Report No. 291

epa Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Assessing Market and Non-market Values of Pollination Services in Ireland (Pollival)

Authors: Jane C. Stout, James T. Murphy and Saorla Kavanagh

www.epa.ie

Rialtas na hÉireann
Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY
The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

Knowledge: *We provide high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.*

Advocacy: *We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.*

Our Responsibilities

Licensing
We regulate the following activities so that they do not endanger human health or harm the environment:
- waste facilities *(e.g. landfills, incinerators, waste transfer stations)*;
- large scale industrial activities (*e.g. pharmaceutical, cement manufacturing, power plants)*;
- intensive agriculture *(e.g. pigs, poultry)*;
- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources)*;
- large petrol storage facilities;
- waste water discharges;
- dumping at sea activities.

National Environmental Enforcement
- Conducting an annual programme of audits and inspections of EPA licensed facilities.
- Overseeing local authorities' environmental protection responsibilities.
- Supervising the supply of drinking water by public water suppliers.
- Working with local authorities and other agencies to tackle environmental crime by co-ordinating a national enforcement network, targeting offenders and overseeing remediation.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Prosecuting those who flout environmental law and damage the environment.

Water Management
- Monitoring and reporting on the quality of rivers, lakes, transitional and coastal waters of Ireland and groundwaters; measuring water levels and river flows.
- National coordination and oversight of the Water Framework Directive.
- Monitoring and reporting on Bathing Water Quality.

Monitoring, Analysing and Reporting on the Environment
- Monitoring air quality and implementing the EU Clean Air for Europe (CAFÉ) Directive.
- Independent reporting to inform decision making by national and local government *(e.g. periodic reporting on the State of Ireland's Environment and Indicator Reports)*.

Regulating Ireland's Greenhouse Gas Emissions
- Preparing Ireland's greenhouse gas inventories and projections.
- Implementing the Emissions Trading Directive, for over 100 of the largest producers of carbon dioxide in Ireland.

Environmental Research and Development
- Funding environmental research to identify pressures, inform policy and provide solutions in the areas of climate, water and sustainability.

Strategic Environmental Assessment
- Assessing the impact of proposed plans and programmes on the Irish environment *(e.g. major development plans)*.

Radiological Protection
- Monitoring radiation levels, assessing exposure of people in Ireland to ionising radiation.
- Assisting in developing national plans for emergencies arising from nuclear accidents.
- Monitoring developments abroad relating to nuclear installations and radiological safety.
- Providing, or overseeing the provision of, specialist radiation protection services.

Guidance, Accessible Information and Education
- Providing advice and guidance to industry and the public on environmental and radiological protection topics.
- Providing timely and easily accessible environmental information to encourage public participation in environmental decision-making *(e.g. My Local Environment, Radon Maps)*.
- Advising Government on matters relating to radiological safety and emergency response.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

Awareness Raising and Behavioural Change
- Generating greater environmental awareness and influencing positive behavioural change by supporting businesses, communities and householders to become more resource efficient.
- Promoting radon testing in homes and workplaces and encouraging remediation where necessary.

Management and structure of the EPA
The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:
- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

Assessing Market and Non-market Values of Pollination Services in Ireland (Pollival)

(2016-NC-MS-6)

EPA Research Report

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

Authors:

Jane C. Stout, James T. Murphy and Saorla Kavanagh

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Communications, Climate Action and Environment. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research. The authors acknowledge funding provided by the EPA.

In particular, the authors would like to thank and acknowledge the project steering committee, namely Dorothy Stewart (EPA Research), Jim Bowman (EPA – retired), Seán Lyons [Economic and Social Research Institute (ESRI)] and Tom Breeze (University of Reading), and Oonagh Monahan (Research Project Manager on behalf of the EPA). The authors would also like to thank Simon Potts, Hannah Hamilton, Sharon Walsh and Joseph Roche for their input and support during the project. The authors are grateful to EU COST Action Super-B for facilitating additional networking and training.

DISCLAIMER

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2014–2020

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-856-0 September 2019

Price: Free Online version

Project Partners

Professor Jane C. Stout
School of Natural Sciences
Trinity College Dublin
Dublin 2
Ireland
Email: stoutj@tcd.ie

Dr James T. Murphy
School of Natural Sciences
Trinity College Dublin
Dublin 2
Ireland

and

Environmental Protection Agency
EPA Headquarters
Johnstown Castle Estate
Co. Wexford
Ireland
Email: J.Murphy2@epa.ie

Dr Saorla Kavanagh
School of Natural Sciences
Trinity College Dublin
Dublin 2
Ireland

and

National Biodiversity Data Centre
Beechfield House
Waterford Institute of Technology West
Campus
Carriganore
Co. Waterford
Ireland
Email: skavanagh@biodiversityireland.ie

Contents

List of Figures

List of Tables

List of Boxes

Executive Summary

Assessing and evaluating natural capital and ecosystem services are key research priorities of the Environmental Protection Agency (EPA), the National Biodiversity Action Plan and the Irish Forum on Natural Capital. By accounting for natural capital, and valuing the ecosystem services that flow from it, and integrating this understanding into decision-making processes, a more sustainable use of natural resources is possible. The Pollival project used pollinators and pollination services, which have public and political appeal, as a case study for assessing the market and non-market values of ecosystem services.

To assess market values, the Pollival project first conducted a review of existing approaches and available data sources. The data selected for calculating current market values were agricultural food crop production and trade data (from the Food and Agriculture Organization of the United Nations) and previously published data on the degree of pollinator dependence for each crop. From these data, the global value of animal pollination to crop production was estimated at US$179–468 billion (€158–412 billion). Using the same approach, the annual value of animal pollination to home-produced crops in Ireland was estimated to be €20–59 million per year. However, given the importance of international trade in animal-pollinated crops, and the fact that Ireland imports more than it produces of these crops, global animal pollinator decline could result in an increased trade deficit for these crops.

Four scenarios, using the highest and lowest estimates of pollinator dependency and two measures of price elasticity (an economic measure of changes in quantity of demand relative to changes in price), predicted the cost of pollinator loss to Ireland at between €153 and €843 million per year. Thus, the risk of pollinator loss globally will have local market impacts in Ireland, in terms of increased food prices and an increased trade deficit in animal-pollinated crops. Scaling up the trade-deficit approach to the global level, the cost of global pollination service loss was quantified at between US$292 billion and US$1.26 trillion per year (between €260 billion and €1.11 trillion) for the period 2005–2014. Although this total value is economically unrealistic, because it represents a scenario of current consumption patterns but reduced global crop production, which is impossible, it does highlight that global pollinator loss could have massive economic impacts. More importantly, this approach illustrates that global pollinator loss can have differential impacts on national economies depending on the national balance of trade for animal-pollinated crops.

In order to understand public perception of the importance of pollination services, and how they are valued by Irish society, the Pollival project instigated two national surveys. The first survey used a stated preference methodological approach to quantify non-market benefits of pollinators to 1000 randomly selected members of the Irish population, using a "willingness-to-pay" approach. Of the 1000 respondents, over 80% were aware that bees were in decline in Ireland, more than 90% agreed that it is important to protect bees and the benefits they provide, and 68% believed that protecting the environment may require funding through taxation. On average, respondents indicated they were willing to pay an average of €4–6 per month (and up to €10) to protect bees and the flowers they pollinate, but further research will be required to develop a robust estimate of the willingness to pay for pollinator conservation.

The second survey was conducted in collaboration with the *Irish Times*, which also showed that the majority (>80%) of respondents believed that the number of wild pollinators in Ireland is decreasing and that it is important to protect pollinators and the benefits they provide, with the majority (>80%) also stating that they like local green spaces to have lots of different flowers. Again, more than half of respondents agreed that protecting pollinators may require funding through taxation, and most preferred the introduction of tariffs on products that harm pollinators and fines for actions that damage the places that pollinators live, breed or eat.

Taken together, the results from the Pollival project suggest that both the market and the non-market values of pollinators in Ireland are currently underestimated. There are many approaches to the valuation of ecosystem services, but market studies

using analysis of global supply chains, and non-market approaches using methods such as willingness to pay, can reveal more about the monetary value of pollinators to the Irish economy. For a more holistic approach to assessing the values associated with pollination services, incorporating monetary and non-monetary approaches, a framework for valuation is proposed. Within this framework, economic, social and health values of pollination services are integrated, but these aspects need to be aligned for a more complete view of the value of natural capital and ecosystem services. By understanding and communicating the monetary and non-monetisable values of key ecosystem services, such as pollination, a better appreciation of natural capital can be developed for both policy and planning decisions at many levels across multiple sectors.

1 Introduction

1.1 Overview

Ecosystems provide various essential amenities, including food and water, and other valuable services to human societies (Joppa *et al*., 2016). However, ecosystems are increasingly threatened by human population growth, increasing urbanisation and intensity of production, and globalisation, which have resulted in loss and fragmentation of biodiversity, pollution and degradation of habitats, and climate change (Ripple *et al*., 2017). In response, policies and initiatives have been developed at global, regional and national scales to articulate the importance of ecosystems and their loss to humanity, in an attempt to highlight the value of nature to humanity.

Valuing nature and the benefits it provides is a complex topic, with various approaches used to derive estimations of value, in both monetary and non-monetary terms (Díaz *et al*., 2015). The Millennium Ecosystem Assessment (MEA), with contributions from leading scientists from more than 100 nations, highlighted the relationship between ecosystems and human well-being, including social, economic and cultural aspirations (MEA, 2003). In 2012, an independent intergovernmental body consisting of 130 Member States, including Ireland, called the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), was launched to provide policymakers with objective scientific assessments on the Earth's biodiversity and ecosystems and the benefits that they provide to people (Pascual *et al*., 2017). IPBES developed a conceptual framework that identified various methodologies for valuing nature and highlighted the importance of developing an inclusive valuation approach for nature's contributions to people (Díaz *et al*., 2015).

In Ireland, the Environmental Protection Agency (EPA) identified the sustainable use of natural resources as one of its 2020 vision goals and highlighted that better integration of environmental and natural resource considerations into the policies, plans and actions of economic sectors is required (EPA, 2007). Furthermore, Ireland's National Biodiversity Plan, *Actions for Biodiversity 2011–2016*, which set out Ireland's vision for biodiversity, specified the need to "carry out further and more detailed research on the economic value of ecosystems and biodiversity in Ireland" (Department of Arts, Heritage and the Gaeltacht, 2011). In the subsequent National Biodiversity Action Plan (2017–2021), "[e]nhanced appreciation of the value of biodiversity and ecosystem services among policymakers, businesses, stakeholders, local communities, and the general public" was highlighted as one of the seven overall objectives (Department of Culture, Heritage and the Gaeltacht, 2017). Nevertheless, challenges arise when attempting to reconcile various approaches to valuing nature (from monetary to socio-cultural) for decision-making processes in the absence of a common standard of measurement (Kolinjivadi *et al*., 2017).

1.2 Ecosystem Services, Including Pollination

Ecosystem services are the outputs from biodiversity and natural ecological processes that have benefits for human society (Wallace, 2007; de Groot *et al*., 2010a; Gómez-Baggethun *et al*., 2010). These outputs can be classified into various frameworks (Feeley *et al*., 2017) and benefits can be expressed in monetary terms, to justify and support biodiversity and ecosystem service management objectives (Boyd and Banzhaf, 2007). There is much debate about the usefulness of monetary valuation alone in biodiversity conservation (Nunes and van den Bergh, 2001).

Animal-mediated pollination is an example of a key ecosystem service that plays a vital role in the reproduction of nearly 90% of plant species, including many on which human society depends (Aizen *et al*., 2008; Ollerton *et al*., 2011; Bailes *et al*., 2015). Sustained declines in managed and wild populations of flower-visiting animals could threaten pollination services, which are essential to food crop production (provisioning services), plant population growth (regulating services) and landscape aesthetics (cultural services), among other things (Ghazoul, 2005; Biesmeijer *et al*., 2006; Garibaldi *et al*., 2011; Potts *et al*., 2010a, Thomann *et al*., 2013). In particular, recent declines observed in populations of pollinators, if left unchecked, could have important socio-economic implications with respect to food production and international trade of cultivated crop species (Gallai *et al*., 2009; Potts *et al*., 2010a).

Approximately 75% of crop species grown for human consumption benefit from animal pollination, including fruit crops such as apples, oranges, strawberries and almonds, as well as coffee and cocoa beans (Klein *et al*., 2007). Case studies of nine crops across four continents showed that wild bees were threatened by agricultural intensification, resulting in risks to pollination service delivery across the landscape (Klein *et al*., 2007). With 70 crop species deemed moderately or highly dependent on animal-mediated pollination, the status of pollinators is of pressing concern with respect to crop production and global food security (Potts *et al*., 2010a; Garibaldi *et al*., 2011; Tscharntke *et al*., 2012).

Pollination services depend on both wild and managed pollinators, with bees playing a primary role in the pollination of many agricultural crops (Potts *et al*., 2010a), although non-bee pollinators (flies, beetles, moths, butterflies, birds and bats, among others) are also important (Rader *et al*., 2016). There is a growing body of evidence demonstrating a decline in both wild and managed pollinators in various parts of the world, driven by multiple anthropogenic drivers (Potts *et al*., 2010b; Vanbergen and Garratt, 2013; Goulson *et al*., 2015). The main drivers of pollinator decline are identified as habitat loss and fragmentation, pathogens, agrochemicals including pesticides, invasive species and climate change (Doublet *et al*., 2015; Kerr *et al*., 2015; Stanley *et al*., 2015; Cameron *et al*., 2016; Kovács-Hostyánszki *et al*., 2017; Senapathi *et al*., 2017; Stout and Tiedeken, 2017). Moreover, these factors can interact to exacerbate the negative effects on populations, which can negatively impact wider ecosystem stability and plant diversity (Goulson *et al*., 2015).

The most globally important managed pollinator for crop production is the European honey bee (*Apis mellifera*). There is clear evidence of regional declines in honey bee stocks in both the USA and Europe (van Engelsdorp *et al*., 2008; Potts *et al*., 2010b). As a result, many agricultural crop species are vulnerable because of their reliance on this single species of pollinator. It is possible that the demand for pollination services could exceed the number of honey bee hives available in the future (Jaffé *et al*., 2010; Breeze *et al*., 2014). Less is understood about changes in wild pollinator populations and communities because of a lack of large-scale, co-ordinated monitoring programmes. There are indications that wild bee populations may be under threat (Patiny *et al*., 2009). For example, evidence of declines in the diversity of bumblebees (*Bombus* spp.) in Europe have been well documented (Goulson *et al*., 2008; Williams and Osborne 2009; Nieto *et al*., 2014; Ollerton, 2017) and, in Ireland, one-third of wild bee species are at risk of extinction (Fitzpatrick *et al*., 2006). The repercussions of pollinator loss for human economies and societies are beginning to be recognised by some, but the implications of the loss of this ecosystem service are not fully appreciated in many decision-making processes, nationally or globally.

1.3 Objectives of the Pollival Project

A wide range of studies has been carried out on the various economic, health and socio-cultural benefits derived from pollinators and the pollination services that they provide (Klein *et al*., 2007; Junge *et al*., 2015; Lindemann-Matthies and Brieger, 2016). However, in Ireland, estimates of the contribution of pollination to agricultural production are more than 10 years old (Bullock *et al*., 2008) and there is a gap in the understanding of the relationships between the diverse methodological approaches to valuing pollinators, from economic to more holistic approaches.

Building on the 2016 IPBES assessment on pollinators, pollination and food production, the Pollival project assessed a range of methodological approaches to the valuation of pollination services to all plants (not just food crops) (IPBES, 2016; Díaz *et al*., 2015; Pascual *et al*., 2017) and integrated them into a multidimensional conceptual framework for valuation. This methodology connected the various approaches taken in the literature to capture the relational value of pollinators and to allow identification of potential methodological gaps. The combined use of economic, socio-cultural and holistic valuation of pollinator gains and losses, using multiple knowledge systems, integrates perspectives from different stakeholder groups. Combining these approaches to produce a cohesive method of valuation could provide more information for the management of, and decision-making about, pollinators and pollination.

The main objectives of the Pollival project were to:

- identify best practice to evaluate the current market values of pollination services – this was achieved by building on the recent IPBES report, which incorporated the views of international experts and existing literature;
- estimate the value of pollinators and the implications of pollinator loss for pollination services in Ireland – market values of pollination were calculated for global crop production and, in the Irish context, using crop production and trade data and pollination dependency ratios;
- review and develop methods to assess the non-market values of pollinators in Ireland – methods for non-market valuation were reviewed and two public surveys were undertaken.

2 Valuing Nature

2.1 Types of Values

Values are influenced by worldviews and geopolitical interactions, and therefore can vary based on the cultural and social context (Brondízio *et al.*, 2010; Descola, 2014). The value of nature may be considered in both intrinsic terms and from a relational (instrumental) viewpoint (Box 2.1). The concept of an objective intrinsic value of nature assumes that nature has value in its own right, independent of human considerations (Soulé, 1985; Rolston, 1986; Katz, 1992; Callicott, 2006). By contrast, an instrumental concept of value is associated with the provision of goods or benefits to people that result in the improvement of their quality of life, either directly or indirectly (Gagnon Thompson and Barton, 1994). Nature may provide direct goods such as food, fuel and fibres (provisioning services), as well as cultural, recreational and spiritual services (Costanza *et al.*, 1997; Boyd and Banzhaf, 2007; Tengberg *et al.*, 2012). In addition, it can provide indirect benefits, for example through regulation of crop pests or the maintenance of soil fertility.

The concept of environmental economics arose in the latter half of the 20th century to address the shortcomings in standard economic systems, which failed to account for both market and non-market values of natural resources (Turner *et al.*, 1993). Traditional economic systems systematically undervalued environmental resources, that is, natural capital, in comparison with financial and manufactured capital (Mebratu, 1998; Benton and Redclift, 2013). The aim of environmental economics was to capture the instrumental non-market values of natural capital in order to be able to incorporate them, along with their market values, into economic decision-making processes (Pearce, 2002). This movement drove the development of different types of economic value to capture a more comprehensive image of the economic value of the environment, termed the total economic value (TEV) (Gómez-Baggethun *et al.*, 2010; Pascual *et al.*, 2010). Although the TEV is conceptually useful to capture a range of values, this approach still does not capture the intrinsic value of nature and is confined to instrumental values from an anthropocentric viewpoint.

