Tools for Conservation and Use of Pollination Services

Economic Valuation of Pollination Services:

Review of Methods

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Review of Methods

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1. Background and Context

A range of studies have shown that pollination makes a very significant contribution to the agricultural production of a broad range of crops, in particular fruits, vegetables, fibre crops and nuts (e.g. Levin, 1984; Costanza et al., 1997; Gordon and Davis, 2003). For instance, the value provided by the pollination service with respect to US agriculture alone is estimated at between US$ 6 and 14 billion per year (Southwick and Southwick, 1992; Morse and Calderone, 2000). However, estimates for the economic value of the pollination service vary widely (e.g. Richards, 1993; Costanza et al., 1997), and there is an urgent need for a review of potential valuation methods and an analysis of the experiences with the valuation of the pollination service to date.

Mango vendors along roadside,
Guinea Bissau

The Food and Agriculture Organization of the United Nations, through its role in coordinating the International Pollinator Initiative, is working to assist a number of member countries to develop strategies for pollinator conservation and management. In this role, FAO has collaborated with the Centre for Development Research on a review of methods of economic valuation of pollination services that will serve to guide activities in member countries, in filling information and knowledge gaps on the value of pollinators and pollination services in different agro-ecosystems. The aim of this review was to analyse the experiences with the economic valuation of the pollination service to date, and to provide a structure for the economic valuation of pollination service in selected agro-ecosystems. The study provides guidance on the appropriate methods for assessing the economic value of pollination including the economic impacts of a decline in the pollination service.

The study has been conducted on the basis of an in-depth review of existing literature on the valuation of ecosystem services in general and the pollination service in particular. Section 2 analyses which valuation methodologies can be used to analyse the pollination service, and Section 3 reviews the experiences with the valuation of the pollination service to date. Section 4 presents a semi-hypothetical case study on pollination in Ethiopian coffee farming.

2. Valuation Methodologies Suitable for Pollination Service

2.1 Concept of Ecosystem Services

In the early 1970s, the concept of ecosystem function was proposed to facilitate the analysis of the benefits that ecosystems provide to society (Odum 1969; Hueting 1980). An ecosystem function is defined as "the capacity of the ecosystem to provide goods and services that satisfy human needs, directly or indirectly" (De Groot 1992). Ecosystem functions depend upon the state and the functioning of the ecosystem. For instance, the function 'production of firewood' is based on a range of ecological processes involving the growth of plants and trees that use solar energy to convert water, plant nutrients and CO2 to biomass. A function may result in the supply of ecosystem services, depending on the demand for the good or service involved. Ecosystem services are the goods or services provided by the ecosystem to society (Costanza et al., 1997; Millennium Ecosystem Assessment, 2003). For example, the amount of firewood extracted from an ecosystem depends on the demand from the local community and the costs at which firewood can be obtained. The supply of ecosystem services will often be variable over time, and both actual and potential future supplies of services should be included in an economic assessment of the ecosystem (Drepper and Månsson 1993; Barbier 2000; Mäler 2000).

Different categories of ecosystem services can be distinguished, and different authors have come up with a range of classification systems. Based on the Millennium Ecosystem Assessment (2003), the following three types of ecosystem service categories have been distinguished: (i) production services; (ii) regulation services; and (iii) cultural services. Pollination services have been considered a regulation service along with pest control and nitrogen fixation; but could equally be considered as a production service.

2.2 The economic value of ecosystem services

2.2.1 The consumer and producer surplus of ecosystem services

According to neo-classical welfare economics, the welfare generated by an ecosystem service, or the economic value of this service, is the (weighted) sum of the utility gained by all individuals as a result of the provision of the ecosystem service. Utility is gained by the person consuming the ecosystem service (e.g. by eating a piece of fruit or walking in a national park). Utility may also be gained, or lost, by the person or institute offering the ecosystem service (the person collecting and selling the fruit, or the ecosystem manager maintaining the recreational facilities of a park). For private ecosystem services, and assuming perfect market conditions, price reflects the marginal economic value of the service. Two central concepts in understanding the utility that consumers and producers gain from a transaction are the consumer and the producer surplus. However, in subsequent analyses developed, it was not felt that consumer surpluses due to pollination services are likely to be of an order of magnitude to significantly affect prices; thus the approach focuses on capturing economic impacts of increasing production through enhanced pollination services.

The producer surplus indicates the amount of welfare a producer gains at a certain production level and at certain price. The estimation of the producer surplus generally requires the construction of a supply curve (see e.g. Perman et al., 1999). In the short term, a producer's fixed costs can be considered foregone. Hence, in micro-economics, the individual producer surplus is defined as total revenues minus variable costs (Varian, 1993). In the valuation of ecosystem services, the producer's surplus needs to be considered if there are costs related to "producing" the ecosystem good or service (Freeman, 1993; Hueting et al., 1998). In general, in the case of private ecosystem good or services, these costs relate to the costs of harvesting or producing the ecosystem good or service (Hueting et al., 1998). For public ecosystem goods, supply curves reflect the costs of measures to restore and conserve the supply of services. For these services, a supply curve is often difficult to construct and the producer surplus is difficult to establish (Hueting et al., 1998). The supply curve will in many cases show a relatively steep increase at higher quantities of ecosystem service supplied – e.g. the costs of providing marginal cleaner water increase as purity becomes higher (Hueting, 1980). For agricultural production, the producer's

Woman holding *Microcarpa* fruits

surplus reflects the net benefits producers of agricultural crops appropriate by obtaining a price higher than the costs of production. Hence, the value of pollination for agricultural producers can be estimated by analysing its contribution to their net benefits, in terms of higher yields or enhanced crop quality. In addition, positive externalities of the pollination service may exist, for instance where insect populations also regulate the reproduction of natural species that provide benefits to society. Furthermore, landscape elements, such as hedgerows or field edges, which regulate the pollination service by providing habitat to insect species, may provide a range of other externalities, such as controlling erosion or maintaining biodiversity. Such externalities need to be considered in addition to the producer surplus in the assessment of the economic value of pollination services.

2.2.2 Types of economic value of ecosystem services

Types of values. Drawing on the concept of Total Economic Value (TEV), there are several types of economic value, and different authors have provided different classifications for these value types (e.g. Pearce and Turner, 1990; Hanley and Spash, 1993; Munasinghe and Schwab, 1993; and Millennium Ecosystem Assessment, 2003). In this study, the following four types of value are distinguished: (i) direct use value; (ii) indirect use value; (iii) option value; and (iv) non-use value.

(i) Direct use value arises from the direct utilisation of ecosystems (Pearce and Turner, 1990), for example through the sale or consumption of a piece of fruit. All production services, and some cultural services (such as recreation) have direct use value.

(ii) Indirect use value stems from the indirect utilization of ecosystems, in particular through the positive externalities that ecosystems provide (Munasinghe and Schwab, 1993). This reflects the type of benefits that regulation services including pollination provide to society.

(iii) Option value relates to risk. Because people are unsure about their future demand for a service, they are willing to pay to keep the option of using a resource in the future – insofar as they are, to some extent, risk averse (Weisbrod, 1964; Cichetti and Freeman, 1971). Option values may be attributed to all services supplied by an ecosystem. Various authors also distinguish quasi-option value (e.g. Hanley and Spash, 1993), which represents the value of avoiding irreversible decisions until new information reveals whether certain ecosystems have values we are not currently aware of (Weikard, 2003). Although theoretically well established, the quasi-option value is in practice very difficult to assess (Turner et al., 2000). Pollination has an option value where there is a willingness to pay for the preservation of the service in a situation where pollination's impact on the provision of welfare is not precisely known.

(iv) None-use value is derived from attributes inherent to the ecosystem itself (Cummings and Harrison, 1995; Van Koppen, 2000). Hargrove (1989) has pointed out that non-use values can be anthropocentric, as in the case of natural beauty, as well as ecocentric, based upon the notion that animal and plant species have a certain 'right to exist'. Kolstad (2000) distinguishes three types of non-use value: existence value (based on utility derived from knowing that something exists), altruistic value (based on utility derived from knowing that somebody else benefits) and bequest value (based on utility gained from future improvements in the well-being of one's descendants). The different categories of non-use value are often difficult to separate, both conceptually (Weikard, 2002) and empirically (Kolstad, 2000).

