crops from the global market. Simultaneously, these crops supply significant proportions of micronutrients in global human diets (Smith et al., 2015); the loss of pollinators will lead to micronutrient deficiencies which would result in severe impacts on the human health and well-being of consumers (Smith et al., 2015; IPBES, 2016). These deficiencies will presumably have a higher impact on the population in subsistence economies that already suffer food and nutrient shortages (Gilland, 2002 ; Eilers *et al.*, 2011; Cely-Santos and Lu, 2019; Chaplin-Kramer *et al.*, 2019). Therefore, governments in LIC and MIC need to acknowledge the importance of insect pollination and engage more in the conservation of insect pollinators.

1.3. Research focus

Actions for the conservation of insect pollination worldwide rarely consider its public good properties mainly because they are based on incomplete information on its costs and benefits to social welfare; valuations focus primarily on marketed use-values of pollinators. These strategies do not acknowledge the difference between farmers' and consumers' perceptions and preferences for the benefits of insect pollination. Most approaches also are very costly to the economy. In this study, we use a double DCE with consumers and farmers to a) measure the true contribution of insect pollination to their welfare, b) assess their knowledge about insect pollination, and c) analyze the heterogeneity in their perceptions and preferences for the benefits of insect pollination, to help set more targeted behavioral change interventions for the protection of pollinators. We choose to conduct this DCE in a MIC, Morocco, to help convince policymakers in LIC and MIC of the importance of insect pollination as a public good that needs protection. Strategies which cost the least to economies are generally important for the conservation of public goods; however, in the context of LIC and MIC, cost-effective and self-sustaining interventions are highly convenient because of the limited means of governments (Christmann, 2019a).

The second section of this paper introduces the DCE methodology and summarizes the main choices for consumers' and farmers' DCE designs. In the fourth section, we give an insight into our data and the structure of the survey. The fifth section exhibits the main results from analyzing our datasets using the mixed logit model (MLM) and latent class model (LCM). The final section is devoted to discussing these results and a conclusion in which we provide concrete cost-effective policy recommendations for HIC, MIC, and LIC.

2. Methodology

2.1. Definition of DCE

The DCE is a stated preference method used to assess individual preferences in hypothetical situations (Louviere and Hensher, 1982; Louviere *et al.*, 2000; Hanley *et al.*, 2001). The DCE method is widely used to study preferences for ES (e.g., (Sandhu *et al.*, 2008; Shoyama *et al.*, 2013; Rai *et al.*, 2015; Diafas *et al.*, 2017; Nordén *et al.*, 2017; Müller *et al.*, 2020)). In these studies, ES are defined by a number of attributes and their levels. These attributes and levels are combined in different choice sets using an experimental design. In each choice set, respondents are presented with two to three alternatives describing hypothetical changes in the service and are asked to choose their most preferred alternative from each choice set (Hanley *et al.*, 2001). In the past, only one study employed the DCE to analyze preferences for the protection of insect pollination (Breeze *et al.*, 2015). This study assessed respondents' WTP to conserve pollinators to prevent marginal losses in the benefits of pollination services. It was conducted in a HIC and did not differentiate between farmers' and consumers' preferences; consequently, we couldn't rely on their choice of attributes and levels to define attributes and levels for this study.

2.2. Attributes, levels, and experimental design

2.2.1. Non-payment attributes

In this study, we designed two different DCE designs; for consumers and farmers. Our choice of non-payment attributes was made based on the utility function of both consumers and farmers for insect pollination. Farmers and consumers derive different benefits from wild pollinators. The enhanced diversity and abundance of wild pollinators is an important production factor that enhances the quantity and the quality of pollinator-dependent crops for farmers (Klein *et al.*, 2007; Garibaldi *et al.*, 2013; Garibaldi *et al.*, 2014; Winfree *et al.*, 2018). The existence of wild pollinators also impacts farmers' ability to have a diverse production (Partap and Ya, 2012). In case of lack of these species on farm, farmers' choice of crops would be limited to non-pollinator-dependent crops, which would impact their income (Ashworth *et al.*, 2009; Christmann *et al.*, 2017). To consumers, insect pollination is an essential factor influencing the supply of major food crops, which are mandatory for a healthy human diet (Eilers *et al.*, 2011; Chaplin-Kramer *et al.*, 2014; Smith *et al.*, 2015). Wild pollinators are also

a factor influencing the survival of most wild plants and biodiversity (Ollerton *et al.*, 2011; Ollerton, 2017), which provide various ES to different communities (IPBES, 2016; Cely-Santos and Lu, 2019), particularly all ES provided by 87% of flowering plants depend on pollinators (Christmann -Pollinator-Loss article). The beauty of the landscape can be a good indicator of the health of ecosystems for regular people. Based on these benefits, we chose the attributes displayed in table 16. The selected levels are also displayed in the same table.

2.2.2. Payment mechanism

The choice of an appropriate payment mechanism is one of the most critical steps in a DCE (Obadha *et al.*, 2019). In LIC and MIC, the use of monetary payment mechanisms can be a factor leading to respondents ignoring the payment attribute while expressing their preferences for the service, which results in biased WTP estimates (Meyerhoff and Liebe, 2009). In this case, labor-based payment mechanisms can be an alternative to monetary-based payment mechanisms (Rai *et al.*, 2015; Tadesse *et al.*, 2017; Khanal *et al.*, 2018; Hagedoorn *et al.*, 2020). However, people in LIC and MIC usually find it difficult to trust that governments will use their work to deliver policies (McCauley and Mendes, 2006). A study by Ando *et al.* (2020) shows that the “Willingness to Volunteer (WTV)” can also be an alternative to monetary payment mechanisms. This study takes place in a HIC, yet, a volunteering payment mechanism can also be socially accepted in LIC and MIC given the high social values, such as altruism, of populations in these countries (Ligon, 2011; Kananurak and Sirisankanan, 2017). Thus, the payment attribute we chose for this study is the number of volunteering days in an association to protect pollinators and their habitats. The time frame for the levels of this attribute is different between farmers and consumers because of the distinct nature of their schedules; farmers plan their schedules a year ahead, and consumers plan their schedules only a month ahead because most of them get paid monthly.

The transition from volunteering days to monetary payments allows the use of our estimates in governmental cost-benefit analysis, comparisons with other studies, etc. Therefore, we use the following formula for the transition:

$$\text{WTP} = \text{Volunteering days} * 1/3 \text{ of the average daily individual income}$$

This transition was included in the attribute “Number of volunteering days in an association for the protection of pollinators and their natural habitats (or *eq*:1/3 of what the farmer gains daily)” to give farmers more options (pay in volunteering or money) and, if they choose the WTV instead of the WTP, to have an idea on the monetary value of their work.

Table 16: Attributes and their levels for farmers and consumers' designs

Attributes for farmers	Levels	Attributes for consumers	Levels
<i>1st attribute</i> - Diversity of agricultural production on your farm	High Low (reference)	<i>1st attribute</i> - Aesthetics of the landscape in your region	Good Bad (reference)
<i>2nd attribute</i> - Quantity of fruits and vegetables produced on your farm	High Low (reference)	<i>2nd attribute</i> - Variety of fruits and vegetables available on the markets in your region	High Low (reference)
<i>3rd attribute</i> - Quality of fruits and vegetables produced on your farm	High Low (reference)	<i>3rd attribute</i> - Quality of fruits and vegetables available on the markets in your region	High Low (reference)
<i>Payment attribute per year per farmer</i> - Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the farmer gains daily)	12, 24, 36, and 48 days per year	<i>Payment attribute per month per consumer</i> - Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	One day, two days, three days, four days













2.2.3. Focus groups

We held four focus groups in total; One focus group was held with Moroccan experts, two focus groups with Moroccan farmers, and one with Moroccan consumers (Appendix 6). During these focus groups, we defined and confirmed our choice of attributes (especially the payment attribute and the transition from WTV to WTP), levels, illustrations for the different levels of attributes, etc. We invited eight to twelve participants for each focus group. Participants were chosen to represent the various social categories of both target groups. In the experts' focus group, we invited both agricultural and market experts.

2.2.4. Experimental designs

Both designs include three alternatives (figure 12). The first two alternatives on the choice sets are combinations of the attributes and their levels produced using an efficient design on the Ngene software. For both groups, the software generated eight choice cards in one block. We also added a third blank alternative (no attributes or levels), which we refer to as the “opt-out” or “no-choice” option. We did not opt for a status-quo in this study because it usually refers to the current situation, which remains unknown in the case of wild pollinators. A pilot study was conducted with 20 farmers and 20 consumers to ensure the effectiveness of the chosen attributes and their levels. The collected data were analyzed, and results helped refine the design for the choice sets in both designs.

Figure 12: Example of choice card from farmers'(left) design and consumers' design (right)

	Alternative1 <i>High diversity:</i>	Alternative2 <i>Low diversity:</i>		Scenario1 <i>Good</i>	Scenario2 <i>Good</i>		
Diversity of agricultural production on the farm			Opt out	1st attribute - Aesthetics of the landscape in your region <i>Good</i>			Opt out
Quantity of agricultural production of fruits and vegetables on the farm	<i>Low quantity:</i> 	<i>High quantity:</i> 		2nd attribute - Variety of fruits and vegetables available on the markets in your region	<i>High</i> 	<i>Low</i> 	
Quality of agricultural production of fruits and vegetables on the farm	<i>High quality:</i> 	<i>Low quality:</i> 		3rd attribute - Quality of fruits and vegetables available on the markets in your region	<i>High</i> 	<i>Low</i> 	
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or eq: 1/3 of what the farmer gains daily)	12	48		Monetary attribute per month per consumer- Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (eq to 1/3 to what you make on normal day of work)	3 days	2 days	
Your choice			Your choice				

2.3. Bias control

An important limitation of this study is the nature of the valued services and the selected attributes to represent them. They might place a significant comprehension burden on respondents, especially if not aware of the benefits of insect pollination. As mentioned earlier, insect pollination is a factor, among others, influencing the agricultural production of pollinator-dependent crops for farmers and the supply of major food crops along with other ES for consumers. When presented with choice sets, respondents can easily confound the input of pollination to agricultural production and biodiversity with the input of other factors involved in the process. If the farmer is not aware of the importance of insect pollinators to his production, for instance, he can easily ignore their contribution to the quantity and quality of his pollinator-dependent crop and consider other factors, such as rainfall and fertilizers, while choosing an alternative. This confusion leads to biased results of the DCE. To control this bias, in both surveys (farmers and consumers), we proceeded with the following measures:

⇒ An explanatory paragraph:

Farmers' and consumers' knowledge about insect pollinators is important for the success of this study. In literature, some studies found that the level of knowledge among both groups is moderate in LIC and MIC (more than 50% know pollination and can identify some insect pollinators) (Kasina *et al.*, 2009; Tarakini *et al.*, 2020). In Morocco, Christmann *et al.* (2021a) found that 57% of farmers mentioned honeybees as pollinators; however, 76% of farmers never recognized a pollinator nest in or around their farms and rarely recognized flies and bumblebees as pollinators, also they had a blurred understanding which crops depend on pollinators, on the character of pollination problems and the habitat requirements of pollinators. Thus, given the considerable comprehension burden put on farmers and consumers during the decision-making process for the choice cards, we prepared a paragraph explaining what pollination is, the importance of insect pollinators, and the threats facing pollinator populations. To control information bias, this paragraph was read to all respondents before the survey (Appendices 3 and 5).

⇒ Mental preparation for respondents:

We tested their understanding of the information given in the explanatory paragraph. Questions linking the chosen attributes to insect pollination were also asked farmers and consumers to mentally prepare them for the choice cards and indirectly test their knowledge about insect pollination (Appendices 3 and 5).

⇒ Explanatory sheets of the attributes:

These sheets were prepared and confirmed by the focus groups and tested in the pilot study. In these sheets, we clearly state that their choices should be based on the contribution of insect pollination to the different attributes (Appendices 2 and 4):

⇒ Face to Face survey:

We chose to conduct a face-to-face survey to ensure that target groups understood the attributes and how they can be influenced by insect pollination.

⇒ Follow up question to the choice cards:

The aim of this question was to check if respondents considered the contribution of insect pollination while making their choices (more than 90% of them responded positively) (Appendices 3 and 5).

3. Survey and data

3.1. Structure of the questionnaire and sample

The questionnaire prepared for farmers (Appendices 3) is made up of four distinct sections. The first section, “introduction and context,” is divided into two subsections. The first subsection is devoted to the farm, and the second to knowledge about insect pollination. The second section, “benefits of insect pollination,” is comprised of four subsections. The first subsection is devoted to pollination and agricultural products. The second subsection is dedicated to pollination and biodiversity. The third subsection is consecrated to pollination and honey production, and the fourth subsection deals with measures to protect the conservation of insect pollination. The third section displays the choice cards and follow-up questions related to the DCE, and the fourth subsection investigates farmers' personal information.

The structure of the questionnaire prepared for consumers (Appendices 5) is not very different from the one used for farmers. We do not have the subsection on the farm in this questionnaire, and the rest of the questions were kept but asked from a consumer perspective. The DCE section was also different since we used two completely different designs. Questionnaires in both cases were anonymous.

The survey was conducted with a total of 492 farmers and 481 consumers in Morocco (Appendix 7 and 8). However, we only retained 370 questionnaires with farmers and 413 with consumers. The sample of both groups was taken from five bioclimatic regions in Morocco (around 20% from each region for each target group) in order to guarantee its geographical,

climatic, and demographical representativeness (figure 13). Farmers from each region were randomly chosen from lists provided by a Moroccan public institution (Office National de Conseil Agricole). Consumers were randomly approached at gathering points such as local and supermarkets, restaurants, coffee shops, etc.



Figure 13: Map of Morocco with the five bioclimatic regions chosen for the sample

The collected data for both farmers and consumers were analyzed using a mixed logit model (MLM) (Train and Weeks, 2004) and a latent class model (LCM) (Yoo, 2020). The opt-out option was introduced into the design as an alternative specific constant (ASC), and effect coding was used for the two alternatives.

3.2. Profile of the respondents

Table 17 reports the characteristics of the chosen samples of both groups. The sample of consumers seems to be younger, has a higher level of formal education, and has more female respondents. Farmers are mostly married, have children, and on average, their annual revenue is slightly lower than the revenue of consumers. As expected, the level of knowledge about pollination is higher among farmers. Almost half of the interviewed farmers are smallholders (less than 5 ha), and 37% of the interviewed farmers produce pollinator-dependent crops.