2.2 Economic Valuation of Ecosystem Services

The Millennium Ecosystem Assessment contributed to putting ecosystem services firmly on the global policy agenda (MEA, 2003). Ecosystem services have been incorporated in some economic decision-making structures through schemes such as Markets for Ecosystem Services and Payments for Ecosystems Services (Bayon, 2004; Gómez-Baggethun *et al.*, 2010). They are also useful as an educational method to raise public interest in biodiversity conservation and to conceptualise how

Box 2.1. Intrinsic and instrumental values

Intrinsic value is often divided into two concepts: subjective and objective. The concept of an objective intrinsic value of nature assumes that value is inherent and neither conferrable nor revocable (Soulé, 1985; Rolston, 1986; Katz, 1992; Callicott, 2006). If intrinsic value is considered to be subjective, value is created by the valuer, through their evaluative attitudes or judgements (Sandler, 2012). This latter form of intrinsic value is reason oriented and therefore open to evaluation and revision through education and persuasion.

An *instrumental value* of nature involves an anthropocentric or relational viewpoint. Nature may provide cultural, recreational or spiritual services, as well as ecosystem services such as crop pollination or provisioning services. Instrumental value, by definition, is substitutable and replaceable, that is, it assumes that a means or good may justifiably be replaced by an alternative means of equal or greater instrumental value (Sandler, 2012).

humans perceive and relate to nature (Marino and Pellegrino, 2018). Some debate exists around the interpretation of economic approaches, and the potential for commodification, with respect to traditional conservation strategies, but a thorough discussion of this is beyond the scope of this report (Costanza and Daly, 1992; Costanza *et al*., 1997; Corbera *et al*., 2007).

There are various means by which humans value ecosystem services, from a philosophical perspective to an economic perspective (Adams, 2014). From an environmental economics perspective, the TEV links ecosystem services within a broader economic context (Randall, 1987). The economic value of ecosystem services is generally broken down into use values and non-use values (Pascual *et al*., 2010). Use values include the worth of the direct benefits that people derive from a particular ecosystem service, such as growth and yield of food crops (Free, 1993), as well as the indirect benefits that arise as the result of the functioning of ecosystems. Non-use value, on the other hand, refers to the value that people attribute to the existence of an ecosystem service (Brookshire *et al*., 1983; Cicchetti and Wilde, 1992; Hutchinson *et al*., 2018). For example, studies have shown that people value distant coral reefs, even if they never plan to visit them or in any way "use" the resources/services derived from them (Subade and Francisco, 2014; Marre *et al*., 2015). Non-use value can also include the value associated with the currently unrealised but potential future benefits of the ecosystem service (called the bequest value), for example potential future crop production (Raymond *et al*., 2009).

Approaches to valuing services can be both monetary and non-monetary (Table 2.1). Although monetary valuations can be more controversial, they are useful in cost–benefit analyses, the cost of environmental degradation can be integrated into macroeconomic indicators and they are useful as a communication tool for policymakers and the business sector (Coscieme and Stout, 2019). Non-monetary approaches, using biophysical accounts, are less controversial but produce results that are less impactful for policymakers and which are difficult to aggregate into a total ecosystem value or use in cost–benefit analyses.

2.3 Value of Pollinators and Pollination Services

Pollination plays a vital role in many aspects of both agricultural and horticultural industries, as well as in terms of supporting and regulating healthy ecosystems and maintaining biodiversity (Free, 1993; O'Neill, 1997; Allen-Wardell *et al*., 1998). Pollination is an intermediate ecosystem service in that it indirectly benefits humans by facilitating other goods and services, such as crop production or landscape aesthetics, through mediating the reproduction of flowering plants. The value of pollination services may thus be measured indirectly through the final goods that are produced (e.g. food crops or wild flower diversity in the landscape). The direct use, or consumptive, value of these goods can be estimated by using their market prices as a proxy, for example the current market price of apples (Garratt *et al*., 2014), or through the cost of replacement of pollinator services by some other means (Allsopp *et al*., 2008). Alternatively, values can be inferred from revealed preferences, for example using travel cost methods for areas of natural beauty. Pollinators can also be valued as final ecosystem services in themselves, but to value this requires alternative approaches to valuation (such as stated preference approaches to

Table 2.1. Methods for assessing ecosystem service values using monetary and non-monetary approaches

Monetary				Non-monetary
Market values		Non-market values		Biophysical accounts
Direct use values	Indirect use values	Preference-based values		
Goods bought and sold on conventional markets	Replacement costs or costs avoided	Revealed preferences: as a result of behaviour or action, e.g. hedonic pricing, travel costs	Stated preferences: contingent valuation, from surveys/ questionnaires, e.g. willingness to pay	Biophysical units over fixed time periods are used to represent amount of service provision

calculate willingness to pay). The Pollival literature review (Murphy and Stout, 2019; carried out as part of this project) focused on market-based valuation approaches for pollinators, with an emphasis on the use (consumptive) value of pollination services (e.g. crop production and honey production). There are a number of different approaches to estimate the economic value of pollinators to crop production, which vary in their complexity and empirical data requirements (see section 3.1) (Breeze *et al*., 2016).

Extensive research has also been carried out into the health and well-being benefits that accrue from green spaces, which pollinators play an important role in sustaining (Maas *et al*., 2006; Lee and Maheswaran, 2011). Other economic values associated with pollination services include option and insurance values. These are both non-use values (Pascual *et al*., 2010), but can be quantified via monetary means. Option values refer to the private willingness to pay (or choice option) for maintaining pollinators even if it is unlikely that an individual will benefit from them in the future (Fisher, 2000). Insurance value is associated with the reduction in the risk of losing the benefits provided by the pollination service (Stefan, 2008).

Pollinators and the pollination services they provide are a good case study for reviewing economic valuation approaches to ecosystem services, as there have been several studies carried out on the various economic, health and socio-cultural benefits they provide (e.g. economic, aesthetic, recreational) (Klein *et al*., 2007; Junge *et al*., 2015; Lindemann-Matthies and Brieger, 2016). The value of pollinators to global food production has previously been estimated as €153–505 billion per year (Gallai *et al*., 2009; Lautenbach *et al*., 2012; Potts *et al*., 2016). The potential economic implications of pollinator decline for the global agri-food sector are substantial. The 2016 IPBES assessment of pollinators, pollination and food production investigated methodological approaches to the valuation of pollination services for food crops, but the value of services to all plants should be considered (Pascual *et al*., 2017). The combined use of economic, socio-cultural and holistic valuation of biodiversity and ecosystem services, using multiple knowledge systems bringing different perspectives from different stakeholder groups, should provide the evidence base for the management of, and decision-making about, biodiversity conservation (Christie *et al*., 2006).

Economic valuation of ecosystem services is a useful approach to inform decision-making processes with respect to conservation and sustainability goals. Many of the economic values associated with ecosystem services are not represented in market transactions, which are limited to consumptive use cases (Costanza *et al*., 1997). This can result in the economic impacts of changes in ecosystem services being systematically underestimated in decision-making processes and lead to unsustainable use of resources (Mace, 2014). Economic valuation can also be a useful method to quantify the impact of changing ecosystem service provision on the economic welfare of specific groups of people (e.g. farmers). Therefore, it can be a useful tool to inform decision-making processes with regard to policy, public spending and management of natural resources (Daily *et al*., 2009; Fisher *et al*., 2009; de Groot *et al*., 2010b).

3 Market Values of Pollination Services

3.1 Methodologies for Calculating the Market Value of Pollination Services

The current body of literature on economic valuation of pollination services takes a number of different approaches to estimate market value, with each approach varying in complexity (Table 3.1). These range from the simple use of crop prices as a proxy for pollination service value to more complex production functions, which attempt to quantify the relationship between crop production and pollination services. These approaches are restricted to capturing the market price of crop production that pollination services underpin, and therefore do not capture the complete value (market and non-market) of these services.

Most economic valuation studies for pollination services focus on scenarios of broad pollinator loss, which gives a static snapshot of current value across all habitat types. An alternative approach is to value ecosystem services relative to a unit change in habitat or yield, referred to as the marginal value (Turner *et al*., 1993). The simplest approach involves applying the market price of animal-pollinated crops as a proxy for the value of pollination services (Matheson and Schrader, 1987). A more refined development of the aggregate crop price method involves assigning a “dependency ratio”, which is an estimate of the proportion of crop production that depends on animal pollinators (Carreck *et al*., 1997; Gallai *et al*., 2009). There is a reasonable body of literature on dependence ratios across a wide range of crop species, which means that this approach is readily applicable for valuation studies (Klein *et al*., 2007). The simplicity of this approach allows it to be used for large-scale global assessments of pollinator value (Gallai *et al*., 2009), but this ignores variability in dependency among crop varieties and in different environmental contexts, and does not take into account the quality of the crop at harvest (e.g. in terms of nutritional content, taste or size of fruit).

Despite the limitations, several studies have used the dependence ratio approach to represent the proportion of total crop output lost in the absence of pollination services to estimate the market value. Gallai *et al*. (2009) calculated the contribution of insect pollination to agricultural output using this approach and estimated that the absence of pollinators would reduce production and diminish the capacity to nourish the world population. They estimated the economic value of pollinators in terms of the economic surplus loss for consumers to assess the social cost of pollinator decline. Smith *et al*. (2015) explored the health risks associated with decreased intake of animal-pollinated foods. They estimated that pollinator loss and resultant dietary changes and micronutrient deficiencies could lead to 1.42 million additional deaths annually from non-communicable and malnutrition-related diseases. These studies highlight the fact that the impact of pollinator loss on global food production can have economic consequences in terms of reduced production and increased health-care costs, as well as impacts on human mortality rates.

Given the restricted data availability for crop pollination in Ireland, and to evaluate the impact of pollinator loss on home-produced crops as well as those that are imported to Ireland, the Pollival project selected the dependence ratio approach to determine direct-use, market values of pollination services. Data on global crop production and trade were available from the Food and Agriculture Organization of the United Nations (FAO) Statistics Division, via FAOSTAT (www.fao.org/faostat), which provides open access to food and agriculture data for over 245 countries and territories worldwide, from 1961 to the present. A global approach was chosen because Ireland is a net importer of animal pollinated crops and the potential impact of global pollinator decline on market prices for tradeable crops such as cocoa beans, through reductions in global supply, could negatively impact Ireland’s trade balance in these crops.

Table 3.1. Some approaches to estimating the market value of pollination services, with pros and cons

Method	Approach	Pros and cons	Citation
Aggregate crop price	Total market value of animal-pollinated crops; assumes a complete dependence of production on pollination services, i.e. all production of animal-pollinated crops would cease in the absence of pollinators	Pros: simple data requirements and applicable at all spatial scales Cons: incorrect to assume complete dependence for most crops and ignores the ability of producers to substitute between crops or pollination sources	Matheson and Schrader (1987)
Dependence ratios	Estimate of the proportion of crop production that depends on animal pollinators or would be lost in the absence of pollinators	Pros: simple, used for large-scale global assessments; data available for a wide range of crops Cons: ratio can vary between varieties; does not take into account nutritional content, taste or size of fruit; assumes services at maximum levels and that the effects of other inputs are minimal; neglects the marginal benefits of changes in pollinator populations or the ability to substitute between crops	Carreck *et al*. (1997); Klein *et al*. (2007); Gallai *et al*. (2009); Garratt *et al*. (2014)
Yield analysis	Conceptually similar to the dependence ratio but depends on primary data collected from the field, as opposed to secondary data sources	Pros: captures more precise variations between cultivars and growing systems of the same crop Cons: more labour intensive – requires specific testing of all combinations of cultivars and growing systems to generalise to different possible scenarios; fails to capture the impact of pollination services on crop quality	Stanley *et al*. (2013); Garratt *et al*. (2014); Klatt *et al*. (2014)
Managed pollinator prices	Measure of the market price of managed pollination services (e.g. rental or purchase of bees)	Cons: restricted to only those species of pollinators that can be managed; restricted to countries with well-developed markets for crop pollination; prices often influenced by other factors, e.g. management costs, honey yield or price of the crop, or prices fixed regardless of crop. Market price for managed pollinators often reflects the market forces influencing the price of producing and supplying bees; role of wild pollinators is not included	Carreck *et al*. (1997); Burgett *et al*. (2004); Sumner and Boriss (2006); Rucker *et al*. (2012)
Replacement costs	Costs of substituting wild pollinators with technology or with managed pollination services	Cons: costs are influenced by factors such as the costs of labour and fuel; efficacy of different forms of artificial pollination can vary between crop species	Delaplane *et al*. (2000); Allsopp *et al*. (2008); Rucker *et al*. (2012); Melathopoulos *et al*. (2014)
Production function models	More complex, mechanistic modelling of interactions between pollinators and crops to describe the functional relationship with crop output	Pros: incorporates a range of inputs (including fertilisers, pesticides and labour) with environmental factors (e.g. water, temperature) to estimate the benefits of pollination relative to other factors. Could be a powerful tool for tracing back landscape-level effects to individual components (e.g. pollinators, floral resources) Cons: high empirical data requirements for ecological functioning and plant–pollinator interactions at a mechanistic level; difficult to reduce the underlying processes to a simple model structure	Lonsdorf *et al*. (2009); Hanley *et al*. (2014)
Surplus valuation models	Econometric modelling approaches (i.e. impact on producer and consumer economic welfare). Based on economic equilibrium models to estimate the impacts of pollinator loss on consumer welfare (measured as consumer surplus or the disparity between the price paid by consumers for a good or service and their maximum willingness to pay)	Cons: does not take into account substitution between crops or the relative effects of other inputs	Southwick and Southwick Lawrence (1992); Kevan and Phillips (2001); Gallai *et al*. (2009)

Table 3.1. Continued

Method	Approach	Pros and cons	Citation
General equilibrium model	Accounts for both the capacity for producers to compensate for pollinator loss with other inputs and the effects of such losses on external linked markets	Pros: can capture the effects of pollination service changes on both the affected crop market and other related markets; can be used for internationally traded crops Cons: sensitive to quality of data, difficult to obtain accurate empirical estimates on a crop-variety-specific basis, need accurate definitions of substitution effects; poorly understood how key ecosystem variables influence key economic variables	Jones (1965); Tschirhart (2000); Farber *et al.* (2006); Bauer and Sue Wing (2016)

The Pollival literature review (Murphy and Stout, 2019) provides more detail on the different economic approaches to the market valuation of pollination services.

Source: adapted from Potts *et al.* (2016).

3.2 Value of Pollinators to Global Trade and Implications of Pollinator Loss

3.2.1 Methodology

A computational framework was developed (in R) to model the impact of pollinator decline on trade in 74 major internationally traded animal-pollinated crops (70 single crop species plus four commodity crops) using trade data from 159 countries from 2005 to 2014 recorded in the FAOSTAT database. Commodity crops are aggregations of closely related crops into one category in the database, for example cucumbers and gherkins are aggregated into one commodity. The four commodity crops used in the analysis were green beans; fresh fruit, NES (not elsewhere specified); tropical fresh fruit, NES; and nuts, NES.

In considering the impact of reduced crop production as a result of pollinator loss on global market crop prices, the economic concept of price elasticity is useful to quantify the price sensitivity of demand for goods/services. This describes the relationship between demand for a particular commodity and the price, as the percentage change in quantity demanded relative to the percentage change in the price. This is generally a negative relationship, with demand decreasing in response to increasing price. For example, a commodity with a price elasticity of 0.7 means that a 10% increase in the price of the commodity is associated with a 7% decrease in the quantity demanded. This simple relationship can be used to make a general estimate of the market prices of animal-pollinated crops under scenarios of reduced production as a result of pollinator loss.

A second important component of this model was the dependence ratio data from Klein *et al*. (2017). The dependence ratio is a measure of the proportional decrease in production of animal-pollinated crops in the absence of pollinators. The dependence ratio can be used to produce a general estimate of the reduction in yields for specific crops in the absence of pollinators.

3.2.2 Results

Together, dependence ratio data and price elasticity statistics were used to estimate the change in production yields and market prices, respectively, under a scenario of total global pollinator loss. Two scenarios were created based on the upper and lower end of each dependency ratio range presented by Klein *et al*. (2007). For example, given a range of 10–40%, the best-case scenario assumes a dependence ratio of 10% and the worst-case scenario assumes a dependence ratio of 40%. A further two scenarios were created by assigning appropriate price elasticities using the upper and lower limits of the 95% confidence intervals calculated by Andreyeva *et al.* (2010). The two price elasticities combined with the two levels for the dependence ratio resulted in four separate scenarios being modelled for each crop: high/low pollinator dependence and high/low price elasticity.

The FAO data record that the net trade (balance of trade, i.e. the difference between imports and exports) for the 74 selected animal-pollinated crops varied between +US$44 and –US$30 billion (unadjusted) per year for each of the five major continental regions of the world (Europe, the Americas, Africa, Asia and Oceania) between 2005 and 2014 (Figure 3.1a). These data do not include home consumption (i.e. crops that are grown and consumed in the same country) or trade in intermediate goods derived from pollinated crops (e.g. re-exporting imported primary products in the form of processed foods). This increases the uncertainty around the results as these factors could lead to an underestimation or an overestimation of the total market value because of differences in the relative importance of these factors in the local economy. The Americas, Africa and Oceania each had a trade surplus with respect to animal-pollinated crops, whereas Europe and Asia had a trade deficit. However, with pollinator loss, under all four modelled scenarios of pollinator dependence and price elasticity, every region was projected to have an annual trade deficit with respect to the study crops, ranging from US$13–50 billion in Europe to US$180–690 billion in Asia (Figure 3.1b).

In total, global pollinator loss would result in an overall global cumulative trade deficit of between US$292 billion and US$1.26 trillion per year (equivalent to €260 billion–€1.11 trillion, using an exchange rate of US$1 = €0.88). In reality, global demand would exceed supply if all countries maintained current levels of consumption after global pollinator loss. In reality this could not occur, as populations would inevitably have to reduce consumption or find alternative food sources in the face of rising costs and limited supply (with potential nutritional and public health consequences (Smith *et al*., 2015). However, this hypothetical scenario is a useful approach to estimate the value of animal pollinators to individual countries. It provides a measure of the cost to maintain current consumption levels in the face of increasing market prices.

