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Assessing Market and Non-market Values of Pollination Services in Ireland: Pollival Literature Review

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Rialtas na hÉireann
Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY
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- 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.

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Assessing Market and Non-market Values of Pollination Services in Ireland: Pollival Literature Review

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EPA Research Report

Prepared for the Environmental Protection Agency

by

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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.

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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 of their loss to humanity, in an attempt to highlight the value of nature to humanity.

However, valuing nature and the benefits that it provides is a complex topic and various approaches have been used to derive estimations of value, in both monetary and non-monetary terms (Díaz *et al*., 2015). The Millennium Ecosystem Assessment, published in 2005, 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 (Millenium Ecosystem Assessment, 2003). In 2012, an independent intergovernmental body, consisting of 130 Member States, including Ireland, and 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). It developed a conceptual framework that identified various methodologies for valuing nature and highlighted the importance of developing an inclusive valuation approach to 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 we need better integration of environmental and natural resource considerations into the policies, plans and actions of economic sectors (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), "Enhanced appreciation of the value of biodiversity and ecosystem services amongst policy makers, 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). However, challenges arise when attempting to reconcile various approaches to valuing nature (from monetary to socio-cultural) into a holistic framework for decision-making processes, in the absence of a common standard of measurement (Kolinjivadi *et al*., 2017). The aim of this review is to summarise the main approaches to valuing nature, as identified from the scientific literature, to serve as a basis for a more integrated approach to valuing nature that can inform policies with regard to conservation and the sustainable use of our natural resources.

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; Gómez-Baggethun *et al*., 2010) (Figure 1.1). These outputs can be classified into various frameworks (Feeley *et al*., 2016) and, ultimately, benefits can be expressed in monetary terms to justify and support biodiversity and ecosystem service management objectives (Boyd and Banzhaf, 2007). However, there is much debate about how useful economic valuation alone is in biodiversity conservation (Nunes and van den Bergh, 2001).

Animal-mediated pollination is a key example of an ecosystem service; it 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, among

