Ecosystems and agro-biodiversity across small and large scale maize prodution systems CONABIO/TEEB

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1st General Report Amended : The valuation of ecosystem services provided by agro-ecosystems

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Introduction.

Ecosystem services are defined as services provided by the natural environment that are essential for people's existence (16, 44, 29). The Millennium Ecosystem Assessment (44) divided ecosystem services into four categories: a) supporting, b) provisioning, c) regulation and c) cultural services. Similarly, de Groot *et al.* (19) also divided ecosystem services into four categories: a) regulation, b) habitat, c) production and d) information.

Regardless of the categorisation, ecosystem services provide outputs or outcomes that affect human well being and, therefore, can be analyzed from an economic approach. However, currently markets, only provide information about the value of a few ecosystem services that are either directly, or indirectly, priced and incorporated in transactions as commodities or services.

Therefore, the ability of markets to provide a thorough valuation of the ecological processes is quite limited (44, 10). Moreover, there are information failures due to the complexity of quantifying most ecosystem services in terms that are comparable with services from human-made assets (16). From this perspective, the logic behind ecosystem valuation is to simplify the complexities of socio-ecological relationships, make explicit how human decisions would affect ecosystem service values, and to express these value changes in units (e.g., monetary) that allow for their incorporation in public decision-making processes. The Convention on Biological Diversity (CBD) states that: '... economic valuation of biodiversity and biological resources is an important tool for well-targeted and calibrated economic incentive measures' and encourages the Parties to 'take into account economic, social, cultural, and ethical valuation in the development of relevant incentive measures' (CBD's Conference of the Parties, Decision IV/10).

Different authors have reviewed the literature related with the valuation of ecosystem services, assessing the body of knowledge from different points of view. Christie *et al.* (14) provide an evaluation of economic and non-economic techniques for assessing the importance of biodiversity to people in developing countries. Through systemized searches in databases, they found

378 studies that valued biodiversity economically and 101 non-economic studies. Richardson and Loomis (40) reviewed studies using the Contingent Valuation Method to value threatened, endangered and rare species, as a part of a meta-analysis which objective was to identify which explanatory variables influencing willingness-to-pay (WTP) for these species have changed over time. Egoh *et al.* (21) searched for peer-reviewed publications to identify spatial indicators that have been used to map and quantify ES. They found 67 papers that actually mapped or modeled ES. de Groot et al. (18) give an overview of the value of ecosystem services expressed in monetary units; approximately 1,350 value estimates from 320 publications were coded and stored in a database. This Ecosystem Service Value Database (47), along with the Environmental Valuation Reference Inventory, are the two main repositories of this kind of data.

Environmental and ecological economists have been designing and applying non-market valuation techniques to such services for many years (like (37, 1, 16, 19, 6, 22, 9)). In addition, the MA (44) broadened the focus of concern to include the loss of ecosystem services (for example, see The Economics of Ecosystems and Biodiversity, (29)) and the UK National Ecosystem Assessment (8).

Ecosystem service literature and accompanying economic analyses can be roughly divided into three types: i) biodiversity and ecosystem functioning research studies that are typically focused on understanding and testing several biodiversity and ecosystem functioning and do not provide an economic valuation (see for instance (5) and (12), they provide a meta-analysis of more than 900 published effects of biodiversity on ecosystem functioning); ii) "How-to" economic valuation manual or guidelines that assess the role of economic analysis for ecosystem service valuation and provide for their implementation (see (9, 14, 29, 4)) and iii) Applied case studies that perform the elicitation of the values of at least one ES (for a thorough review see (14) and (5)).

Among the applied studies is possible to find different types: From all encompassing assessments that combine analysis of Sustainability (i.e. focus on changes occurring up to the present day and assess t the observed development path of an economy) and programme evaluations of different, alternative futures from the present captured in a series of scenario analyses programme evaluation (see (8) as an example of this type) , case studies that try to elucidate the total economic value of many ecosystems (16) to studies that value of at least one ES of one ecosystem using an economic valuation method. Moreover, is possible to differentiate between the latter elucidation studies in two general types: Those who generate their own data, either by on field empirical methods or surveys, and those who use the benefit transfer approach. These studies have been carried out in different biomes like wetlands, forest, marine, coastal and agro-ecosystems ((5, 14)).

Agro-ecosystems and ES services.

The FAO defines Agro-ecosystems as "ecosystems in which humans have exercised a deliberate selectivity on the composition of living organisms". Agro-ecosystems are distinct from unmanaged ecosystems as they are intentionally altered, and often intensively managed, for the purposes of providing food, fibre and other products; hence they inherently have human community, economic and environmental-ecological dimensions" (FAO).