Some countries were not included in the analysis, which was restricted to 159 countries for which sufficient data were available on the FAOSTAT database to make an estimate of the net trade balance for animal-pollinated crops. However, even for the countries for which data were available, it must be noted that the FAOSTAT database is limited in its ability to capture locally traded commodities within countries or unofficial trade across borders, and there is some variation in the quality of the data reported between countries. Therefore, per-country estimates of the cost of pollinator decline are likely to be underestimated, particularly in poorer nations and for particular crops, where local exchange of goods predominates over international trade.

3.3 European Context

At a European level, the cost savings that pollinators accrued to individual nations over the study period varied considerably depending on their level of exposure. For example, in several European countries the cost of pollinator loss was calculated to exceed 20% of the total value of agricultural production (i.e. Ukraine, Sweden and Bulgaria; Figure 3.2). For all of the European countries studied, the predicted impact of pollinator loss (under the worst-case scenario of high dependency and total global pollinator decline) is

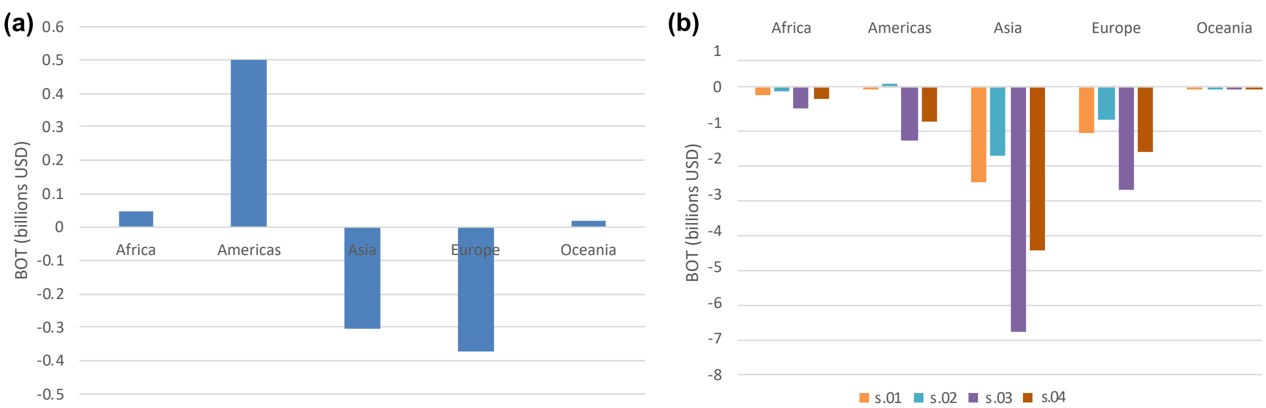

Figure 3.1. Balance of trade (BOT) for animal-pollinated food crops (a) for the five major continental regions of the world and (b) under each of the four scenarios of pollinator loss. DR (dependence ratio) and E_d (price elasticity of demand) input values: s.01 = low DR, low E_d; s.02 = low DR, high E_d; s.03 = high DR, low E_d; s.04 = high DR, high E_d.

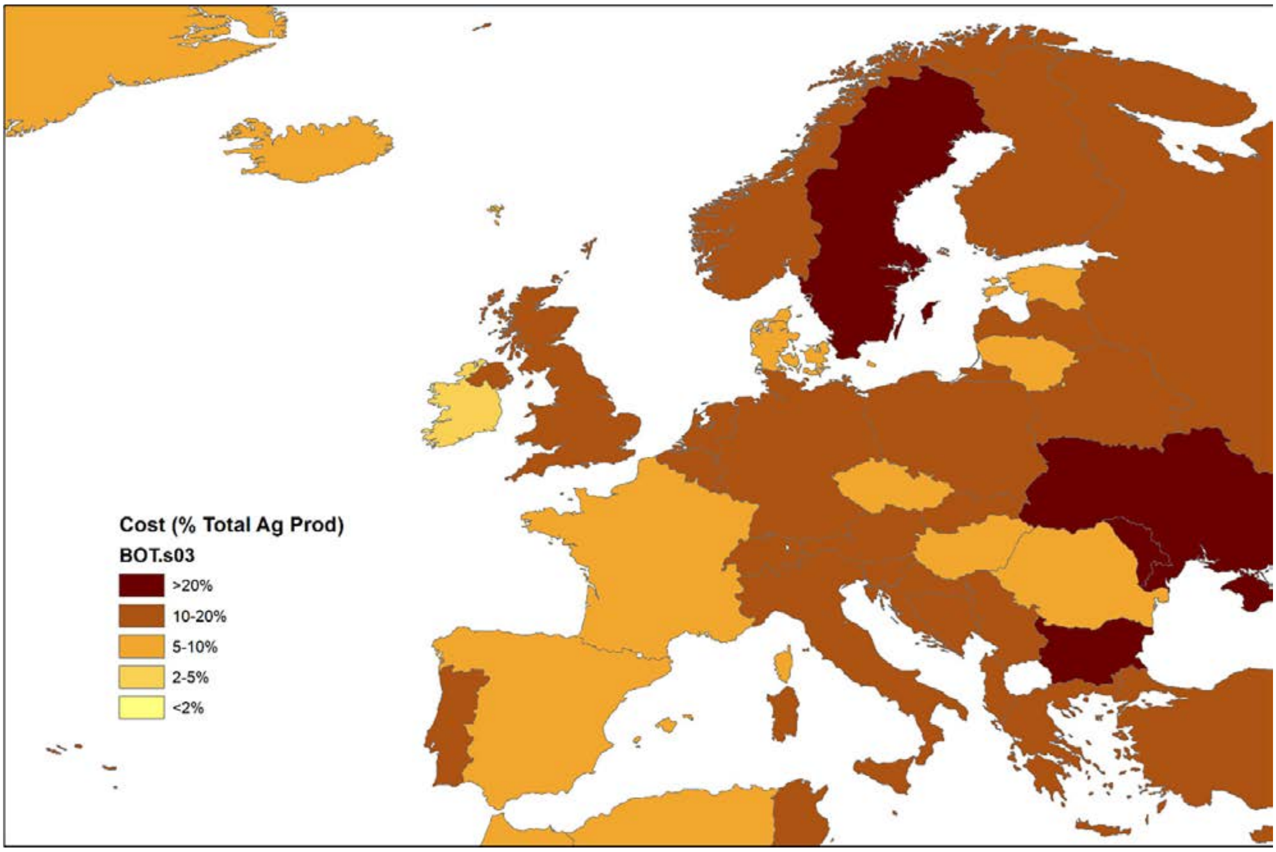

Figure 3.2. Model predictions of the cost of pollinator decline across Europe (in terms of decreased home production and increased cost of imports of animal-pollinated crops) expressed as a percentage of the gross value of total agricultural production. BOT, balance of trade, using DR (dependence ratio) and E_d (price elasticity of demand) input values for s.03, i.e. high DR, low E_d.

expected to be at least 2% of total agricultural output. In Ireland, the predicted impact represents 2–4% of the total gross value of agricultural production.

3.3.1 Case study countries

In this study, four European countries, some of Ireland's nearest neighbours and important trading partners (the UK, France, Spain and Germany), were selected to demonstrate how variation in the crop profile of different countries can influence the economic risks associated with pollinator decline (Figure 3.3). A common theme across all four European nations was the importance of imported animal-pollinated crops, particularly cocoa beans and coffee, for the local economy. For example, in the case of the UK, France and Germany, a large proportion of the economic impact of global pollinator decline is expected to be associated with three crops in particular: apples, cocoa beans and coffee (green). Of these, only apples are produced locally in significant quantities in these countries, highlighting their vulnerability to disruptions to their supply chains.

On the other hand, Spain is an important producer and exporter of peaches, nectarines and melons. Therefore, the economic impact of pollinator decline will be felt most through impacts on local production yields of these crops. Spain is also somewhat more diversified than the other countries, with the top three crop categories making up only 42% of the total impact of pollinator decline, compared with 44% and 48% in France and the UK, respectively. Germany is the least diversified of the four nations studied, with the majority (61%) of the cost of pollinator decline concentrated in the top three crop categories (cocoa, coffee and apples). Indeed, the top two commodities on which Germany would suffer economic losses in the event of pollinator decline are both imported. This makes the German economy more susceptible to changes in the global market prices of these commodities.

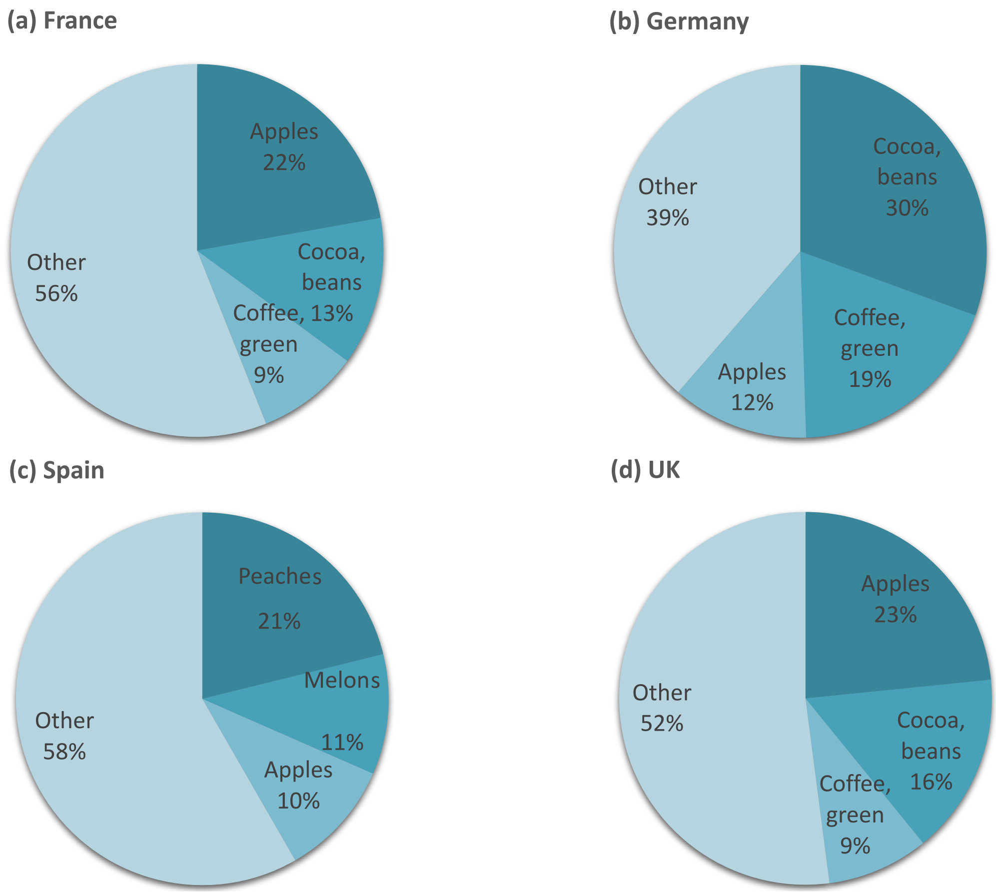

Figure 3.3. Case studies: a summary of the top three animal-pollinated crops that, in the event of global pollinator loss, are predicted to have the biggest local economic impact for (a) France, (b) Germany, (c) Spain and (d) the UK.

3.4 Discussion

The scale of the potential financial costs and risk associated with global pollinator decline is considerable, with costs and risks similar to those driven by climate change. The financial costs are likely to affect economies to different degrees around the world, depending on their levels of exposure, reliance on animal-pollinated crops and whether they are producer or consumer nations. Therefore, from an economic perspective, maintaining healthy pollinator populations should be a matter of utmost priority on national and international policy agendas (Potts *et al*., 2016; Tengö *et al*., 2017). However, when considering the value of pollinators to a particular country, it is important to go beyond local impacts on home-produced crops and consider the network of trading partners relied on to meet local demand. In an era of globalised markets and global supply chains, the effects of pollinator decline in one country can have far-reaching impacts across all economic regions around the world. In addition, declines in pollinators also risk reinforcing global inequalities in trade and prosperity because of developing nations having a reduced economic capacity to absorb these costs. The results demonstrate that even large established economies such as those of the UK or Germany are not insulated against the risks of pollinator decline, because of potential effects on both local production capacity and trade in key crop species such as soybeans, cocoa beans and fresh fruit.

This approach has its limitations. For simplicity, the model ignored substitution effects (i.e. the potential for growers to replace animal-pollinated crops with other crops) because of a lack of reliable empirical estimates of substitutional elasticities at a crop-specific level. This could result in overestimation of the economic impact of pollinator decline, if suitable alternative crops could be substituted into diets without detrimental health effects. Similarly, if crops complement one another and one is impacted by pollinator loss and the other not, but the demand for the second falls because of loss of the first, this approach could underestimate the economic impacts of pollinator loss. Again, it was not possible to incorporate this complexity into the model. In addition, a constant price elasticity was assumed in this study, regardless of changes in the quantity of supply. This is acceptable for crops with a low ratio of dependence, as the price range will not vary as much from current prices. However, it is less reliable for crops with a high ratio of dependence as the supply, and thus price, would change considerably from its current value. Despite being limited to short-run/first-round impacts only, the lack of inclusion of substitution or complementarity in demand for agricultural products and the fact that no effects on intermediate production or profits on exports of processed goods are considered, this method is useful for comparing potential economic impacts of pollinator loss between countries and regions.

3.5 Importance of Animal-pollinated Crops to the Irish Economy

There are well documented reports of declines of pollinators in Ireland, with more than half of Ireland's bee species declining since 1980 and 30% of species considered threatened with extinction from Ireland according to International Union for Conservation of Nature (IUCN) criteria (Fitzpatrick *et al*., 2007). There are several sectors of the economy whose activity may affect pollinators and the provision of services in Ireland. This includes the agri-food and drink sector, including food processing, which in 2018 accounted for 7.7% of the goods and services produced by Ireland's economy, 10.0% of Ireland's exports, and 173,000 jobs (DAFM, 2019). The Food Harvest 2020 strategy (Department of Agriculture, Food and the Marine) and the Going for Growth strategy (Agri-Food Strategy Board, Northern Ireland) highlight the importance of the agri-food sector to export-led economic recovery. Pollinators play a key role in fulfilling this by maximising yields from current crops and those that may be important in the future, for example with the changing climate and changing consumer preferences and demands.

The TEV of pollinators to the Irish economy is likely to be greater than currently estimated (Bullock *et al*., 2008). Relative to other countries, Ireland does not currently grow large numbers of crops that are animal pollinated (see Table 3.2 for a list of the main animal-pollinated crops grown in Ireland). In addition, current estimates do not take into account

Table 3.2. Main animal-pollinated crops grown in Ireland

Crops		Area of each crop (hectares)	Market value (€ × 10^6)
Outdoor crops			
Apples (culinary and dessert)	*Malus domestica*	439	4.1
Apples (cider)	*M. domestica*	176	0.8
Blackcurrants	*Ribes nigrum*	68.2	0.3
Strawberries	*Fragaria* spp.	15.3	0.5
Blueberries	*Vaccinium* spp.	NA	NA
Raspberries	*Rubus idaeus*	4	0.1
Other soft fruit		2.2	0
Indoor crops			
Strawberries	*Fragaria* spp.	153.3	27.8
Raspberries	*R. idaeus*	19.8	2.1
Tomatoes	*Lycopersicon esculentum*	9.9	6.9
Cucumbers	*Cucumis sativus*	8	1.4
Other soft fruit		11	0.9

Sources: Department of Agriculture, Food and the Marine – National Soft Fruit and Protected Vegetable Census 2013 (see URL: https://www.agriculture.gov.ie/media/migration/farmingsectors/horticulture/horticulturestatistics/SoftFruitProtectedVegetableCensus2013050515.PDF; accessed 13 February 2019); National Field Vegetable Census 2009 (see URL: https://www.agriculture.gov.ie/media/migration/farmingsectors/horticulture/horticulturestatistics/NationalFieldVegetableCensus2009270710.pdf; accessed 13 February 2019); and National Apple Orchard Census 2012 (see URL: https://www.agriculture.gov.ie/media/migration/farmingsectors/horticulture/horticulturestatistics/NationalAppleOrchardCensus2012221013.pdf; accessed 13 February 2019).
NA – not available.

the full value of pollinators to forage crops (including clovers), in pest control (e.g. the role of hoverflies as natural enemies of pests of cereal) or to private gardeners and communities, who grow a wide range of animal-pollinated fruits and vegetables. In addition, globally, the market share of animal-pollinated crops is rising, and Ireland imports large quantities of animal-pollinated crops for local processing and consumption. Pollinators also play an important role in maintaining healthy farm ecosystems, which are a prerequisite for sustainable agricultural production. Maintaining biodiversity in the farm system futureproofs how the land can be used for generations to come. Reliable data on the full value of pollinators to the Irish agri-economy are not available but, using data on production and trade, along with data on pollinator dependence, quantification of the cost of pollinator loss to the Irish economy can be made.

3.5.1 Methodology for calculating changes to net trade balance under global pollinator loss

The results for Ireland were calculated using the methodology described in section 3.2. An R script was developed for the purposes of processing and calculating the change in trade balance for the selected subset of crop species with and without pollinators. The main data sources, from the United Nations FAOSTAT database, were global crop production data ("crops" and "crops processed") and trade data (from the "detailed trade matrix"). These data (for all countries) were downloaded from the FAOSTAT database on 13 November 2018. A list of animal-pollinated crop species (Table 3.3) was then used to filter the data and import it into R for further processing and analysis.

Step 1 of the pipeline involved general extraction and transformation of the data to extract production data and import/export data (values in thousands of US dollars and quantities in tonnes) by crop type and year (Table 3.4).