Nevertheless, it is important to recognize that there are different motives to attach non-use value to an ecosystem service, and that these motives depend upon the moral, aesthetic and other cultural perspectives of the stakeholders involved.

2.2.3. General classification of valuation methods.

These four value types all need to be considered in the assessment of the total value of the services supplied by an ecosystem. In principle, the values are additive (Pearce and Turner, 1990). Insofar as commensurable value indicators have been used, they may be summed in order to obtain the total value of the services supplied by the ecosystem. With respect to pollination, it mainly has indirect use value through its contribution to maintaining agricultural production and natural ecosystems that, in turn, provide a range of material and non-material benefits to society.

Following neo-classical welfare economics, valuation requires analysis and aggregation of the consumer and producer surpluses (Freeman, 1993). In the last 3 decades, a range of economic valuation methods for ecosystem services has been developed. They differ for private and public goods.

(i) Valuation of private goods. In the case of private goods or services traded in the market, price is the measure of marginal willingness to pay and it can be used to derive an estimate of the economic value of an ecosystem service (Hufschmidt et al., 1983; Freeman, 1993). The appropriate demand curve for the service can - in principle - always be constructed. However, in practise this is often difficult, as (i) it is not always known how people will respond to large increases or decreases in the price of the good, and (ii) it may be difficult to assess when consumers will start looking for substitute goods or services. In case of substantial price distortions, for example because of subsidies, taxes, etc., an economic (shadow) price of the good or service in question needs to be constructed. In some cases, this can be done on the basis of the world market prices (Little and Mirrlees, 1974; Little and Scott, 1976). In case the private good is not traded in the market, because it is bartered or used for auto-consumption, shadow prices need to be constructed on the basis of: (i) the costs of substitutes; or (ii) the derived benefit of the good (Munasinghe and Schwab, 1993).

(ii) Valuation of public goods. For public goods or services, the marginal willingness to pay can not be estimated from direct observation of transactions, and the demand curves are usually difficult to construct (Hueting, 1980). Two types of approaches have been developed to obtain information about the value of public ecosystem services: the indirect and the direct approach (Pearce and Turner, 1990). Pearce and Howarth (2000) call them revealed and expressed preference methods, respectively. The *indirect* approaches use a link with a marketed good or service to indicate the willingness-to-pay for the service. There are two main types of indirect approaches:

- *Physical linkages.* Estimates of the values of ecosystem services are obtained by determining a physical relationship between the service and something that can be measured in the market place. The main approach in this category is the damage-function (or dose-response) approach, in which the damages resulting from the reduced availability of an ecosystem service are used as an indication of the value of the service (Johanson, 1999). This method can be applied to value, for instance, the hydrological service of an ecosystem.
- Behavioural linkages. In this case, the

value of an ecosystem service is derived from linking the service to human behaviour – in particular the making of expenditures to offset the lack of a service, or to obtain a service. An example of a behavioural method is the Averting Behaviour Method (ABM). There are various kinds of averting behaviour: (i) defensive expenditure (a water filter); (ii) the purchase of environmental surrogates (bottled water); and (iii) relocation (OECD, 1995; Pearce and Howarth, 2000). The travel cost method and the hedonic pricing method are other indirect approaches using behavioural linkages (Van Kooten and Bulte, 2000).

With direct approaches, various types of questionnaires are used to reveal the willingness-to-pay of consumers for a certain ecosystem service. The most important direct approaches are the Contingent Valuation Method (CVM) and Choice Modelling (CM), which fall into the broad category of choice experiments (CE). In the last decades, CVM studies have been widely applied (see e.g. Nunes and van den Bergh, 2001 for an overview). It is the only valuation method that can be used to quantify the non-use values of an ecosystem in monetary terms. Information collected with well-designed CVMs has been found suitable for use in legal cases in the U.S. - as in the case of the determination of the amount of compensation to be paid after the Exxon Valdez oil spills (Arrow et al., 1993). Nevertheless, various authors question their validity and reliability - both on theoretical and empirical grounds. There are two main points of criticism against CVM. First, CV estimates are sensitive to the order in which goods are valued; the sum of the values obtained for the individual components of an ecosystem is often much higher than the stated willingness-to-pay for the ecosystem as a whole. Second, CV often appears to overestimates economic values because respondents do not actually have to pay the amount they express to be willing to pay for a service (see e.g. Diamond and Hausman, 1994; Cummings and Harrison, 1995; Hanemann, 1995 and Carson, 1998). These limitations of CVM have, in the last few decades, raised the need for the application of CM in measuring ecosystem benefits. Unlike CVM, CM does not require survey respondents to place a direct monetary value on a contingency. Rather, individuals are asked to make comparisons among environmental alternatives, with the environmental commodity or service described in terms of its attributes, or characteristics, and the levels that these take. It is the attributes that are important and it is these that are eventually assigned a monetary value. In order to do so, one of the attributes must constitute a monetary amount (Hanley et al., 2001).

2.3 Economic valuation of the pollination service

2.3.1 Introduction

Pollination is a critical link in the functioning of ecosystems, and it is essential for the production of a wide range of crops. Its value is derived from its contribution to the maintenance of ecosystems as well as its impact on agriculture. The value related to the maintenance of natural ecosystems is mostly a derived value; it is a function of the value of services of the ecosystem supplied directly to society. For instance, a forest ecosystem may supply wood, fruits, carbon sequestration, regulate downstream river flows and contain important biodiversity. The maintenance of the supply of these services depends on a range of ecological processes including pollination (in the terminology of the Millennium Ecosystem Assessment, 2003: pollination is one of the 'supporting services'). Therefore, pollination in the forest has economic value, as has pollination that supports agricultural production.

To date, there is no experience with the valuation of the pollination service as a process required for the functioning of natural ecosystems (Southwick and Southwick, 1992; Morse and Calderone, 2000). Much more information is available with respect to the value of pollination as a contributor to the maintenance of agricultural production. Nevertheless, sometimes conflicting value estimates for the pollination service have been produced and the available information is prone to considerable uncertainty. The remainder of this report therefore focuses on the value of pollination in relation to maintaining agricultural production and food security.

Whereas the economic valuation of the pollination service in natural ecosystems is not further analysed in a quantitative manner in this paper, some general, qualitative guidelines are formulated in this paragraph. If the pollination service is considered for economic costs benefit analysis to support decision making, it is crucial to define the object of the valuation. If the target of the valuation study is to reveal the economic value of the bee population of a forest, clearly the impact of the pollination process on all the other services supplied by the forest needs to be considered. The situation changes if the object of the valuation is the forest itself. The total value supplied by a specific forest, for example, depends on the value of the services provided by the forest. It may, or may not be necessary to consider pollination as a separate service depending on the positive externalities this service provides. If pollination is only important for the maintenance of the other services supplied by the forest, e.g. the supply of fuel wood, timber, food products, carbon sequestration and the regulation of water flows, and pollination does not by itself provide a benefit to people, there is no need to include the value of the pollination service in the total value estimate of the forest as this would lead to double counting. However, to the contrary, if a patch of forest contains pollinators that are crucial for an adjacent ecosystem, and the object of the valuation study is the specific patch of forest, pollination is a regulation service which has an added value not contained in the other services of the forest (e.g. Ricketts et al., 2004). In this case, it should be included. For more info on double counting, see e.g. Hein et al. (2005).

As becomes clear from a review of valuation methods presented in the previous section, there are a number of approaches that can be followed to value the pollination service. These include (i) using market prices; (ii) the damage cost method; and (iii) the production factor method. These three principal methods suitable for valuation of the pollination service are reviewed below.

The methods selected for further review are all indirect (revealed preference) methods. For the pollination service, it is anticipated that Contingent Valuation Methods or Choice Experiments are not suitable. The reason is that these valuation methods require respondents to have a sound knowledge of the quantitative contribution that pollination makes to agricultural production in their field. In view of the substantial uncertainties that exist in ecological literature on the contribution of pollination to crop growth under specific ecological circumstances it is not likely that farmers have a quantitative comprehension of this. Furthermore, application of this method requires a clear payment vehicle including a scenario of how pollination services would be reduced or enhanced as a function of the willingness to pay of the farmer, which is also difficult to envisage, in particular for the case study countries selected for the GEF project (Brazil, Ghana, Kenya, South Africa, Pakistan, India, and Nepal).