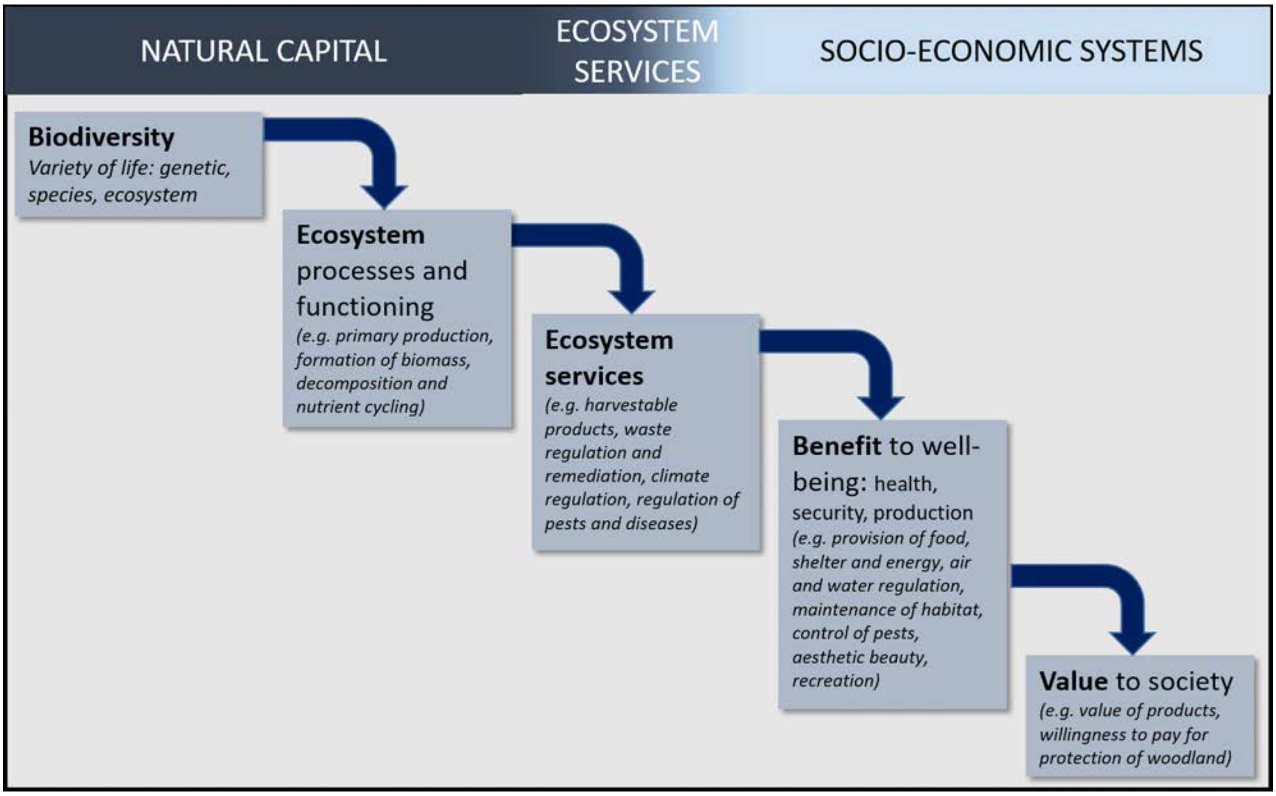

Figure 1.1. The "cascade model" of the relationship between biodiversity, ecosystems, services, benefits and values to society (adapted from Haines Young and Potschin, 2010). Ecosystem services link natural capital and socio-economic systems, and their benefits can have both market and non-market values to society, which can be expressed in monetary and non-monetary forms.

other things, pollination services essential to food crop production (provisioning services), pest control (regulating services) and landscape aesthetics (cultural services) (Ghazoul, 2005; Biesmeijer *et al*., 2006; Potts *et al*., 2010a; Garibaldi *et al*., 2011; 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 on four continents revealed that agricultural intensification threatened wild bee communities, which provide a stabilising effect on landscape-level pollination services (Klein *et al*., 2007). With 70 crop species assessed as 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 in particular 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) also play an important role (Rader *et al*., 2016). However, there is a growing body of evidence demonstrating a decline in both wild and managed pollinators at a global scale, driven by multiple anthropogenic drivers (Potts *et al*., 2010a; 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 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*), but 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 agricultural reliance on this single species of pollinator. It is possible that the demand for pollination services could exceed the number of honey bee hives (and thus number of bees) available in the future (Jaffé *et al*., 2010; Breeze *et al*., 2014). However, 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 has been well documented (Goulson *et al*., 2007; Williams and Osborne, 2009; Nieto *et al*., 2014; Ollerton, 2017) and, in Ireland, one-third of bee species are at risk of extinction (Fitzpatrick *et al*., 2006).

The value of pollinators to global food production has variously been estimated at between €153 billion and US$577 billion per annum (Gallai *et al*., 2009; Lautenbach *et al*., 2012; Potts *et al*., 2016). Therefore, the potential economic implications of pollinator decline for the global agri-food sector are substantial. Building on the 2016 IPBES assessment of pollinators, pollination and food production (IPBES, 2016), we carried out a thorough review of the literature to assess methodological approaches to the valuation of pollination services for all plants (not just food crops) (Pascual *et al*., 2017). It is hoped that 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, will provide the evidence base for the management of, and decision-making about, biodiversity conservation (Christie *et al*., 2006). In this review, we will summarise the methodological approaches for estimating the economic value of pollinators, in the context of economic studies and the broader definitions of values associated with nature.

1.3 Valuing Nature

Values are influenced by worldviews and geopolitical interactions and therefore can vary based on cultural and social context (Brondízio *et al*., 2010; Descola, 2014). The value of nature may be considered both in intrinsic terms and from a relational (instrumental) viewpoint (Box 1.1). 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). In contrast, an instrumental concept of value is associated with the provision of goods or benefits to people that result in improvements to their quality of life, either directly or indirectly (Gagnon Thompson and Barton, 1994). For example, nature may provide cultural, recreational or spiritual services or provisioning services such as crop pollination (Costanza *et al*., 1997; Boyd and Banzhaf, 2007; Tengberg *et al*., 2012).

Box 1.1. Intrinsic and instrumental value

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.

Instrumental value of nature involves an anthropocentric or a relational viewpoint. For example, 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, i.e. it assumes that a means or goods may justifiably be replaced by an alternative means or goods of equal or greater instrumental value (Sandler, 2012).

The concept of environmental economics arose in the latter half of the 20th century to address the shortcomings in standard economic systems to account for environmental resources by accounting for both market and non-market values of natural resources (Turner *et al*., 1993). This was motivated by the fact that traditional economic systems systematically undervalued environmental resources, and natural capital in comparison with economic services and manufactured capital, by not taking into account non-market values (Mebratu, 1998; Benton and Redclift, 2013). The aim of environmental economics was to capture the 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).