In step 2, the cumulative net trade in animal-pollinated crops for Ireland over the years 2005–2014 was calculated by subtracting the value of imports from the value of exports (in thousands of US dollars) for each crop type (equation 3.1). Local demand (D_c) for each crop species was calculated by summing the production (P_c, tonnes) plus the difference between the quantity of imports (I_c, tonnes) and quantity of exports (E_c, tonnes) for that country:

$$D_c = (P_c + I_c) - E_c \tag{3.1}$$

Calculating the local demand for a crop species is an important step in estimating the impact of pollinator loss as it is used in the model to calculate the shortfall in production compared with demand under scenarios of pollinator loss.

In step 3, a scenario of global pollinator loss was modelled by calculating the impact that this would have in terms of the production of crops and their market prices. The existing market prices were calculated for each crop species based on the unit price for imports/exports as recorded on the FAOSTAT trade matrix, which represents the value of the goods as recorded for crossing between countries (including transportation costs).

The predicted price of each crop under the scenario of pollinator loss (P_l) was estimated as a function of the price elasticity of demand (E_d) and the dependence ratio (D) (equation 3.2):

$$P_l = P\left(1.0 + \frac{D}{E_d}\right) \tag{3.2}$$

The price elasticity of demand for each crop is listed in Table 3.3. In each case, two alternative scenarios were applied, representing the higher and lower values from the 95% confidence intervals calculated by Andreyeva *et al*. (2010).

In step 4, the updated trade balance for each crop was calculated, assuming the absence of pollinators. First, the production figures for each crop were calculated by applying the dependence ratios from Klein *et al*. (2007) to represent the reduction in yields. Klein *et al*. (2007) listed four categories of dependence with ranges for each category (>0% to <10%; 10% to <40%; 40% to <90%; and ≥90%). We carried out analyses for two scenarios, the first of which used the lower end of the ranges from Klein *et al*. (2007) (0%, 10%, 40% and 90%) and the second of which used the higher end of the Klein *et al*. (2007) ranges (10%, 40%, 90% and 100%).

The next step involved calculating the difference in demand (in tonnes) compared with local production under the new Klein *et al*. (2007) scenarios. Where a shortfall exists, the quantity of exports of that crop

Table 3.3. Input parameter values used in the model and list of animal-pollinated crops included in the analysis

Item code (FAO)	Crop/commodity	DR (low)	DR (high)	E_d (low)	E_d (high)
89	Buckwheat	0.4	0.9	0.44	0.71
176	Beans, dry	0	0.1	0.41	0.98
181	Broad beans, horse beans, dry	0.1	0.4	0.41	0.98
195	Cow peas, dry	0	0.1	0.44	0.71
197	Pigeon peas	0	0.1	0.44	0.71
203	Bambara beans	0	0.1	0.44	0.71
211	Pulses, NES	0	0.1	0.44	0.71
217	Cashew nuts, with shell	0.4	0.9	0.41	0.98
220	Chestnuts	0.1	0.4	0.41	0.98
229	Brazil nuts, shelled	0.9	1	0.41	0.98
231	Almonds, shelled	0.4	0.9	0.41	0.98
234	Nuts, NES	0	0.1	0.41	0.98
236	Soybeans	0.1	0.4	0.41	0.98
237	Oil, soybean	0.1	0.4	0.29	0.66
242	Groundnuts, with shell	0	0.1	0.41	0.98
249	Coconuts	0.1	0.4	0.41	0.98
257	Oil, palm	0	0.1	0.29	0.66
258	Oil, palm kernel	0	0.1	0.29	0.66
263	Karite nuts (shea nuts)	0.1	0.4	0.41	0.98
267	Sunflower seeds	0.1	0.4	0.41	0.98
268	Oil, sunflower	0.1	0.4	0.29	0.66
270	Rapeseed	0.1	0.4	0.41	0.98
271	Oil, rapeseed	0.1	0.4	0.29	0.66
280	Safflower seeds	0	0.1	0.41	0.98
281	Oil, safflower	0	0.1	0.29	0.66
289	Sesame seeds	0.1	0.4	0.41	0.98
290	Oil, sesame	0.1	0.4	0.29	0.66
292	Mustard seeds	0.1	0.4	0.41	0.98
329	Cottonseed	0.1	0.4	0.41	0.98
333	Linseed	0	0.1	0.41	0.98
334	Oil, linseed	0	0.1	0.29	0.66
388	Tomatoes	0	0.1	0.44	0.71
394	Pumpkins, squash and gourds	0.9	1	0.44	0.71
397	Cucumbers and gherkins	0.4	0.9	0.44	0.71
399	Eggplants (aubergines)	0.1	0.4	0.44	0.71
401	Chillies and peppers, green	0	0.1	0.44	0.71
414	Beans, green	0	0.1	0.44	0.71
420	Broad beans, green	0.1	0.4	0.41	0.98
430	Okra	0.1	0.4	0.44	0.71
490	Oranges	0	0.1	0.41	0.98
495	Tangerines, mandarins, clementines, satsumas	0	0.1	0.41	0.98
497	Lemons and limes	0	0.1	0.41	0.98
507	Grapefruit (inc. pomelos)	0	0.1	0.41	0.98

Table 3.3. Continued

Item code (FAO)	Crop/commodity	DR (low)	DR (high)	E_d (low)	E_d (high)
515	Apples	0.4	0.9	0.41	0.98
521	Pears	0.4	0.9	0.41	0.98
523	Quinces	0.4	0.9	0.41	0.98
526	Apricots	0.4	0.9	0.41	0.98
527	Apricots, dry	0.4	0.9	0.41	0.98
530	Cherries, sour	0.4	0.9	0.41	0.98
531	Cherries	0.4	0.9	0.41	0.98
534	Peaches and nectarines	0.4	0.9	0.41	0.98
536	Plums and sloes	0.4	0.9	0.41	0.98
544	Strawberries	0.1	0.4	0.41	0.98
547	Raspberries	0.4	0.9	0.41	0.98
550	Currants	0.1	0.4	0.41	0.98
552	Blueberries	0.4	0.9	0.41	0.98
554	Cranberries	0.4	0.9	0.41	0.98
567	Watermelons	0.9	1	0.44	0.71
568	Melons, other (inc. cantaloupes)	0.9	1	0.44	0.71
569	Figs	0.1	0.4	0.41	0.98
571	Mangoes, mangosteens, guavas	0.4	0.9	0.41	0.98
572	Avocados	0.4	0.9	0.41	0.98
587	Persimmons	0	0.1	0.41	0.98
592	Kiwi fruit	0.9	1	0.41	0.98
600	Papayas	0	0.1	0.41	0.98
603	Fruit, tropical fresh, NES	0	0.1	0.41	0.98
619	Fruit, fresh, NES	0	0.1	0.41	0.98
656	Coffee, green	0.1	0.4	0.14	0.53
661	Cocoa, beans	0.9	1	0.14	0.53
692	Vanilla	0.9	1	0.14	0.53
702	Nutmeg, mace and cardamoms	0.4	0.9	0.14	0.53
711	Anise, badian, fennel, coriander	0.1	0.4	0.14	0.53

Dependence ratio (DR) data for each crop were derived from Klein *et al.* (2007). Low and high values represent the low end and high end of the ranges provided by Klein *et al.* (2007). Price elasticity of demand (E_d) was applied to each crop by assigning values for the relevant food category from Andreyeva *et al.* (2010). Low and high values represent the upper and lower values from the 95% confidence intervals calculated by Andreyeva *et al.* (2010).

are reduced by the calculated shortfall, assuming a conservative scenario whereby local demand is prioritised over exports. If a shortfall still exists following the removal of all exports of a crop, only then is the quantity of imports increased to make up the remaining shortfall. This represents an unrealistic scenario as it assumes that imported crop varieties may be readily replaced by home-grown produce, which may not always be the case because of seasonality or unsuitable climatic conditions. However, it was chosen as it represents the most conservative scenario.

The updated prices for imports and exports, as calculated using the price elasticity of demand above, were used to recalculate the value of imports and exports under each pollen loss scenario and updated balances of trade were computed. The predicted trade balances under all four scenarios (high/low price elasticity and high/low dependency values) are listed in Table 3.4.

In addition, the value of Irish pollinators to home-produced food crops was calculated by excluding price elasticity from the calculations. This represents a

Table 3.4. The model inputs and outputs for all animal-pollinated crops/commodities considered in the analysis for Ireland

Item code (FAO)	Crop/commodity	Value of imports (US$ × 1000)	Value of exports (US$ × 1000)	Production quantity (tonnes)	Net trade (US$ × 1000)	Model-predicted BOT (US$ × 1000): four pollinator-loss scenarios			
						Scenario 1	Scenario 2	Scenario 3	Scenario 4
515	Apples	710,978	83,420	165,100	–627,558	–1,402,303	–999,525	–2,596,420	–1,558,904
661	Cocoa, beans	196,977	2140	0	–194,837	–1,447,361	–525,692	–1,586,530	–562,454
237	Oil, soybean	440,023	10,088	728	–429,935	–579,320	–496,046	–1,030,959	–695,909
656	Coffee, green	215,884	23,128	0	–192,756	–330,439	–229,125	–743,487	–338,232
271	Oil, rapeseed	288,724	24,697	90,439	–264,027	–368,408	–315,451	–722,586	–487,753
521	Pears	151,280	9011	0	–142,269	–281,068	–200,338	–454,567	–272,924
544	Strawberries	117,377	36,694	56,900	–80,683	–136,340	–120,791	–387,967	–276,533
268	Oil, sunflower	192,988	1461	0	–191,527	–257,571	–220,546	–455,702	–307,604
397	Cucumbers and gherkins	81,817	6752	17,900	–75,065	–163,676	–134,037	–301,722	–224,659
257	Oil, palm	652,293	7255	0	–645,038	–645,038	–645,038	–867,465	–742,771
568	Melons, other (inc. cantaloupes)	86,082	1780	0	–84,302	–256,738	–191,164	–275,897	–203,037
270	Rapeseed	26,315	49,203	334,100	22,888	–526	–466	–138,995	–99,072
534	Peaches and nectarines	79,940	6616	0	–73,324	–144,860	–103,252	–234,279	–140,662
592	Kiwi fruit	70,894	6226	0	–64,668	–206,622	–124,057	–222,395	–130,656
536	Plums and sloes	64,033	4435	0	–59,598	–117,742	–83,924	–190,423	–114,331
414	Beans, green	33,904	1903	32,876	–32,001	–79,534	–76,186	–160,012	–136,297
388	Tomatoes	527,534	44,128	56,900	–483,406	–483,406	–483,406	–606,162	–563,474
394	Pumpkins, squash and gourds	41,100	390	0	–40,710	–123,980	–92,314	–133,233	–98,048
572	Avocados	42,391	316	0	–42,075	–83,124	–59,248	–134,435	–80,715
236	Soybeans	121,725	28,594	0	–93,131	–115,846	–102,634	–183,991	–131,144
231	Almonds, shelled	32,167	1662	0	–30,505	–60,268	–42,957	–97,470	–58,522
567	Watermelons	49,535	20,435	0	–29,100	–88,623	–65,987	–95,236	–70,086
401	Chillies and peppers, green	281,046	32,441	3889	–248,605	–248,605	–248,605	–306,241	–284,674
495	Tangerines, mandarins, clementines, satsumas	246,998	24,706	0	–222,292	–222,292	–222,292	–276,510	–244,975
490	Oranges	228,667	12,689	0	–215,978	–215,978	–215,978	–268,656	–238,017
692	Vanilla	8095	839	0	–7256	–53,917	–19,583	–59,101	–20,952
571	Mangoes, mangosteens, guavas	23,510	148	0	–23,362	–46,154	–32,898	–74,644	–44,817
619	Fruit, fresh, NES	87,262	1620	84,453	–85,642	–85,642	–85,642	–133,683	–118,437
531	Cherries	17,296	498	0	–16,798	–33,196	–23,661	–53,688	–32,234
550	Currants	5050	181	3,250	–4869	–10,039	–8895	–34,911	–24,883
554	Cranberries	13,262	76	0	–13,186	–26,068	–18,581	–42,160	–25,313
176	Beans, dry	33,643	1742	152,500	–31,901	–31,901	–31,901	–58,146	–51,515
702	Nutmeg, mace and cardamoms	3689	39	0	–3650	–14,086	–6408	–27,129	–9854
497	Lemons and limes	87,704	3459	0	–84,245	–84,245	–84,245	–104,793	–92,841

Table 3.4. Continued

Item code (FAO)	Crop/commodity	Value of imports (US$ × 1000)	Value of exports (US$ × 1000)	Production quantity (tonnes)	Net trade (US$ × 1000)	Model-predicted BOT (US$ × 1000): four pollinator-loss scenarios			
						Scenario 1	Scenario 2	Scenario 3	Scenario 4
526	Apricots	9613	373	0	–9240	–18,255	–13,011	–29,523	–17,726
711	Anise, badian, fennel, coriander	6654	190	0	–6464	–11,081	–7684	–24,933	–11,342
229	Brazil nuts, shelled	7030	33	0	–6,997	–22,363	–13,427	–24,070	–14,141
290	Oil, sesame	12,179	97	0	–12,082	–16,251	–13,915	–28,752	–19,408
527	Apricots, dry	7456	358	0	–7098	–14,027	–9998	–22,685	–13,620
399	Eggplants (aubergines)	16,491	192	0	–16,299	–20,003	–18,595	–31,116	–25,482
249	Coconuts	11,887	74	0	–11,813	–14,694	–13,018	–23,338	–16,635
289	Sesame seed	9578	39	0	–9,539	–11,871	–10,517	–18,853	–13,438
507	Grapefruit (inc. pomelos)	40,183	3825	0	–36,358	–36,358	–36,358	–45,226	–40,068
267	Sunflower seed	8734	1427	0	–7307	–9089	–8053	–14,436	–10,289
234	Nuts, NES	26,512	856	0	–25,656	–25,657	–25,657	–31,915	–28,275
334	Oil, linseed	16,327	161	0	–16,166	–16,166	–16,166	–21,740	–18,615
258	Oil, palm kernel	16,226	176	0	–16,050	–16,050	–16,050	–21,584	–18,482
217	Cashew nuts, with shell	2610	148	0	–2462	–4888	–3484	–7905	–4746
600	Papayas	2067	67	0	–2000	–4010	–4010	–4988	–4419
569	Figs	2771	85	0	–2686	–3341	–2960	–5306	–3782
292	Mustard seeds	2525	59	0	–2466	–3069	–2719	–4874	–3474
329	Cottonseed	2417	31	0	–2386	–2968	–2629	–4714	–3360
333	Linseed	15,175	7483	0	–7692	–7692	–7692	–9568	–8477
181	Broad beans, horse beans, dry	1940	142	0	–1798	–2238	–1983	–3554	–2533
552	Blueberries	685	0	0	–685	–1347	–960	–2179	–1308
89	Buckwheat	648	11	0	–637	–1216	–996	–1940	–1444
220	Chestnuts	1307	26	0	–1281	–1603	–1421	–2547	–1815
530	Cherries, sour	363	0	0	–363	–707	–504	–1144	–687
523	Quinces	258	0	0	–258	–508	–362	–821	–493
281	Oil, safflower	1311	4	0	–1307	–1307	–1307	–1758	–1505
603	Fruit, tropical fresh, NES	654	0	0	–654	–651	–651	–810	–717
587	Persimmons	161	0	0	–161	–161	–161	–200	–177
Total	5,483,945	464,629	1,006,235	–5,019,316	–8,712,487	–6,545,161	–13,450,073	–8,768,759	
Change in BOT (pollinator loss)					–3,693,171	–1,525,845	–8,430,757	–3,749,443	

Inputs are the cumulative total import and export values (in US$ ×1000) for the years 2005–2014 and the cumulative total production (in tonnes), downloaded from the FAOSTAT database (on 13/11/2018). The net trade balance was calculated under four hypothetical scenarios of global pollinator loss, assuming different DR (dependency ratio) and E_d (price elasticity of demand) input values (see Table 3.3): scenario 1 = low DR, low E_d; scenario 2 = low DR, high E_d; scenario 3 = high DR, low E_d; scenario 4 = high DR, high E_d.

BOT, balance of trade.

scenario whereby pollinator loss is localised to Ireland and therefore affects only locally produced food crops. As Ireland is a small economy, this type of localised decline is assumed to not affect global market prices. Two scenarios, assuming low or high dependence ratios, were modelled giving a total value of pollinators to locally produced crops of €20–59 million. This range includes a previous estimate for Ireland of €53 million from Bullock *et al*. (2008), but note that this previous estimate included €29 million for clover, a forage crop not included in our analysis.

3.5.3 Trade in animal-pollinated crops

Large quantities of animal-pollinated crops are imported into Ireland (Table 3.5). Thus, threats to pollinators globally can impact Ireland locally and increase food prices on the open market. Relative to its imports, Ireland does not export large quantities of animal-pollinated crops, so the resulting price increases of exports would not be enough to offset increased import costs. Ireland's main exports are fruits, such as apples and strawberries, and rapeseed oil (Table 3.6). Even so, almost 10 times more apples are imported than exported (see Table 3.5). Ireland re-exports a lot of imported primary products in the form of processed foods (e.g. tomatoes in frozen pizzas), but these were not considered in the analysis because of the danger of double-counting. However, if these imported crops were to increase in price, Ireland could pass at least part of the cost on to consumers in other countries who buy the processed food.

As a result of these factors, global pollinator decline is predicted to result in an increased Irish trade deficit in animal-pollinated crops (although Ireland has an overall trade surplus when considering trade across all sectors of the economy) (Figure 3.4). Four scenarios of global pollinator decline were modelled

Table 3.5. Top 10 animal-pollinated crop imports to Ireland, ranked by import value

Crop	Import value (€ × 10^6)
Apples	71.1
Oil, palm	65.2
Tomatoes	52.8
Oil, soybean	44.0
Oil, rapeseed	28.9
Chillies and peppers, green	28.1
Tangerines, mandarins, clementines, satsumas	24.7
Oranges	22.9
Coffee, green	21.6
Cocoa, beans	19.7

Source: United Nations FAO Trade Matrix, 2005–14 (http://www.fao.org/faostat/en/#data/TM, accessed 12 November 2018).