Table 17: Framers' and consumers' characteristics in the sample

Descriptors	Farmers	Consumers
Gender	⇒ F: 7% ⇒ M: 93%	⇒ F: 29% ⇒ M: 71%
Age	⇒ 5% between 18 & 29 years ⇒ 35% between 30 & 44 years ⇒ 42% between 45 & 60 years ⇒ 16% between 60 & 75 years ⇒ 2% 75 years and plus	⇒ 19% between 18 & 29 years ⇒ 43% between 30 & 44 years ⇒ 31% between 45 & 60 years ⇒ 7% between 60 & 75 years
Personal situation	89% married	⇒ 66% married ⇒ 28% single ⇒ 4% divorced ⇒ 3% widow
Children	89% have Children	65% have children
Area of residence	⇒ 100% rural areas	⇒ 44% live in the urban areas ⇒ 37% live in suburban areas ⇒ 19% live in rural areas
Education	⇒ 27% have an elementary education ⇒ 17% have secondary education ⇒ 14% have a college education ⇒ 16% have no formal education ⇒ 13% have preschool education ⇒ 13% have a high school education	⇒ 49% have a college education ⇒ 16% have a high school education ⇒ 12% have secondary education ⇒ 12% have an elementary education ⇒ 4% have no education ⇒ 7% have preschool education ⇒ 4% have no formal education

Revenue/year	<p>⇒ 10% less than 2251 €</p> <p>⇒ 17% between 2251 & 4503 €</p> <p>⇒ 19% between 4503 & 6754 €</p> <p>⇒ 14% between 6754 & 9006 €</p> <p>⇒ 9% between 9006 & 11257 €</p> <p>⇒ 7% between 11257 & 13508 €</p> <p>⇒ 3% between 13508 & 15760 €</p> <p>⇒ 20% make more than 15760 €</p>	<p>⇒ 8% less than 2251 €</p> <p>⇒ 13% between 2251 & 4503 €</p> <p>⇒ 17% between 4503 & 6754 €</p> <p>⇒ 14% between 6754 & 9006 €</p> <p>⇒ 12% between 9006 & 11257 €</p> <p>⇒ 9% between 11257 & 13508 €</p> <p>⇒ 10% between 13508 & 15760 €</p> <p>⇒ 17% make more than 15760 €</p>
Pollination knowledge	88% know the process of pollination	82% know the process of pollination
Pollination vector knowledge	87% know at least one pollination vector	77% know at least one pollination vector
Knowledge of the difference between wild and managed pollinators	60% know the difference between wild and managed pollinators	54% know the difference between wild and managed pollinators
Employment sector	⇒ 100% agribusiness	<p>⇒ 49% services sector</p> <p>⇒ 24% industry and energy</p> <p>⇒ 20% agribusiness</p> <p>⇒ 1% environment</p> <p>⇒ 6% other sectors</p>
Farm size	<p>⇒ 29% from 0 to 3 ha</p> <p>⇒ 19% from 3 to 5 ha</p> <p>⇒ 24% from 5 to 10 ha</p> <p>⇒ 14% from 10 to 20 ha</p> <p>⇒ 14% from 20 to plus 200</p>	-
Level of crop dependence on pollinators	37% produce crops that depend on pollinators	-

4. Results

In this section, we analyze our datasets from both designs using mixed logit in preference space and LCMs to explore farmers' and consumers' preferences for the benefits of insect pollination. To estimate farmers' and consumers' WTP to protect these benefits, we analyzed our datasets using a mixed logit in WTP space.

4.1. Mixed logit model in preference space

The MLM analysis (table 18) shows that the ASC, which represents the “no-choice” option, is high and positive for both designs, which suggests that both consumers and farmers prefer the first two alternatives to the “no-choice” option. In farmers’ design, the attribute “Quality of produced fruits and vegetables” has the highest taste parameter. The “Quality of fruits and vegetables on the market” also has the highest taste parameter for consumers. The MLM analysis also shows significant heterogeneity in preferences, mainly for the attribute “Quality of produced fruits and vegetables” for farmers and the attribute “Quality of fruits and vegetables on the market” for farmers.

Table 18: Mixed logit results for farmers and consumers

	MLM farmers		MLM consumers
Mean		Mean	
ASC	10.31***	ASC	9.74***
	(1.86)		(1.01)
Diversity of agricultural production on your farm	0.58***	Aesthetics of the landscape in your region	0.46***
	(0.10)		(0.07)
Quantity of fruits and vegetables produced on your farm	0.22***	Variety of fruits and vegetables available on the markets in your region	0.05
	(0.07)		(0.04)
Quality of fruits and vegetables produced on your farm	1.20***	Quality of fruits and vegetables available on the markets in your region	0.64***

	(0.17)		(0.10)
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq:1/3</i> of what the farmer gains daily)	-2.19***	Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq:1/3</i> of what the consumer gains daily)	-1.02***
	(0.50)		(0.18)
Standard deviation		Standard deviation	
Diversity of agricultural production on your farm	0.20	Aesthetics of the landscape in your region	0.86***
	(0.22)		(0.10)
Quantity of fruits and vegetables produced on your farm	0.06	Variety of fruits and vegetables available on the markets in your region	0.01
	(0.05)		(0.05)
Quality of fruits and vegetables produced on your farm	1.70***	Quality of fruits and vegetables available on the markets in your region	1.01***
	(0.20)		(0.13)
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq:1/3</i> of what the farmer gains daily)	2.24*	Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq:1/3</i> of what the consumer gains daily)	3.15***
	(0.87)		(0.56)
N_Cluster	370.00	N_Cluster	413.00
AIC	2543.59	AIC	3854.48
BIC	2607.41	BIC	3919.30

Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.2. Latent Class Model

4.2.1. Model specification

Given the high standard deviation of coefficients in both designs, we analyzed the data using an LCM to identify classes of people sharing the same preferences for the benefits of insect pollinators within both target groups. Many model specifications that considered different numbers of classes were tested for each design. Table 19 reports the fitness of each model for farmers' and consumers' designs. The indicators used to choose the best fit model for the data for both designs are the Akaike information criterion (AIC), the Bayesian information criterion (BIC), and the consistent Akaike information criterion (CAIC). The AIC, BIC, and CAIC are the lowest for the design with four classes for both farmers and consumers; therefore, the design with four classes is the best fit for datasets of both consumers and farmers.

Table 19: LCM specification for farmers and consumers designs

Number of classes	Farmers			Consumers		
	AIC	CAIC	BIC	AIC	CAIC	BIC
2	3446.21	3500.26	3489.26	4099.65	4154.91	4143.91
3	3150.69	3234.22	3217.22	3382.66	3468.06	3451.06
4	2091.88	2204.89	2181.89	3071.15	3186.69	3163.70
5	2454.03	2596.52	2567.52	3060.40	3206.08	3177.08
6	2493.03	2664.00	2629.00	3065.31	3241.13	3206.13

4.2.2. Conditional latent four classes model estimation for farmers

Table 20 shows the results of the estimation of the LCM (4 classes) for farmers using the `lcmlogit2` and `lcmlogitml2` commands on Stata. In class 3, which represents 28% of our sample, farmers are willing to give up the high quantity and quality of yields to have a diversity of production. In this class, farmers listed at least four crops as their primary farm orientation. Like many other LIC and MIC, Morocco has a dry climate and is exposed to climate change. When exploring farmers' characteristics within this class, we found that 55% of them are smallholders. This category of farmers is more vulnerable to the impacts of climate change (IPBES-IPCC, 2021). Therefore, a diversified production represents an insurance prime for farmers in this class; in case of severe climatic conditions affecting a specific crop, the farmer will still have other yields from other crops.

The diversity of production in class 2 has a negative coefficient. Our analysis of the types of farms detained by farmers in this class shows that 53% of farms are medium-sized and 16% are large farms. Monoculture is usually the cultivation system adopted by these larger types of farms. The diversity of production might impact their income in the short run, which explains the negative coefficient.

Farmers within the fourth class appreciate the benefits of insect pollinators the most, mainly the increase in the quality of yields of pollinator-dependent crops. Almost 60% of farmers in this category are from arid and hyper-arid regions. The level of aridity might as well be impacting preferences for the benefits of insect pollination (Chapter 2).

Table 20: Latent four classes model estimation for farmers

Attributes Farmers	Class1	Class2	Class3	Class4
ASC	13.513	-1.678**	8.760***	40.899
Diversity of agricultural production on your farm	0.234 (0,41)	-0.222 (0,32)	1.024*** (0,13)	0.292 (0,16)
Quantity of fruits and vegetables produced on your farm	0.788*** (0,15)	0.817* (0,39)	-0.185 (0,13)	0.515** (0,19)
Quality of fruits and vegetables produced on your farm	1.007* (0,46)	0.600* (0,27)	-0.402*** (0,09)	2.319*** (0,18)
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the farmer gains daily)	-3.285*** (0,13)	-0.537* (0,21)	-1.246*** (0,08)	-0.114 (0,12)
Class Share	0.324	0.051	0.279	0.346

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.2.3. Conditional latent four classes model estimation for consumers

Table 21 displays the results of the estimation of the LCM (4 classes) for consumers also using the `lclogit2` and `lclogitml2` commands on Stata. In the first class, consumers have negative taste parameters for the attributes “Variety of fruits and vegetables on the market” and “Quality of fruits and vegetables on the market.” In this class, the level of instruction of consumers is high ; 46% have a college education, and 17 % attended high school. Therefore, this negative preference is not necessarily related to knowledge about insect pollinators and their benefits.

Consumers within the second class value the benefits of wild pollinators to the quality of fruits and vegetables the most. 60% of consumers in this class are from arid and hyper-arid regions. As with farmers, the level of aridity might have an impact on preferences for the benefits of wild pollinators especially, the increase in quality of pollinator-dependent crops (chapter 3).

In the third class, which represents 11% of our sample, consumers value the attribute “Aesthetics of the landscape” the most. Almost 40% of consumers in this class are from one region, a semi-arid rainfall-dependent region. Thus, the high preference for this benefit can be a particularity of this climate range or the region.

Consumers in the fourth class, which represents 4% of our sample, are not indifferent towards the “no-choice” options.

Table 21: Latent four classes model estimation for consumers

Attributes consumers	Class1	Class2	Class3	Class4
ASC	12.257***	6.160***	5.302***	-2.539**
Aesthetics of the landscape in your region	0.192** (0,09)	0.693*** (0,08)	1.750*** (0,17)	1.124* (0,56)
Variety of fruits and vegetables available on the markets in your region	-0.459*** (0,1)	0.310*** (0,05)	0.132 (0,1)	0.109 (0,52)
Quality of fruits and vegetables available on the markets in your region	-0.137 (0,1)	1.511*** (0,11)	1.088*** (0,19)	0.778 (0,5)
Number of volunteering days per month in an association for the protection of	-3.037*** (0,23)	-0.276* (0,14)	-0.612** (0,28)	-0.490 (0,41)

pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)				
Class Share	0.365	0.487	0.107	0.042

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3. Mixed logit in WTP space

Table 22 represents the estimation of WTP for the different benefits of wild pollinators using a mixed logit in WTP space. In average, the aggregated WTP for the protection of all the benefits of wild pollinators to farmers is 15,26 volunteering days/year *eq.* to ≈ 170 euros/year. To consumers, the aggregated WTP for the protection of the services of wild pollinators is 20 volunteering days/year *eq.* to ≈ 200 euros/year.

Table 22: estimation of the mixed logit in WTP space for farmers and consumers

	ML farmers		ML consumers
Mean		Mean	
ASC	56,59***	ASC	6,83***
	(3,82)		(0,58)
Diversity of agricultural production on your farm	3,47***	Aesthetics of the landscape in your region	0,53***
	(0,66)		(0,09)
Quantity of fruits and vegetables produced on your farm	1,13	Variety of fruits and vegetables available on the markets in your region	0,07*
	(0,58)		(0,03)
Quality of fruits and vegetables produced on your farm	10,66***	Quality of fruits and vegetables available on the markets in your region	1,06***
	(0,78)		(0,12)

Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the farmer gains daily)	-1,88***	Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	-0,23*
	(0,10)		(0,14)
Standard deviation		Standard deviation	
Diversity of agricultural production on your farm	0,34	Aesthetics of the landscape in your region	0,24
	(0,30)		(0,13)
Quantity of fruits and vegetables produced on your farm	-0,10	Variety of fruits and vegetables available on the markets in your region	-0,06*
	(0,30)		(0,03)
Quality of fruits and vegetables produced on your farm	1,30***	Quality	1,33***
	(0,58)		(0,18)
Number of volunteering days per year in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the farmer gains daily)	1,25***	Number of volunteering days per month in an association for the protection of pollinators and their natural habitats (or <i>eq</i> :1/3 of what the consumer gains daily)	0,80***
	(0,17)		(0,14)
N_Cluster	370.00	N_Cluster	413.00

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5. Implications of our results on national strategies and regional initiatives worldwide

To date, conservation strategies are based on limited assessments of the benefits and costs of insect pollination to humans. The lack of accurate measurements of the contribution of this public good to the economic welfare of societies led to the design of inefficient and untargeted

strategies (Hall and Steiner, 2019; EU, 2020; Gemmill-Herren *et al.*, 2021). In this study, we assess Moroccan WTP to protect insect pollinators. This assessment reflects direct and indirect use values of insect pollination to farmers and consumers but also some non-use values (e.g., through the attribute beauty of the landscape for consumers who seem to consider the existence of pollinators as a part of a beautiful landscape). The only study using a DCE to assess the benefits of insect pollination that we have found in the literature is by Breeze *et al.* (2015) for the UK. This study assessed mostly use values of insect pollination for consumers. In Morocco, the only assessment for insect pollination was conducted by Sabbahi (2021). This study assessed the economic value of insect pollination for crop production for human consumption in Morocco, using the dependency ratio approach (Gallai *et al.*, 2009). Both of these studies deliver a different assessment of different values of insect pollination to different target groups despite the similarities of method and context with our study. The difference in findings of these studies might be explained, in addition to different values assessed and targeted groups, by many other societal and contextual factors. This shows how multiple assessments of different values of ES in different contexts with different targeted populations can enhance our knowledge about their contribution to the economic welfare of societies. These assessments will allow the different components of insect pollination to be accounted for in the governmental decision-making processes. Thus, the conception of targeted and efficient conservation strategies of insect pollination requires more assessments of its values.

Some countries, e.g., the Netherlands and Nigeria, have conservation strategies almost entirely based on awareness-raising. Conducting this study in a MIC, we surprisingly found that farmers' and consumers' knowledge about insect pollination is moderate (More than 80% of farmers and consumers know the pollination process, more than 70% can name honey bees as pollinators, and more than half of them can even state the difference between managed and wild pollinators). A survey by Christmann *et al.* (2021a) on farmers' knowledge about pollinators in Morocco, Turkey, and Benin unveiled that this type of knowledge might not be sufficient for pollinators conservation. In HIC, farmers' knowledge of pollinators is likely aligned with their level of instruction (Tarakini *et al.*, 2020). Hanes *et al.* (2013) and Hevia *et al.* (2020) showed that farmers' knowledge in HIC about insect pollinators is moderate to high. Therefore, the inefficiency of strategies focused on awareness-raising in HIC insinuates that knowledge, by itself, does not necessarily translate into pro-pollinator behavior and readiness to protect these

species (Liu *et al.*, 2020), they might need an incentive to change behaviour (Marselle; Christmann *et al.* 2021a).

For consumers, one possible hypothesis as to why knowledge by itself does not necessarily translate into pro-environmental behavior is that at this stage of pollinator decline, the outcome of people's actions does not affect them directly or significantly. However, it can affect other people who live in areas where the consequences of the decline are advanced to the point where they start to genuinely affect social well-being (e.g., regions with high levels of aridity and extreme weather conditions). Knapp *et al.* (2020) attested that socio-psychological factors could go beyond knowledge in affecting people's behavior towards insect pollination. Therefore, strategies should consider other psychological and contextual factors in order to achieve pro-environmental behavior.