2.3.2 Valuation on the basis of market prices

The market price method estimates the economic value of ecosystem services that are bought and sold in markets. In the case of perfectly functioning markets (full information, no transaction costs, etc.) and no distortion through taxes or subsidies, the market prices paid by farmers to commercial beekeepers reflect the marginal value of the pollination service. In order to calculate the total value of the pollination service, for instance in a country, the consumer's and producer's surplus have to be calculated. The consumer's surplus is reflected in the demand curve that represents farmer's willingness to hire commercial bee-hives for pollination at different prices. The producer surplus reflects the revenues of the commercial beekeepers minus their costs (inputs, material, transport of beehives, capital costs and shadow costs of labour). Clearly, data on marginal or total value of the pollination service using a market prices approach are only available for pollinators that have been domesticated including honeybees and, recently, bumblebees. Furthermore, currently, the pollination services needs to be 'traded' on the basis of demand from farmers and supply from beekeepers. However, some markets, in particular the agricultural markets in the EU and the US, are characterised by large-scale subsidies that provide a bias in the value estimate. As these subsidies increase farmer's income per unit of agricultural product produced, it can be expected that, in general, these subsidies lead to an upward bias in the value estimate, i.e. the value is likely to be lower than the market price paid to commercial beekeepers. The advantage of using commercial prices is that information on these prices is readily available for a range of different crops, and provides a suitable indication for the marginal value of the pollination service. However, data only extend to domesticated pollinators.

2.3.3 Cost-based methods (preventive expenditure/damage costs avoided/replacement costs)

The preventive expenditure, damage costs avoided and replacement cost methods are related methods that estimate values of ecosystem services based on either the costs of avoiding damages due to lost services, the cost of replacing ecosystem services, or the cost of providing substitute services. In the case of the pollination service, damage costs result from a reduction in agricultural production following a reduction in the amount of pollinators available. In some cases, a complete loss of pollinators may cause only a reduction in the production (as in the case of coffee), in other cases this may lead to a complete loss of the production of a specific crop. In some cases, the damage may be limited by switching to a, possibly less profitable, crop, in other cases, as in the case of orchards, damage is less easy to avoid. The costs of action taken to avoid damages may comprise the use of commercial bee-hives in case the local, natural pollinators have lost their effectiveness, or, in specific cases, pollination by hand (as practised in some greenhouses producing high value crops or, in a well-known example, in the case of apple orchards in Maoxian county, China where, after the local pollinators became extinct, farmers now have to pollinate orchards by hand.

Hand pollination of apple orchards, Maoxian, China

Because cost-based methods are based on using costs to estimate benefits, it is important to note that they do not provide a technically correct measure of economic value, because this is properly measured by the maximum amount of money or other goods that a person is willing to give up to have a particular good, less the actual cost of the good. Instead, it is assumed that the costs of avoiding damages or replacing natural assets or their services provide useful estimates of the value of these assets or services. This is based on the assumption that, if people incur costs to avoid damages caused by lost ecosystem services, or to replace the services of ecosystems, then those services must be worth at least what people paid to replace them. This assumption may or may not be true. However, in some cases it may be reasonable to make such assumptions, and measures of damage cost avoided or replacement cost are generally much easier to estimate than people's willingness to pay for certain ecosystem services. The methods are most appropriately applied in cases where damage avoidance or replacement expenditures have actually been, or will actually be, made.

2.3.4 Production function approaches

Production function approaches are particularly useful for ecosystem services that support economic activities. It consists of a two-step procedure. *First*, the physical effects of changes in a biological resource or ecological function on an economic activity are assessed. This means that the precise impact of the pollination service on agricultural output has to be determined. The impact of pollination on crop yields varies per crop, ranging from over 90% in mango and almonds to between 10 and 20% for peanuts and grape ((Morse and Calderone, 2000; Roubik, 2002). In addition, pollination may increase the quality of the produce, as has been reported for cotton (Free, 1993) and coffee (Marco and Coelho, 2004). *Second*, the impact of these environmental changes needs to be valued in terms of the corresponding change in the marketed output of the corresponding activity. In other words, the ecosystem service is treated as an 'input' into the economic activity, and, like any other input, its value can be equated with its impact on the productivity of the marketed output.

In a formal manner (following Freeman, 1993), consider an agricultural production process in which output (y) depends on purchased inputs (x), ecosystem services such as pollination (q), and another fixed factor (k) representing the fixed costs such as land and capital investments. In this case,

$$y = f(x, q, k).$$

Output sells for a price p, and inputs can be purchased for a price w. Standard arguments establish that the effect on welfare of a change in the quantity in which ecosystem services are provided can be measured as the change in competitive profits in the industry affected. Following the production function approach, the social welfare W, associated with production y as a function of the variable inputs of all firms in a sector v_{ij} and the supply of ecosystem service q, is the area under the demand curve for y minus the costs of the inputs (see e.g. Freeman, 1993):

$$W(v_j, q) = \int_0^y p(u)d \;\; - \sum_i \;\; F.V_i$$

Where ∫ (p(u)du) reflects the consumer surplus, F is a vector representing the prices of agricultural inputs and Vi is a vector representing the variable factor inputs to the agricultural sector. In a perfectly functioning economy, under the assumption that every firm is a price-taker, the competitive equilibrium is reached at the welfare optimum. Considering the first order conditions for the welfare function, the change in welfare for a change in the supply of an ecosystem service q can be expressed as:

$$\frac{\partial W}{\partial q} = p \cdot \frac{\partial y}{\partial q}$$

Hence, in a situation with perfectly functioning markets, the value of the pollination service can be determined by analysis of how the production of agricultural commodity *y* changes following a change in the supply of the pollination service *q*. Theoretically, this involves analysis of (i) how the demand and supply curve shift to a new equilibrium following changes in the relative supply of factor inputs, and (ii) changes in the price of the agricultural commodity under consideration. A critical point in this equation is that □y represents the increase in y that would occur if all other inputs are held constant (see Freeman, 1993 for details).

Hence, application of the production function approach requires full information on the responses of producers (farmers) and consumers to shifts in the supply of the pollination service and commodity prices, for which the data is often lacking. In practice, therefore, it is often assumed that the loss of a local pollination service does not affect markets and the change in welfare simply follows from a change in production multiplied with the economic farm-gate price of the product (e.g. Carreck and Williamms, 1999; Morse and Calderone, 2000). This technique has been labelled the 'effect on production' method. It is commonly used in situation where it is difficult to construct both demand (for consumers) and supply curves (for producers). It has, however, its limitations. A reduction in crop output due to a loss of pollination will increase crop prices (provided that demand is inelastic) which will affect both the benefits for the remaining producers (it will increase the producer surplus for these producers) and the benefits of the consumers that are facing higher prices (it will reduce the consumer surplus). Hence, whereas multiplying crop losses with the current economic farm-gate price will provide an approximation of the economic value of the pollination service, the resulting figures are prone to considerable uncertainty. The uncertainty will increase with the proportion of the agricultural production that depends on pollination (this varies from over 90% for e.g. almonds to less than 10% for e.g. artichokes) as the impact on farmers' practices and prices will be larger for large losses in agricultural production.

2.3.5 Comparison of valuation methods

The three valuation methods described above measure different aspects of the value of pollination and are most appropriate at different scales. This is illustrated in Table 1. Market prices indicate the marginal value of pollination under the condition that the market for the pollinator is well-established and that there is full information on the benefits of pollination among farmers and beekeepers. The first condition means that it is only suitable for honey-bees and bumble bees in selected countries. Although the latter condition will in many cases be met, there may also be crops and countries where there is less certainty on the impact of pollinators on crop production and, hence, a reduced willingness-to-pay of farmers for pollinators. Prices reflect the value of a single bee-population under these conditions, but do not provide much information on the value of the pollination service at the scale of the community or country.