Table 3.6. Top 10 animal-pollinated crop exports from Ireland, ranked by export value

Crop	Export value (€ × 10^6)
Apples	8.3
Rapeseed	4.9
Tomatoes	4.4
Strawberries	3.7
Chillies and peppers, green	3.2
Soybeans	2.9
Tangerines, mandarins, clementines, satsumas	2.5
Oil, rapeseed	2.5
Coffee, green	2.3
Watermelons	2.0

Source: United Nations FAO Trade Matrix, 2005–14 (http://www.fao.org/faostat/en/#data/TM, accessed 12 November 2018).

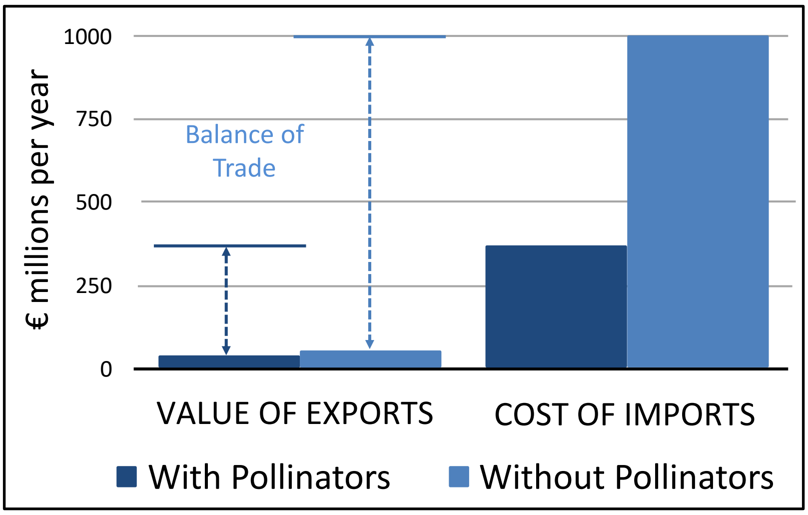

Figure 3.4. The net trade in animal-pollinated crops in Ireland currently (with pollinators – dark blue) and under hypothetical pollinator loss (without pollinators – light blue).

(scenario 1 = low dependency ratio, low price elasticity of demand; scenario 2 = low dependency ratio, high price elasticity of demand; scenario 3 = high dependency ratio, low price elasticity of demand; scenario 4 = high dependency ratio, high price elasticity of demand), with a predicted cost to Ireland's economy of €153–843 million per year. In the event of global pollinator decline, the cost of imports to meet local demand would increase substantially because of rising food prices, resulting in an increased trade deficit in animal-pollinated crops (up to threefold predicted increase in deficit). A detailed analysis of the effects on international supply chains was beyond the scope of this study but these results highlight the importance of further study into the trade dynamics of animal-pollinated crops when making policy decisions in relation to pollinator conservation. This is because reduced yields in crops such as cocoa and coffee beans, as a result of pollinator decline in producer nations, would result in increased costs for consumer nations, including Ireland. As a net importer of animal-pollinated crops, Ireland is particularly vulnerable to changes in pollinator populations at a global scale.

3.5.4 The most valuable animal-pollinated crops to Ireland by market value

The most valuable animal-pollinated crops to Ireland by market value are defined in this context as those that would have the biggest negative financial impact on Ireland in the event of global pollinator decline. These are a mix of home-produced crops (e.g. apples) and important global crops that are imported in large quantities (e.g. palm oil) (Figure 3.5). The most valuable animal-pollinated crop to Ireland by market value is apples. This is because large quantities are produced for both home consumption and export and significant quantities are also imported. Other high market value commodities such as cocoa and coffee (see Table 3.5) are important because of their high dependence on pollinators and relatively low-price elasticities.

3.5.5 Summary of Irish market values

- A decline in pollinators could result in reduced quality and/or yields for many important food crops produced in Ireland and imported from abroad.
- The average annual value of animal pollinators to home-produced crops in Ireland is estimated to have been €20–59 million per year between the years 2005 and 2014.
- However, if imports of animal-pollinated crops are taken into account, the estimated cost of global pollinator loss to the Irish economy rises to €150–840 million per year.
- This represents 2–4% of the total gross value of all agricultural production in Ireland.
- As a net importer of animal-pollinated crops, Ireland is particularly vulnerable to global declines in pollinator populations. As a net exporter of processed foods containing animal-pollinated crops, this vulnerability could be offset or reinforced.

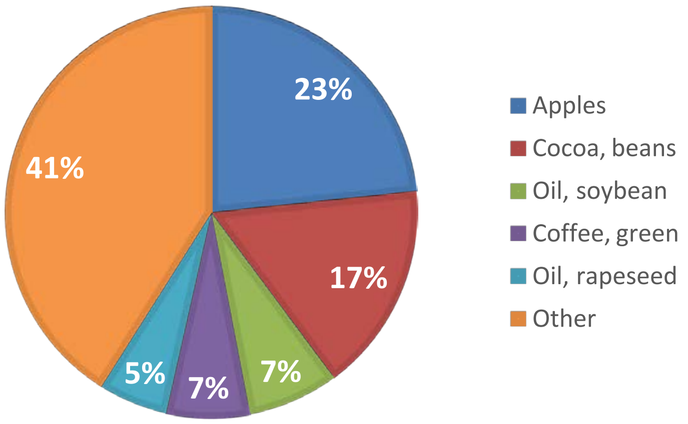

Figure 3.5. The five most valuable animal-pollinated crops to the Irish economy as a proportion of all animal-pollinated crops consumed in the country. Other = 57 other animal-pollinated crops/commodity crops considered in the analysis.

4 Non-market Values

4.1 Methodologies for Calculating the Non-market Value of Pollination

As markets for trading and price discovery do not exist for many of the “non-use” services that pollinators provide, alternative approaches to determining monetary values can be implemented. “Non-use” values associated with pollinators and pollination services include maintenance of populations of wild flowers for preserving landscape aesthetics, which contributes to human health and well-being, as well as future option values, existence values and bequest values (Pascual *et al*., 2010). For these services, non-market financial or monetary values can be estimated using preference-based approaches (see Table 2.1). These approaches are generally categorised into “revealed preferences” and “stated preferences” (Coscieme and Stout, 2019).

Revealed preference methods use market data to extrapolate the value of benefits derived from ecosystem services (Richter, 1966), for example the travel costs associated with visiting a particular natural recreational area or increased real estate value in proximity to a natural amenity (Sander and Haight, 2012; Ruhl *et al*., 2013; Price, 2014). Stated preference approaches rely on survey methodologies to elicit people’s priorities and preferences for gaining or maintaining a benefit that exists outside current markets (Breeze *et al*., 2015, 2016; Stevens *et al*., 2015; Mwebaze *et al*., 2018).

To explore non-market values, the Pollival project carried out two public surveys, one a stated preference (willingness-to-pay) survey to explore the existence value of pollinators and pollination services and the other an opinion survey to assess the potential routes of revenue for pollinator conservation strategies in Ireland.

4.2 Willingness-to-pay Public Survey

A stated preference methodological approach was used to quantify non-market existence values of pollinators (Adamowicz *et al*., 1994). An economic survey instrument was used to estimate the respondents’ welfare from the maintenance or improvement of non-market benefits from a good or service (Breeze *et al*., 2015). This approach is useful because it captures benefits beyond direct market effects and can be used to analyse public opinion. It requires complex modelling for analysis and it is important to avoid bias effects in the survey responses by ensuring a representative sample and accurate responses.

In order to ensure a representative sample of responses while ensuring adherence to European Union General Data Protection Regulations, an independent market research company was used to manage the survey (RED C Research & Marketing Ltd). The survey was conducted by developing questions that were then included on an online omnibus (the RED Line), wherein set-up costs are spread among a number of clients. Should there be a requirement to ask further questions in the future, the methodology can be easily replicated in a quick and cost-effective manner. The RED Line omnibus consists of an online panel of 40,000 members, from which a representative sample of 1000 adults aged 18+ years across Ireland was taken. Quotas across gender, age, region and class were applied to ensure that the final sample was representative of the Irish population aged 18+ years.

The survey was carried out in August 2017. Six questions were delivered online to 1000 adults over the course of a weekend, with the questions finalised (closed off to further answers) on the Wednesday and the results delivered by RED C a week later. The total cost for RED C to implement this survey was €5006 on a data-only basis (i.e. not including data analysis).

The aim of the survey was to assess the general public’s willingness to pay for public measures to halt or reverse the decline of pollinators in Ireland and to gain insight into their opinions, in order to inform policy. Before filling in the survey, respondents were asked to read a brief introduction to pollinators in Ireland (Box 4.1).

The stated preference approach involves using survey or experimental-based instruments to elicit

Box 4.1. Text on pollinators in Ireland included in the RED C survey

In Ireland, almost 80% of our flowering plants benefit from bees, and other insect pollinators, which move pollen between plants and fertilise them to produce seeds and new plants. Without pollinators there would be significantly less variety of flowers in our landscapes (Figure 4.1). However, there is evidence that half of our 100 bee species in Ireland are in decline, and one-third are threatened with extinction by 2030. These declines are due to a lack of food (flowers) and safe nesting sites for insects, and the declines are expected to continue unless action is taken. One option is for the Irish government to use public funds to help reverse these declines. This could involve sponsoring educational programmes in schools and local communities or paying farmers and landowners some small subsidies to create and maintain habitats for bees, for example sowing flowers alongside road verges or planting meadows on less productive farmland.

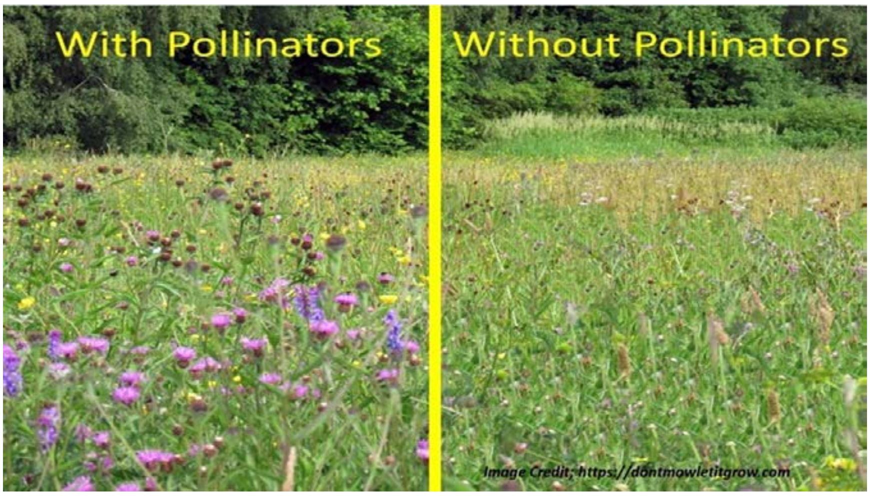

Figure 4.1. A visual example of what a natural meadow in Ireland would look like with and without insect pollinators.

respondents' willingness to pay for ecosystem goods and services within a hypothetical market. Respondents were presented with a questionnaire consisting of discrete choices (option sets) for bundles of ecosystem goods or services. Prices were assigned to these bundles to estimate the economic value of each bundle to respondents.

The order of options for the following five scenarios was rotated for each scenario. For every scenario the "I do not currently pay tax" was always the first option shown. Each scenario (1–5; Tables 4.1–4.5) contained three different options (options 1–3; Tables 4.1–4.3). The respondents were asked to select between the three costed approaches.

Q6 consisted of a series of 10 statements (Box 4.2) about the environment and personal attitudes towards it. Respondent were asked to state to what extent they agreed or disagreed with each statement, using the following five options: "agree strongly", "agree slightly", "neither agree or disagree", "disagree slightly" or "disagree strongly".

4.2.1 Key findings

The stated preference approach to estimating willingness to pay requires complex modelling for analysis and it is important to avoid bias effects in the survey responses by ensuring a representative sample and accurate responses. However, during the survey design phase, an initial assumption (that the cost of saving the bees would go up proportionally with the number of bees saved) introduced a strong fundamental bias. This was only picked up during the subsequent analysis phase, which means that it was not possible to produce an accurate willingness-to-pay estimate. Given the cost of the survey, it was not possible to repeat it within the Pollival project.

Table 4.1. Option set 1

	Option 1	Option 2	Option 3
Amount of bees living in the landscape compared with now	40% less	30% less	Same as now
Variety of wild flowers in local green spaces compared with now	30% less	20% less	10% less
Monthly tax increase to you	€0	€1.50 (€18 per year)	€12.50 (€150 per year)
Select only 1			

Table 4.2. Option set 2

	Option 1	Option 2	Option 3
Amount of bees living in the landscape compared with now	40% less	10% less	20% less
Variety of wild flowers in local green spaces compared with now	30% less	Same as now	30% less
Monthly tax increase to you	€0	€6 (€72 per year)	€2.50 (€30 per year)
Select only 1			

Table 4.3. Option set 3

	Option 1	Option 2	Option 3
Amount of bees living in the landscape compared with now	40% less	Same as now	10% less
Variety of wild flowers in local green spaces compared with now	30% less	20% less	20% less
Monthly tax increase to you	€0	€11.50 (€138 per year)	€6.50 (€78 per year)
Select only 1			

Table 4.4. Option set 4

	Option 1	Option 2	Option 3
Amount of bees living in the landscape compared with now	40% less	10% less	30% less
Variety of wild flowers in local green spaces compared with now	30% less	20% less	30% less
Monthly tax increase to you	€0	€5 (€60 per year)	€1.50 (€18 per year)
Select only 1			

Table 4.5. Option set 5

	Option 1	Option 2	Option 3
Amount of bees living in the landscape compared with now	40% less	10% less	10% less
Variety of wild flowers in local green spaces compared with now	30% less	20% less	Same as now
Monthly tax increase to you	€0	€4 (€48 per year)	€6 (€72 per year)
Select only 1			

Box 4.2. Attitudinal statements

1. I believe that protecting the environment may require funding through taxation.
2. It is important to protect bees and the benefits they provide.
3. I visit green areas (e.g. parks, forests, nature reserves) on a regular basis (i.e. at least once a month).
4. I am concerned about the state of the global environment.
5. Before reading the introduction to this research, I was already aware that bees in the island of Ireland were in decline.
6. I am involved in wildlife conservation (on a voluntary or professional basis); this can include bee keeping.
7. I like my local neighbourhood to have lots of different types of bees.
8. I like to be able to see lots of flowers when I visit local green spaces.
9. I like my local green spaces to have lots of different flowers.
10. I like to be able see lots of bees in my local neighbourhood.

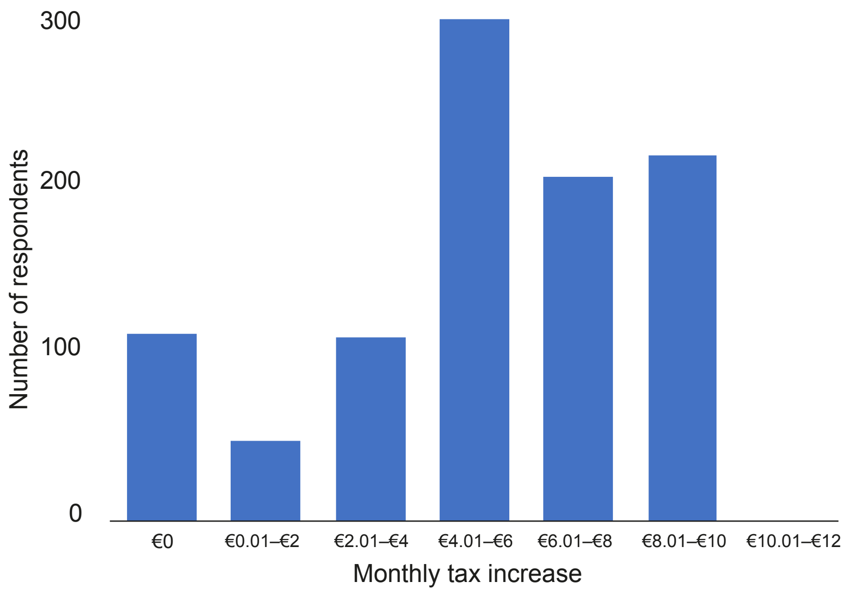

Figure 4.2. The distribution of responses to the willingness-to-pay option sets, based on the mean value for each respondent across all five option sets.

The distribution of people's responses to option sets 1–5 showed a clear peak at €4–6 per month (Figure 4.2). This could be used as a proxy for the value that people attach to the existence of bees and a variety of wild flowers in their local landscapes. However, given the methodological limitations outlined above, further research is required to develop a robust estimate of the willingness to pay for the conservation of bees.

Of the 1000 respondents, over 90% agreed that it is important to protect bees and the benefits they provide, with 70% of respondents strongly agreeing with this statement (Figure 4.3, statement 2).

Interestingly, in terms of protecting the environment in general, 68% believed that this may require funding through taxation (statement 1). More than two-thirds of respondents regularly visited green areas (statement 3) and more than 80% of respondents were concerned about the state of the environment globally (statement 4).

Overall, 81% of respondents were already aware that bees in Ireland were in decline and over 60% of respondents strongly agreed with the statement (see Figure 4.3, statement 5). Only 16% of respondents were involved in wildlife conservation (statement 6), with one-third strongly disagreeing with this

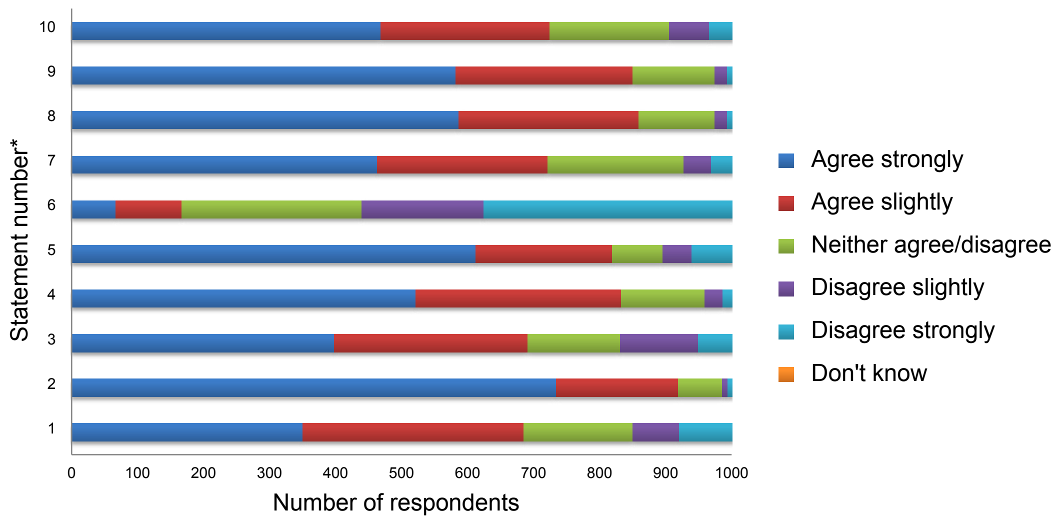

Figure 4.3. The extent to which the respondents agreed or disagreed with the 10 statements in Q6 of the survey. *The order of the statements (see Box 4.2) was randomised for each respondent.

statement, suggesting that they are not involved in any conservation initiatives. Statements 8 and 10 and 7 and 9 aimed to disentangle whether or not people were interested in the abundance of bees/flowers or diversity. A similar majority (approx. 70%) of respondents agreed to liking many different types of bees in their local neighbourhood (statement 7) and lots of bees overall (statement 10). Similarly, more than 85% of respondents agreed to liking lots of flowers in local green spaces (statement 8) and a diversity of flowers (statement 9).