Another issue with current national and regional pollinator conservation strategies is that they base their interventions on people ready to engage. However, the analysis of preferences for the benefits of insect pollination shows that some classes of farmers and consumers have a low preference and sometimes even negative preferences (willing to pay in order not to have that benefit) for some of these benefits because of personal and contextual factors. These factors can affect the response to any conservation strategy (Knapp *et al.*, 2020). For instance, “the increase in the diversity of flowers within agroecosystems” (through agri-environmental schemes, for instance) is a major intervention in many action plans of national conservation strategies (e.g., France, UK, Ireland, etc.). This intervention was also promoted by the “EU pollinator initiative,” and even in Nigeria, “planting pollinator forage in selected farms” is a part of the envisioned action plan. However, our analysis of preferences of farmers shows that 5% of farmers have a negative preference for the diversity of agricultural production, and almost 70% of them have a very low preference for this diversity. Admittedly, this study was conducted in a MIC, and the obtained findings cannot necessarily be transferred to HIC given the contextual differences. However, farmers who have a negative preference for the diversity of crops on the farm are medium- to large-scale farmers who practice monoculture. In the EU, for instance, 35% of farms are medium- to large-scale farms, covering 94% of the utilized agricultural area; up to 22% of the production in these farms is produced in monoculture (<https://ec.europa.eu/eurostat/>). Consequently, this type of intervention will not be acceptable among these farmers because of the conflict of interest. Promoting labeling and food

certification, however, can be a good alternative to protect insect pollinators in the agroecosystems. Our results show that the quality of fruits and vegetables seems to be an important trait for the majority of classes of both farmers and consumers in a MIC. On the basis of the success of labels in HIC, the organic label, for instance (De Canio and Martinelli, 2021), we can transfer this result to HIC, in which people seem to appreciate quality as well. Some countries envisioned this type of intervention in their action plans, namely the Netherlands, Switzerland, the USA, and Canada. Currently, many pollinator-based labels exist; the most notorious one is “Bee Better Certified.” A study by the Michigan state university showed that consumers valued products that were labeled “bee-friendly” compared to a product with other eco-practices labels (Wollaeger, 2016).

All classes of consumers seem to appreciate the diversity and beauty of the landscape. This result can also be transferrable to HIC since the share of people practicing nature sports (such as hiking) and eco-tourism in these countries is rather high. For consumers, current national strategies focus primarily on raising awareness and encouraging civic commitment to protect insect pollination. Contrarily to farmers, consumers can be welcoming of incentives that promote the creation of pollinator-friendly habitats. These incentives can be in the form of donations to associations (in the national strategy of Canada, for instance, working with associations is promoted), free distribution of seeds (in the action plan of Norway, for instance, one of the objectives is to facilitate the access to pollinator-friendly seeds), etc.

The implementation of current national strategies is very costly to the economy, most of the involved countries invest billions in these strategies; the EU and the US spend billions on the rewarding schemes for farmers (Batáry *et al.*, 2015; Dicks *et al.*, 2015) which failed their objectives of protection (EU, 2020). Christmann (2019b) provided a cost-effective framework with mostly self-sustaining measures in order to lower the cost of conservation strategies to economies. This framework is intended for LIC and MIC given the limited means of governments; however, HIC can also use these measures.

6. Implications for LIC and MIC

The high WTP stated by consumers and farmers can be used as an argument for public authorities in these countries to launch actions for the protection of wild insect pollination as a public good. To our knowledge, this study is the first to assess use and non-use values of wild

insect pollination in a MIC. Findings from other studies using the dependency ratio approach in other LIC and MIC can also be used to support the conservation of wild pollinators in these countries (e.g. (Brading *et al.*, 2009; Shammout *et al.*, 2014; Alebachew, 2018)).

Our findings also bring forward the heterogeneity in preferences for both consumers and farmers towards the benefits of insect pollination. In table 23, we use these findings to specify implications and set policy recommendations for both target groups.

Table 23: Implications and targeted policy recommendations for farmers and consumers

Target groups	Result	Implication	Targeted policy recommendations
Farmers	28% of farmers have a very high preference for the diversity of crops on the farm	The diversity of production is very important to this class of farmers because it represents an insurance premium to face climatic variations and other risks (Christmann <i>et al.</i> , 2017; Christmann <i>et al.</i> , 2021a)	“Farming with Alternative Pollinators (FAP)*” (Christmann and Aw-Hassan, 2012; Christmann <i>et al.</i> , 2017; Christmann <i>et al.</i> , 2021a; Christmann <i>et al.</i> , 2021b) Eco-tourism** (Kiss, 2004; Christmann, 2019b)
	5% of farmers have a negative coefficient for the diversity of crops on the farm	Most farmers in this class have medium to large-scale farms in which they practice monoculture. They believe that the diversity of production might negatively impact their income	Legislations Obligatory farming practices (e.g., flowering strips of marketable plants in predefined distances) (Christmann, 2019b).
	37% of consumers within this class have negative	Unobserved contextual and psychological factors might be affecting people’s	Education (include information on wild pollinators into curricula

Consumers	preferences for two out of 3 benefits of wild pollinators	preferences' within this category	of primary and secondary schools and promote broadcasts of mass media on pollinators, their importance, and habitat requirements, etc.) (Christmann, 2019b; Christmann <i>et al.</i> , 2021a) ***Scientific research
Farmers and consumers	35% of farmers and 49% of consumers have a very high preference for the attributes representing the contribution of wild pollinators to the quality of fruits and vegetables	These results can be used as indicators for the acceptability and effectiveness of stewardships for pollinator-protecting agriculture and wild pollinator labeled products in LIC and MIC	**** Promotion of labeling and stewardships

*FAP is a cost-effective approach focusing on marketable habitat enhancement plants and method-inherent farmer motivation, it can be used as an alternative to reward schemes (Christmann, 2019b). The latter reward farmers for maintaining permanent grasslands, providing buffer strips for pollinators, and land lying fallow for melliferous plants (EU, 2021). Instead of rewards, FAP provides farmers with an incentive to protect wild pollinators through the higher income they gain through increased productivity of the main crop, lower pest abundance, and the fact that they gain income also from the habitat enhancement zone (Christmann and Aw-Hassan, 2012; Christmann *et al.*, 2017; Christmann *et al.*, 2021a; Christmann *et al.*, 2021b).

**In LIC and MIC, pollinator-based eco-tourism can be a popular tool supporting the conservation of these species (Kiss, 2004; Christmann, 2019b). Higher attractivity to eco-

tourism due to more flowering and diverse landscapes can be an incentive for farmers but also a way of educating and convincing people of the importance of wild pollinators (Azman, 2015).

*** Consumers within this class have negative preferences for two out of 3 benefits of wild pollinators. These negative preferences can be related to their personal perceptions of pollinators and their benefits. The level of instruction within this class is high (46% have a college education, and 17 % attended high school); therefore, these perceptions might be connected to psychological and contextual factors (not necessarily to knowledge), as attested by Knapp *et al.* (2020). Therefore, plus educational and awareness-raising interventions to alter these perceptions, governments can invest in scientific research to understand the psychological blockings of pro-pollinator behavior.

**** In LIC and MIC, promoting stewardship and labels are considered an effective environmental restructuring intervention in behavioral change models (Marselle *et al.*, 2020). These two interventions were also recommended by Christmann (2019b) for the protection of wild pollinators in LIC and MIC. A study by Lambarraa-Lehnhardt *et al.* (2021) exploring consumers' preferences toward labeled local products in LIC and MIC shows that labeling products based on their quality can be successful. A study by Khai and Yabe (2015) examining consumer preferences for agricultural products considering the value of biodiversity conservation in the Mekong Delta, Vietnam, demonstrates that consumers are willing to pay more for environmentally certified rice in order to protect biodiversity, which confirms our assumption about the acceptability and effectiveness of labels and stewardships in LIC and MIC.

7. Conclusion

In this study, we analyze how assessments of public goods can help improve their conservation strategies. The consideration of individual economic perceptions and preferences within societies can help improve the policy design process and hence result in better outcomes in terms of conservation in the future. To our knowledge, our study is the first to combine both consumption and production perceptions to value the public good. Burns *et al.* (2021) pointed out the importance of understanding public perceptions of ES in the process of designing successful conservation strategies. This combination helps to determine specific knowledge gaps and under-engaged groups and sectors in the protection of public goods (Hall and Martins, 2020). This study is a base to help progress research on the efficiency of conservation strategies

of insect pollination in HIC, MIC, and LIC. However, given the major contextual differences, further studies and analysis are needed to confirm our assumption for HIC.

**CHAPTER 6 - FARMING WITH ALTERNATIVE POLLINATORS
BENEFITS POLLINATORS, NATURAL ENEMIES, AND YIELDS, AND
OFFERS TRANSFORMATIVE CHANGE TO AGRICULTURE**

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Abstract

Low- and middle-income countries cannot afford reward-based land sparing for wildflower strips to combat pollinator decline. Two small-grant projects assessed, if an opportunity-cost saving land-sharing approach, Farming with Alternative Pollinators, can provide a method-inherent incentive to motivate farmers to protect pollinators without external rewards. The first large-scale Farming-with-Alternative-Pollinators project used seven main field crops in 233 farmer fields of four agro-ecosystems (adequate rainfall, semi-arid, mountainous and oasis) in Morocco. Here we show results: higher diversity and abundance of wild pollinators and lower pest abundance in enhanced fields than in monocultural control fields; the average net-income increase per surface is 121%. The higher income is a performance-related incentive to enhance habitats. The income increase for farmers is significant and the increase in food production is substantial. Higher productivity per surface can reduce pressure on (semi)-natural landscapes which are increasingly used for agriculture. Land-use change additionally endangers biodiversity and pollinators, whereas this new pollinator-protection approach has potential for transformative change in agriculture.

1. Introduction

“Land sparing” provides direct benefit only for biodiversity, e.g. through forest areas or fallow land. “Land sharing” allows direct benefit for both, farmer and nature, e.g. through marketable flowering plants. The terms are mostly used to describe areas for nature protection on landscape level (Phalan *et al.*, 2011; Tscharntke *et al.*, 2012), whereas we employ them to describe the purpose(s) of the field area necessary to sustain wild pollinators and natural enemies, two important production factors (Garibaldi *et al.*, 2016; Potts *et al.*, 2016; Christmann *et al.*, 2017; Aizen *et al.*, 2019; Albrecht *et al.*, 2020; Christmann, 2020a; Reilly *et al.*, 2020).

State-of-the-Art pollinator protection in agricultural land are corridors spared from production and dedicated entirely to the purpose of biodiversity conservation, mainly by wildflower strips (WFS), to a lower extent by hedgerows and fallow land (Garibaldi *et al.*, 2014; Batary *et al.*, 2015; Feltham *et al.*, 2015; Dicks *et al.*, 2015; Garibaldi *et al.*, 2016; Kleijn *et al.*, 2019). Farmers cannot generate income from these parts of their capital and assume the risk of spreading weeds (Christmann *et al.*, 2017). Farmers have to invest in seeds and need a seed market for wildflowers. The EU and USA both pursue the land-sparing approach and invest billions in agro-ecological schemes (AES) to reward e.g., farmers for seeding WFS (Batáry *et al.*, 2015; Dicks *et al.*, 2015). The net economic impact of WFS is rarely assessed (Kleijn *et al.*, 2019). Despite the financial compensation for opportunity costs, farmers dislike WFS (Kleijn *et al.*, 2019). Pollinator decline remains high in the European Union (Biesmeijer *et al.*, 2006; Hallmann *et al.*, 2017; Powney *et al.*, 2019; EU, 2020) and USA (Burkle *et al.*, 2013). Pollinator protection by the EU is described as inefficient because policies are not sufficiently targeted and harmonized (EU, 2020) and the human factor is widely overseen (Marselle *et al.*, 2020). Low- and middle-income countries cannot afford AES, they need economically self-sustaining approaches for pollinator protection (Christmann *et al.*, 2017).

Farms are business entities; farmers consider benefits for future generations but increase in income is a more convincing argument (Christmann *et al.*, 2017). The Economics of Ecosystems and Biodiversity (TEEB) (Kumar, 2010)-approach suggests assess the economic value of ES and use it as an incentive for protection. Farming with Alternative Pollinators (FAP) (Christmann and Aw-Hassan, 2012; Christmann *et al.*, 2017; Christmann, 2019b) is based on TEEB, assesses the value of pollination and pest control. FAP avoids high opportunity costs by using only marketable habitat enhancement plants (MHPEP) and cross-sector policies to support

pollinator protection in a cost-saving manner (Christmann, 2019b). Particularly in dry regions with irrigation systems, crops can sustain natural enemies more effectively than natural habitats (Tscharrntke *et al.*, 2016). Wild flower visitors might benefit similarly. FAP is a targeted approach in the tradition of diversified farming systems (Kremen and Miles, 2021)²⁶. Different to WFS, FAP includes nesting and water support out of low-cost local materials and waste products (Christmann *et al.*, 2017). Two small pilot projects in Uzbekistan⁵ and Morocco (Christmann *et al.*, 2021a) assessed the actual impacts on net income per surface on the example of cucumber (Christmann *et al.*, 2017; Christmann *et al.*, 2021a) and sour cherry Christmann *et al.*, 2017) and demonstrated agronomic replicability of FAP across countries, but also the need for farmer trainings in LIC and MIC (Christmann *et al.*, 2021a).

For decades, the growing demand for pollinator dependent crops (Potts *et al.*, 2016) is met by intensification and expanding the cultivation areas on cost of (semi-) natural land (Aizen and Harder, 2009; An and Chen, 2011; Deguines *et al.*, 2014; Aizen *et al.*, 2019; Lark *et al.*, 2020). Lack of pollinators due to agricultural intensification reduces the productivity of pollinator-dependent crops in various countries (Deguines *et al.*, 2014; Aizen *et al.*, 2019; Reilly *et al.*, 2020). The increase of global population and a balanced diet within the boundaries of our planet³² can boost the demand for pollinator-dependent crops⁷ and accelerate the trend of expanding agricultural land into former (semi-) natural land (Aizen and Harder, 2009; Aizen *et al.*, 2019). However, many wild pollinator species depend entirely on natural land³³. The shift to a globally scalable agricultural approach contributing to higher yields per surface and biodiversity protection is pressing, because conservation of pollinators is crucial for human wellbeing (Potts *et al.*, 2016). As 87% of all flowering plants require pollinators (Ollerton *et al.*, 2011) all ES highly depend on pollinators, namely those ES provided by the pollinator-dependent flowering plants (Christmann, 2019a). Pollinator loss can cause interlinked environmental degradation and poverty spirals leading to social tension and even conflicts (Christmann, 2019a). Therefore, both are necessary: (1) sustain diversity of crop-pollinators in agricultural land of all countries including LIC and MIC (Christmann, 2020b) for higher productivity and food security and (2) safeguard pollinators depending on natural areas (Kleijn *et al.*, 2015) by refraining from land use changes. We assessed if FAP has potential to serve both goals and transformative change of agriculture.

Therefore, we compared FAP fields (75% of the field area is used for the main crop, 25% for MHEP and low-cost nesting and water support) with monocultural control fields concerning (1) diversity and abundance of flower visitors, natural enemies and pests, and (2) net income

per surface of 100% of field areas. The trials were conducted in four considerably different Moroccan agro-ecosystems. The semi-arid region (Settat) produces mainly barley, wheat and durum and increasingly olives in monocultures. Among the four agro-ecosystems selected, wild pollinators face highest threats in semi-arid regions. The mountainous region (Sefrou in Middle Atlas) still has flowering field margins and semi-natural areas, but increasingly shifts to large orchards particularly for apple, cherry and olives and large onion monocultures. The region with adequate rainfall (Kenitra) is not far from the Atlantic Ocean, smallholder farmers produce cereals, but mostly and increasingly vegetables. Farms often have some fruit trees. The most diverse agro-ecosystem are oasis (Errachidia) with high diversity of crops in small-parceled fields. Here, alfalfa is a mass-flowering crop. In oasis, humans use the limited area with access to water for their purposes to a high extent, in consequence there are nearly no sites with wilderness or weeds as additional forage for pollinators. Protection of wild pollinators was not of concern in any of the agro-ecosystems when the project started, neither for the agricultural research and extension services nor on farmers' level. For the assessment, if FAP has potential to reduce land-use change, the results concerning total produce and the area needed to grow this amount of food were simulated using different assumptions.