The damage cost method assesses the value of pollination on the basis of the (potential) loss of agricultural production without the pollination service. The costs may reflect either the loss of crop production, or the costs of bringing in alternative pollinators. The latter may be impossible in the case of particular climatic or ecological conditions (as in Maoxian, China, see figure 3) or in case pollination is performed by specific species such as bats for which there is no experience with the breeding and release to stimulate pollination. It also needs to be considered that farmers may switch to alternative products if the pollinators for one type of crop are lost. Hence, the method is most suitable for perennial crops or orchards where it is more complicated to switch to another crop. Because this method does not involve the construction of supply and demand curves, and does not result in an analysis of producer and consumer surplus, is less suitable for calculating the value of pollination service at the scale of a country.

The production function approach is most suitable for analysing the value of the pollination service at larger scales, including the scale of the country. If correctly applied, this method involves the construction of supply and demand curves for the crops involved. This requires information on the behaviour of producers and consumers for the markets involved. These markets may be organised at the scale of the country, or, in specific cases, a free trade zone. Table 1 presents a summary of the three methods. Table 2 presents the data requirements of the three methods.

Particular attention needs to be paid to the issue of multiple benefits of an ecosystem service. For instance, bees can also result in the production of honey, and patches of forest or hedgerows that cater as natural habitat for pollinators can also harbour spiders or other animals that are useful for integrated pest management. Clearly, these

Table 1. Comparison of valuation methods

Valuation method	Remarks
Market prices of bee hives	The price of rented bee colonies provides, under a number of conditions, an indication of the marginal value of pollination. These condition include: (i) there is a (non-distorted) market for the pollinator, and (ii) there is full information on the impacts of pollination on crop production among farmers and beekeepers. This assumption may or may not be realistic depending on the crop and country.
Cost-based methods	This method can be used to calculate the value of (natural) pollination, in particular if there is a clear with/without pollination scenario. The method is mostly applicable to the scale of the farmer of the community as it does not involve analysis of market responses to reductions or increases in the supply of the pollination service
Production function approaches	To assess the economic value of pollination for specific crops at the scale of a country. This method requires the construction of supply and demand curves to calculate the consumer and producer surplus related to pollination.

Table 2. Data requirements of the three selected valuation methods

Valuation method	Principal data requirements
Market prices of bee hives	- Price data on bee rentals per crop per season
Cost-based methods	- Impact on production of the (potential / temporary / actual) loss of the pollination service - Costs of responses (e.g. labour costs for hand-pollination; or costs of bee rentals where available) - Price data of the affected crops

benefits have to be considered in the analysis. For instance, the loss of bee-pollinators will evoke an additional loss of welfare related to honey production. The loss of welfare can, under the same conditions as described above for pollination, be approximated by the economic farm-gate price of honey multiplied by the decline in honey production. In the case of establishment of hedgerows, the additional benefits have to be added to the welfare from pollination.

2.3.6 Analysis of the costs of providing pollination services.

The valuation of ecosystem services also requires that the costs of providing the services are analysed (e.g. Hueting, 1980). In the case of the pollination service, these costs relate either to hiring bee hives, or to implementing agricultural practises that promote or conserve populations of natural pollinators. In terms of hiring bees, at present, the large majority of bees that are used commercially for pollination are European honey bees (*Apis melifera*). However, a range of other bees are also used, for instance bumble bees (especially for high value greenhouse crops including tomatoes) and leafcutter bees (for US alfalfa crops). In this case, the costs are relatively easily established on the basis of market rates for bee rentals. In Europe and the US, prices range from some US$100 per honey bee hive per season to US$ 300 per bumble bee colony per crop (Henkes, 1997; Morse and Calderone, 2000).

With respect to costing agricultural practises promoting pollination services, market tariffs are not available and other approaches have to be used. These need to consider a broad range of possible costs for the farmers. First of all, opportunity costs my be present where farmers need to preserve specific areas for maintaining a habitat suitable for pollinators, as in the case of hedgerows, corridors, forest patches, or field edges. Normally, farmers will select the areas least suitable for agricultural production for this, but the lost, net benefits from agricultural production nevertheless impose a cost to the farmer. Second, there may be specific costs related to the planting of species that provide a suitable habitat, including the costs of seedlings, labour costs, costs of implements, etc. Third, costs may be related to maintaining these areas, e.g. labour costs related to pruning of hedgerows. And fourth, costs may stem from adapting pollinator friendly agricultural practices, such as adjusted spraying or weeding practises or IPM. This latter category may also impose a cost to the farmer in terms of lost production. However, care needs to be taken in the analysis: IPM practises are much more likely to increase yields rather than reduce yields through maintaining natural pest control mechanisms. Furthermore, IPM or reduced spraying practises will generally reduce labour and pesticide costs.

In general, the costs will be strongly dependent on the agro-ecological setting including the crops grown, the local insect populations, and the ecological relations between farm land and surrounding natural or semi-natural areas. They will also differ per farm, depending on the crops grown, the agro-ecological context, etc. Their analysis will generally require analysis of net revenues per hectare of cropland, labour inputs and costs, and, in specific cases, costs of seedling, implements, and costs and benefits of adjusted pesticide usage.

3 Experiences with the valuation of the pollination service

3.1 Introduction

Since around the late 1960s, there has been a substantial increase in interest for the economic value of ecosystem services (Helliwell, 1969; Costanza et al., 1997; Millennium Ecosystem Assessment, 2003). In the scientific and policy domains, it was becoming increasingly clear that degradation of ecosystems was starting to hamper economic growth and human wellbeing, in particular in the poorest countries that are least able to mitigate or adjust to a loss of the natural resource base (Balmford et al., 2002). One of the ecosystem services that received much interest is the pollination service. This was triggered by the increasing number of cases where reductions in insect populations led to pollination deficit: yield reduction because of insufficient pollination. These reductions in pollinator availability were caused by agricultural intensification, use of pesticides, loss of natural habitats, diseases and parasites killing bees, etc. For instance, in England, populations of bumblebees have declined and the number of species has fallen from 19 to 16 in the 2nd half of the 20th century (Williams, 1982). Agricultural producers in the OECD and many developing countries responded by hiring bees and other pollinators to pollinate fields and greenhouses. Clearly, adaptation to a situation with reduced natural pollinations brings costs, either in the form or damage costs (reduced yields) or adaptation costs (e.g. related to hiring commercial bee hives).

Hence, there has been an increasing scientific interest in valuation of the pollination service, expressed through a substantial published and grey literature that comprise a multitude of valuation estimates. The topic received particular interest in the US, several European countries, Australia and New Zealand, where estimates of the value of pollination have been made for a wide range of different crops. Estimates of the annual monetary value of pollination have also been made for the global scale. However, estimates vary widely, both for the value of specific pollinators at the scale of the country, as for the value of the pollination service at the global scale. For instance Costanza et al. (1997) provide a value estimate of $120 billion per year for all pollination ecosystem services, whereas Richards (1993) finds that the value of pollination in global agriculture alone amounts to $200 billion per year. The range of these numbers reflects the lack of common methods for valuing the pollination services. As most studies were interested in the value of the pollination service at a large scale, e.g. the scale of a country, the production factor approach has been the valuation methodology of choice in these studies. However, the actual application of this valuation approach shows considerable variation among the studies. To highlight this, and to examine the reliability of existing value estimates for the pollination service, a number of studies have been examined in more detail for this paper. Existing experiences with the valuation of the pollination service are examined first at the local scale and, subsequently, at the national scale. This is followed by a synopsis and comparison of the valuation approaches that have been used to date.

3.2 The local value of the pollination service

To assess the local value of the pollination service, both damage cost approaches and valuations on the basis of market prices can be used (see chapter 4). Importantly, if the local value of the pollination service is assessed, i.e. the value for the local community or farmer, the impact of pollination on the consumer surplus can generally be assumed to be zero. The reason is that the production of the crop at this scale has no impact on the price of the crop on the regional or national markets. An exceptional case is, however, where there are high costs related to the import of the crop from other areas (e.g. in isolated areas) or if there are few other sources of income or food for a local community – in which case the impact of a loss of pollination service on consumers needs to be analysed as well.