4.2.2 Discussion

Only 11% of respondents chose the status quo option of paying nothing to halt a decrease in the abundance of bees in the landscape and the variety of wild flowers in local green spaces. This finding suggests that the majority of people would be willing to pay something for the existence of bees and a variety of wild flowers in their local green spaces. On average (using the mode as a measure of centrality), respondents were willing to pay €4–6 a month, indicating that people highly value bees and flowers. If this figure was multiplied across the tax-paying population of Ireland, it would approximate €120–180 million per year. However, this is an oversimplification and this survey should be repeated, without methodological biases (as outlined in section 4.2.1), before a firm estimate of willingness to pay can be determined.

Regarding the attitudinal statements (see Box 4.2), more than half of the respondents agreed with 9 out of the 10 statements. The vast majority (>80%) of respondents were concerned about the state of the environment globally and were aware that bees in Ireland were in decline. Given that this survey was unbiased in terms of the socio-demographics of the respondents, this indicates that people are well informed nationally and concerned globally. More than two-thirds of respondents regularly visited green areas and there was strong support for both the abundance and the diversity of bees and flowers in local neighbourhoods. The largest agreement among respondents was for the question of whether or not it is important to protect bees and the benefits they provide, with 919 people (92%) agreeing that it is important. This suggests that Irish people care about the conservation of bees and, given that 68% of respondents agreed that protecting the environment may require funding through taxation, they may be willing to pay for this conservation.

The statement with the lowest level of agreement was statement 6 ("I am involved in wildlife conservation"); this statement had the highest number of responses for the "neither agree/disagree" option, but no-one selected the "don't know" option. With hindsight, this question was poorly phrased, and an alternative, such as "I would like to be involved in conservation activities", could be used in the future.

By developing the willingness-to-pay method and repeating this kind of survey, useful metrics on the non-market values of pollinators and pollination services can be generated. This survey engendered greater insight into public knowledge on bee decline and public opinion on the protection and conservation of pollinators. The fact that the majority of the respondents would be willing to pay to protect pollinators and pollination services in Ireland is encouraging.

4.3 Public Opinion Survey

As part of an EPA and Science Foundation Ireland-funded Discover Programme project, Trinity College Dublin researcher Dr Joseph Roche initiated a series of public surveys in collaboration with the *Irish Times* to raise awareness of the concept of citizen science. The first survey in this series was designed by the Pollival team on pollinators (https://tinyurl.com/ybqdb3hg). The target audience was *Irish Times* readers, but through advertisement on social media (Facebook and Twitter) it is likely that members of the general public who do not read the *Irish Times* also took part in the survey.

The survey was available online to members of the public from 7 December 2017 and was followed up with an article on the importance of pollinators on 18 January 2018 (https://tinyurl.com/y7urghhf). Four questions were asked, with the goal of the survey being to gather insight into the general public's perception of pollinators and to determine if they would be willing to pay to protect pollinators. The survey focused on three particular areas:

1. respondents' knowledge of the abundance of wild pollinators in Ireland;
2. whether or not respondents believe that pollinators are important;
3. whether or not protecting pollinators should be funded and where that funding should come from.

4.3.1 Key findings

Although 590 people responded to the survey, not all respondents answered all of the questions (21 respondents did not answer Q1, four did not answer Q2, four did not answer Q3 and five did not answer Q4; average response rate per question = 98.6%).

Question 1

Respondents were knowledgeable about pollinator decline in Ireland, with the vast majority (96%) of respondents appreciating that the number of wild pollinators in Ireland is decreasing (Figure 4.4).

Question 2

The vast majority of respondents (94%) strongly agreed that it is important to protect pollinators and the benefits they provide, with 82% of respondents strongly agreeing that they like local green spaces to have lots of different flowers (Figure 4.5). Only 43% of respondents strongly agreed that protecting

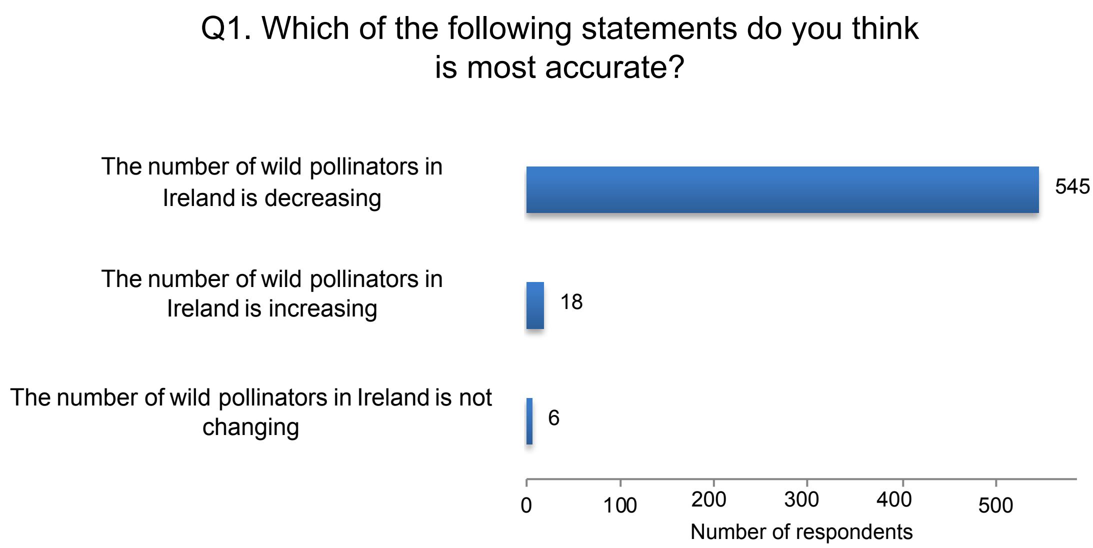

Figure 4.4. Responses to Q1 of the *Irish Times* survey.

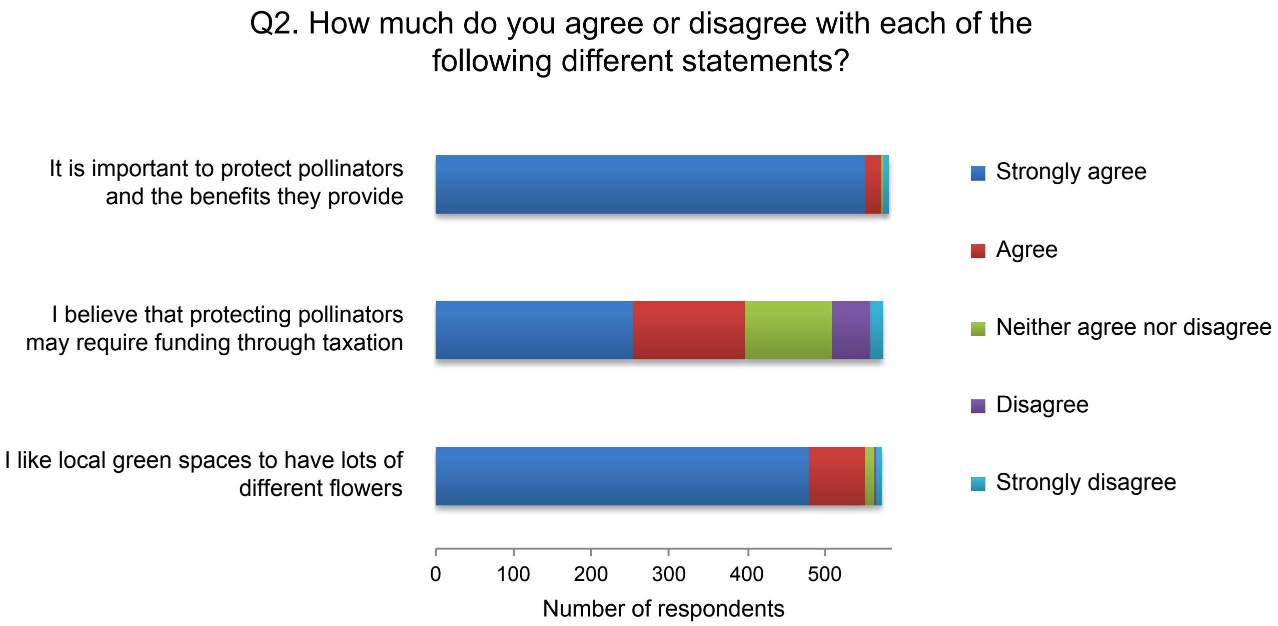

Figure 4.5. Responses to Q2 of the *Irish Times* survey.

pollinators may require funding through taxation, with 16 respondents (3%) strongly disagreeing with this statement.

Question 3

In terms of where the money to protect and conserve both pollinators and pollination services should come from, the majority of respondents suggested that tariffs should be placed on products that harm pollinators (82%) or fines should be given for actions that damage the places where pollinators live, breed or eat (81%) (Figure 4.6). In total, 6% of respondents selected the “other option” in response to Q3, but the majority of respondents did not provide any additional comments. However, two respondents who did leave comments that addressed the question suggested that money to protect pollinators could come from the budget (i.e. from Exchequer or State funds) or that only those who harm pollinators should pay.

Question 4

In terms of expertise, Q4 asked if respondents had ever been involved in wildlife conservation (on a voluntary or professional basis) or kept any kind of bees. In total, 56% of respondents replied “yes”, 38% replied “no” and the remaining 6% were either “unsure” or did not provide an answer.

4.3.2 Discussion

The findings from this survey suggest that people have a good knowledge of the state of Ireland’s wild pollinators. This is encouraging and, although it is not possible to definitively say why this is the case, it could be the result of both national media attention on bee decline and pollination services and international news coverage of honeybee colony collapses (in North America) and impacts of stressors such as pesticides on bees.

Nearly 43% of respondents strongly agreed that protecting pollinators may require funding through taxation (253/586 respondents to Q2), but only 13–15% were willing to pay for this protection themselves through higher food prices or income tax (Q3). Of course, indirectly they may still end up paying if food prices increase as a result of tariffs or fines. However, over half of the respondents had previously been involved in wildlife conservation and so may already be motivated to pay for conservation. This is one of the limitations of this type of survey – those motivated to complete it may have an existing interest.

This survey is not representative of the general public in Ireland: respondents volunteered to take the survey as a result of reading about it in the *Irish Times*. Such readers may represent only part of one social category in Ireland. Additionally, sharing via social media platforms also introduces bias as people tend to share

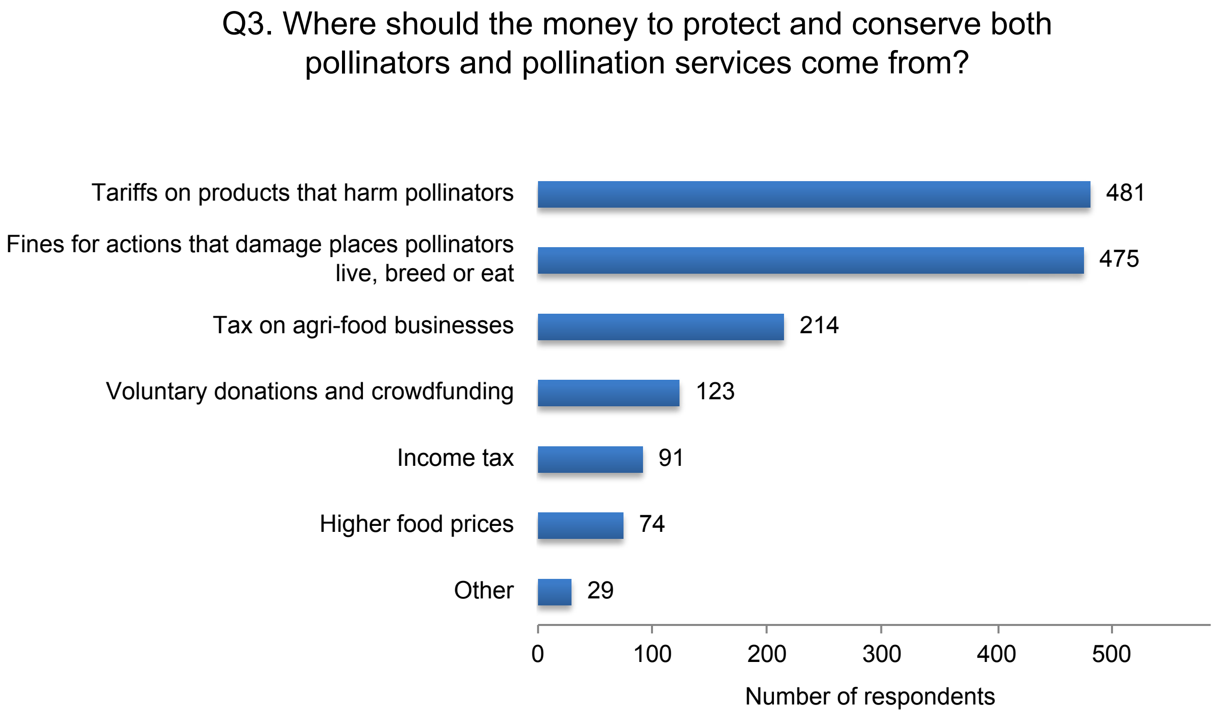

Figure 4.6. Responses to Q3 of the *Irish Times* survey.

information with like-minded people. The fact that more than half of the respondents were already involved in some form of wildlife conservation, or had kept bees, demonstrates this bias.

Despite these limitations, the survey revealed that people are concerned about pollinators and that they value them, with more than 50% of respondents agreeing that pollinator conservation should be funded through taxation.

Coincidentally, in September 2018, the market research agency iReach Insights published the results of a survey on attitudes towards bees (https://ireachinsights.blogspot.com/2018/09/88-of-individuals-believe-irish.html). That survey employed a similar approach to the willingness-to-pay survey conducted for this research (see section 4.2) and was based on 1000 nationally representative adults from Ireland. The iReach survey findings concluded that 75% of people are aware that bees are threatened with extinction and 87% believe that bees contribute to the economy. Additionally, 88% of respondents believed that the Irish government has not done enough to help save bees and 72% felt that there was a need for more education on the benefits of bees and how people can help to conserve them. This supports the conclusion drawn here that Irish people are aware of pollinator decline and the importance of pollinators and that they believe that more needs to be done at government level to conserve bees.

5 Conclusions and Recommendations

From reviewing existing methodological approaches to valuing pollinators and pollination services, the many uncertainties and limitations involved in valuing complex systems have become apparent. However, progress has been made in adapting techniques from ecology, economics and social sciences to come to a more holistic approach to valuing nature and ecosystem services. By expanding the market-based approach to valuing pollinators to incorporate trade dynamics and price elasticity, the Pollival project demonstrated that the economic value of ecosystem services extends far beyond national boundaries. Although the case presented was an overly simplified representation of the complex trade dynamics and economic interactions, as well as the complexity of crop pollination systems, it was a useful exercise to demonstrate the concept of value as it transcends national borders and to highlight the importance to local policymakers of considering the global impacts of conservation decisions. Similarly, survey instruments can be used to gain a qualitative understanding from a social science perspective of attitudes to pollinators and the services they provide. Although a full willingness-to-pay analysis was not conducted as part of the Pollival project, the potential of, and a pathway for, this approach has been demonstrated.

Although there have been several studies on the economic, health and socio-cultural benefits derived from pollinators and the pollination services they provide internationally (Junge *et al*., 2015; Lindemann-Matthies and Brieger, 2016; Klein *et al*., 2007), integrating diverse methodological approaches to valuing pollinators remains a challenge. Efforts have been made to capture use and non-use values through the TEV framework (Randall, 1987). This can be used to estimate output values (e.g. food production or recreational value) and option/insurance values generated by an ecosystem or species in economic terms (Pascual *et al*., 2010). However, this framework is limited in its ability to incorporate values that cannot be expressed in monetary terms. The combined use of economic, socio-cultural and health values of pollinator gains and losses, using multiple knowledge systems, brings different perspectives from different stakeholder groups. Combining these approaches to produce an integrated method of valuation will provide more information for the management of, and decision-making about, pollinators and pollination.

5.1 Future Directions: Towards a More Holistic Valuation of Nature

As well as using quantitative methodologies to determine the monetary value of pollinators and pollination services, including market and non-market methods, the use of qualitative, participatory and deliberative methods to elicit a more holistic value for biodiversity is needed (Chan *et al*., 2012). Qualitative approaches, such as in-depth interviews and focus groups, can be used to not only understand the preferences underlying people's economic values, but also uncover local socio-cultural values distinct from the financial value system (Scholte *et al*., 2015). Socio-cultural valuations of biodiversity are grounded in the social context (Berkes, 2009) and are subject to histories and geopolitical interactions over time (Berkes and Turner, 2006). Attempts have been made by global organisations such as IPBES and United Nations Educational, Scientific and Cultural Organization (UNESCO) to contextualise value systems by taking into account indigenous and local knowledge systems (Tengö *et al*., 2017). This process involves identification of the actors involved and use of ethnographical methods (e.g. primary or secondary data analysis, formal or semistructured interviews, participant observation) to elicit values (Barnett-Page and Thomas, 2009).