2. Results

For both years, our results show similar trends concerning insect diversity and abundance (Figure 14a-f). Even on genus level we observed an overall higher taxa richness of wild flower visitors in FAP fields ($W = 2836$, $p\text{-value} < 0.001$) (Figure 14a), and also higher abundance (Figure 14b) compared to control fields. This includes e.g. *Amegilla* spp., *Andrena* spp., *Anthophora* spp., *Bombus* spp., *Ceratina* spp., *Colletes* spp., *Dasypoda* spp., *Eucera* spp., *Halictus* spp., *Hoplitis* spp., *Hylaeus* spp., *Lasioglossum* spp., *Melecta* spp., *Melitta* spp., *Osmia* spp., *Panurgus* spp., *Thyreus* spp., *Xylocopa* spp., Syrphidae family, Lepidoptera order, and other minor flower visitors. The slightly mosaic planting (four to eight MHEP; supplementary data file) in the 25% zone of FAP fields also provided nectar and pollen for wild flower visitors over a longer period (on average 93 days in FAP fields; 63 days in control fields) according to flowering data in field books. Whereas control fields were attractive for beneficial insects only during the flowering of the main crop, flower visitors and natural enemies used FAP fields as forage sites also before and after the flowering of the main crop, as the insect samplings before and after the flowering time of the main crop showed. This is important for pollinator protection and pest control. The diversity (Figure 14c) and abundance (Figure 14d) of natural enemies was on average higher in FAP fields than in control fields, whereas pest diversity (Figure 14e) and

abundance (Figure 14f) was on average higher in control than in FAP fields. In FAP fields, pest abundance was on average reduced by 64.8% (p-value < 0.001). The average net additional income per surface of fields was 121% (2018: 161%; 2019: 82%, Figure 15a) in FAP compared to control fields. Average rainfall in Morocco was lower in 2019 (124.5 mm; <https://fr.hespress.com/123120-pluviometrie-la-campagne-agricole-2019-2020-pas-si-verte-que-ca.html>) than in 2018 (199.5 mm; <https://fr.hespress.com/123120-pluviometrie-la-campagne-agricole-2019-2020-pas-si-verte-que-ca.html>), which might have affected diversity and abundance of flower visitors, in particular of aquatic syrphids – and in consequence economic results. Environmental and climatic variabilities are typical under dry Mediterranean conditions. However, higher net income of FAP was significant across all locations.

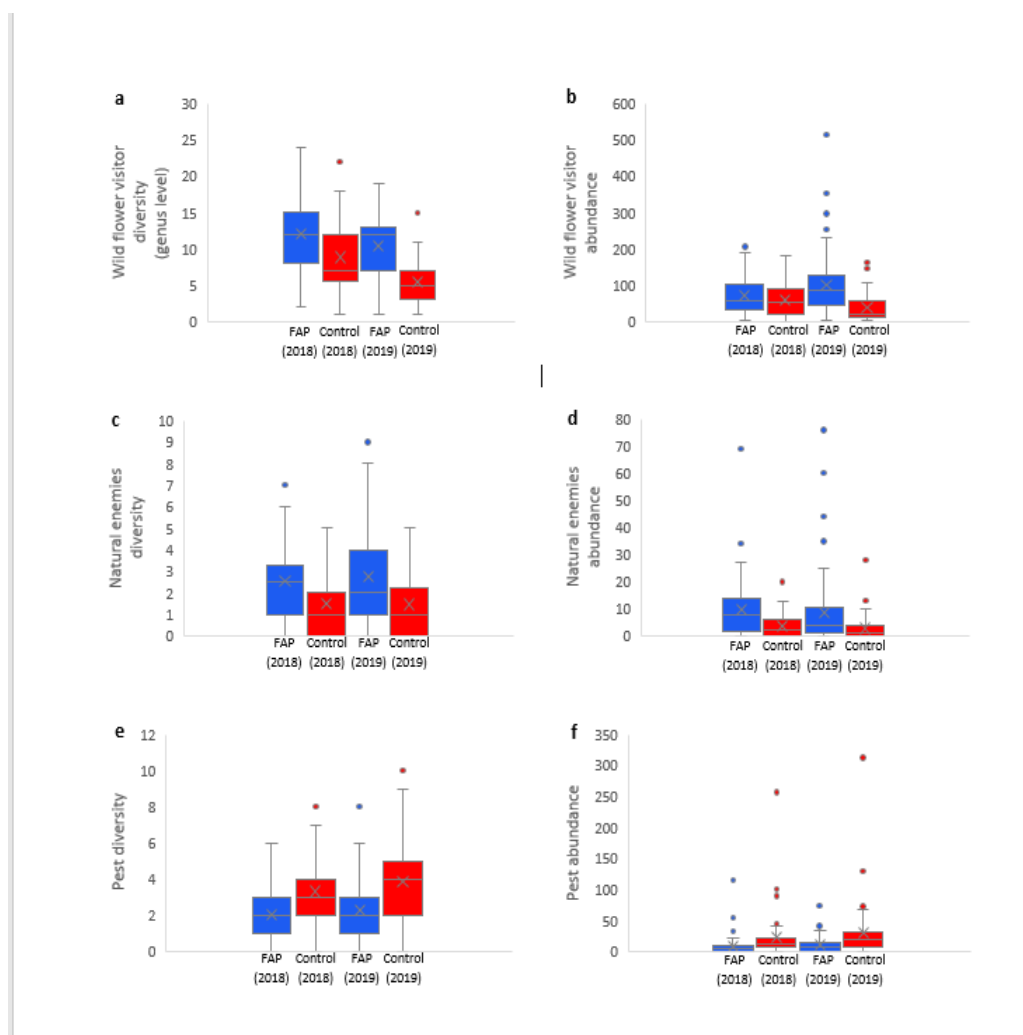


Figure 14: Average impact of Farming-with-Alternative-Pollinators on diversity and abundance of insects in 2018 and 2019

14a: diversity of wild flower visitors (genus level); 14b: abundance of wild flower visitors; 14c: diversity of natural enemies; 14d: abundance of natural enemies; 14e: pest diversity; 14f: pest abundance

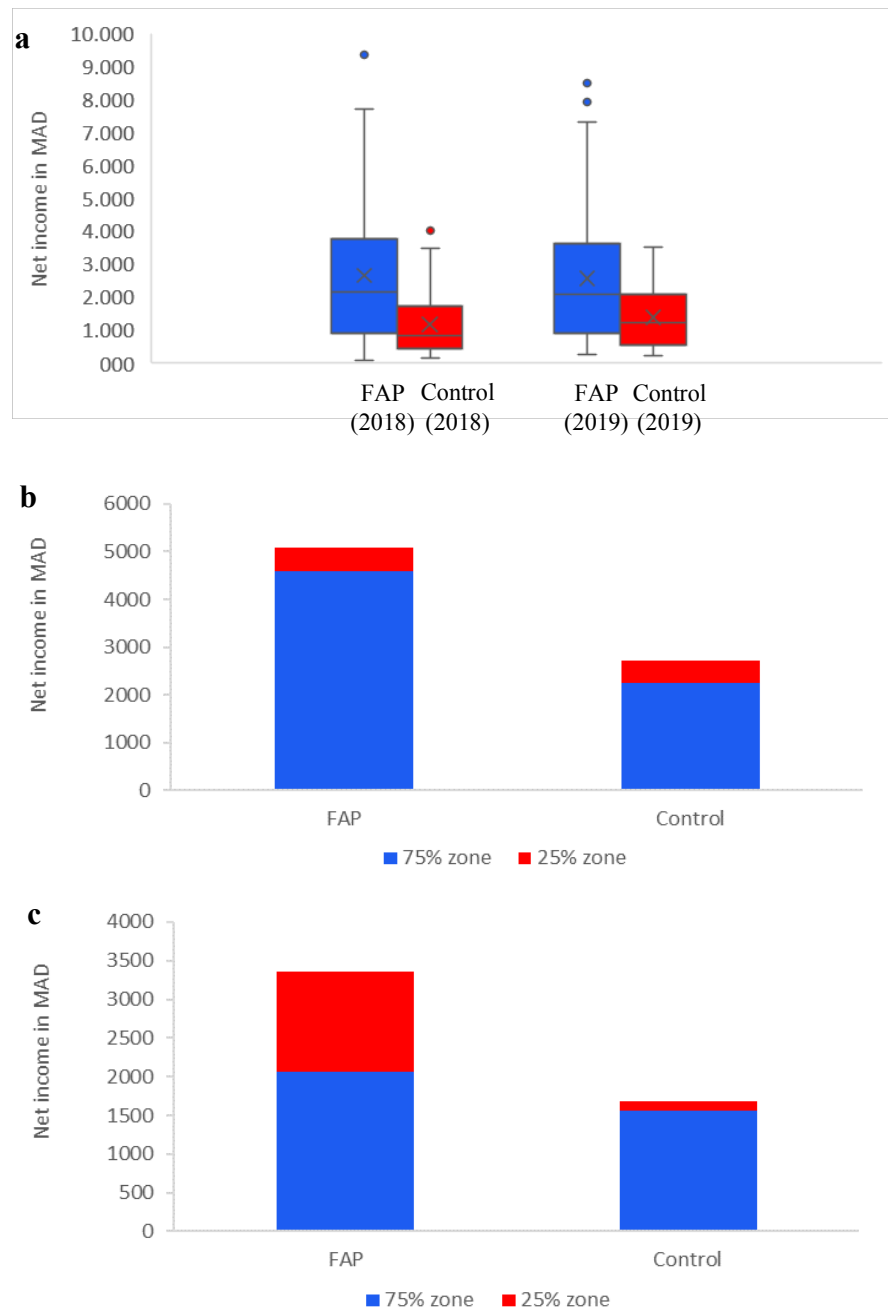


Figure 15: Impact of Farming-with-Alternative-Pollinators on net income per surface in Moroccan Dirham (MAD)

15a: average net income in 2018 and 2019; 15b: in most trials, the net-income increase results mainly from the 75% zone as in this tomato trial (2019, region with adequate rainfall); 15c: marketable habitat enhancement plants buffer against income loss in case of threats to the main crop as in this pumpkin trial (2018, mountainous region)

The total average net income increase FAP versus control for pumpkin was 152%, for melon 61%, zucchini 111%, okra 79%, faba bean 112%, eggplant 214% and tomato 83%. The income increase was significant in all cases ($p \leq 0.05$ for okra, $p \leq 0.01$ for zucchini, tomato, melon and $p \leq 0.001$ for eggplant, faba bean, pumpkin). Results per trial crop in the same agro-ecosystem vary partly substantially in both years concerning insect diversity and abundance. There are seasonal weather variations and natural fluctuations of insect populations, but these differences do not alter the general trend of FAP-induced higher income and the reliability of the FAP-induced incentive. The impact of pollinators on zucchini, pumpkin and melon is “essential”, on faba bean, okra and eggplant “modest” and on tomato “little” (Klein *et al.*, 2007), but the FAP impact on eggplant (four trials) was highest due to higher number of fruits, higher weight and better shape of fruits from FAP fields. It would require more trials to analyze, why FAP performed less with melon than with zucchini and pumpkin or why it performs extraordinary with eggplant.

In the semi-arid region FAP rose income per surface by 185%, in the mountainous region by 130%, in oasis by 88% and in the region with adequate rainfall by 80%, which shows that the FAP impact is higher in less diverse agro-ecosystems, but the incentive is reliable in the four agro-ecosystems. In 29 out of 31 trials the income from the 75% zone of FAP fields was higher than from 100% of the control fields. In 25 out of 31 trials the average income from the 25% zone in FAP was higher than from the 25% in control fields, though, based on farmers' rankings, we used the best performing cultivars for the 25% zones of control fields. For melon, zucchini, eggplant and pumpkin the investment costs for MHEP were on average 42.96% higher than the investment in the 25% zone of control fields, but for faba bean, okra and tomato (these seeds are expensive in Morocco), the investment in seeds for MHEP was on average 39.9% lower than for control fields. Four aspects induce high income increase per surface already in the first year: the absence of relevant direct costs for seeding and the lack of opportunity costs (farmers can use the entire field for production and do not spare a part of their field for biodiversity protection as in the WFS-approach), higher diversity and abundance of wild flower visitors and lower pest abundance.

The higher net income per surface is mostly based on the higher income from the 75% zones as e.g., in the tomato trial in the region with adequate rainfall 2019 (Figure 15b). However, in the pumpkin trial in the mountainous region 2018 for example, the main crop was heavily affected by strong rainfall. In this trial MHEP contributed 38.73% (Figure 15c) of the total additional net income, so MHEP buffered against income loss.

3. Discussion

Current land-sparing protection schemes, in particular reward-based wildflower strips have been criticized as inefficient (Dresselhaus and Franklin-Tong, 2013; Kleijn *et al.*, 2019; Marselle *et al.*, 2020) and not scalable globally (Christmann *et al.*, 2017; Christmann, 2020b), while the urgency of pollinator protection is recognized (Biesmeijer *et al.*, 2006; Potts *et al.*, 2016; Hallmann *et al.*, 2017; Powney *et al.*, 2019; EU, 2020; Zattara and Aizen, 2021). Recent suggestions for pollinator protection focus on land-sparing with landscape approach, e.g. interconnected and well-managed habitats (Cole *et al.*, 2020) or mixed agricultural and silvo-pastoral landscapes (Kremen and Merenlender, 2018). These suggestions address the need to protect pollinators but not the need to increase simultaneously agricultural productivity per surface for the growing demand. We propose to discuss our results in a broader context, in particular concerning four aspects: (1) farmers' preferences concerning plants in their fields (de Snoo *et al.*, 2013; Uyttenbroeck *et al.*, 2016; Christmann *et al.*, 2017; Kleijn *et al.*, 2019) and thus the probability of FAP adoption, (2) agricultural productivity (Deguines *et al.*, 2014; Aizen *et al.*, 2019; Christmann, 2020a; Lark *et al.*, 2020; Reilly *et al.*, 2020) as an important parameter as global population increases, (3) food insecurity (Chaplin-Kramer *et al.*, 2014; Springmann *et al.*, 2018; Chaplin-Kramer *et al.*, 2019) and its socio-economic impacts on regional, national and global stability (Christmann, 2019a), and (4) the potential of the pollinator-protection approach FAP to promote transformative change towards highly productive and biodiversity-oriented agriculture.

The prolonged flowering time in the fields and the diversity of flowers are important for diversity and conservation of wild flower visitors in agricultural land. Besides higher diversity and abundance of floral resources, nesting opportunities, reduced pesticides and landscape have been identified as additional crucial aspects for pollinator protection (Scheper *et al.*, 2014; Goulson *et al.*, 2015). FAP includes – different to WFS – also nesting support out of local or waste materials e.g., for cavity nesting pollinators (Christmann *et al.*, 2017; Christmann *et al.*, 2021a). Pest abundance was on average reduced by 64.8% (Figure 14f), so farmers have reason to reconsider if they need to invest additionally in chemicals or not. The high reduction of pest abundance is an incentive to seed MHEP and reduce chemical threats to pollinators.