We review the approaches for estimating economic values for ecosystem services, with pollination as a case study. Pollination plays a vital role in many aspects of our 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). Pollinators and the pollination services that they provide represent a good case study for reviewing economic valuation approaches to ecosystem services, as a wide range of studies has been carried out on the various economic, health and socio-cultural benefits that they provide (e.g. economic, aesthetic, recreational) (Klein *et al*., 2007; Junge *et al*., 2015; Lindemann-Matthies and Brieger, 2016).

1.4 Economic Valuation of Ecosystem Services

There are various means by which humans value pollinators and the services they provide, from a philosophical perspective and an economic perspective (Adams, 2014). From an environmental economics perspective, the concept of TEV links ecosystem services within a broader economic context (Randall, 1987). The economic value of ecosystem services is generally broken down into use case values and non-use case values (Pascual *et al*., 2012). Use cases include the value of the direct and indirect benefits that people derive from a particular ecosystem service, such as pollination of food crops (Free, 1993). 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 were willing to pay for conservation of distant coral reefs, even if they never plan to visit or in any way directly "use" the resources/services derived from these reefs (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).

In the case of pollinators, they can be valued directly for the products that arise from their foraging behaviour (fruit and seed crops and, from bees, honey) and the aesthetic and leisure values associated with the presence of pollinated wild plants in the landscape (Lindemann-Matthies *et al*., 2010; Junge *et al*., 2015; Lindemann-Matthies and Brieger, 2016; Schüpbach *et al*., 2016). They can also be indirectly valued for the supporting and regulating services that they provide through facilitating the reproduction of wild and cultivated plants (Aizen *et al*., 2008). There is also extensive research into the health and well-being benefits that accrue from green and blue spaces, which pollinators play an important role in sustaining (Maas *et al*., 2006; Lee and Maheswaran, 2011). Other economic values associated with ecosystem services include the option value and insurance value. Option value refers to an individual's private willingness to pay (or choice option) for maintaining pollinators even if it is unlikely that the 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).

Economic valuation of ecosystem services is a useful tool 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 under-estimated in decision-making processes and lead to unsustainable use of resources (Mace, 2014). Economic valuation can also be a useful tool 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*., 2010).

1.5 Valuing Pollination as an Ecosystem Service

The Millennium Ecosystem Assessment contributed to putting ecosystem services firmly on the global policy agenda (Millennium Ecosystem Assessment, 2003). Ecosystem services have been incorporated into 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). However, they are also useful as an educational tool to raise public interest in biodiversity conservation and to conceptualise how humans perceive and relate to nature. Some debate exists around the interpretation of ecosystem services and the potential for commodification, with respect to traditional conservation strategies, but a thorough discussion of this is beyond the scope of this review (Costanza and Daly, 1992; Costanza *et al*., 1997; Corbera *et al*., 2007).

Pollination is an intermediate ecosystem service in that it indirectly benefits humans by supporting other benefits, such as crop production or landscape aesthetics, through mediating the reproduction of flowering plants. Therefore, the value of pollination services may be measured indirectly through the final goods that are produced (e.g. food crops or wild flower diversity in the landscape). The 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). Pollinators can also be valued as final ecosystem services in themselves, but to value this would require alternative approaches to market valuation (such as stated preference approaches to calculate willingness to pay). This review will focus on market-based valuation approaches for pollinators, with an emphasis on the 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 (Breeze *et al*., 2016).

2 Methodologies for Calculating the Market Value of Pollination

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. 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.

2.1 Marginal Versus Static Value

Most economic valuation studies for pollination services focus on scenarios of broad pollinator loss, which give a static snapshot of current value across all habitat types. However, an alternative approach is to value ecosystem services relative to a unit change in habitat or yield, referred to as marginal value (Turner *et al*., 1993). This allows more fine-grained approximations of value by identifying how the next increment of habitat change could impact on ecosystem services. Marginal values can be incorporated into more dynamic ecological models of ecosystem change to support landscape optimisation and dynamic conservation planning (Polasky *et al*., 2011). For example, Ricketts and Lonsdorf (2013) estimated the marginal value of pollination services to coffee farms in Costa Rica by simulating deforestation events. They estimated that deforestation events could result in marginal losses varying from US$0 to US$700/ha across the landscape.

However, to accurately estimate the marginal value, the functional relationship between the dependent variable (e.g. crop yield) and the independent variable (e.g. pollination services) must be explicitly defined. For a linear functional relationship, the marginal value of crop yield would simply be a coefficient of the pollination services. However, in the case of a non-linear relationship, the marginal value changes with different levels of pollination services, and a clear understanding of the functional relationship between crop yield and pollination services is required. Therefore, because of a limited understanding of this functional relationship in most contexts, most studies from the literature tend to focus on static values for ecosystem services (Carpenter *et al*., 2006; Priess *et al*., 2007; Nelson *et al*., 2009).