In case the consumer surplus is assumed to be zero, it is the local producer surplus that determines the value of the pollination service. In the short term, for marginal changes, it can be assumed that the individual producer surplus equals the total revenues minus variable costs (Varian, 1993). Hence, in this case, the value of the pollination service equals the revenues generated through pollination (e.g. a crop increase compared to a situation without pollination) minus the variable costs (labour, agricultural inputs such as fertilisers and pesticides). In the longer term, or if changes are non-marginal, producers will respond to changes in the supply of the pollination service by adjusting their production, e.g. in case a substantial part of the production is lost following a decline of the pollination service. In this case, farmers are likely to start growing other crops. Clearly, a switch to other crops is easier in the case of annuals than in the case of perennial crops, in particular orchards.

There have been a number of studies that examined the local value of pollination in coffee cultivation, which will be briefly reviewed to illustrate the valuation of pollination at the local scale. The case will be limited to *C. arabica*, which accounts for over 75% of the global coffee production. The contribution of pollination to coffee production has been shown in a range of studies. Klein et al. (2003) show that a loss of the pollination service led to a 12.3% lower yield in Indonesian *C. arabica* plantations. Ricketts et al. (2004) found that enhanced pollination of Costa Rican coffee plants near forest edges led to a 20.8% higher yield in comparison with coffee plants in the centre of the field. Through statistical analysis of coffee yields before and after the introduction of African honey bee in the neotropics, Roubik (2002) demonstrates that African honey bee, that became wide-spread in the neotropics during the 1980s, makes an important contribution to coffee production worldwide. Roubik (2002) estimates that pollination of coffee plants (all insects) increases global *C. arabica* yields by on average some 36%.

Ricketts et al. (2004) provide a simple method to calculate the value of the pollination service for a large coffee producer in the Valle General, Costa Rica. The plantation comprises both sites located close to remaining patches of natural forest, and sites further away from natural forest. The forest patches provide a habitat to non-native honey bees as well as 10 native species of Meliponini stingless bees. Rickett et al. (2004) show that the bees have difficulties reaching the parts of the coffee plantation located farthest from the forest, and establish that bee pollination makes an important contribution to coffee yields. The formula that they use to calculate the economic benefits of the pollination service at the local scale is:

$$W = S \cdot \Delta q \cdot (p - c)$$

with W = benefits for the farmer;

S = area

Δq = increase in production as a consequence of pollination

p = farm-gate coffee price

c = variable costs related to coffee harvest.

In the Costa Rican study, 480 ha of coffee fields (S) are close (<1 km) to two patches of forest that have been conserved on the plantation, the increase (Δq) in coffee is 20.8% x 14.240 kg/ha, the farm-gate price (p) is US$ 0.071 /kg, the labour costs of harvesting (c) are US$ 0.028 /kg, and the resulting value (W) of the two patches of forest that maintain pollinator populations that cater the coffee plantation is US$ 62,000. This represents 7% of the annual income of the plantation (Ricketts et al., 2004). This example clearly demonstrates that pollination can make an important economic contribution at the scale of the individual plantation.

However, note that this approach reveals the 'total' benefits of the pollination service for a specific farmer, or a specific community, not the marginal values. Hence, although it serves to communicate the economic importance of the overall pollination service, it does not provide sufficient guidance for the management of the pollination service. For instance, it can not be derived from this experiment how much forest patches need to be preserved in order to maintain the pollination service in a plantation; either more (if not all coffee fields are sufficiently pollinated) or less (if populations could do with smaller habitats) forest patches could be optimal for the farmer.

In order to assess the marginal benefits of the pollination service at the local scale, it needs to be analysed by how much agricultural production (Δq) changes for a marginal change in the supply of the pollination service (expressed e.g. as a marginal change in the insect population, or a marginal change in hedgerow area or forest patches providing the pollination service). In reality, ecological data will often be insufficient to predict, a priori, changes in the Δq following marginal changes in insect populations or insect habitats. Specific targeted, regional research trials may reveal this relation by measuring Δq in different agro-ecological settings. Note that, in the calculation of the welfare effects of changes in the pollination service, it also needs to be considered at which costs the pollination service is provided. These costs include opportunity cost in case the area used for forest or hedgerows could otherwise be used for agricultural production, as well as potential establishment (seedlings, planting) and maintenance costs.

3.3 The value of the pollination service at the national scale

As described in the previous chapter, the economic value of the pollination service at the national scale can only be assessed with production function approaches. Production function approaches have been used to analyse the economic value of the pollination service since the 1960s. For instance, Metcalf and Flint (1962) calculated the annual value of insect-pollinated crops in the US at around US$ 4.5 billion. In this paper, five more recent, often-cited studies addressing the value of the pollination service are reviewed. These studies are: (i) Levin (1984) who valued the pollination service with respect to the US agricultural sector; (ii) Carreck and Williams (1998) who analysed pollination in UK agriculture; (iii) Morse and Calderone (2000) who also studied pollination in the US agriculture; (iv) Southwick and Southwick who estimate the consumer surplus of the pollination service in US agriculture; and (v) Gordon and Davis (2003) who examine the value of pollination for Australian agriculture.

The first three of these case studies follow a somewhat simplistic approach; they estimate the benefits of the pollination service on the basis of the crop value of the pollinated crops. Whereas this approach gives an order of magnitude estimate of the value of the pollination service, the results should be interpreted with substantial caution. The fourth study (Southwick and Southwick, 1992) analyses the consumer surplus using a more detailed analysis, whereas the fifth study (Gordon and Davis, 2003) is most comprehensive in that it examines both the consumer and the producer surplus generated by the pollination service. This review illustrates why the estimates for the total value of the pollination service vary so widely: there are very few studies available that follow an appropriate economic methodology to estimate this value.

Nevertheless, the reviews provide an order of magnitude indication of the value of the pollination service in selected countries. Note that these studies calculate the total value of the pollination service at the scale of the country. This total value can illustrate the importance of maintaining the overall pollination service to policy makers and society as a whole (Richards, 1993; Levin, 1994; Costanza et al., 1997). The review demonstrates the methodological uncertainties, and the approaches taken in various, often-cited studies, to overcome these issues. Note that, in terms of the management of the pollination service, an important indicator is also the marginal value of the pollination service.

The value of pollination for US agriculture according to Levin (1984)

Levin (1984) estimated the US honey bee's value to agriculture to be almost 19 billion dollars, of which around US$ 10 billion related to the production of crops (fruits, vegetables, nuts) and the remaining US$ 9 billion mostly for the production of hay. According to Levin (1984), the value of the pollination services in 1983 was some 140 times the value of honey and wax production by bees. In terms of methodology, Levin multiplied the value of the crop production with the amount of crop production depending on pollination (which ranges from 10% for soybean to 90% for apples). Table 3 presents some selected results focusing on fruits, vegetables and nuts. Consumer and producer surplus are not distinguished or analysed separately.

Table 3. Estimated bee pollination value in 1983 for different crops (in US)

Fruits, vegetables seeds and fibre categories	Bee pollination value in US (US $/ha)	Bee pollination value in US (US million $)
Apple	4423	757
Almond	3068	473
Peaches	4156	368
Strawberries	16438	288
Cantaloupes	2981	161
Watermelon	1810	149
Citrus	380	155
Pickles (processed; fresh)		100
Soybean	48	1300
Sunflower	274	410
Cotton (seed; lint)	110	464
Alfalfa		114

Table 4. Value of insect pollination in the UK (outdoor crops)

Crop	Need for insect pollination	Area grown (ha)	Market value (£M)	Value of insect pollination (£M)
Oilseed rape	0.1	429000	419	41.9
Field bean	0.1	100200	49	4.9
Broad bean	0.1	2256	3.5	0.4
Runner bean	0.5	3689	16.1	8.1
Apple	0.9	17896	90.8	81.7
Pear	0.5	2941	14.8	7.4
Plum	0.5	1644	7.9	2.8
Cherry	0.9	604	6.2	5.6
Mixed orchard	0.5	185	1	0.5
Raspberry	0.1	2568	30.6	3.1
Strawberry	0.1	4622	55.8	5.6
Blackcurrant	0.9	2389	10.3	9.3
Other soft fruit	0.1	843	11.8	1.2
Total			716.8	172.2

Table 5. Value of insect pollination in the UK (greenhouse crops)

Crop	Need for insect pollination	Production (1000 ton)	Price (£ / ton)	Market value (£ M)	Value of insect pollination (£ M)
Tomatoes (heated)	0.5	103.2	529.89	54.68	27.34
Tomatoes (cold)	0.5	10.1	360.71	3.64	1.82
Sweet peppers	0.1	7.3	880.65	6.43	0.64

The value of pollination for UK agriculture according to Carreck and Williams (1998)

Carreck and Williams (1998) find that, in the UK, 39 crops grown for fruit or seed are insect pollinated, whereas a further 32 need insect pollination for propagative seed production. By far the most important pollinators are honey bees and bumble bees, the latter being used mostly in greenhouses. They report that there are 200,000 honey bee colonies owned by some 35,000 beekeepers in the UK. Key input data in the study are the 1996 economic farm-gate prices (excluding taxes and subsidies, and they distinguished three categories of pollination requirement : 0.1, 0.5 and 0.9. of crop production dependent on pollination. Carreck and Williams find that the total value of pollination amounts to 172 million for outdoor crops and 30 million pound for greenhouse crops, see Tables 4 and 5.