The buffering effect against income loss in case a pest, disease or weather incident affect the main crop was reported also from both pilot studies (Christmann *et al.*, 2017; Christmann *et al.*, 2021a) and can become more important and valuable for farmers in the course of climate change related uncertainties. The fact that the income from the 75% zone in FAP fields was higher than

the income of 100% of control fields in 29 out of 31 trials can be a convincing argument for farmers. In the FAP-sour-cherry trial in Uzbekistan the participating large-scale farmers focused on the higher productivity of the main crop and regarded the yield of MHEP as a (negligible) by-product (Christmann *et al.*, 2017). The FAP-induced net income gain is much higher than in State-of-the-Art studies (Blaauw and Isaacs, 2013; Garibaldi *et al.*, 2014; Feltham *et al.*, 2015; Tschumi *et al.*, 2016; Kleijn *et al.*, 2019; Albrecht *et al.*, 2020) and achieved already in the first year, whereas, using WFS, it can take several years to gain net profit (Blaauw and Isaacs, 2013). Not only in LIC and MIC, where AES are hardly affordable, but also in high-income countries (HIC) these two aspects, higher income already in the first year and reduced pest abundance, can motivate farmers to use FAP instead of WFS and to change their behavior. Recent research²⁰ highlights the need for incentives and "behavioral drivers" (Marselle *et al.*, 2020) for transformative change. The absence of opportunity costs (through land sharing instead of land sparing) and the non-necessity of a seed market for wild flowering plants can additionally support change of behavior and adoption. Farmers are the decision makers on their land, pollinator protection might become more successful if farmers' preferences for habitat enhancement plants would gain more attention (de Snoo *et al.*, 2013; Uyttenbroeck *et al.*, 2016; Christmann *et al.*, 2017; Kleijn *et al.*, 2019). MHEP play a most crucial role in FAP planting schemes and their environmental and economic impacts. Therefore, the impacts of different MHEP and farmers' criteria to prioritize specific MHEP have been assessed in detail, the publication is under preparation.

Do our results have value for the broader, but often separated research areas and political discussions on food security/agronomy/agricultural research (Springmann *et al.*, 2018) and pollinator protection/biology (Biesmeijer *et al.*, 2006; Powney *et al.*, 2019; Zattara and Aizen, 2021)? We want to stimulate more integrated research including both, food security/agronomy/agricultural research and pollinator ecology/pollinator protection (Blaauw and Isaacs, 2013; Tschumi *et al.*, 2016; Chaplin-Kramer *et al.*, 2019; Christmann, 2019a; Christmann, 2020a; Hall and Martins, 2020a). More holistic research could promote transformative change. Therefore, we simulated potential impacts of FAP-habitat-enhancement measures concerning (1) food production/security and (2) reduced need for land-use change from semi-natural areas to cultivated areas.

Worldwide, smallholder farms with less than two ha contribute 28-31% of total crop production for human consumption (Ricciardi *et al.*, 2018), farms up to 50 ha provide 51-77% of all commodities and nutrients (Herrero *et al.*, 2017). The simulations of potential FAP impacts use

three different adoption rates (μ : 10%, 30% and 50%) and two different assumptions for technology effectiveness (50% and 70%). The simulations show both, (1) substantially higher food production per surface and thus higher food security (Figure 16a) and (2) highly reduced need for agricultural land (Figure 16b)

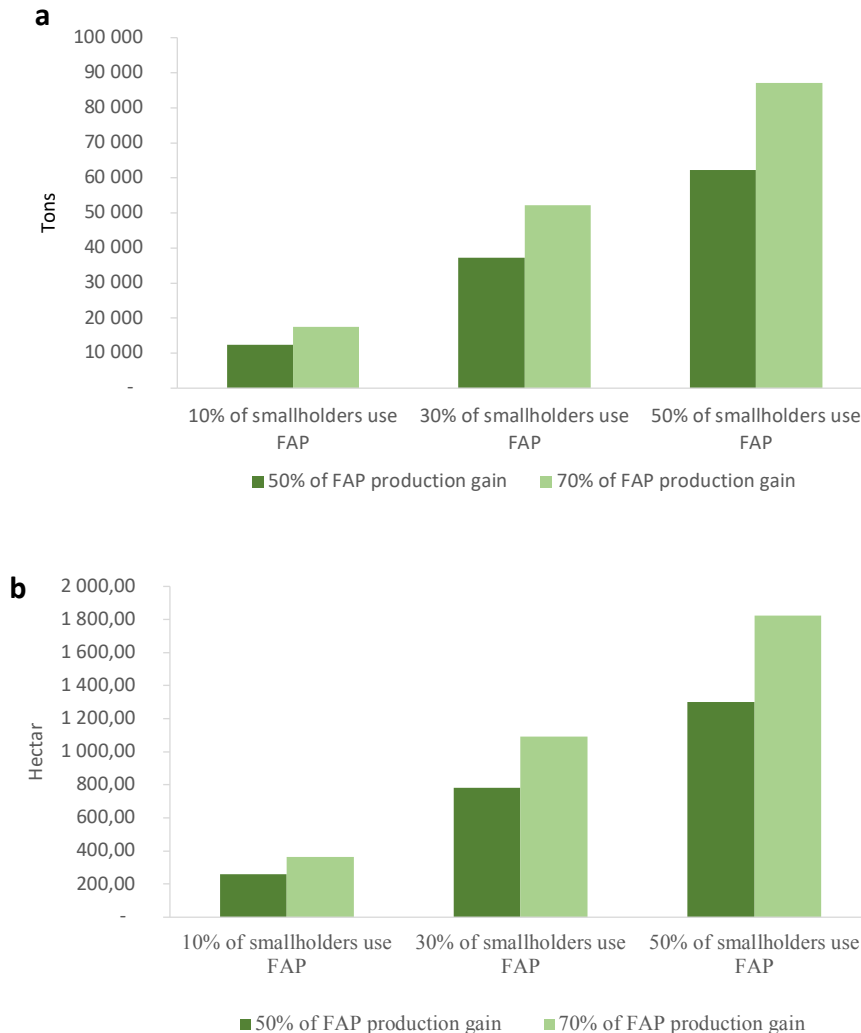


Figure 16: Simulation of potential impacts of Farming-Alternative Pollinators on food security and saving land for nature through smallholders based on 6 vegetables and Moroccan production data 2016-2017

16a: simulated potential increase of production; 16b: simulated potential for land saving

Even these conservative simulations of impacts of broader FAP use by Moroccan smallholders encourage introduction of FAP in more countries. Reduced land-use change to expand agricultural land would contribute to the protection of pollinators entirely depending on natural areas. The results confirm that FAP has potential to contribute to SDGs 1, 2, 3, 13 and 15 (Christmann, 2020a), that an integrated approach has advantages to meet the challenges in both areas, food insecurity and pollinator decline. The simulations unveil much higher potential for

synergies between pollinator protection and food production than suggested as an outcome of WFS (Blaauw and Isaacs, 2013; Garibaldi *et al.*, 2016; Albrecht *et al.*, 2020).

FAP was developed to serve pollinator protection, food security and climate change resilience (Christmann and Aw-Hassan, 2012). Particularly, the target higher national food security can be more attractive for strong national protagonists such as Ministry for Agriculture and agricultural extension services than a pure environmental target like pollinator protection. Thus, FAP has higher potential to promote transformative change in agricultural land (Aichi target 7) than approaches focusing on biological targets only. In Morocco, the FAP-team collaborates intensively with the national agricultural extension service (l'Office National du Conseil Agricole, ONCA) and started FAP-trials also with large-scale producers. Morocco joined the Coalition of the willing on pollinators (<https://promotepollinators.org/>) 10 May 2019 as first Arab country and works on a cross-sector protection action plan for pollinator protection.

There might be one more advantage of FAP: The rewards paid for land sparing and the seeding service (WFS-approach) do not benefit nature if farmers overuse chemicals after plant establishment. Whereas land sharing opens a dialogue with farmers based on environmentalists' respect for farmers' priorities (Christmann *et al.*, 2017; Christmann *et al.*, 2021a). The TEEB(Kumar, 2010)-based FAP-approach primarily targets the human factor and a change of behavior (Christmann *et al.*, 2017; Hall and Martins, 2020a; Marselle *et al.*, 2020), a focus described as most important^{5,20,21}. The incentive is not service related but coupled with productivity and performance: FAP rewards farmers for months of environmentally friendly performance (Christmann *et al.*, 2017; Christmann *et al.*, 2021a). This is important for pollinator conservation and transformative change. Eager to gain higher income per surface, farmers can gain motivation to observe and guard insects in their fields attentively. This might require information campaigns for farmers as additional enabling factor, as farmers knowledge on pollinators and pollination is limited, notably in many LIC and MIC (Christmann *et al.*, 2021a). A survey focused on knowledge necessary for FAP, which was conducted in three culturally different LIC and MIC (Benin, Turkey and Morocco) clearly showed the need for capacity building among farmers to recognize wild pollinators, nests, pollination problems etc. (Christmann *et al.*, 2021a) In all countries including HIC, it is necessary to build capacity to vision multiple benefits of pollinator protection e.g., their contributions to various Sustainable Development Goals (Christmann, 2020a) and to all ES (Christmann, 2019a) and to realize interlinked impacts of pollinator decline and pollinator loss on ecosystems, human wellbeing, economy and conflicts (Christmann, 2019a).

By now, pollinator decline is tackled as an environmental problem through WFS, hedgerows and fallow land, however the notion “environmental problem” reflects a “fundamental misconception” as most disturbances of ecosystems stem from maladaptive human behavior (Amel et al., 2017). In the Anthropocene, people have the strongest impact on our planet, therefore the Anthropocene requires pollinator protection through skilled and intrinsically motivated humans: pollinator protection not as paid environmental add-on, but as an outcome of skilled ecological society (Christmann, 2020b). The clue to this change of paradigm and to transformative change in agriculture might be the shift from land-sparing to respectful land-sharing.

4. Materials and Methods

4.1. The participants of the on-farm trials

The farmers taking part in the trials own between 0.3 and 40 ha. Most of them were smallholders (less than 2 ha) and used to plant vegetable fields of around 300 m² per crop. Two out of 233 participating farmers are female, farmers’ age ranges from 24 to 68 years. All farmers learned agriculture from their parents, 70% are literate. Farmers and fields were visited 10-12 times per trial. In 2018, we started with 112 farmers, but some farmers did not follow strictly the obligatory agricultural practices (e.g., concerning fertilizer, irrigation, harvest), some lost the entire or parts of fields (e.g., by flood, grazing livestock), therefore all assessments concerning 2018 include the fields of 99 farmers. In 2019, we started with 136 farmers, two farmers did not follow the agreed farming practices, so assessments for 2019 are based on fields of 134 farmers.

4.2. The design of participatory field trials

We conducted 14 trials in 2018 and 17 in 2019, each trial encompasses five FAP fields and three control fields in neighbouring villages. Minimum distance between FAP fields and between FAP and control fields was two thousand meters for nearly all fields, at least more than one thousand meters. In the mountainous region we used pumpkin, zucchini and faba bean as main crops (two years), in oasis okra and zucchini (two years), faba bean and pumpkin (2019), in the semi-arid region melon, zucchini, pumpkin, eggplant and faba bean (two years) and in the region with adequate rainfall tomato, faba bean, zucchini and eggplant (two years)

and pumpkin (2019). The main crops were selected by farmers and agricultural advisors of the respective regions, MHEP by farmers of the respective trials and researchers.

Field size was 300 m² as recommended for smallholders⁵ with a 75% zone for the main crop in both, FAP and control. Except for okra, the 75% zone had four cultivars with four replications in a randomized system as recommended as enhanced practice by farmers in the pilot project in Morocco²⁷. For okra only two cultivars are available in Morocco and trials used only seeds accessible also for farmers. FAP fields employed the 25% zones for habitat enhancement, whereas control fields had the main crop also in this zone. We used coriander, basil, cumin, dill, anise, celery, sunflower, canola, flax, zucchini, okra, melon, tomato, green pepper, cucumber, Armenian cucumber, eggplant, chia, arugula, watermelon, pumpkin, grass pea, cultivated lupinus, alfalfa, clover, vetch, faba bean and wild lupinus as MHEP, per trial between four and eight different MHEP. As faba bean starts flowering in end of February in Morocco, MHEP were partly forage crops as they flower early. MHEP were seeded in a way that around 2/3 flowered at the same time as the main crop and 1/3 before or after to prolong the foraging season on site for flower visitors. The habitat enhancement zones included also nesting and water support out of local materials, e.g., hollow stems, wood and dry mud with holes.

4.3. Field management

In oasis, all fields were irrigated by gravity flow, in the other sites all farmers used drip irrigation. The amount of dung used is based on farmers' decision and varies per region: semi-arid region 500 kg/300m², mountainous region 1000 kg/300m², oasis 1500 kg/300m² and region with adequate rainfall 3000 kg/300m². Soil analysis was conducted for all fields but does not explain the income gaps between FAP and control. Pesticides (mainly neonicotinoids and broad-spectrum insecticides) were prohibited during trials. In some urgent cases with permission of the plant protection specialist, one foliar insecticide application for pest management was accepted when pest density reached the economic threshold.

4.4. Insect sampling and methods to analyse the data

The taxa richness of flower visitors was assessed by a combination of transect net samplings and pan trappings. In each field, insects were sampled four times, once before the flowering of the main crop, twice during its flowering and once afterwards. Each sampling took two days for each trial (four fields per day). Two sets of three pan traps (blue, yellow and white) were located in each field at the beginning of the first day of sampling and were collected the second

day after 24 hours. The samplings in 75% zones consisted of walking along two twenty-eight meters transect lines for five min each. In the 25% zones flower visitors were collected once along an 80 meters transect line around the 75% zone for ten minutes. The flower visitors were collected and kept separately per MHEP, but the respective time needed was recorded and added to the transect. The insects were collected using both sweep nets and insect vacuums. All flower visitors were collected except *Apis mellifera*, *Bombus terrestris* and *Xylocopa pubescens* that were identified visually on site. The collected insects were first fainted with ethyl acetate and afterwards placed inside killing jars filled with cyanide, afterwards pinned and labelled. Wild bees were identified to the genus level using the most recent key for wild bees in Europe⁵². The other flower visitors were identified to genus level or to family level. Significance concerning diversity was measured by Wilcoxon test (Dwivedi *et al.*, 2017).

In the 75% zones, pest insects, predators and parasitoid wasps were collected four times. Per farmer field, four one-square-meter quadrates were randomly selected, within the quadrates ten randomly selected plants) were beaten five times, so in total we used 320 crop samples per trial. In the 25% zones, the beating method was similarly used for each MHEP (five sample plants per MHEP). Specimen were collected in plastic bags and kept in plastic tubes containing 70% ethanol for conservation. Abundance of pests was estimated by counting the number (*i*) recorded on each sample crop. Pest reduction was calculated by the rate of pest reduction (%) using the following formula: $\% = (1 - A_{FAP(i)} / A_{Control(i)}) \times 100$, where $A_{FAP(i)}$ is the average of the abundance in the FAP plot; $A_{Control(i)}$ is the average of the abundance in the control plot (Capinera, 2008).

4.5. Economic assessments

The economic assessments use the same calculation as the pilot projects (Christmann *et al.*, 2017; Christmann *et al.*, 2021a): the number of fruits was counted and weighed. Investment costs in FAP and control fields are the same in the 75% zones. The income from the 75% zones was assessed by multiplying total weight with market price per kg. The income from the 25% zones of control fields was assessed by total produce weight multiplied by market price per kg; investment costs were deducted. The income of the 25% zone of FAP fields was computed by multiplying total weight with market price per kg of MHEP minus respective investment costs and minus 100 MAD (1.5 person days per FAP field) as calculated labor costs for harvesting MHEP, though in our trials, farmers harvested themselves.

4.6. Simulations

The simulation of potential FAP impacts on food security and sparing natural land for pollinator and biodiversity protection is based on following assumptions. Basis is the total production (2016-2017 differentiated per crop; provided by the Moroccan Ministry of Agriculture on request) for faba bean (share of harvested crop with green pods as in the experiments, 105760 ton in 10205 ha), zucchini and pumpkin (179519 ton in 7539 ha), melon (618588 ton in 20163 ha), eggplant (52966 ton in 1885 ha) and tomato (1293761 ton in 15888 ha). We did not include okra due to lack of national production data. For the simulation on potential increase of production through smallholders (≤ 2 ha), we use 13% as share of smallholders in North Africa for vegetable production⁴⁹. For the simulation of the land-saving potential through smallholders, we used 11% (North Africa, share of smallholders' land for food crops) (Lowder *et al.*, 2016).