2.2 Aggregate Crop Price

The simplest approach involves applying the total market value of animal-pollinated crops as a proxy for the value of pollination services (Matheson and Schrader, 1987). This approach assumes a complete dependence of production on pollination services, that is, all production of pollinator-dependent crops would cease in the absence of pollinators (Costanza *et al*., 1997). This means that this approach has simple data requirements and is applicable at all spatial scales. However, it is incorrect to assume complete dependence for most crops, as this ignores all mitigating factors that may reduce the impact of pollinator loss on production yields, such as wind pollination, the ability to self-pollinate or manual pollination techniques (Garibaldi *et al*., 2009). In addition, it ignores the ability of producers to substitute between crops or pollination sources.

2.3 Dependence Ratios

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). This is an estimate of the proportion of crop yield that would be lost in the absence of pollinators. This ratio can vary between species and between varieties of crop and does not take into account qualitative differences in crop output (e.g. nutritional content, taste or size of fruit) (Garratt *et al*., 2014). Dependence ratios are usually estimated for individual crop species using secondary agronomic data from experiments comparing yields with and without biotic pollination agents (Allsopp *et al*., 2008).

There is a large 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). Several studies have used the dependence ratio approach to represent the proportion of total crop output lost in the absence of pollination services in order to estimate the market value (Box 2.1) (Gallai *et al*., 2009; Lautenbach *et al*., 2012). However, this method tends to generalise across different cultivars and growing systems and depends on a number of unrealistic assumptions: that services are currently at maximum levels and that the relative effects of other inputs or ecosystem services are minimal. In addition, it neglects the marginal benefits of changes in pollinator populations or the ability to substitute between crops (Hanley *et al*., 2015). Nevertheless, the simplicity of this approach allows it to be used for large-scale global assessments of pollinator value (Gallai *et al*., 2009).

2.4 Yield Analysis

Yield analysis differs from the dependence ratio approach in that it depends on primary data collected from the field, as opposed to secondary data sources. However, it is conceptually similar to the dependence ratio in that it measures the proportion of crop yield that depends on pollination. This is estimated using field studies to analyse the difference in yield between open-pollinated and pollinator-excluded samples of a crop (Garratt *et al*., 2014; Klatt *et al*., 2014). For example, this approach was used to estimate the economic value of insect pollination to oilseed rape in Ireland at €3.9 million per annum (Stanley *et al*., 2013).

The direct measurement of the contribution of pollinators to crop yield means that this approach can capture more precise variations between cultivars and growing systems of the same crop. However, it is more labour intensive as it requires specific testing of all combinations of cultivars and growing systems in order to generalise to different possible scenarios (Hanley *et al*., 2015). Furthermore, like the dependence ratio approach, this approach fails to capture the impact of pollination services on crop quality, such as the size and taste characteristics of fruit (Garratt *et al*., 2014). Nevertheless, the yield analysis approach can be used as an alternative to the dependence ratio method at a local scale to capture more precisely the pollination service benefits of different cultivars of crops (Box 2.2).

Box 2.1. Case study: global nutritional value of pollinator-dependent crops

Gallai *et al*. (2009) analysed the contribution of insect pollination to world agricultural output using a dependence ratio approach. They estimated that reduced production of crops would amount to a loss of €153 billion per year, or a loss of 9.5% of agricultural production for human food based on 2005 production figures. They also expressed this in terms of economic welfare, by estimating the loss in consumer surplus to be between €190 and €310 billion. They concluded that global food production would be vulnerable to pollinator declines. Furthermore, they calculated the capacity to nourish the world population in the absence of pollinators and identified that there would be a shortfall in three crop categories.

The effects of animal pollinator decline on human nutrition and global health were assessed in a study by Smith *et al*. (2015), which explored the health outcomes associated with decreased intake of pollinator-dependent foods. They quantified the nutrient composition of pollinator-dependent foods to estimate the dietary reduction in micronutrients (vitamin A and folate) associated with replacement by staple foods of similar calorific content. They estimated that 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 both reduced production and perhaps increased healthcare and human costs associated with increased mortality. Therefore, the value of pollinators is best captured through a multi-dimensional approach that incorporates both economic and health values, as illustrated in these examples.