A value framework (Figure 5.1) that incorporates a holistic approach to valuation to better capture the inherent, integrated value of pollinators and the services they provide is proposed. This framework aims to recognise the diverse ways in which different stakeholders approach ecosystem valuation, while illustrating how different concepts of value relate to one another. Three major (overlapping) themes of the instrumental value of nature, based on the 2016 IPBES assessment of pollinators, pollination and food production, are proposed: (1) economic, (2) socio-cultural and (3) health. These categories are not mutually exclusive and often overlap, but they

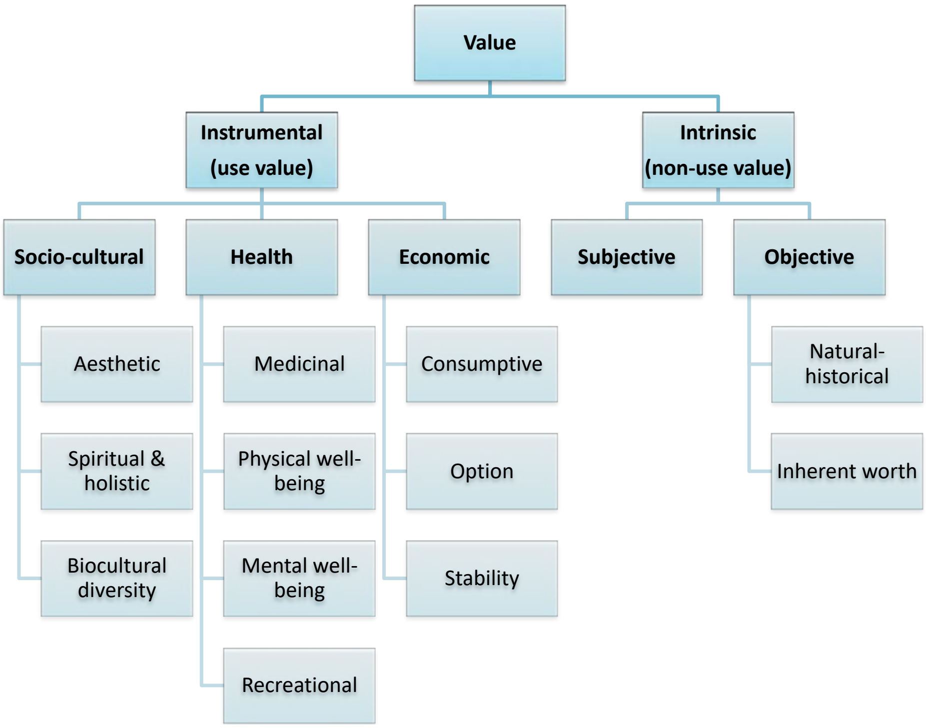

Figure 5.1. An integrated valuation framework for nature that incorporates socio-cultural, economic and health value perspectives.

represent three distinct perspectives of the concept of valuing nature (see Figure 5.1).

For example, there is a value attached to "health" benefits that derive from a medicinal property of an animal-pollinated plant, but there may equally be an indirect market value in terms of reduced health-care costs, as well as a socio-cultural value in terms of cohesiveness in the local society. Similarly, the qualitative value of "health", that is, the satisfaction from being in a state of good health, can sometimes be considered independently from the economic value of good health (e.g. reduced health-care costs, increased productivity). Nevertheless, in practice, these concepts are closely interlinked. For example, health and economic value overlap when considering people's willingness to pay for "good" health. It is important to highlight the connections between all three forms of value when making decisions in relation to conservation.

Ideally, from a conservation management perspective, an integrated and holistic interpretation of value that considers all three approaches should be implemented. However, in practice, this is complicated by the absence of a common measure across these value systems. For example, in economic terms, value can be expressed in quantitative monetary terms; however, concepts of socio-cultural value (such as cultural identity associated with indigenous and local knowledge systems) may not be readily translated into monetary terms. It is therefore important to consider decision support tools, such as multi-criteria analysis, to account for different concepts of value in decision-making systems (Mendoza and Martins, 2006; Huang *et al.*, 2011).

From a pollinator management perspective, it is possible to integrate different stakeholders' perceptions of value into the proposed framework. However, in practice, this is complicated by the conflicting priorities of various stakeholder groups and the different measures and approaches (e.g. qualitative vs quantitative) used. For example, in economic terms, value can be expressed in quantitative monetary terms (e.g. monetary value of crop production); however, concepts of socio-cultural value (such as cultural identity associated with indigenous and local knowledge systems) may not be readily translated into quantitative monetary terms. It is therefore important to use multi-criteria analysis (e.g. an integrated valuation framework) to account for different concepts of value in decision-making systems with regard to natural resource management (Linkov *et al.*, 2006; Mendoza and Martins, 2006). This approach still requires some development before it can be implemented.

5.2 Key Conclusions from the Pollival Project

- Pollination is an important input to the agri-food industry in Ireland, which was worth an estimated €20–59 million per year between the years 2005 and 2014 in terms of home-grown produce. Furthermore, as a consumer nation, the agri-food industry is at risk from pollinator losses overseas. If all of the animal-pollinated crops that are imported are taken into account, the estimated value of global pollinators to Ireland rises by an additional €153–843 million per year. As a net importer of animal-pollinated crops, Ireland is particularly vulnerable to global declines in pollinator populations.
- The value of animal pollination services to the global agri-food sector globally was conservatively estimated to be at least €260 billion and up to €1.11 trillion per year. However, the financial costs of pollinator loss will affect countries differently, depending on their national reliance on animal-pollinated crops, and could risk reinforcing global inequalities in trade and prosperity. In an era of globalised markets and global supply chains, the effects of pollinator decline in one country can have far-reaching impacts across the globe. Even large established economies are vulnerable to the risks of pollinator decline, because of potential effects on both local production capacity and trade in key crop species, such as soybeans, cocoa beans and fresh fruit.
- Irish people have demonstrated that they value the existence of pollinators, are concerned about pollinator loss and the impact of loss on pollination services, and are willing to pay to protect to pollinators. However, the indications are that people would prefer a “polluter pays” model rather than a direct tax on income, and that people believe that the government needs to take more action to support pollinator conservation.
- Pollinators and pollination services are not only important financially and economically, but also have many other non-market and non-use values for human well-being and society. People value the non-market and non-use benefits that derive from pollinators and the social and cultural values of pollinators and pollination services. Further work is needed to assess, disseminate and integrate these values into a holistic framework of values.

5.3 Policy-relevant Recommendations

- *Pollinator conservation* – support conservation of pollinators in Ireland, not only for crop pollination, but also for preserving ecosystems that are valued by Irish people and deliver vital services. This can be delivered through the All-Ireland Pollinator Plan, whose implementation is listed as an action (4.1.8) in the National Biodiversity Action Plan (2017–2021), appropriate agri-environmental schemes, supporting businesses to invest in biodiversity and promoting the natural capital approach.
- *Financing* – identify and enable mechanisms to finance pollinator conservation in Irish agricultural and natural landscapes, for example through taxation of organisations/activities/products that threaten pollinators.
- *Awareness raising* – increase support for island-wide cross-sectoral awareness raising programmes, such as the All-Ireland Pollinator Plan, and other appropriate initiatives. The surveys conducted as part of the Pollival project can be repeated in the future to determine whether awareness has been improved. In addition, better links should be established between research and the media to allow for greater knowledge exchange with an evidently receptive public.
- *Sustainable practices through the supply chain* – engage with stakeholders to identify risks associated with pollinator loss and encourage conservation by promoting ethical sourcing and sustainable practices to reduce supply chain risks; as part of the international Coalition of the Willing on Pollinators, use national influence to encourage pollinator conservation overseas.
- *Improve the evidence base* – collect more-detailed information on global supply chains for animal-pollinated crops to analyse the vulnerability and consequences of pollinator decline; collaborate with other academics to support knowledge exchange, particularly of methods for monitoring and assessing the marginal value of pollinators within landscapes; establish mechanisms for integrating values measured on different scales by encouraging transdisciplinary research on valuing nature.

References

Adamowicz, W., Louviere, J. and Williams, M., 1994. Combining revealed and stated preference methods for valuing environmental amenities. *Journal of Environmental Economics and Management* 26: 271–292.

Adams, W.M., 2014. The value of valuing nature. *Science* 346: 549–551.

Aizen, M.A., Garibaldi, L.A., Cunningham, S.A. and Klein, A.M., 2008. Long-term global trends in crop yield and production reveal no current pollination shortage but increasing pollinator dependency. *Current Biology* 18: 1572-1575. https://doi.org/10.1016/j.cub.2008.08.066

Allenwardell, G., Bernhardt, P., Bitner, R., Burquez, A., Buchmann, S., Cane, J., Cox, P.A., Dalton, V., Feinsinger, P., Ingram, M., Inouye, D., Jones, C.E., Kennedy, K., Kevan, P., Koopowitz, H., Medellin, R., Medellinmorales, S., Nabhan, G.P., Pavlik, B., Tepedino, V., Torchio, P. and Walker, S., 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology* 12: 8–17.

Allsopp, M.H., de Lange, W.J. and Veldtman, R., 2008. Valuing insect pollination services with cost of replacement. *PLOS ONE* 3: e3128.

Andreyeva, T., Long, M.W. and Brownell, K.D., 2010. The impact of food prices on consumption: a systematic review of research on the price elasticity of demand for food. *American Journal of Public Health* 100: 216–222.

Bailes, E.J., Ollerton, J., Pattrick, J.G. and Glover, B.J., 2015. How can an understanding of plant–pollinator interactions contribute to global food security? *Current Opinions in Plant Biology* 26: 72–79.

Barnett-Page, E. and Thomas, J., 2009. Methods for the synthesis of qualitative research: a critical review. *BMC Medical Research Methodology* 9: 59.

Bauer, D.M. and Sue Wing, I., 2016. The macroeconomic cost of catastrophic pollinator declines. *Ecological Economics* 126: 1–13.

Bayon, R., 2004. Making environmental markets work: lessons from early experience with sulfur, carbon, wetlands, and other related markets. Katoomba Group Meeting, Locarno, Switzerland, pp.1–26.

Benton, T. and Redclift, M., 2013. *Social Theory and the Global Environment*. Routledge, Abingdon.

Berkes, F., 2009. Community conserved areas: policy issues in historic and contemporary context. *Conservation Letters* 2: 20–25.

Berkes, F. and Turner, N.J., 2006. Knowledge, learning and the evolution of conservation practice for social-ecological system resilience. *Human Ecology* 34: 479.

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. and Kunin, W.E., 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313: 351–354.

Boyd, J. and Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63: 616–626.

Breeze, T.D., Vaissière, B.E., Bommarco, R., Petanidou, T., Seraphides, N., Kozák, L., Scheper, J., Biesmeijer, J.C., Kleijn, D., Gyldenkærne, S., Moretti, M., Holzschuh, A., Steffan-Dewenter, I., Stout, J.C., Pärtel, M., Zobel, M. and Potts, S.G., 2014. Agricultural policies exacerbate honeybee pollination service supply-demand mismatches across europe. *PLOS ONE* 9: e82996.

Breeze, T.D., Bailey, A.P., Potts, S.G. and Balcombe, K.G., 2015. A stated preference valuation of the non-market benefits of pollination services in the UK. *Ecological Economics* 111: 76–85.

Breeze, T.D., Gallai, N., Garibaldi, L.A. and Li, X.S., 2016. Economic measures of pollination services: shortcomings and future directions. *Trends in Ecology & Evolution* 31: 927–939.

Brondízio, E.S., Gatzweiler, F.W., Kumar, M. and Zografos, C., 2010. The socio-cultural context of ecosystem and biodiversity valuation. In Kumar, P. (ed.), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, London, pp. 149–182.

Brookshire, D.S., Eubanks, L.S. and Randall, A., 1983. Estimating option prices and existence values for wildlife resources. *Land Economics* 59: 1–15.

Bullock, C., Kretch C. and Candon E., 2008. *The Economic and Social Aspects of Biodiversity: Benefits and Costs of Biodiversity in Ireland*. Department of the Environment, Heritage and Local Government, Dublin.

Burgett, M., Rucker, R.R. and Thurman, W.N., 2004. Economics and honey bee pollination markets. *American Bee Journal* 144: 269–271.

Callicott, J.B., 2006. Explicit and implicit values. In Goble, D.D., Scott, J.M. and Davis, F.W. (eds), *The Endangered Species Act at Thirty*. Island Press, Washington, DC, pp. 36–48.

Cameron, S.A., Lim, H.C., Lozier, J.D., Duennes, M.A. and Thorp, R., 2016. Test of the invasive pathogen hypothesis of bumble bee decline in North America. *Proceedings of the National Academy of Sciences of the United States of America* 113: 4386–4391.

Carreck, N.L., Williams, I.H. and Little, D.J., 1997. The movement of honey bee colonies for crop pollination and honey production by beekeepers in Great Britain. *Bee World* 78: 67–77.

Chan, K.M.A., Satterfield, T. and Goldstein, J., 2012. Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics* 74: 8–18.

Christie, M., Hanley, N., Warren, J., Murphy, K., Wright, R. and Hyde, T., 2006. Valuing the diversity of biodiversity. *Ecological Economics* 58: 304–317. https://doi.org/10.1016/j.ecolecon.2005.07.034

Cicchetti, C.J. and Wilde, L.L., 1992. Uniqueness, irreversibility, and the theory of nonuse values. *American Journal of Agricultural Economics* 74: 1121–1125.

Corbera, E., Kosoy, N. and Martínez Tuna, M., 2007. Equity implications of marketing ecosystem services in protected areas and rural communities: case studies from Meso-America. *Global Environmental Change* 17: 365–380.

Coscieme L. and Stout J.C., 2019. Ecosystem service evaluation. In Fath B. (ed), *Encyclopaedia of Ecology, Second Edition*. Elsevier B.V., Amsterdam, pp. 288–293.

Costanza, R. and Daly, H.E., 1992. Natural capital and sustainable development. *Conservation Biology* 6: 37–46.

Costanza, R., Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253–260. https://doi.org/10.1038/387253a0

DAFM (Department of Agriculture, Food and the Marine), 2019. *Fact Sheet on Irish Agriculture 2018*. DAFM, Agriculture House, Dublin, Ireland.

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J. and Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment* 7: 21–28.

de Groot, R., Fisher, B., Christie, M., Aronson, J., Braat, L., Gowdy, J., Haines-Young, R., Maltby, E., Neuville, A., Polasky, S., Portela, R. and Ring, I., 2010a. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In Kumar, P. (ed.), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, London.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L. and Willemen, L., 2010b. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7: 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

Delaplane, K.S., Mayer, D.R. and Mayer, D.F., 2000. *Crop Pollination by Bees*. CABI, Wallingford, UK.

Department of Arts, Heritage and the Gaeltacht, 2011. *Actions for Biodiversity 2011–2016: Ireland's National Biodiversity Plan*. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin.

Department of Culture, Heritage and the Gaeltacht, 2017. *National Biodiversity Action Plan 2017–2021*. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Dublin.

Descola, P., 2014. Modes of being and forms of predication. *HAU: Journal of Ethnographic Theory* 4: 271.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., *et al.*, 2015. The IPBES Conceptual Framework – connecting nature and people. *Current Opinion in Environmental Sustainability* 14: 1–16.

Doublet, V., Labarussias, M., de Miranda, J.R., Moritz, R.F.A. and Paxton, R.J., 2015. Bees under stress: sublethal doses of a neonicotinoid pesticide and pathogens interact to elevate honey bee mortality across the life cycle. *Environmental Microbiology* 17: 969–983. https://doi.org/10.1111/1462-2920.12426

EPA (Environmental Protection Agency), 2007. *2020 Vision: Protecting and Improving Ireland's Environment*. EPA, Johnstown Castle, Ireland.

Farber, S.C., Costanza, R. and Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41: 375–392. https://doi.org/10.1016/S0921-8009(02)00088-5

Feeley, H.B., Bruen, M., Bullock, C., Christie, M., Kelly F., Remoundou, K., Siwicka, E. and Kelly-Quinn, M., 2016. *ESManage Literature Review: Ecosystem Services in Freshwaters*. EPA Research Report 187, Environmental Protection Agency.

Fisher, A.C., 2000. Investment under uncertainty and option value in environmental economics. *Resource and Energy Economics* 22: 197–204.

Fisher, B., Turner, R.K. and Morling, P., 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643–653.

Fitzpatrick, Ú., Murray, T.E., Byrne, A., Paxton, R.J. and Brown, M.J.F., 2006. *Regional Red List of Irish Bees*. Higher Education Authority of Ireland, Dublin.

Fitzpatrick, U., Murray, T. E., Paxton, R.J. and Brown, M.J.F., 2007. Building on IUCN regional red lists to produce lists of species of conservation priority: a model with Irish bees. *Conservation Biology* 21**:** 1325–1332.

Free, J.B., 1993. *Insect Pollination of Crops*. Academic Press, London.

Gagnon Thompson, S.C. and Barton, M.A., 1994. Ecocentric and anthropocentric attitudes toward the environment. *Journal of Environmental Psychology* 14: 149–157.

Gallai, N., Salle, J.-M., Settele, J. and Vaissière, B.E., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics* 68: 810–821.

Garibaldi, L.A., Aizen, M.A., Klein, A.M., Cunningham, S.A. and Harder, L.D., 2011. Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences of the United States of America* 108: 5909–5914.

Garratt, M.P.D., Breeze, T.D., Jenner, N., Polce, C., Biesmeijer, J,C. and Potts, S.G., 2014. Avoiding a bad apple: insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems & Environment* 184: 34–40.

Ghazoul, J., 2005. Buzziness as usual? Questioning the global pollination crisis. *Trends in Ecology & Evolution* 20: 367–373.

Gómez-Baggethun, E., de Groot, R., Lomas, P.L. and Montes, C., 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. *Ecological Economics* 69: 1209–1218.

Goulson, D., Lye, G.C. and Darvill, B., 2008. Decline and conservation of bumble bees. *Annual Review of Entomology* 53: 191–208.

Goulson, D., Nicholls, E., Botías, C. and Rotheray, E. L., 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* 347: 1255957.