The formula used for the simulation on the potential FAP impacts on food security (PIFS) is:

$$\text{PIFS} = (\text{SSP} * (1 - \mu)) + (\text{SSP} * \mu) * (1 + (\text{GFT} * \text{TE})) - \text{SSP}$$

PIFS: Potential increase in crop production because of FAP (t)

SSP: Smallholders' share of production in (t)

GFT: FAP production gain in farm trials (%)

μ : the share of smallholder-producers adopting FAP

TE: Technology effectiveness

The GFT employed is 85,2% which represents the average FAP production gain of the vegetables used in the simulation process. For μ we used either 10%, 30% or 50% and for TE we assumed that smallholder-producers gain either 50% or 70% of the total production gain achieved in on-farm trials with smallholder-farmers since farmers will adapt MHEP and their planting to their personal preferences.

The formula used for the simulation of potential land saving (PLS):

$$\text{PLS} = ((\text{SAP} * \text{PIFS}) / \text{SSP}) - \text{SAP}$$

PLS: Potential land saving in ha

SAP: Smallholders' area of production in ha

GENERAL CONCLUSION

The first aim of this Ph.D. thesis was to assess the contribution of insect pollination to the economic welfare of populations in dry LIC and MIC on the example of Morocco. In the past, many methods have been used to evaluate the different values humans derive from insect pollination. In this study, we use a DCE for its capacity to account for all types of values derived from ES (use, non-use, and option). This method is based on the analysis of economic preferences stated by individuals. For insect pollination, these preferences can be classified into preferences associated with agricultural production behaviors and consumption behaviors. Thus, we designed different choice experiments for farmers and consumers. We collected data from our benchmark site, Morocco, with a sample of almost 1000 participants divided between farmers and consumers. This sample was chosen to represent the different categories of farmers and consumers in LIC and MIC. Results substantiate the importance that farmers and consumers in aridity-prone areas place on values they derive from insect pollination. The WTP of both groups to protect these values should support the protection of insect pollinators in dry LIC and MIC, in which governments often seem to oversee the contribution of these species to human welfare.

The analysis of preferences of both farmers and consumers revealed significant heterogeneity in mean for the different attributes chosen to represent the benefits of insect pollination. In HIC, which seem to make more efforts to protect pollinators, many conservation strategies were criticized for not being sufficiently targeted and successful concerning conservation. These strategies fail to account for the different perspectives and preferences of individuals for the benefits of insect pollination. Most current conservation strategies for pollinators were designed based on global trends which do not consider this heterogeneity in preferences nor perspectives. Therefore, to help design targeted strategies for LIC and MIC, we thoroughly analyze the heterogeneity in preferences from both farmers' and consumers' perspectives.

Many studies in dry climates highlight the impact of aridity on economic preferences for ES. In drylands, the increase in aridity levels can be an indicator of CC. In our analysis, aridity is a significant explanatory variable of the heterogeneity of preferences of both farmers and consumers. Thus, the second aim of this Ph.D. thesis was to explore the effect of aridity on

farmers' preferences for the benefits of insect pollination and the value they attribute to it. To achieve this objective, we divided the farmers' database into five sub-datasets based on the bioclimatic regions they live in and then analyzed them separately. These five bioclimatic regions were selected to represent the different levels of aridity (hyper-arid, irrigation-based semi-arid, rainfall-based semi-arid, and dry sub-humid) in dry LIC and MIC. In each bioclimatic region, we had a sample of almost a hundred farmers. One of the main findings of this analysis is that farmers' WTP for the protection of the values they derive from insect pollination is strongly related to the level of aridity of the region in which they live. The link between farmers' WTP and the level of aridity can be perceived as a precautionary attitude or an insurance premium towards future risks of pollinator decline. Thus, farmers pay to have an option value of pollinators in the future as the level of aridity becomes higher. Farmers in drier climates are more likely to engage in any conservation strategy voluntarily. Besides, preferences for the different benefits of insect pollination differ between the five bioclimatic regions. Thus, designing locally targeted interventions that fit the context of each bioclimatic region can influence the level of success of these interventions.

The third aim of this Ph.D. thesis was to explore the effect of aridity and CC on preferences for the benefits of insect pollination and their value in LIC and MIC from consumers' perspectives. Also, for this purpose, we analyze consumers' sub-datasets in the same five bioclimatic regions. As for farmers, results show that consumers' WTP increases as the level of aridity becomes higher. This connection between the WTP to protect insect pollination and the level of aridity insinuates that aridity increases farmers' and consumers' sensitivity to pollinator decline in dry LIC and MIC. In this case, insect pollination can be perceived as an option that helps mitigate the implications of the increase in aridity levels due to CC on both groups. Consumers' preferences for the benefits of insect pollination also change according to the bioclimatic region they live in, which confirms our assumption about the need to shape locally targeted interventions for better protection of insect pollinators. Thus, the design of pollinator conservation strategies should be based on local assessments to uncover any source of heterogeneity, which can occur even within the same country.

Following the second and third aims of this Ph.D. thesis, we show that aridity can be a factor explaining the heterogeneity in preferences of both farmers and consumers. However, the level of aridity can only explain a part of this heterogeneity; other unobserved factors can be

involved. Thus, the fourth aim of this Ph.D. thesis was to investigate the impact of the heterogeneity in preferences of farmers and consumers for insect pollination on the design of pollinator conservation strategies in dry LIC and MIC. To achieve this objective, we analyze both datasets using an LCM. This model defines the different classes of farmers and consumers who are likely to share the same economic preferences for the benefits derived from insect pollination. Results revealed four classes of preferences within farmers and four classes within consumers. Some classes of farmers and consumers are more likely to accept pollinator conservation strategies than others. The types of interventions needed for each class changes according to its set of preferences. This analysis will, therefore, further help in the design of targeted strategies.

Because of the limited means of governments in LIC and MIC, interventions should be cost-effective and self-sustaining. Setting targeted interventions can indeed be cost-effective (many HIC spent billions of dollars because of untargeted interventions), yet, this might not be sufficient for LIC and MIC, given their particular context. Therefore, the fifth aim of this study was to discuss and test a new cost-effective strategy, Farming with Alternative Pollinators, which can be used to incentivize and motivate farmers to protect pollinators without external rewards. The economic assessment of this strategy shows that it increases the average net income for farmers per surface by 121%. Higher productivity per surface can enhance food security and reduce pressure on natural landscapes, increasingly used for agriculture. The potential impacts was simulated concerning food security and reduced need for land-use change.

One of the primary limits of this Ph.D. thesis is associated with the use of a stated preference approach in a MIC. Many studies highlighted the challenges related to the use of the DCE in developing and subsistence economies. These challenges are mainly associated with the choice of suitable payment attributes. In this Ph.D. thesis, we use WTV instead of WTP or WTW, which was well accepted among farmers and consumers, and hence, can be used to value other ES in these countries. Another limit of this thesis is linked to the fact that the central topic was the assessment of an indirect regulating service. This type of assessment puts a significant comprehension burden on respondents, especially in LIC and MIC, where education is lower. The understanding of the benefits derived from insect pollination was, however, mandatory to get correct estimates. Thus, we elaborated a protocol to control this comprehension burden bias.

In conclusion, the impact of the level of aridity on preferences for the values they derive from insect pollination could be a particularity of dry LIC and MIC or even aridity-prone climates. In any case, it raises questions about the use of global guidelines for policy design. We demonstrate how different perspectives and different contextual factors can impact preferences for insect pollination. Preferences and stated WTP to protect pollinators can vary considerably within the same country because of contextual factors. In this study, we highlight aridity, yet, we also show that other unobserved factors can impact preferences and perceptions for ES. The use of average values and global trends for policy making for the protection of ES is thus not convenient. Therefore, more assessments of the different values individuals derive from ES in other contexts are needed for better protection.

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APPENDICES

Appendix 1 : Review of the main current strategies for the conservation of wild pollinators worldwide

Country	Strategies	Axes
France	Plan national d'actions :« France Terre de pollinisateurs » pour la préservation des abeilles et des insectes pollinisateurs sauvages (2016-2020)	<ul style="list-style-type: none"> - Scientific research for better protection of pollinators (taxonomy, identifying drivers of the decline, valuation of the benefits derived from pollinators, etc.); - Raising awareness (training professionals on the identification of wild pollinators, develop technical sheets, etc.); - Promote pro-environmental behavior (lower the use of pesticides, better forest management, etc.).
Germany	Action program for insect protection (2019)	<ul style="list-style-type: none"> - Legislation changes to protect insect pollinators (use of agrochemicals, fertilizers, etc.); - Invest in scientific research (use results to promote the protection of pollinators); - Protection and restoration of insect habitats (landscape and urban spaces); - Provide clear guidance on the use of pesticides and other harmful substances; - Promotion and support of civic commitment for the benefit of pollinators.
Netherlands	NL Pollinator Strategy: “Bed & Breakfast for Bees” (2018)	<ul style="list-style-type: none"> - Promoting biodiversity (increasing the number of nesting sites, providing perspective of actions for citizens, raising awareness, monitoring the measures, etc.);

		<p>Improving nature agriculture interaction (promoting nature based agriculture, exploring pollinator labels, green education, etc.).</p>
Norway	National pollinator strategy: A strategy for viable populations of wild bees and other pollinating insects (2018)	<p>Increasing scientific knowledge (monitoring of trends in pollinator species, their habitats and threats, scientific research about plant-pollinator interactions and cost effective management, etc.);</p> <p>Ensuring good habitats (encourage private sector to consider pollinator, facilitate access to seeds for pollinator-friendly plants, cross sectoral management to ensure provision of good habitats, etc.);</p> <p>Communicating information to all target groups (encourage stakeholders to communicate knowledge within their own sectors, reach various target groups with online information, etc.).</p>
Switzerland	Switzerland National Action Plan for Bee Health 2014	<p>Instant measures: safety certification for pesticides, scientific research on the impact of agrochemicals on bee health and ways to test this impact;</p> <p>Measures which require scientific research: biodiversity conservation in urban and natural areas, find the best seed combination for flower strips, develop an indicator for agro-environmental monitoring, develop a pollination label.</p>
UK(Scotland)	Pollinator Strategy for Scotland 2017-2027	<p>Pollinator friendly measure to reverse the decline (promote diversity on farms, encourage habitat friendly management, map the existent habitat friendly and identify gaps);</p> <p>Improve our understanding of pollinators and their pollination service (support research on plant protection products and the impact of CC on plant-</p>

		<p>pollinator interactions, Investigate crop compositions to benefit pollinators);</p> <p>Manage the commercial use of pollinators to benefit native pollinators (Support and sustain a healthy honey bee, minimize the risk of honey bees on native bees;</p> <p>Raise awareness and encourage action across sectors (Develop regionally-based species advice, Develop guidance, make information accessible for the public through web platforms, etc.);</p> <p>Monitor and evaluate whether pollinators are thriving (publish regular updates on the status of pollinators, monitor achievements of this strategy, etc.).</p>
UK(England and Wales)	<p>UK Insect Pollinators Initiative 2010-2015</p> <p>The National Pollinator Strategy: For Bees and Other Pollinators in England 2014-2024</p> <p>The Action Plan for Pollinators in Wales 2013</p>	<p>Initiating programs in factor of pollinator protection (focus on scientific research to define status, trends, mitigation and management methods, develop monitoring indicators, build evidence to support pollinator protection, etc.);</p> <p>Promote and enhance flower rich habitats in rural areas and cities;</p> <p>Raise awareness among citizens (engage citizens in the management).</p>
Ireland	<p>All-Ireland Pollinator Plan (2015-2020)</p> <p>All-Ireland Pollinator Plan (2021-2025)</p>	<p>Making farmland pollinator friendly (increase awareness of pollinators and their foraging and nesting resources);</p>

		<p>Making public land pollinator friendly (include councils, Transport Authorities, Local Communities and others in pollinator protection;</p> <p>Making private land pollinator friendly (gardens, to businesses, faith communities and sports clubs,);</p> <p>All-Ireland Honeybee Strategy (balance managed and wild pollinator populations;</p> <p>Conserving rare pollinators (improve knowledge on rare pollinators, and by raising awareness through dedicated initiatives;</p> <p>Strategic coordination of the Plan raising awareness, addressing gaps in knowledge through research; tracking where pollinators occur and how populations are changing.</p>
USA	National strategy to promote the health of honey bees and other pollinators 2015	-
Canada	<p>Canadian Pollination Initiative 2010-2014</p> <p>Toronto Pollinator Protection Strategy 2018</p>	<p>Create and enhance habitat (plant pollinator friendly plants in parks, cities, etc., demonstration garden in cities, pollinator patches in cities, review landscaping practices, etc.);</p> <p>Design and connect green spaces (improve connections between existing habitat, encourage the creation of "pollinator pathways" to foster corridor creation across the city, green roofs, etc.);</p> <p>Partner and build relationships (engage with association, boards, etc. to encourage the creation of pollinator habitat through native plantings, provide native pesticide-free plant material and seed for pollinator habitat, etc.).</p>

		<p>Invest and incentivize (e.g. provide modest financial support to encourage community-led pollinator habitat creation or enhancement, and pollinator education initiatives);</p> <p>Educate and train (pollinator stewardship, develop pollinator-friendly gardening practices tips and share lists of pollinator-friendly native plants, etc.).</p>
Colombia	Colombian Pollinator Initiative 2018	<p>Address the research of pollinators and pollination services and the economic valuation of the pollination services;</p> <p>Conservation and restoration of pollinator habitat through the diversification of agroecosystems and urban spaces;</p> <p>Raising of awareness on the importance of pollinators, and the incorporation of sustainable pollinator management into policy.</p>
Sri Lanka	Butterfly Conservation Action Plan of Sri Lanka 2014	<p>Scientific research (assess the state of current knowledge on butterfly fauna in Sri Lanka and review the conservation status of and threats to Sri Lankan butterfly species);</p> <p>Conservation recommendations (promotion of butterfly breeding, reduction of habitat destruction, creation of a national database of species-specific knowledge, conducting taxonomical, ecological, and conservation research);</p> <p>Raising awareness (trainings, workshops, communication materials, etc.).</p>
Nigeria	National actions on land degradation neutrality, pollinators and food security in Nigeria from the BES-Net Phase I, Regional Trialogue	<p>Scientific research (develop national data-base, categorization of potential threats, development of education and outreach materials, develop models for nature based infrastructure and agroforestry, etc.)</p>

	meetings (adopted in July 2019)	<p>Cross sectoral cooperation (exchange knowledge with other countries, join promote pollinators coalition, organize outreach programs,</p> <p>Raising awareness (on agrochemicals, biological method in growing crops, pollinator demonstration plots, etc.)</p>
Ethiopia	Ethiopia's National Biodiversity Strategy and Action Plan 2015-2020	<p>Scientific research (characterization, identification and collection of Ethiopian pollinators (insects).</p> <p>Re-examination of agricultural and land use policies (Encourage for alternative forage and breeding sites for pollinators, conservation and restoration of ecosystems; and capacity building, etc.)</p> <p>Public awareness and education.</p>

Appendix 2: Farmers' questionnaire

Questionnaire: Economic evaluation of pollination service (Farmers)

Explanatory paragraph:

Hello, my name is Soukaina ANOUGMAR. I am a PhD student in the 2nd year at the Economics and Management Doctoral School (EDEG) in Montpellier. Can you give me some of your time (around 30 min) to answer a questionnaire on pollinating insects?