Box 2.2. Case study: economic value of tropical forest to coffee production

Ricketts *et al*. (2004) demonstrated the economic value of habitat conservation in tropical forests to coffee farmers in Costa Rica, using ecological experiments and economic calculations. The societal benefits of native ecosystems are largely unquantified, but in this case study the authors valued the pollination services supplied by tropical forests to local agriculture. They used pollination experiments to analyse the impact of wild pollinators on coffee (*Coffea arabica*) yield. They found that both coffee quality and yield were increased by proximity to forest-based pollinators. Based on their experiments, they estimated that the economic value of pollination services to Costa Rican farms could be approximately US$60,000 per year per farm. They proposed that this type of assessment could be used to inform conservation investments in human-dominated landscapes.

2.5 Managed Pollinator Prices

This approach involves measuring the market price of managed pollination services (e.g. rental of honey bee hives or purchase of bee colonies or solitary bee aggregations) as a proxy for the value of pollination services to crop production (Burgett *et al*., 2004; Rucker *et al*., 2012). This approach is restricted to only those species of pollinators that can be managed, including honey bees and a few species of bumble bees, stingless bees and solitary bees. As the value of managed pollinators is assumed to be dictated by traditional market forces, this approach is compatible with standard economic theory. However, many countries do not have well-developed markets for honey bee rental for crop pollination and, where markets exist, prices are often influenced by other factors that are independent of the benefits to crop production, such as management costs, honey yield or the price of the crop, or the use of fixed prices regardless of the intended crop (Carreck *et al*., 1997; Sumner and Boriss, 2006).

This means that the market price for managed pollinators often reflects the market forces influencing the price of producing and supplying the pollinators and thus is not an effective proxy for the value of pollination services. Furthermore, this approach cannot be used to evaluate pollination services from wild pollinators, which play a significant role in many crop production systems (Garibaldi *et al*., 2013). Therefore, this approach would tend to underestimate the value of pollinators as it excludes all consideration of other secondary ecosystem services that they provide.

2.6 Replacement Costs

An alternative approach to value the role of pollinators is to consider the replacement costs of substituting wild pollinators with technology or with managed pollination services (e.g. honey bee hive rental) (Allsopp *et al*., 2008; Rucker *et al*., 2012). However, these costs are influenced by factors such as the costs of labour and fuel, making it difficult to directly relate them to the value of the pollination service benefits (Melathopoulos *et al*., 2014). For example, changes in market prices of fuel may result in different estimations for the value of the pollination services that technology or other managed pollination services replace.

In addition, the efficacy of different forms of artificial pollination can vary between crop species (Delaplane *et al*., 2000). This factor may cause misrepresentations when, for example, the social benefits that are lost when an ecosystem service is unavailable are less than the cost of replacement (Farber *et al*., 2002). For example, one study showed that rising wages in China for hand pollination resulted in the widespread replacement of fruit crops with wind-pollinated crops in Sichuan Province because of an increasingly unviable business model (Partap and Ya, 2012). Replacement costs do not reflect the economic value of the pollination service directly but rather the market price of the replacement method, which can be affected by other factors such as, in this case, rising wages. If factors such as high wages persist, then the farmers' willingness to pay for these services will be limited. Valuation using replacement costs can result in a higher value being attributed to pollinators than market prices for commercial pollination, and lower dependence ratio estimates, but this may vary according to context and other market factors (Allsopp *et al.*, 2008).

2.7 Production Function Models

A more complex, mechanistic approach to measure pollinator benefits is to use crop production function models (Hanley *et al.*, 2015). These involve explicitly modelling the interactions between pollinators and crops in order to describe the functional relationship with crop output. Production functions incorporate a range of inputs (including fertilisers, pesticides and labour) and environmental factors (e.g. water, temperature) to estimate the benefits of pollination relative to other factors. Theoretically, this method could be used to capture the benefits of pollination relative to other inputs and ecosystem services and to extrapolate these to various locations and scales. This can be achieved by incorporating the costs of inputs (e.g. the cost of renting managed pollinators) to determine economically optimal cost-based solutions.

For example, Lonsdorf *et al.* (2009) developed a production function model that used information on nesting and floral resources, along with foraging distance, to predict the relative abundance of wild bee pollinators on a landscape level. This information could be used to predict the relative abundance of pollinators on farms requiring pollination services. However, the accuracy of pollinator abundance predictions was limited by the availability of fine-scale information on the floral and nesting resources of bees within the landscape. Nevertheless, it demonstrated the potential for this approach to provide quantitative and mechanistic predictions to inform policy decisions and land-use plans.