The value of pollination for US agriculture according to Morse and Calderone (2000)

Morse and Calderone (2000) examine the economic value of pollination of honey bees in US agriculture, based on national agricultural statistics, interviews with beekeepers, extensionists and researchers (Table 6). They estimate that there were 2,500,000 colonies rented for pollination purposes in 1998, and that the pollination service contributes

Table 6. Value of honey bee pollination in the US according to Morse and Calderone (2000). The table only includes the crops with an annual value of the pollination service of at least US$ 10 million; the last column does therefore not add up to US$ 14.6 billion. See the original report for the full data.

Crop	1996-1998 US average value ($ millions)	Dependence on insect pollination	Proportion of pollinators that are honey bees	Annual value attributable to honey bee pollination ($ millions)
almond	959.2	1	1	959.2
alfalfa hay	7,647.90	1	0.6	4,588.80
alfalfa seed	109	1	0.6	65.4
apple	1,502.60	1	0.9	1,352.30
apricot	37.8	0.7	0.8	21.2
asparagus	183.2	1	0.9	164.9
avocado	254.6	1	0.9	229.2
broccoli	483.8	1	0.9	435.4
carrot	467.5	1	0.9	420.7
cauliflower	233.5	1	0.9	210.2
celery	230.1	1	0.8	184.1
cotton	5359	0.2	0.8	857.7
cranberry	294.9	1	0.9	265.4
grape	2,704.60	0.1	0.1	27
grapefruit	297.4	0.8	0.9	214.1
kiwifruit	18.1	0.9	0.9	14.6
legume seed	34.1	1	0.9	30.7
lemon	268.2	0.2	0.1	53.6
macademia	41.6	0.9	0.9	33.7
nectarine	108.1	0.6	0.8	51.9
orange	1,869.80	0.3	0.9	504.9
peach	426	0.6	0.8	204
peanut	1013.7	0.1	0.2	20.3
pear	291.2	0.7	0.9	183.5
plum/prune	243.6	0.7	0.9	153.5
soybean	16,490.70	0.1	0.5	824.5
strawberry	900.1	0.2	0.1	18
sugarbeet	951.5	0.1	0.2	19
sunflower	455.4	1	0.9	409.9
sweet cherry	242.4	0.9	0.9	196.3
tangerine	112.5	0.5	0.9	50.6
Total				14,564

to US$ 14.6 billion of agricultural output in 2000. The most important crops for which bee colonies were rented are almonds, apples, melons, alfalfa seeds, plums and avocados. The method they used to calculate the economic value comprises a mere multiplication of the average annual value of the crop with the dependency of the crop on insect pollination with the proportion of the pollinators that are honey bees. The value of the pollination service as a whole (including also natural pollinators) would, according to the same data be US$ 20.7 billion for the US. However, as the previous studies, the methodology of Morse and Calderone (2000) is simplistic in that it does not account for the consumer and producer surpluses relevant for the pollination service, and it only provides an order-of-magnitude estimate of the total value of the pollination service in the US..

The consumer surplus related to US crop pollination according to Southwick and Southwick (1992)

Contrary to the previous studies, Southwick and Southwick (1992) consider the consumer surplus related to crop pollination in the USA. In other words, they calculate the economic benefits that accrue to US consumers because pollination increases crop yields of a range of crops. They have constructed demand curves for a range of agricultural commodities on the basis of long-term price and market data. The corresponding change in the consumer's surplus related to changes in the availability of the pollination service is calculated by Southwick and Southwick (1992) according to:

$$\Delta CS = Q_0(P_0 - P_1) + \int_{Q_0}^{Q_1} [P(demand)]dQ$$

The first term of the equation is the difference in revenues to farmers without pollination and the revenues with pollination. The second term is the value placed on the product by consumers who will buy at the lower price but would not have bought at the higher price of the product in the absence of pollination. Note that an important omission is made by Southwick and Southwick: they disregard international trade. If pollination services in the US would decline, and, consequently, the prices of the affected commodities would increase, imports of agricultural commodities could partially offset the resulting decrease in consumer surplus. Hence, their estimate of the consumer surplus generated by the pollination service is likely to be an overestimate.

Based on some 20 years of price and consumption data, Southwick and Southwick estimate the demand curve for 50 different crops. Furthermore, the contribution of honey bee pollination to crop production is considered, for each crop. The results are presented, for selected crops, in Table 7. The consumer surplus of honey bee pollination for US agriculture is calculated to be US$ 6.0 billion. Note that, for some crops, the loss of consumer surplus associated with the potential loss of pollination is larger than the crop value (e.g. for almonds and apples), whereas for other crops it is smaller (e.g. asparagus, cabbage). This reflects the elasticity of demand for the crops: consumers would be willing to pay relatively high prices to obtain apples or almonds, if required, but would be much less willing to do so for asparagus or cabbage.

There are a number of methodological issues related to the analysis of Southwick and Southwick (1992), as also acknowledged in their study. The neglect of import substitution opportunities for crops affected by a decline in the pollination service was mentioned already. Furthermore, Southwick and Southwick (1992) estimate the demand functions for each crop independently. However, this is not entirely realistic, if alfalfa production is strongly reduced due to reduced pollination, farmers may turn to increase their use of soybean as alternative source of fodder, leading to a relatively low consumer surplus related to alfalfa. If soybean and

Table 7. Value of honey bee pollination in the US according to Southwick and Southwick (1992).

Crop	1986 Crop value (million US$)	Contribution of bees	Value of honey bee pollination (million US$)
Alfalfa	171	0.7	315
Almonds	462	0.9	847
Apples	1068	0.8	2437
Asparagus	144	0.9	13
Avocado	154	0.2	36
Beans, dry	431	0.1	44
Broccoli	227	0.9	45
Bush berry	111	0.7	80
Cauliflower	188	0.9	42
Cottonseed	298	1	105
Cranberry	195	0.4	130
Grape	1170	0.15	187
Orange	1074	0.3	354
Pear	200	0.5	140
Plum	111	0.5	58
Soybean seed	9326	1	94
Strawberry	504	0.3	148

alfalfa production are affected at the same time, the preferences of the farmers to maintain their consumption of the two products may be higher. In addition, there are substantial differences between the assumed need for pollination of different crops compared with Morse and Calderone (2000).

Furthermore, Southwick and Southwick (1992) assume that the profits accruing to US *producers* of honey bee pollinated crops tend to diverge to zero in the long term, and that, hence, the consumer surplus represents the full economic value of the pollination service. In particular, they assume that in the US, as honey bee pollinated crops only represent a small part of the agricultural production, the long-run aggregate supply curve for these crops is likely to be almost perfectly elastic, as farmers can easily switch to and from the cultivation of honey-bee pollinated crops. However, this assumption is subject to considerable uncertainty. First, it neglects the short-term losses for producers, who may incur costs related to switching to new commodities or finding new markets for these commodities. Second, losses in the pollination service may strongly decrease the income earning opportunities for farmers that have invested in specific production methods (for instance greenhouses) or that paid premium prices for agricultural land most suitable for specific honey bee pollinated crops. Therefore, it can not generally be assumed that the producer surplus related to agricultural production is zero in the assessment of the value of the pollination service, and the consumer surplus represents only a lower value of the full economic value of the pollination service.