Pollinating insects ensure the function of pollination. This function is important for agricultural crops production, food security and preservation of biodiversity in natural environments. Nevertheless, these pollinating insects are currently declining in many places mainly because of human practices and CC.

Thus, we are conducting this study to understand how farmers and consumers perceive the role of pollinating insects and whether they are ready to protect them.

In this study, we will survey 1000 people in 5 different regions. I would like to point out that the results of our investigation will be made public and that your anonymity will be guaranteed.

Our results aim to convince public decision-makers and local stakeholders of the pollinating insects' importance.

Part 1: Introduction and contextualization

Subpart 1 : Territory

Question1: How big is your farm?

- 0 to 1
- 1 to 3
- 3 to 5
- 5 to 10
- 10 to 20
- 20 to 50
- 50 to 100
- 100 ha to 200 ha
- More than 200 ha

Question2: Is your exploitation in a perimeter?

- Rainfall dependent
- Irrigated = **Questions 3, 4**

Question3: If you are in an irrigated area, what type of irrigation do you use?

- Gravity
- Aspersion

- Drip
- Question4: If you are in an irrigated area, where does the water you use come from?
 - Well, borehole
 - River
 - Barrage
 - Other, **specify?**

Subpart 2: Knowledge level on pollinators and pollination

- Question5: Do you know the function of «pollination»?
 - No
 - Yes = **Question 6**
- Question6: If yes, can you define this function (services) in a few words?

- Question7: Do you know the pollination vectors?
 - No
 - Yes, which ones?

- Question8: Insect pollinators are an important pollination vector; did you know that there are managed pollinating insects and wild pollinating insects in nature?
 - No
 - Yes = **Question 9**
- Question9: If yes, can you clarify, in a few words, the difference between wild and managed pollinators?

- Question10: In your opinion, what services are provided by pollinating insects?
 - No service rendered
 - Rather a negative role (bites, embarrassment, ...)
 - Increase in agricultural yields
 - Improving the quality of agricultural products
 - Protection and improvement of biodiversity
 - Improving the landscape aesthetics
 - Honey production
 - Others, which ones?

- Question11: In your opinion, do wild pollinators and managed pollinators:
 - Provide the same services?
 - Do wild pollinators provide more services than domestic pollinators?
 - Do domestic pollinators provide more services than wild pollinators?

- Question12: *Did you know that pollinating insects are in danger?*
 - *No*
 - *Yes = Question 13*
- Question13: If yes, can you clarify why these pollinating insects are in danger?
 - Human behavior (phytosanitary treatments, pollution, etc.)
 - Climate change (heat, lack of water, etc.)
 - Other, **specify?**

Part 2: Pollination service

Subpart 1: Pollination and agricultural products

Question14: What do you produce on your farm?

- Fruit trees
- Horticulture, viticulture
- Cereals (wheat, barley, corn, ...)
- Oilseeds (sunflower, rapeseed, soybeans, etc.)
- Protein crops (peas, field beans, etc.)
- Market gardening
- Cattle breeding
- Sheep farming
- Goat breeding
- Other, **specify?**

Question15: Of these products, what is the main focus of your exploitation?

- Fruit trees = **Sub-part annex 1**
- Viticulture
- Cereals (wheat, barley, corn, ...)
- Oilseeds (sunflower, rapeseed, soybeans, etc.) = **Subpart annex 1**
- Protein crops (peas, field beans, etc.) = **Subpart annex 1**
- Market gardening = **Sub-part annex 1**
- Horticulture
- Cattle breeding
- Sheep farming
- Goat breeding
- Other, **specify?**

Question16: During the past 10 years have you changed the orientation of your exploitation?

- No
- Yes = **Question 17, 18, 19**

Question17: If so, how did you change it?

Question18: If so, how do you find this change?

- Rather positive
- Rather negative

Question19: If so, why did you change it?

- Climate change (drought, etc.)
- Soil quality
- Economic profitability
- Other, **specify?**

Subpart annex 1: Only for farmers who produce fruit and vegetables

Question20: Have you noticed an evolution in fruits and vegetables production in recent years?

- No
- Yes = **Question 21, 22**

Question21: If so, this evolution is rather:

- Positive
- Negative

Question22: If so, this development concerns:

- Rather the quality
- Rather the quantity
- The two
- The production cost
- Other, **specify?**

4.1.1. Subpart annex 2: Only for farmers who do not produce

fruit and vegetables

Question23: Why do not you produce fruits and vegetables?

- Lack of water/drought
- Little favorable or unfavorable soil
- Decline of pollinators
- High production cost
- Lack of expertise
- Other, **specify?**

Question24: If you had the conditions to produce fruits and vegetables, would you produce them?
Or would you prefer not to change your current farm direction?

- No
- I do not know
- Yes, maybe
- Of course

Question25: Do you think it is important to conserve fruits and vegetables diversity, yield and quality for future generations?

- Yes
- No

Subpart 2: Pollination and biodiversity

Question26: Are there wild natural spaces near your farm?

- No
- Yes, but they are a bit far
- Yes

Question27: Do you appreciate the presence of wild natural spaces next to your farm?

- No
- Yes = **Question 28**

Question28: If so, what are the elements that you appreciate in these wild natural spaces? (rank these items from 1 to 5)

- Flowers diversity
 - Flower density
 - Trees
 - Greenery
 - Insects (butterflies, bees, dragonflies, etc.)
- Question29: Have you noticed an evolution in these natural spaces in recent years?
- No
 - Yes = **Question 30, 31, 32**
- Question30: If so, this evolution is rather:
- Positive
 - Negative
- Question31: This evolution concerns:
- Flowers density and diversity
 - Trees
 - Greenery
 - Insects (butterflies, bees, dragonflies, etc.)
 - Area
- Question32: In your opinion, is the evolution of natural spaces state in your region linked to:
- Weather conditions
 - Human behavior (ex: pollution, etc..)
 - Pollinator problem
 - Other, **specify?**
- Question33: Did you know that these wild natural spaces play a role in attracting pollinators to your plot?
- No
 - Yes
- Question34: Did you know that pollinators' health depends on natural environments state?
- No
 - Yes
- Question35: For you, is the conservation of natural spaces and biodiversity important for future generations?
- Yes
 - No

Subpart 3: Pollinators and honey production?

- Question36: Do you produce honey?
- Yes = **Question 37, 38**
 - No, but I had produced it in the past
 - No = **Question 39**
- Question37: If so, how many beehives do you have?
- Question38: Are you moving your beehives?
- Yes
 - No
- Question39: If not, why do you not or no longer produce honey?

- Unfavorable climatic conditions for bee rearing
- Vegetation cover (absence of flowers) not favorable for foraging
- Bees loss due to disease
- Bees loss due to phytosanitary treatments
- Other, **specify?**

Question40: For you, is bees' conservation for the production of honey for future generations important?

- Yes
- No

Subpart 4: Actions to be taken for the pollinators' protection

Question41: Do you use these agri-environmental practices?

- Polyculture
- Rotation
- Reasoned pest management
- Biological control
- None
- Other practices, **specify?**

Question42: Do you think these practices have an effect on pollinating insects?

Practice	Rather positive effect	Rather negative effect	No effect
Polyculture			
Rotation			
Reasoned pest management			
Biological control			

Question43: Are you a member of a Professional Agricultural Organization (PAO)?

- No
- Yes

Question44: If so, is the environment protection (in particular pollinators and their habitats) one of the areas targeted by this PAO?

Question45: Are you a member of one or more environmental associations?

- No
- Yes

Question46: Are you ready to contribute personally for pollinators' protection and the preservation of their services?

- No
- Yes = **Question 47**

Question47: If so, how would you be prepared to invest?

- A financial contribution (to contribute to the financing of an association which participates in pollinators' preservation, to supply a fund intended for pollinators' protection, etc.)
- By providing my expertise and/or my knowledge (e.g. during training sessions organized by an association)
- Voluntary assistance (eg providing field assistance for an association which participates in pollinators protection)
- By modifying my daily practices (ex: respect for natural habitats)
- Other, **specify?**

Part 3 : Assessments

Subpart 1 : Choice experiment

Choice Cards

Question48: Out of all of your choices, are there any attributes that you didn't consider? Which?

- Production diversity
- Quantity produced of fruits and vegetables
- Quality of fruits and vegetables produced
- Currency attribute

Question49: Out of all of your choices, which attributes did you take into consideration the most (Rank the attributes from 1 to 4)

- Production diversity
- Quantity produced of fruits and vegetables
- Quality of fruits and vegetables produced
- Currency attribute

Question50: While responding to the choice cards, did you only consider the contribution of insect pollination to the different attributes ?

- Yes
- No

Question51: If not, what other factors did you consider?

- Irrigation
- Rainfall
- Fertilizers
- Pesticides
- Other, specify

Subpart 2: Contingent assessments

Question1: Is it important to you to preserve the services rendered by pollinators for future generations?

- No = **Question 51**
- Yes

Question52: If so, are you ready to invest in preserving the services provided by pollinators (for agriculture, for nature, for biodiversity, etc.) for future generations?

- No
- Yes = **Question 52**

Question53: If so, what's your maximum willingness to pay to preserve the services for future generations?

Part 4: Personal information

Subpart 1: personal situation

- Question54: You are?
- Man
 - Woman
- Question55: How old are you?
- 18 to 29
 - 30 to 44
 - 45 to 60
 - 60 to 75
 - 75 and more
- Question56: What is your personal situation?
- Single
 - Married
 - Widower
 - Divorced
- Question57: Do you have children?
- No
 - Yes, how many ?
- Question58: What's your education level?
- None
 - Preschool
 - Primary
 - Secondary school
 - Qualifying secondary
 - Higher bac+2
 - Higher bac+5
 - Higher bac+5 and more

Subpart 2: Professional situation

- Question59: Do you have any other profession besides agriculture?
- No,
 - Yes, which?
- Question60: How many children are you responsible for?
- Question61: How many of your children regularly work with you on the farm?

Subpart 3: Financial situation

- Question62: What's your annual farm income?
- Less than 2000 MAD
 - 24000 to 48000 MAD
 - 48000 to 72000 MAD
 - 72000 to 96000 MAD

- 96000 to 120000 MAD
- 120000 to 144000 MAD
- 144000 to 168000 MAD
- 168000 MAD and more




Question63: If you have other work, what is your monthly income?


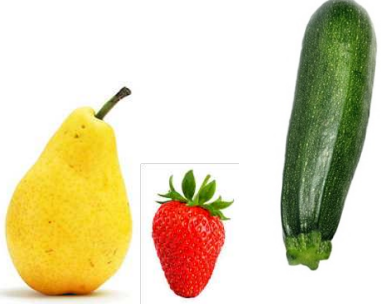

- Less than 2000 MAD
- 2000 to 4000 MAD
- 4000 to 6000 MAD
- 6000 to 8000 MAD
- 8000 to 10000 MAD
- 10000 to 12000 MAD
- 12000 to 14000 MAD
- 14000 MAD and more

Question64: If you are married what's your partner's monthly income?

- Less than 2000 MAD
- 2000 to 4000 MAD
- 4000 to 6000 MAD
- 6000 to 8000 MAD
- 8000 to 10000 MAD
- 10000 to 12000 MAD
- 12000 to 14000 MAD
- 14000 MAD and more

Appendix 3: Explanatory sheets of attributes and their levels for farmers

Attributes	levels	Illustration
<p><u>1st attributes: Diversity of agricultural production on the farm</u></p> <p>The diversity of agricultural production corresponds to <u>the possibility of producing pollinator dependent crops and pollinator independent crops</u> during the same agricultural campaign or during several agricultural campaigns.</p> <p>Pollinating insects' diversity and abundance are among the key production factors that influence the <u>possibility of diversifying production on the farm.</u></p>	<p><u>High diversity:</u></p> <p>The possibility of agricultural production diversification is great when the farmer can freely choose the crops to be produced : Pollinator dependent crops (fruit trees, vegetables, etc.) and pollinator independent crop (e.g., wheat)</p> <p>The farmer can only freely choose the crops he wants to produce when there is an abundant and diverse presence of pollinating insects in nature.</p> <p>In the absence of pollinators in nature, most crops (pollinator dependent crops) cannot be produced despite the presence of all agricultural inputs (water, soil, etc.).</p>	
	<p><u>Low diversity:</u></p> <p>The possibility of agricultural production diversification is low when the farmer cannot freely choose the crops he would like to produce (only pollinator independent crops).</p> <p>In the absence of pollinating insects and despite the presence of all agricultural inputs (water, soil ...), the farmer is obliged to produce crops that do not require the presence of pollinating insects (cereals).</p>	
<p><u>2nd attribute: Quantity produced of fruits and vegetables on the farm</u></p> <p>The amount of fruits and vegetables produced on the farm corresponds to <u>the number of kilograms or tons of fruits and</u></p>	<p><u>High quantity :</u></p> <p>The amount produced of fruits and vegetables is large when the pollinating insects are diverse and abundant in nature.</p> <p><u>Despite the availability of all agricultural inputs</u> (water, soil, etc.), the harvested quantity of most fruits and vegetables would only be large in the presence of diverse and abundant pollinating insects in nature.</p>	

<p><u>vegetables harvested in an agricultural campaign.</u></p> <p>Pollinating insects' diversity and abundance in nature are two key production factors affecting the <u>amount of agricultural production of vegetables and fruits on the farm.</u></p>	<p><u>Low quantity :</u></p> <p>The amount produced of fruits and vegetables is low when the abundance of diversity of pollinating insects are low or inexistent in nature.</p> <p><u>Despite the availability of all agricultural inputs,</u> the quantity harvested would be low if there was a shortage or absence of pollinating insects.</p>	
<p><u>3rd attribute: Quality of fruits and vegetables produced on the farm</u></p> <p>The quality of fruits and vegetables is assessed based on the following criteria:</p> <ul style="list-style-type: none"> * Caliber (big or small); * Taste (good or bad); * Shape (normal, abnormal); * Smell (good, bad) 	<p><u>High quality :</u></p> <p>The quality of vegetables and fruits is high when they have a large size, a delicious taste, a good smell and a normal shape.</p> <p>This could only take place in the <u>abundant and diverse presence of pollinating insects in nature.</u></p>	
<p>The abundance and diversity of pollinating insects' in nature are among the key production <u>factors affecting the quality of fruits and vegetables.</u></p>	<p><u>Low quality :</u></p> <p>Fruits and vegetables have a low quality when they have a small caliber, a bad taste and a distorted natural shape</p> <p>The low quality of the fruits and vegetables produced is the result of a <u>lack or absence of pollinating insects in nature.</u></p> <p><u>Despite the presence of all agricultural inputs,</u> the quality of fruits and vegetables would be low if there was a <u>lack or absence of pollinating insects.</u></p>	

**Payment vehicle per year
per farmer**

Number of days of
volunteering per year in
an association for the
protection of pollinators
and their natural
habitats.

(or equivalent: 1/3 of
what you earn daily)

- 12 days/year
- 24 days/year
- 36 days/year
- 48 days/year



Appendix 4: Consumers' questionnaire

Questionnaire: Economic evaluation of pollination service (consumers)

Date:

Hour:

Region:

Questionnaire number:

Explanatory paragraph:

Hello, my name is Soukaina ANOUGMAR. I am a PhD student in the 2nd year at the Economics and Management Doctoral School (EDEG) in Montpellier. Can you give me some of your time (around 30 min) to answer a questionnaire on pollinating insects?

Pollinating insects ensure the function of pollination. This function is important for agricultural crops production, food security and the maintenance of biodiversity in natural environments. Nevertheless, these pollinating insects are currently in decline in many places, mainly because of human practices and CC.