However, literature on functional modelling approaches is limited because of the high empirical data requirements of this type of approach. For example, for accurate forecasting, extensive empirical data on ecological functioning and on plant–pollinator interactions at a mechanistic level would be required. Furthermore, the complexity of the interactions between the floral resources, pollinators and environmental parameters means that it is difficult to reduce the underlying processes to a simple model structure. The combination of model complexity and precise empirical data requirements limits the accuracy of the model outputs as predictors of pollination service benefits. However, by using appropriate aggregation of parameters to simplify the model, and cognisant of its limitations, the production function-based approach could be a powerful tool for tracing back landscape-level effects to the effects of the individual components (e.g. pollinators, floral resources).

2.8 Surplus Valuation Models

In addition to models of the functional relationship between pollination services and crop production, econometric modelling approaches can also be used to capture the economic value of pollinator services (i.e. their impact on producer and consumer economic welfare). These are 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 a consumer for goods or services and their maximum willingness to pay) (Kevan and Phillips, 2001).

The simplest form of this approach is the partial equilibrium model, which estimates the welfare value of price changes to the available income of producers and consumers of a single crop market (Southwick and Southwick Lawrence, 1992; Gallai *et al.*, 2009). This does not take into account substitution between crops or the relative effects of other inputs. The model is based on the supply and demand curve from standard economic models and estimates how shifts in supply (because of changes in pollination services) impact prices and economic welfare. Price changes are accounted for by incorporating the concept of price elasticity of supply, which expresses the ratio between the percentage change in price and the percentage change in supply (Marshall, 2009).

A more comprehensive approach to capture economic value is the general equilibrium model (Jones, 1965; Farber *et al.*, 2006; Bauer and Sue Wing, 2016). This method accounts for both the capacity of producers to compensate for pollinator loss with other inputs and the effects of such losses on external linked markets. This allows it to capture the effects of pollination service changes on both the affected crop market and other related markets. This could be used to identify the effects of pollinator loss on other secondary sectors. However, this brings added complexity and data requirements, including accurate definitions of substitution effects, and this approach is highly sensitive to the quality of the data on pollination benefits. It is difficult to obtain accurate empirical estimates for many of these parameters on a crop- or variety-specific basis and it is poorly understood how key ecosystem variables influence key economic variables (Tschirhart, 2000).

General equilibrium models require extensive ecological analyses, as well as economic analysis from a range of different markets, to determine the range of substitutions involved (Jones, 1965). In the case of minor crop markets, where degrees of substitutions are unclear, it may be difficult to obtain detailed information to parameterise the model. It is also difficult to interpret the contributions of the different variables to the resultant estimates of welfare change. However, these approaches can be used for internationally traded crops for which clear substitution data are available, in order to evaluate the impacts on crop production and consumer/producer welfare of national- or international-scale policy decisions (Banse *et al*., 2011).

3 Methodologies for Calculating the Non-market Value of Pollination

The approaches listed in Chapter 2 are limited to capturing the market value of pollination services. However, for many services that pollinators provide there is not a mature market structure for trading and price discovery. This is often the case when it comes to the indirect and "non-use" values associated with nature, for example the benefits derived from pollination of wild flowers in the landscape. Alternative approaches must be applied to capture the non-market value of pollination services in terms of maintaining landscape aesthetics and human health and well-being or preventing biodiversity loss. These approaches are generally categorised into "revealed preferences" and "stated preferences".

3.1 Revealed Preferences

The revealed preferences (or inferential valuation) approach uses market data to extrapolate the value of benefits derived from ecosystem services (Richter, 1966). This assumes that, for non-marketed goods, such as environmental attributes, there exists some market that contains an implicit value for these goods (Rosen, 1974; Meinard *et al*., 2016). Examples of revealed preferences include travel costs (e.g. the travel costs associated with visiting a particular natural recreational amenity) and hedonic pricing (e.g. increased real-estate value in proximity to parkland) (Loomis *et al*., 2000; Sander and Haight, 2012; Ruhl *et al*., 2013).

The travel cost method has most commonly been used in outdoor recreational resource valuation studies, since first being recommended to the National Park Service of the USA by Harold Hotelling in 1947 (Smith and Kaoru, 1990). For example, the travel cost method was used to estimate the value of recreational fishing in the Brazilian Pantanal (a natural region encompassing the world's largest tropical wetland area) by using data on the costs associated with people visiting the area (Shrestha *et al*., 2002). Meanwhile, hedonic pricing calculates the value of a natural attribute by estimating its impact on real-estate markets. For example, the impact of sediment loading to lakes on the price of neighbouring real-estate transactions has been used to estimate the value of sediment control by forested public land (Yoo *et al*., 2014). Neither approach has been used so far to value pollination services.