The value of crop pollination in Australia according to Gordon and Davis (2003)

Gordon and Davis (2003) examined the value of honey bee pollination in relation to Australian agriculture. They examined the value of pollination in 35 crops that either required pollination

Table 8. Economic value of the pollination service for Australian crops. Note that the columns do not add up to the total value estimates as the table only contains a selection of crops. For full information, see Gordon and Davis (2003).

Crop	Dependence on honey-bees (%)	Lost producer surplus/1 (AU$m)	Lost producer surplus/2 (AU$m)	Lost consumer surplus/3 (AU$m)	Total lost surplus/1 (AU$m)	Total lost surplus/2 (AU$m)
Almond	100	21	11	8	29	19
Apple	90	174	89	125	299	214
Asparagus	90	26	13	1	27	14
Avocado	100	30	15	11	41	26
Broccoli	100	35	18	89	124	107
Brussels sprout	30	35	18	1	36	19
Carrot	100	95	48	82	177	130
Cauliflower	100	32	16	78	110	94
Cotton lint	20	120	61	0	120	61
Cucumber	90	10	5	5	15	10
Macadamia	90	26	13	6	32	19
Mango	90	28	14	22	50	36
Onion	100	67	34	174	241	208
Orange	30	29	15	23	52	38
Watermelon	70	9	5	15	24	20
Total		887	452	839	1726	1291

Key: /1 Under the assumption that producers do not change activities following a loss of the pollination service, even if this means aTable 8. Economic value of the pollination service for Australian crops. Note that the columns do not add up to the total value estimates as the table only contains a selection of crops. For full information, see Gordon and Davis (2003). 100% loss in income, i.e. farmers have no alternative crops to grow (reduced harvest costs have been accounted for).
/2 Under the assumption that producers change activities following a reduction of 30% in income following a loss of the pollination service.
/3 The consumer surplus equals the full economic value in case it is assumed that farmers are not willing to incur any losses before switching to a new crop.

for fruit setting, or in which pollination makes an important contribution to yields or quality (Table 12). Gordon and Davis (2003) estimated both the consumer surpluses and the producer surpluses related to honey bee pollination, for the 35 examined agricultural commodities. For the demand curve, the study accounts for the effect that Australian consumers can replace Australian products by imported ones, if the Australian products become expensive following the loss in the pollination service. Both the elasticity of the domestic demand and the elasticity of the export demand are calculated. The latter is around 10 times the domestic demand elasticity as, on the international market, Australian products can in many cases relatively easily be replaced by products from other countries. In terms of the supply curve, the producer surplus is calculated for three assumptions regarding the loss of income that farmer will incur before they switch to another crop following a decline in the pollination service. Specifically, calculations are carried out for 0%, 30% and 100% loss. If farmers, following a loss of the pollination service, immediately switch to a new crop that does not depend on pollination (the 0% assumption), the producer surplus is assumed to be zero (equivalent to Southwick and Southwick, 1992). Additional calculations are made for a 30% and 100% acceptance of income loss before farmers switch to new crops – which correspond to a situation in which farmers have few alternative crops to grow. Note that the farmers' response is also a function of time: in the long run more farmers will switch to new crops following losses in the pollination service (and the long-term changes in producer surplus, which were calculated by Southwick and Southwick, 1992, tend to diminish to 0).

Hence, the total lost surplus following a loss of honey bee pollination is estimated at around Australian $ 1.5 billion (equivalent to US$ 1.1 billion[1]) depending on the assumptions made regarding the supply curve for the commodities involved. Furthermore, Gordon and Davis (2003) examine the multiplier effect: a loss in agricultural production will have an impact on other economic activities, such as the agricultural processing industry. Their calculations show that, in the case of Australian agriculture, the multiplier effect is very significant: the loss in economic surplus of US$ 1.1 billion would cause a further US$ 1.5 billion income loss for agricultural supply and processing industries. Note that this loss is only an approximate indicator of the indirect economic loss associated with a loss of the pollination service. Also note that the multiplier effect is highly country specific and the calculated multiplier may be relatively high due to the relative isolation, at least in terms of distances, of the Australian market. For instance, for Dutch agriculture an average value of 1.5 is often used to compare the economic output of agricultural processing industries with the economic output of primary agricultural production (in other words, every euro agricultural output generates 0.5 euro value added in the agricultural processing industry), see Briene and Wienhoven (2003).

3.4 Experiences to date, a synopsis

Currently, the most comprehensive assessments for the value of the pollination service are available for Australia, the USA and the UK – notwithstanding the various studies that provide value estimates for the pollination service in other countries. Critical factors in the assessment are the contribution of pollinators to crop production, and the method applied to calculate the economic benefits of pollination. As explained in Section 4.3.4, the use of demand and supply functions to calculate the benefits from pollination is more accurate than multiplying production losses with farm-gate prices. If the studies of Southwick and Southwick (1992), who estimate demand functions, and Levin (1984) and Morse and Calderone (2000) who follow the second approach are compared, it appears that multiplication of potential production losses

Table 9. Comparison of the value estimates of the reviewed case studies.

Country	Total value agricultural production/[1]	Value of honey bee pollination (US$ billion)	Value of other bees (US$ billion)	Source
Canada	25	1.2		Winston and Scott (1984)
USA	219	6 - 14		Southwick and Southwick (1992); Morse and Calderone (2000)
EU-15	188	4.2	0.8	Borneck and Merle (1989)
France	53	0.5		Borneck and Bricout (1984)
United kingdom	18	0.3	0.04	Carreck and Williams (1998)
Australia	16	1.1		Gill (1991); Gordon and Davis (2003)
New Zealand	5	0.2		Honey Hive (1993)
World	868			

Key: /1 : Source: World Bank World Development Indicators (2003).

and farm-gate price may lead to a substantial overestimate of the value of the pollination service. Whereas Southwick and Southwick (1992) estimate the value of the consumer surplus generated by honey bee pollination in US agriculture to be around US$ 6 billion, the other two studies' value estimates range from US$ 14 to 19 billion (Morse and Calderone, 2000; respectively Levin, 1984). Consideration of the producer surplus generated by the pollination service may partially close the gap between the two approaches, but it is unlikely (compare Gordon and Davis, 2003) that the producer surplus would be twice the consumer surplus, which would be required to bring the value estimate of Southwick and Southwick (1992) in line with those of Levin (1984) and Morse and Calderone (2000). Hence, it is clear that caution needs to be taken in the interpretation of valuation studies that follow strongly simplified methodologies.

Table 9. presents an overview of the outcomes of the evaluated valuation studies (excluding potential multiplier effects). The review conducted in this chapter does not provide a suitable basis to estimate the current global value of the pollination service as there are no tropical countries, with the specific crops grown, included. Nevertheless, a very preliminary indication of the order-of-magnitude of the global value of honey bee pollination related to agriculture can be extracted from the table. The examined countries (USA, EU-15, Canada, Australia, New Zealand) together represent around 60% of the value of the world's agricultural production (World Bank, 2005). The summed value of the honey bee pollination service in these countries is some 13 to 21 billion euro. If it is assumed that the relative value of honey bee pollination is comparable in other countries, the global value of honey bee pollination in agriculture would be some 13 to 21 / 0.6 = in the order of US$ 20 to 35 billion. Clearly, this figure is somewhat speculative (though possibly not more speculative than the estimates of Costanza et al. (1997) and Robinson (1993) which were also based on a very limited number of country studies).

Estimates of the economic value of the pollination service not do justice to the role of pollination in supporting food security in many countries. Whereas OECD countries may be able to switch from pollinated to non-honey bee-pollinated crops if the pollination service is lost, this may be much more difficult for developing countries. Whereas the main staple crops are wind-pollinated, (partly) insect pollinated crops, or crops that require pollination for seed production, such as beans, onions, cucumbers, water melons, sweet potatoes, carrots and cabbages are essential elements of the human diet in a large number of countries. Furthermore, some crops that fully or partially depend on pollination can be essential for a sustainable cropping rotation, e.g. because they are nitrogen fixing plants (soybean, peanuts) or because they allow farmers to maintain a cropping rotation that includes sufficient cash crops. Hence, it is clear that the pollination service is not only of economic importance, but that it also specifically supports agricultural diversification and healthy diets for poor farmers in developing countries.