Thus, we are conducting this study to understand how farmers and consumers perceive the role of pollinating insects and whether they are ready to protect them.

In this study, we will survey 1000 people in 5 different regions. I would like to point out that the results of our investigation will be made public and that your anonymity will be guaranteed.

Our results aim to convince public decision-makers and local stakeholders of the pollinating insects' importance.

Part 1: Introduction and contextualization

Subpart 1: Territory

Question65: Do you live in this region (regions defined according to the last administrative division)?

- Yes
- No = **Question 2**

Question66: If not, in which region do you live?

Question67: How long have you lived in your region?

Question68: If less than a year, in which region you previously lived?

(continue the investigation in relation to the region where the person previously lived)

Question69: In your region you live in which province / municipality / douar?

Question70: How would you classify the territory in which you live?

- Urban territory
- Peri-urban territory
- Rural territory

Subpart 2: Knowledge level on pollinators and pollination

Question71: Do you know the function of «pollination»?

- No
- Yes = **Question 8**

Question72: If yes, can you define this function (services) in a few words?

Question73: Do you know the pollination vectors?

- No
- Yes, which ones?

Question74: Insect pollinators are an important pollination vector; did you know that there are managed pollinating insects and wild pollinating insects in nature?

- No
- Yes = **Question 11**

Question75: If yes, can you clarify, in a few words, the difference between wild and managed pollinators?

Question76: In your opinion, what services are provided by pollinating insects?

- No service rendered
- Rather a negative role (bites, embarrassment, ...)
- Increase in agricultural yields
- Improving the quality of agricultural products
- Protection and improvement of biodiversity
- Improving the landscape aesthetics
- Honey production
- Others, which ones?

Question77: In your opinion, do wild pollinators and managed pollinators:

- Provide the same services?
- Do wild pollinators provide more services than domestic pollinators?
- Do domestic pollinators provide more services than wild pollinators?

Question78: *Did you know that pollinating insects are in danger?*

- No
- Yes = **Question 15**

Question79: *If yes, can you clarify why these pollinating insects are in danger?*

- Human behavior (phytosanitary treatments, pollution, etc.)

- Climate change (heat, lack of water, etc.)
- Other, **specify?**

Part 2: Pollination service

Subpart 1: Pollination and agricultural products

Question80: Do the fruits and vegetables you usually eat come from your region?

- I do not know
- Yes, they are all from the region
- Yes, in part } = **Question 17**
- No

Question81: If not (or yes in part), why do these fruits and vegetables not come (in whole or in part) from your region?

- Unfavorable or not very favorable climatic conditions (drought, low water reserves, etc.)
- Type and quality of soil unfavorable or not very favorable
- Pollination problem
- e pollination
- Other, **specify?**

Question82: Have you noticed an evolution in fruits, vegetables and legumes supply in the markets in your region in recent years?

- No
- Yes = **Questions 19, 20**

Question83: This development is rather:

- Positive
- Negative

Question84: This development concerns:

- Quality (size, taste, ...)
- Quantity (increasingly low supply)
- Diversity (disappearance / increasing fruits and vegetables scarcity)
- Price

Question85: Do you think it is important to conserve the diversity, yield and quality of fruits and vegetables for future generations?

- Yes
- No

Subpart 2: Pollination and biodiversity

Question86: Do you appreciate natural spaces (forests, national and regional parks, green spaces)?

- No
- Yes = **Questions 23, 24, 25**

Question87: If so, what are the elements that you appreciate in these natural spaces? (Rank these items from 1 to 5)

- The diversity of flowers
- Flower density
- Trees
- Greenery
- Insects (butterflies, bees, dragonflies, etc.)

Question88: Do you frequently visit these spaces?

- No
- Yes

Question89: If so, what is the state of natural spaces in your region?

- Good
- Bad
- Average

Question90: Have you noticed an evolution in these natural spaces in recent years?

- No
- Yes = **Question 27, 28, 29**

Question91: If so, this evolution is rather:

- Positive
- Negative

Question92: This development concerns:

- The density and diversity of flowers
- Trees
- Greenery
- Insects (butterflies, bees, dragonflies, etc.)

Question93: In your opinion, is the evolution of natural spaces state in your region linked to:

- Weather conditions
- Human behavior (ex: pollution, etc.)
- Pollinator problem
- Other, **specify?**

Question94: Did you know that pollinators' health depends on natural environments state?

- No
- Yes

Question95: For you, is the conservation of natural spaces and biodiversity important for future generations?

- Yes
- No

Subpart 3: Pollinators and honey production?

Question96: Do you consume honey?

- No
- Yes = **Question 33, 34, 35**

Question97: Does the honey you consume come from your region?

- Yes
- No

Question98: If not, why do you think the honey you consume does not come from your region?

- Unfavorable climatic conditions for bee rearing
- Vegetation cover (absence of flowers) not favorable for foraging
- Bees loss due to disease
- Bees loss due to phytosanitary treatments
- Other, **specify?**

Question99: For you, is bees' conservation for the production of honey for future generations important?

- Yes
- No

Subpart 4: Actions to be taken for the pollinators' protection

Question100: Are you ready to contribute personally for pollinators' protection and the preservation of their services?

- No,
- Yes = **Question 37**

Question101: If so, how would you be prepared to invest?

- A financial contribution (to contribute to the financing of an association which participates in pollinators' preservation, to supply a fund intended for pollinators' protection, etc.)
- By providing my expertise and/or my knowledge (e.g. during training sessions organized by an association)
- Voluntary assistance (eg providing field assistance for an association which participates in pollinators protection)
- By modifying my daily practices (ex: respect for natural habitats)
- Other, **specify?**

Question102: Are you a member of one or more environmental associations?

- No
- Yes

Part 3 : Assessments

Subpart 1 : Choice experiment

Choice Cards

Question103: Out of all of your choices, are there any attributes that you didn't consider?
Which?

- Landscape aesthetics
- Fruits and vegetables variety
- Fruits and vegetables quality
- Volunteering in an association for environment protection

Question104: Out of all of your choices, which attributes did you take into consideration the most (Rank the attributes from 1 to 4)

- Landscape aesthetics
- Fruits and vegetables variety
- Fruits and vegetables quality
- Volunteering in an association for the protection of the environment

Question105: While responding to the choice cards, did you only consider the contribution of insect pollination to the different attributes ?

- Yes
- No

Question106: If not, what other factors did you consider?

- Irrigation
- Rainfall
- Fertilizers
- Pesticides
- Other, specify

Subpart 2: Contingent assessments

Question107: Is it important to you to preserve the services rendered by pollinators for future generations?

- No
- Yes = **Question 42**

Question108: If so, are you ready to invest in preserving the services provided by pollinators (for agriculture, for nature, for biodiversity, etc.) for future generations?

- No
- Yes = **Question 43**

Question109: If so, what's your maximum willingness to pay to preserve the services for future generations?

Part 4: Personal information

Subpart 1: personal situation

Question110: You are?

- Man
- Woman

Question111: How old are you?

- 18 to 29
- 30 to 44
- 45 to 60
- 60 to 75
- 75 and more

Question112: What is your personal situation?

- Single
- Married
- Widower
- Divorced

Question113: Do you have children?

- No
- Yes, How many?

Question114: What's your education level?

- None
- Preschool
- Primary
- Secondary school
- Qualifying secondary
- Higher bac+2
- Higher bac+5
- Higher bac+5 and more

Subpart 2: Professional situation

Question115: How many children are you responsible for?

Question116: Can you tell us your profession?

- No,
- Yes, what's your job?

Question117: What's your professional situation?

- Employer
- Independent
- Employee in the public sector
- Employee in the private sector
- Apprentice
- Associate or partner
- Retirement

- You do not work, where does your income come from?

Question118: What sector of activity do you work in?

- Agriculture and agribusiness
- Environment
- Industry and energy
- Services (tourism, health, finance, education, etc.)
- Other, which one?

Subpart 3: Financial situation




Question119: What is your monthly income?

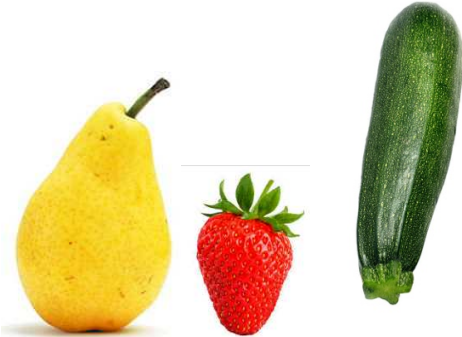


- Less than 2000 MAD
- 2000 to 4000 MAD
- 4000 to 6000 MAD
- 6000 to 8000 MAD
- 8000 to 10000 MAD
- 10000 to 12000 MAD
- 12000 to 14000 MAD
- 14000 MAD and more

Question120: If you are married what's your partner's monthly income?

- Less than 2000 MAD
- 2000 to 4000 MAD
- 4000 to 6000 MAD
- 6000 to 8000 MAD
- 8000 to 10000 MAD
- 10000 to 12000 MAD
- 12000 to 14000 MAD
- 14000 MAD and more

Appendix 5: Explanatory sheets of attributes and their levels for consumers

Attributes	levels	Illustration
<p><u>1st attribute - Aesthetics of the landscape in your region</u></p> <p>The aesthetics of the landscape are assessed based on two criteria:</p> <ul style="list-style-type: none"> * <u>The diversity of the vegetation cover</u>: presence or absence of forests, wild lands, flowers, etc. * <u>the density of the vegetation cover</u>: if the soil is completely covered with plants or partially covered. <p>The diversity and abundance of pollinating insects in nature are among the major factors influencing the <u>diversity and density of the vegetation cover</u> and, therefore, affecting the aesthetics of the landscape.</p>	<p><u>Good aesthetics:</u></p> <p>The aesthetics of the landscape are good when the vegetation cover is dense and very diverse (presence of flowers of different colors and shapes, etc.). This can only happen if <u>pollinating insects are diverse and abundant in nature.</u></p>	
<p><u>2nd attribute - Variety of fruits and vegetables available in the markets in your region:</u></p> <p>The variety of fruits and vegetables <u>corresponds to the number of species and varieties of fruits and vegetables available in the markets.</u></p> <p>The diversity and abundance of pollinating insects in nature are among the key production factors affecting <u>the diversity of production of fruits and vegetable and hence their availability on the market.</u></p>	<p><u>High variety :</u></p> <p>The variety of vegetables and fruits in the market is high when <u>pollinating insects are diverse and abundant in nature.</u></p>	
	<p><u>Low variety:</u></p> <p>The variety of fruits and vegetables in the markets is low when <u>pollinating insects are few or absent in nature;</u> and this despite the presence of all</p>	

	agricultural inputs (water, soil, etc.).	
<p><u>3rd attribute: Quality of fruits and vegetables available in the markets of the region where you live:</u></p> <p>Assessment of the vegetables and fruits quality is based on the following criteria:</p> <ul style="list-style-type: none"> * Caliber (big or small); * Taste (good or bad); * Shape (normal, abnormal); * Smell (good, bad) * Nutrient intake (rich or poor); <p><u>The abundance and diversity of pollinating insects in nature are among the key production factors affecting fruits and vegetables quality.</u></p>	<p><u>High quality:</u></p> <p>Vegetables and fruits quality is high when they have a large size, delicious taste, good smell, normal shape and when they are rich in nutrients. This can only happen if <u>pollinating insects are diverse and abundant in nature.</u></p> <p><u>Low quality:</u></p> <p>Vegetables and fruits quality is low when they are small in size, bad taste, abnormal shape, bad odor and when they are poor in nutrients. This happens when there is a <u>lack or absence of pollinating insects in nature,</u> even in the presence of all agricultural inputs (water, soil, etc.).</p>	 
<p><u>Payment mechanism per month per person:</u></p> <p>Number of days of volunteering per month in an association for the protection of pollinators and their natural habitats.</p> <p>(Where equivalent: 1/3 of what you earn daily)</p>	<ul style="list-style-type: none"> ○ 1 day/month ○ 2 days/month ○ 3 days/month ○ 4 days/month 	

Appendix 6: Pictures of focus groups



Picture 1: Focus group with consumers



Picture 2: Participants of the focus group with experts



Picture 3: Shared meal with farmers after the focus group

Appendix 7: Pictures of interviews with farmers



Picture 4: Interviews with farmers in the region of Laayoun Sakia El Hamra



Picture 5: Interviews with farmers in the region of Fes-Meknès



Picture 6: Interviews with farmers in the region of Casablanca-Settat

Appendix 8: Pictures of interviews with consumers



Picture 7: Interviews with consumers in the region of Draa-Tafilalet



Picture 8: Interviews with consumers in the region of Fes-Meknès

Short Abstract

Human practices and climate change (CC) are driving pollinator decline worldwide. Changes in human behavior can mitigate the impacts of CC on pollinators and protect them from endangering practices. Economic preferences partly drive human behavior. Thus, analyzing preferences for insect pollinators and assessing their values to human welfare can provide policy-makers with the necessary information to engage in their protection. Economic preferences for the benefits derived from pollinators can be divided into farming and consumption preferences. We conduct a choice experiment to analyze farmers' and consumers' preferences for the benefits derived from pollinators, assess the values placed on these benefits, and make conservation policy recommendations. Farmers and consumers in dry, low- and middle-income countries (LIC and MIC) are particularly vulnerable to pollinator decline. Thus, we chose Morocco, a dry MIC, as our benchmark site. We find that both farmers and consumers highly value the benefits derived from pollinators. We also find that aridity, a particularity of drylands, has a strong effect on farmers' and consumers' preferences for pollinators. We anticipate an increase in values farmers and consumers derive from pollinators following shifts in aridity levels due to CC. We show that some farmers and consumers are more ready to engage in pro-pollinator behaviors than others, highlighting the importance of using targeted interventions to achieve behavioral changes.

Résumé

Les pratiques humaines et le Changement Climatique (CC) entraînent le déclin des pollinisateurs dans le monde entier. Les changements dans le comportement humain peuvent atténuer les impacts du CC sur les pollinisateurs et les protéger des pratiques dangereuses. Les comportements humains sont en partie déterminés par les préférences économiques, ainsi, l'analyse des préférences pour les insectes pollinisateurs et l'évaluation de leurs valeurs pour le bien-être humain peuvent fournir aux décideurs des informations nécessaires pour s'engager dans la protection de ces espèces. Dans les préférences économiques pour les pollinisateurs nous distinguons les préférences de producteurs agricoles et de consommateurs. Nous menons une expérience de choix pour a) analyser les préférences des agriculteurs et des consommateurs pour les pollinisateurs, b) évaluer les valeurs dérivées des pollinisateurs et c) formuler des recommandations de politiques de conservation. Les populations dans les pays arides à revenu faible et intermédiaire sont particulièrement vulnérables au déclin des pollinisateurs. Ainsi, nous avons choisi le Maroc, un pays sec à revenu intermédiaire, comme site de référence pour cette étude. Nous constatons que les agriculteurs et les consommateurs accordent une grande valeur aux pollinisateurs. Nous constatons également que l'aridité a un effet important sur les préférences des agriculteurs et des consommateurs pour les pollinisateurs. Nous prévoyons une augmentation des valeurs que les agriculteurs et les consommateurs tirent des pollinisateurs à cause de l'évolution de l'aridité, suite au CC. Nous montrons que certaines classes d'agriculteurs et de consommateurs sont plus disposées à adopter des comportements pro-pollinisateurs que d'autres, ce qui souligne l'importance de l'utilisation d'interventions ciblées pour obtenir des changements de comportement en faveur des insectes pollinisateurs.