The revealed preference approach relies on the identification of a proxy market for which there is a clear implicit relationship with the goods being valued, on which market-based calculations can be carried out. However, if the functional relationship between the ecosystem service and the proxy market is unclear, or there are other unknown confounding variables, it is difficult to derive an accurate estimate of the contribution of the environmental attribute to the market price. For example, in the case of real-estate market prices, these are often determined by a combination of factors, including supply and demand, labour costs and macro-economic conditions, which could confound estimates of value based on a hedonic pricing model.

3.2 Stated Preferences

Often, it is not possible to infer the value of ecosystem services using a revealed preference approach if, for example, there are no quantifiable data on the costs associated with obtaining the goods or benefits in question. In this case, one of the most common techniques used to quantify non-market values of pollinators is the stated preference method (Adamowicz *et al*., 1994). The stated preference approach involves using economic survey-based or experimental instruments to elicit respondents' willingness to pay for the maintenance of or improvement of ecosystem goods and services within a hypothetical market (Adamowicz *et al*., 1998; Breeze *et al*., 2015). This is useful because it captures benefits beyond direct market effects and can be used to analyse public opinion. It requires complex modelling to analyse and it is important to avoid bias effects in the survey responses by ensuring a representative sample and accurate responses. Respondents are usually presented with a questionnaire consisting of discrete choices for bundles of ecosystem goods or services. Prices are assigned to these bundles in order to estimate the economic value of each bundle to respondents. The questionnaire is used to calculate respondents' willingness to pay to gain an increase, or avoid a loss, in the goods or services. Alternatively, it can be used to calculate the willingness to accept payments to allow the degradation, or forego a gain, in the goods or services (Plott and Zeiler, 2005).

Stated preference approaches may be broken down into:

- contingent valuation methods, which offer respondents a complete bundle of goods with an attached price and a zero-cost alternative representing a degraded or current state;
- choice experiments, which follow similar principles except that respondents are given multiple alternatives to the zero-cost option.

Through repeated observations of such choices, typically across many respondents and using different attached prices, discreet choice modelling methods can estimate the probability of respondents within the sample selecting a given bundle, depending on its price, and a typical respondent's willingness to pay or willingness to accept value (Díaz *et al.*, 2015).

The stated preference approach can be used, for example, to estimate the existence value of pollinators by estimating respondents' willingness to pay for the maintenance of pollinator populations (Mwebaze *et al.*, 2010). This approach is potentially applicable to any non-market benefits from pollination services regardless of the existence of a market, and it can also be used to differentiate willingness to pay/willingness to accept based on demographic information if available. However, questionnaire-based approaches are costly to undertake and require large, unbiased and representative samples for statistically robust analysis. The design and wording of questionnaires also forms an important part of obtaining reliable and representative results, and respondents may have difficulty forming preferences for unfamiliar goods such as ecosystem services. Nevertheless, with careful survey design and rigorous statistical analyses to reduce the impacts of biases, it is possible to derive meaningful information on non-market values associated with pollinators using this approach.

4 Future Directions: Towards a More Holistic Valuation of Nature

As documented in the previous chapters, various methodologies can be utilised to elicit the monetary value associated with non-market benefits of ecosystem services, such as questionnaires and willingness-to-pay calculations. However, some commentators have advocated the use of qualitative, participatory and deliberative methods to elicit a more holistic value for biodiversity (Chan *et al*., 2012). Qualitative approaches, such as in-depth interviews and focus groups, can be used not only to understand the preferences underlying people's economic values, but also to uncover local socio-cultural values distinct from the economic value system (Scholte *et al*., 2015).

Socio-cultural or holistic valuations of biodiversity are grounded in the social context of a given individual or group of people (Berkes, 2009). They are therefore subject to the social histories and geopolitical interactions within a community or region over time (Berkes and Turner, 2006). Attempts have been made to contextualise value systems by taking into account indigenous and local knowledge systems (Tengö *et al*., 2017). An indigenous and local knowledge system is defined as the cumulative knowledge, practices and beliefs of a cultural system about the relationship between living beings and their environment (e.g. farmers' or anglers' knowledge) (Díaz *et al*., 2015). These systems are dynamic and adaptive bodies of social-ecological knowledge that are grounded in a particular local or regional context (Jackson and Palmer, 2014; Pert *et al*., 2015). Therefore, it is important to identify the actors involved by posing questions such as "Who benefits from the ecosystem services?" and "Whose practices impact the ecosystem service provision?". Ethnographical methods (e.g. primary or secondary data analysis, formal or semi-structured interviews, participant observation) are often used to elicit values (Barnett-Page and Thomas, 2009).