Furthermore, if the benefits of the pollination service are compared with the other benefits of honey bee keeping, it is clear that the benefits from pollination are substantially higher than the benefits from honey production. For instance, in the UK, the annual value of honey production can be estimated at around US$ 27 million, whereas the value of the pollination service is in the order of US$ 240 million.

A critical issue, as in any economic value assessment, is the consideration of the total value versus the marginal value. As this review showed, the large majority of the currently available studies address the total value of the pollination service, at either the scale of the farm or at the scale of the country. Clearly, the average per hectare value (total value of the pollination service for a specific crop divided by the crop area) and the marginal value will often differ substantially. This is illustrated in Table 10. The average per hectare value of several crops grown in the US is derived

Table 10. Comparison of per hectare average In terms of their application, the total values are most useful to communicate the economic importance of pollination to stakeholders, whereas the marginal values can provide guidance on the optimal management of the pollination service. In principle, comparison of the marginal values of the pollination service with the costs of enhancing pollination processes (section 2.3.6) allows the formulation of recommendations for enhanced management of pollination services. and marginal values (indicated by the payments of farmers for beehives) of pollination of selected crops in the USA

	Total value of pollination (US$ million) /1	Area (1000 ha) /2	Average value of pollination per hectare (US$/year)	Average number of rented bee colonies per hectare /3	Costs of bee rental to the farmer
almonds	847	203	4,172	5	500
apples	2437	174	14,006	2	200
cauliflower	42	18	2,333	1	100
cucumber	113	64	1,766	1	100
watermelon	92	67	1,373	4	400

Sources /1 Southwick and Southwick (1992); /2 FAOSTAT (2005); /3 Morse and Calderone, 2000.

by dividing the total value (from Southwick and Southwick, 1992) by the amount of hectares on which the selected crops are grown. The price of bee rentals per hectare, for the selected crops, is taken as a rough indicator for the marginal value of the pollination service. Under some assumptions (e.g.: the farmer has full information on the benefits he obtains from pollination, all the benefits of pollination are captured by the farmer that hires the beehives), this price is an indicator for the marginal value of the pollination service. Farmers pay around US$ 100 per colony, and they generally use some 1 to 5 bee colonies per hectare, on average throughout the country, for the selected crops. Hence, their payments for pollination are in the order of US$ 100 to 500 depending on the crop. Table 10 shows, as could be expected, that the marginal value is substantially lower than the average per hectare value.

4. Economic valuation of the pollination service; a semi-hypothetical case study for Ethiopian coffee production

4.1 Introduction

All cultivated species of coffee have their origin in Africa. Since many centuries, Ethiopians use the berries of *C. arabica* to produce a beverage. Arabs introduced coffee from Ethiopia to Yemen around the 10th century, where the habit of drinking coffee became widespread in the 15th century. The drinking of coffee subsequently spread to the rest of the world. The Dutch introduced coffee in Java in 1690 (Ferwerda, 1976) and, subsequently, a coffee plant from Java was taken to Amsterdam. Its progeny was taken to Paris and from there to all French colonies in the tropics, especially in the Caribbean and Latin America. Through French Guyana, coffee also reached Brazil, which is currently the world's largest coffee producer. Other main coffee producers are Colombia, Guatemala, Mexico and Ethiopia (*C. arabica*) and Vietnam (*C. canephora*). Around 75% of the world coffee production is from *C. arabica*, the remainder from *C. canephora*.

In Ethiopia, *C. arabica* is, apart from some introduced Robusta coffee, the only coffee species present (Van der Graaff, 1981). The drinking of coffee is an important tradition in Ethiopia, and coffee is one of the most important crops grown in the country. The Ethiopian coffee belt can be defined as below the frost-line of about 2,240 meters altitude, and with a rainfall regime of 2 to 3 dry months. The crop is grown in all provinces of the country, but the main production areas are located in the western and south-western highlands. In total, there is around 500,000 ha of coffee in Ethiopia. Coffee is grown in three main systems:

- forest coffee ("wild" coffee) (60%), which comprises stands of coffee in a semi-natural environment. Self sown coffee seedlings have been transplanted to give a dominant, but irregular understorey in the forest.
- Small holder coffee (37%) plots of various sizes around dwellings.
- Plantation coffee (10%). Plantations established on cleared land. Seedlings raised in nurseries, and shade trees often planted.

Total coffee production is in the order of 200,000 ton per year, of which around 110,000 ton is exported. Coffee accounts for 4-5% of Ethiopian GDP and 60% of export earnings. It provides a livelihood to 25% of its population (Tafesse, 1996).

In small-holder farms and in forest cultivation, coffee growing is not likely to be hampered by a lack of pollination as there are normally ample foraging and nesting opportunities for pollinators nearby the coffee plants. With respect to plantation, it is not currently known if there have been any pollination deficiencies to date. Although there is no lack of pollination, clearly, pollination is an essential service to Ethiopian coffee cultivation (Roubik, 2002; Ricketts, 2004), and, hence, to the livelihood of the Ethiopian people. In this hypothetical case study, an analysis is made of the benefits of the pollination service for a (hypothetical) Ethiopian coffee farmer, based on average/indicative coffee production data for an Ethiopian smallholder coffee grower. Due to a lack of data on consumer preferences and coffee consumption as a function of coffee prices, a demand curve can not be constructed and a proper assessment of the economic value of the pollination service at the national scale is not feasible in the context of this study.

4.2 Methodology and data

In order to examine the value of the pollination service at the scale of the farm, data have been collected from the ZEF Ethiopian coffee project (COCE), which is implemented in collaboration with Ethiopian partners including the Ethiopian Agricultural Research Organization (EARO), Addis Ababa University (National Herbarium, Department of Biology, Department of Economics), the Ethiopian Wildlife and Natural History Society and the Coffee and Tea Authority (Ministry of Agriculture), Ethiopia. These data reflect the average conditions (yields, production costs, prices) for an Ethiopian coffee farmer. The basic data are shown in Table 11.

In order to estimate the contribution of pollination to coffee growing, the value calculated by Roubik (2004) has been used. Roubik estimated that, as a global average, *C. arabica* coffee yields would be reduced by 36% in the absence of pollination. It is assumed that this average value is also valid for Ethiopia. It is assumed that a reduction in coffee yields following a loss of the pollination service would only affect the labour costs of coffee harvesting and post-harvest handling, i.e. the farmer would not change the use of fertilisers and fungicides. A standard equation is used to calculate the economic benefits of the pollination service at the scale of the farm (Ricketts et al., 2004):

$$W = S \cdot \Delta q \cdot (p - c)$$

with W = benefits for the farmer;
S = area
Δq = increase in production as a consequence of pollination
p = farm-gate coffee price
c = variable costs related to coffee harvest.

4.3 The value of pollination for an Ethiopian coffee farmer

The average labour costs related to harvesting coffee berries are: 0.06 man-day / kg x 0.45€ / man-day = 0.027€ / kg. Following the equation presented in the previous section, the value of pollination for the average farmer can be estimated as follows:

$$W = 0.5ha \cdot 0.36 * 1000kg/ha \cdot (0.25 - 0.027)$$
$$= 40 \text{ € / farmer / year}$$

Hence, if the average Ethiopian farmer would lose the pollination service in his fields, he would lose an income equivalent to around 40 euro per year.

Clearly, if a substantial part of Ethiopian coffee farmers would lose the pollination service, the validity of these calculations would be reduced because of price effects. At the national scale, a substantial change in the supply of the pollination service may also have an impact on the producers' surplus, as the remaining producers would get higher prices, and on the consumers surplus, because consumers would need to pay higher prices

Table 11. Data for the coffee pollination case study.

Variable	Value
Size of the area planted with coffee	0.5 ha
Yields	1000 kg green berries/ha
Coffee prices (average 2001-2003)	2.8 Birr/ kg (0.25 euro/kg)
Labour requirements related to harvesting	60 man-days/ha
Labour costs	5 Birr / man-day (0.45 euro/day)

for their coffee – unless imports could make up for the changes in coffee production.

In general, if substantial price effects can be expected, a production function approach (as described in section 2) would need to be conducted. If, however, it can be assumed that crop prices will not change much (e.g. because of only limited changes in overall production, or because imported commodities can substitute for nationally grown crops), the approach presented in this section can also be used to obtain a crude estimate at the national scale.

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