Haines-Young, R. and Potschin, M., 2010. *Proposal for a Common International Classification of Ecosystem Goods and Services (CICES) for Integrated Environmental and Economic Accounting*. Report to the European Environment Agency, Contract No. EEA/BSS/07/007. United Nations, New York, NY.

Hanley, N., Breeze, T.D., Ellis, C. and Goulson, D. 2015. Measuring the economic value of pollination services: principles, evidence and knowledge gaps. *Ecosystem Services* 14: 124–132.

Huang, I.B., Keisler, J. and Linkov, I., 2011. Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. *Science of the Total Environment* 409: 3578–3594.

Hutchinson, G.W., Chilton, S.M. and Davis, J., 2018. Measuring non-use value of environmental goods using the contingent valuation method: problems of information and cognition and the application of cognitive questionnaire design methods. *Journal of Agricultural Economics* 46: 97–112.

IPBES (Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services), 2016. Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. In Potts, S.G., Imperatriz-Fonseca, V.L., Ngo, H.T., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. and Vanbergen A.J. (eds). Secretariat of IPBES, Bonn, Germany.

Jaffé, R., Dietemann, V., Allsopp, M.H., Costa, C., Crewe, R.M., Dall'olio, R., de la Rúa, P., El-Niweiri, M.A., Fries, I., Kezic, N., Meusel, M.S., Paxton, R.J., Shaibi, T., Stolle, E. and Moritz, R.F., 2010. Estimating the density of honeybee colonies across their natural range to fill the gap in pollinator decline censuses. *Conservation Biology* 24: 583–593. https://doi.org/10.1111/j.1523-1739.2009.01331.x

Jones, R.W., 1965. The structure of simple general equilibrium models. *Journal of Political Economy* 73: 557–572.

Joppa, L.N., Boyd, J.W., Duke, C.S., Hampton, S., Jackson, S.T., Jacobs, K.L., Kassam, K.-A.S., Mooney, H.A., Ogden, L.A., Ruckelshaus, M. and Shogren, J.F., 2016. Government: plan for ecosystem services. *Science* 351: 1037–1037.

Junge, X., Schüpbach, B., Walter, T., Schmid, B. and Lindemann-Matthies, P., 2015. Aesthetic quality of agricultural landscape elements in different seasonal stages in Switzerland. *Landscape and Urban Planning* 133: 67–77. https://doi.org/10.1016/j.landurbplan.2014.09.010

Katz, E., 1992. The call of the wild: the struggle against domination and the technological fix of nature. *Environmental Ethics* 14: 265–273.

Kerr, J.T., Pindar, A., Galpern, P., Packer, L., Potts, S.G., Roberts, S.M., Rasmont, P., Schweiger, O., Colla, S.R., Richardson, L.L., Wagner, D.L., Gall, L.F., Sikes, D.S. and Pantoja, A., 2015. Climate change impacts on bumblebees converge across continents. *Science* 439: 177–180.

Kevan, P. and Phillips, T., 2001. The economic impacts of pollinator declines: an approach to assessing the consequences. *Conservation Ecology* 5: 8.

Klatt, B.K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E. and Tscharntke, T., 2014. Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of the Royal Society B: Biological Sciences* 281: 20132440.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. and Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences* 274: 303–313.

Kolinjivadi, V., Van Hecken, G., Rodríguez de Francisco, J.C., Pelenc, J. and Kosoy, N., 2017. As a lock to a key? Why science is more than just an instrument to pay for nature's services. *Current Opinion in Environmental Sustainability* 26–27: 1–6. https://doi.org/10.1016/j.cosust.2016.12.004

Kovács-Hostyánszki, A., Espíndola, A., Vanbergen, A.J., Settele, J., Kremen, C. and Dicks, L.V., 2017. Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology Letters* 20: 673–689. https://doi.org/10.1111/ele.12762

Lautenbach, S., Seppelt, R., Liebscher, J., and Dormann, C.F., 2012. Spatial and temporal trends of global pollination benefit. PLOS ONE 7: e35954. https://doi.org/10.1371/journal.pone.0035954

Lee, A.C.K. and Maheswaran, R., 2011. The health benefits of urban green spaces: a review of the evidence. *Journal of Public Health* 33: 212–222.

Lindemann-Matthies, P. and Brieger, H., 2016. Does urban gardening increase aesthetic quality of urban areas? A case study from Germany. *Urban Forestry and Urban Greening* 17: 33–41.

Linkov, I., Satterstrom, F.K., Kiker, G., Batchelor, C., Bridges, T., Ferguson, E., 2006. From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications. *Environment International* 32: 1072–1093.

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N. and Greenleaf, S., 2009. Modelling pollination services across agricultural landscapes. *Annals of Botany* 103: 1589–1600.

Maas, J., Verheij, R.A., Groenewegen, P.P., de Vries, S. and Spreeuwenberg, P., 2006. Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health* 60: 587–592.

Mace, G.M., 2014. Whose conservation? Changes in the perception and goals of nature conservation require a solid scientific basis. *Science* 345: 1558–1560.

Marino, D. and Pellegrino, D., 2018. Can payments for ecosystem services improve the management of natura 2000 sites? A contribution to explore their role in Italy. *Sustainability* 10: 665.

Marre, J.-B., Brander, L., Thebaud, O., Boncoeur, J., Pascoe, S., Coglan, L. and Pascal, N., 2015. Non-market use and non-use values for preserving ecosystem services over time: a choice experiment application to coral reef ecosystems in New Caledonia. *Ocean & Coastal Management* 105: 1–14. https://doi.org/10.1016/j.ocecoaman.2014.12.010

Matheson, A.G. and Schrader, M., 1987. *The Value of Honey Bees to New Zealand's Primary Production*. Ministry of Agriculture and Fisheries, Nelson, New Zealand.

MEA (Millenium Ecosystem Assessment), 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. Island Press, Washington, DC.

Mebratu, D., 1998. Sustainability and sustainable development: historical and conceptual review. *Environmental Impact Assessment Review* 18: 493–520.

Melathopoulos, A.P., Tyedmers, P. and Cutler, G.C., 2014. Contextualising pollination benefits: effect of insecticide and fungicide use on fruit set and weight from bee pollination in lowbush blueberry. *Annals of Applied Biology* 165: 387–394.

Mendoza, G.A. and Martins, H., 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest Ecology and Management* 230: 1–22.

Murphy, J.T. and Stout, J.C., 2019. *Assessing Market and Non-market Values of Pollination Services in Ireland: Pollival Literature Review*. Environmental Protection Agency, Johnstown Castle, Ireland.

Mwebaze, P., Marris, G.C., Budge, G.E., Brown, M., Potts, G., Breeze, T.D. and Macleod, A., 2010. Quantifying the value of ecosystem services: a case study of honeybee pollination in the UK. 12th Annual BIOECON Conference "From the Wealth of Nations to the Wealth of Nature: Rethinking Economic Growth", 27–28 September, Venice.

Neieto, A., Roberts, S., Kemp, J., Rasmont P., Kuhlmann, M., Garcia Criado, M., Biesmeijer, J., Bogusch, P., Dathe, H., De La Rúa, P., De Meulemeester, T., Dehon, M., Dewulf, A., Ortiz-Sánchez, F.J., Lhomme, P., Pauly, A., Potts, S.G., Praz, C., Quaranta, M., Radchenko, V., Scheuchl, E., Smit, J., Straka, J., Terzo, M., Tomozii, B., Window, J. and Michez, D. 2015. *European Red List of Bees*. IUCN, Gland, Switzerland.

Nunes, P.A.L.D. and van den Bergh, J.C.J.M., 2001. Economic valuation of biodiversity: sense or nonsense? *Ecological Economics* 39: 203–222.

Ollerton, J., 2017. Pollinator diversity: distribution, ecological function, and conservation. *Annual Review of Ecology, Evolution, and Systematics* 48: 353–376.

Ollerton, J., Winfree, R. and Tarrant, S., 2011. How many flowering plants are pollinated by animals? *Oikos* 120: 321–326.

O'Neill, S.D., 1997. Pollination regulation of flower development. *Annual Review of Plant Physiology and Plant Molecular Biology* 48: 547–574.

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., Armsworth, P., Christie, M., Cornelissen, H., Eppink, H., Farley, J., Loomis, J., Pearson, L., Perrings, C. and Polasky, S., 2010. The economics of valuing ecosystem services and biodiversity. In Kumar, P. (ed.), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, London.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., *et al*., 2017. Valuing nature's contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability* 26–27: 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Patiny, S., Rasmont, P. and Michez, D., 2009. A survey and review of the status of wild bees in the West-Palaearctic region. *Apidologie* 40: 313–331.

Pearce, D., 2002. An intellectual history of environmental economics. *Annual Review of Energy and the Environment* 27: 57–81.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. and Kunin, W.E., 2010a. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution* 25: 345–353.

Potts, S.G., Roberts, S.P.M., Dean, R., Marris, G., Brown, M.A., Jones, R., Neumann, P. and Settele, J., 2010b. Declines of managed honey bees and beekeepers in Europe. *Journal of Apicultural Research* 49: 15–22.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. and Vanbergen, A.J., 2016. Safeguarding pollinators and their values to human well-being. *Nature* 540: 220.

Price, C., 2014. Regulating and supporting services and disservices: customary approaches to valuation, and a few surprising case-study results. *New Zealand Journal of Forestry Science* 44: S5.

Rader, R., Bartomeus, I., Garibaldi, L.A., Garratt, M.P.D., Howlett, B.G., Winfree, R., et al., 2016. Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences* 113: 146–151.

Randall, A., 1987. Total economic value as a basis for policy. *Transactions of the American Fisheries Society* 116: 325–335.

Raymond, C.M., Bryan, B.A., MacDonald, D.H., Cast, A., Strathearn, S., Grandgirard, A., and Kalivas, T., 2009. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68: 1301–1315.

Richter, M.K., 1966. Revealed preference theory. *Econometrica: Journal of the Econometric Society* 34: 635–645.

Ripple, W.J., Wolf, C., Newsome, T.M., Galetti, M., Alamgir, M., Crist, E., Mahmoud, M.I. and Laurance, W.F., 2017. World scientists' warning to humanity: a second notice. *BioScience* 67: 1026–1028. https://doi.org/10.1093/biosci/bix125

Rolston, H., 1986. *Philosophy Gone Wild: Essays in Environmental Ethics*. Prometheus Books, Amherst, NY.

Rucker, R.R., Thurman, W.N. and Burgett, M., 2012. Honey bee pollination markets and the internalization of reciprocal benefits. *American Journal of Agricultural Economics* 94: 956–977.

Ruhl, J.B., Kraft, S.E. and Lant, C.L., 2013. *The Law and Policy of Ecosystem Services*. Island Press, Washington, DC.

Sander, H.A. and Haight, R.G., 2012. Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing. *Journal of Environmental Management* 113: 194–205.

Sandler, R., 2012. Intrinsic value, ecology, and conservation. *Nature Education Knowledge* 3: 4.

Scholte, S.S.K., van Teeffelen, A.J.A. and Verburg, P.H., 2015. Integrating socio-cultural perspectives into ecosystem service valuation: a review of concepts and methods. *Ecological Economics* 114: 67–78.

Senapathi, D., Goddard M.A., Kunin W.E. and Baldock K.C.R. 2017. Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps. *Functional Ecology* 31: 26–37.

Smith, M.R., Singh G.M., Mozaffarian, D. and Myers, S.S., 2015. Effects of decreases of animal pollinators on human nutrition and global health: a modelling analysis. *The Lancet* 386: 1964–1972.

Soulé, M.E., 1985. What is conservation biology? *BioScience* 35: 727–734.

Southwick, E.E. and Southwick Lawrence, J., 1992. Estimating the economic value of honey bees (Hymenoptera: Apidae) as agricultural pollinators in the United States. *Journal of Economic Entomology* 85: 621–633.

Stanley, D.A., Gunning, D. and Stout, J.C., 2013. Pollinators and pollination of oilseed rape crops (*Brassica napus* L.) in Ireland: ecological and economic incentives for pollinator conservation. *Journal of Insect Conservation* 17: 1181–1189.

Stanley, D.A., Garratt, M.P.D, Wickens J.B., Wickens V.J., Potts S.G. and Raine N.E., 2015. Neonicotinoid pesticide exposure impairs crop pollination services provided by bumblebees. *Nature* 528: 548–550.

Stefan, B., 2008. The insurance value of biodiversity in the provision of ecosystem services. *Natural Resource Modeling* 20: 87–127.

Stevens, T., Hoshide, A.K. and Drummond, F.A., 2015. Willingness to pay for native pollination of blueberries: a conjoint analysis. *International Journal of Agricultural Marketing* 2: 68–77.

Stout, J.C. and Tiedeken, E.J., 2017. Direct interactions between invasive plants and native pollinators: evidence, impacts and approaches. *Functional Ecology* 31: 38–46.

Subade, R.F. and Francisco, H.A., 2014. Do non-users value coral reefs? Economic valuation of conserving Tubbataha Reefs, Philippines. *Ecological Economics* 102: 24–32.

Sumner, D.A. and Boriss, H., 2006. Bee-conomics and the leap in pollination fees. *Agricultural and Resource Economics Update* 9: 9–11.

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K. and Wetterberg, O., 2012. Cultural ecosystem services provided by landscapes: assessment of heritage values and identity. *Ecosystem Services* 2: 14–26. https://doi.org/10.1016/j.ecoser.2012.07.006

Tengö, M., Hill, R., Malmer, P., Raymond, C.M., Spierenburg, M., Danielsen, F., Elmqvist, T. and Folke, C., 2017. Weaving knowledge systems in IPBES, CBD and beyond – lessons learned for sustainability. *Current Opinion in Environmental Sustainability* 26–27: 17–25. https://doi.org/10.1016/j.cosust.2016.12.005

Thomann, M., Imbert, E., Devaux, C. and Cheptou, P.-O., 2013. Flowering plants under global pollinator decline. *Trends in Plant Science* 18: 353–359.

Tscharntke, T., Clough, Y., Wanger, T.C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J. and Whitbread, A., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation* 151: 53–59. https://doi.org/10.1016/j.biocon.2012.01.068

Tschirhart, J., 2000. General equilibrium of an ecosystem. *Journal of Theoretical Biology* 203: 13–32.

Turner, R.K., Pearce, D.W. and Baterman, I., 1993. *Environmental Economics: An Elementary Introduction*. Harvester Wheatsheaf, Hemel Hempstead, UK.

Vanbergen, A.J. and Garratt, M.P., 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment* 11: 251–259.

van Engelsdorp, D., Hayes, J., Underwood, R.M. and Pettis, J., 2008. A survey of honey bee colony losses in the US, fall 2007 to spring 2008. *PLOS ONE* 3: e4071. https://doi.org/10.1371/journal.pone.0004071.

Wallace, K.J., 2007. Classification of ecosystem services: problems and solutions. *Biological Conservation* 139: 235–246.

Williams, P.H. and Osborne, J.L., 2009. Bumblebee vulnerability and conservation world-wide. *Apidologie* 40: 367–387.

Abbreviations

BOT	Balance of trade
EPA	Environmental Protection Agency
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
NES	Not elsewhere specified
TEV	Total economic value

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

EPA Research Report 291

Assessing Market and Non-market Values of Pollination Services in Ireland (Pollival)

epaResearch
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Authors: Jane C. Stout, James T. Murphy and Saorla Kavanagh

Identify pressures

Pollination has been identified as a key ecosystem service that is threatened globally by anthropogenic activities. Estimation and consideration of the economic benefits of pollination can contribute to land-use decision-making to better support pollinator biodiversity and the sustainability of pollination service delivery. The Pollival project (1) identified best practice to evaluate the current market values of pollination services, (2) estimated the value of pollinators and the implications of pollinator loss on pollination services in Ireland and (3) reviewed and developed methods to assess non-market values of pollinators in Ireland. Using FAOSTAT data on crop production, along with existing data on the degree of reliance of each crop on animal pollination, the Pollival project assessed the economic risks associated with pollinator loss in terms of crop production. However, the total value of pollinators extends beyond food production systems. The full value of pollinators extends to other aspects of economy, cultural and societal benefits, and human health and well-being. Public opinion surveys carried out as part of the Pollival project determined that people in Ireland are aware of pollinator decline and the need to act to reverse this decline.

Inform policy

By assessing and valuing natural capital assets (using pollinators as an example) and the resultant services (in this case, pollination), nature could be better integrated into decision-making processes. Currently, pollination services are provided for "free" by wild pollinators, with an estimated value of up to nearly €900 million to the Irish economy through production and trade in animal-pollinated crops. Allied to this are the ongoing qualitative, but less quantifiable, societal and health-related benefits. The findings from this research indicate that the majority of people surveyed value pollinators and the services they provide. People surveyed also believe that it is important to conserve pollinators. Nonetheless, the service of pollination is under threat from land-use change, habitat loss, climate change, novel diseases and contamination of vegetation, soils and water with pesticides, among other things. A collaborative approach to ensure continued and future protection of pollinators and maintain the delivery of pollination services is needed to meet Ireland's national and international policy commitments and obligations, including the Sustainable Development Goals (SDGs). The findings from this research also indicate that that there is a strong economic rationale for further investment in the conservation of wild pollinators. Continued investment would also enhance visibility nationally and internationally and this could enable Ireland to be a "flagship" of "best practice" for conservation and biodiversity. In identifying the need for pollinator protection, the findings from this research entirely align with the All-Ireland Pollinator Plan and can help to inform current and future relevant agri-environment policies and measures.

Develop solutions

By developing an open-source tool (in R) to estimate the impacts of pollinator decline on global trade balances for animal-pollinated crops, this research identified that pollination services are worth up to €902 million per year in Ireland, in terms of food crop production and trade. This research project developed a framework for holistic evaluation for natural capital and ecosystem services, including non-market and non-use values, and provides solutions and recommendations to facilitate Ireland's transition to a future that sees the economy, environment and society in harmony.

EPA Research: McCumiskey House,
Richiew, Clonskeagh, Dublin 14.

Phone: 01 268 0100
Twitter: @EPAResearchNews
Email: research@epa.ie

www.epa.ie

EPA Research Webpages
www.epa.ie/researchandeducation/research/