Economic and non-economic approaches to valuation are not mutually exclusive and often overlap, but they represent different perspectives to the concept of valuing nature (Box 4.1; see also Box 2.1). For example, there is value attached to "health" benefits that derive from a medicinal property of a plant, but there may equally be economic value in terms of reduced healthcare costs, as well as 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 healthcare 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 – economic, health and socio-cultural – when making decisions in relation to conservation.

Ideally, from a conservation management perspective, an integrated and holistic interpretation of value that considers economic, health and socio-cultural values 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 (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 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).

Box 4.1. Case study: the monarch butterfly as an example of socio-cultural value

The monarch butterfly has been studied for its importance as an emblem of conservation in North America. Monarch butterflies have high cultural value (they are the official insect of seven US states) and their annual migration between the northern USA/Canada and central Mexico is closely observed as a natural phenomenon. For this reason, they have been the focus of many studies around the socio-cultural value of nature.

In one study, Diffendorfer *et al*. (2014) performed a contingent evaluation approach to evaluate people's willingness to pay for monarch butterfly conservation. They calculated a TEV to US households of the monarch butterfly of US$4.78–6.64 billion. They argued that this approach could be used to generate new funding for monarch butterfly conservation through incentive-based approaches.

In a separate study, Gustafsson *et al*. (2015) analysed the sociological significance of the monarch butterfly as a conservation icon at the science–policy-–practice interface. They investigated the role that it plays in shaping public conversations around policy and practice across diverse organisational boundaries. They argued that the monarch butterfly represents a powerful communication vehicle in environmental politics through its historical and contemporary construction as a conservation icon.

These two studies are good examples of alternative approaches to evaluate the socio-cultural significance of nature. In both cases, they are looking at a similar phenomenon: the public perception of the monarch butterfly as a valuable entity to humans. However, they look at it from different perspectives, using the tools of their respective domains (economics and sociology). By incorporating all of these approaches into decision-making processes, it is possible to gain a more holistic understanding of the value of monarch butterflies.

5 Conclusions

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, there is a gap in our understanding of the relationships between the diverse methodological approaches to valuing pollinators, from economic to more holistic approaches.

Efforts have been made to capture use and non-use values through methodologies such as the TEV framework (Randall, 1987). This can be used to estimate the output value (e.g. food production or recreational value) and option/insurance value generated by an ecosystem or species in economic terms (Pascual *et al*., 2012). However, this framework is limited in its ability to incorporate more holistic approaches to valuation, which cannot necessarily be expressed in monetary terms. The combined use of economic, socio-cultural and holistic valuation 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.

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Abbreviations

EPA	Environmental Protection Agency
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
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.

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Assessing Market and Non-market Values of Pollination Services in Ireland: Pollival Literature Review

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

Authors: James T. Murphy and Jane C. Stout

Identifying pressures

Pollination has been identified as a key ecosystem service that is threatened globally by anthropogenic activities. Estimation and consideration of 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 literature review assesses approaches to valuing nature and focuses on methods for valuing pollination services. The financial contribution of pollinators and pollination services to crop yields, and the implications of pollinator loss for food production, have been estimated for a range of crop types globally, using a variety of methods. Less attention has been afforded to non-market values of pollinators and pollination services, and integrating monetary and other values remains a challenge.

Informing policy

"Valuing and protecting our natural environment" was articulated as a key aim of the Environmental Protections Agency's (EPA) 2012 State of the Environment Report, but in 2016 it was acknowledged that the value of ecosystem services was still not normally integrated into business decisions and policymaking. Furthermore, the European Union (EU) Biodiversity Strategy to 2020, the EU 7th Environmental Action Programme (EAP), the Convention on Biological Diversity's Aichi Targets and the Paris Agreement all highlight the need to consider the value of nature. The Pollival literature review considers different approaches to valuing the market and non-market value of pollinators and pollination services for integration into environmental accounts, justification for financial input to conservation, and general appreciation of the value of nature among public and private bodies. Pollinators and their services are useful exemplars, as they provide tangible case studies that resonate with private citizens, businesses and policymakers.

Developing solutions

The identification of approaches to valuing market and non-market use and non-use values of pollinators and pollination services, as outlined in the Pollival literature review, is a key step in efforts to incorporate the value of nature into public and private decision-making. This review details the state of the art with regards to valuing pollinators and pollination services and highlights data needs and knowledge gaps, particularly with respect to integrating values calculated using different metrics. Ultimately, by understanding both the financial and the non-financial contributions of pollinators and pollination services to human society and well-being, the impacts of spatio-temporal changes in service delivery can be predicted and informed decision-making based on cost–benefit analyses can be progressed.

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