Agriculture represents the largest engineered ecosystem which is actively managed by humans to optimize the flow of provisioning ES (49). It constitutes the main source of food, however, it is also widely recognized as one of the activities that contribute most to the loss of biodiversity in the world (3, 35). Its management practices can reduce the capacity of ecosystems to produce goods and services (46) including water quality, pollination, nutrient cycling, soil retention, carbon sequestration, and biodiversity conservation (17); they play a key role in the emission and global flow of greenhouse gases (41) by contributing 30% of total anthropogenic emissions of these (20) and significantly alter natural habitats (3).

The rise in global food production has been the result of cropping systems intensification, among other factors (20). Agricultural intensification is defined as the practices that increase productivity per area unit involving some cost in labor or capital investment (30). It consists of three main axes: a) spatial,

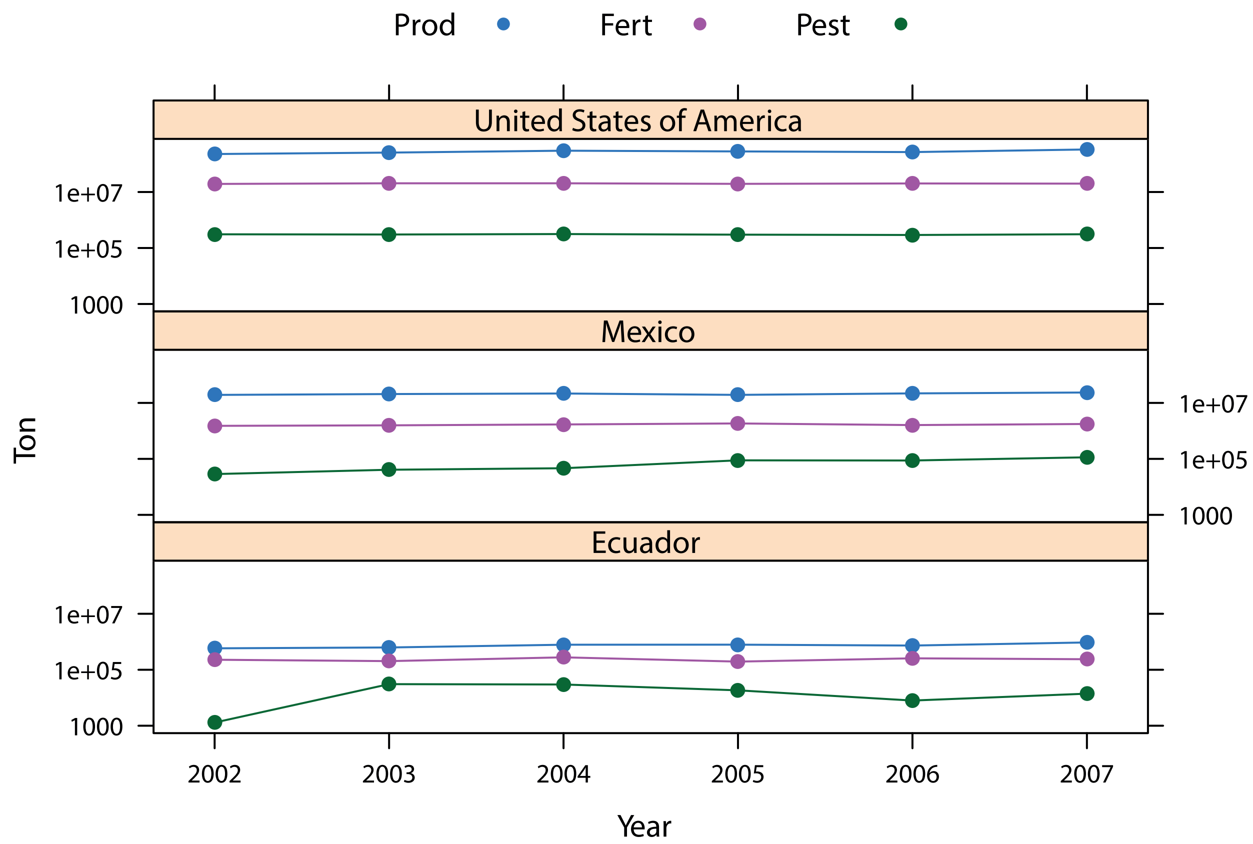

Figure 1: Maize production and total amount of fertilizers and pesticides applied to all agricultural land in the three countries.

b) temporal and c) technological (35). The degree of intensification of an agricultural area can be determined using indicators such as cultivated area, the degree of mechanization, and the amount of inputs used (26, 25, 27). According to FAO (2015), the three countries to be assessed in the present study follow a gradient of agricultural intensification, as can be seen in figures 1, 2 and 3.

The primary interest in agro-ecosystems is a set of provisioning services – the production of foods, fuels, and fibres – for which there are well developed markets. There are, however, other services that is necessary to consider such as improved water quality, the protection and enhancement of biodiversity, climate stabilization via carbon sequestration and greenhouse gas abatement, and social amenities such as verdant landscapes and agro-tourism (39, 43).

In addition, agriculture`s management practices may also constitute a source

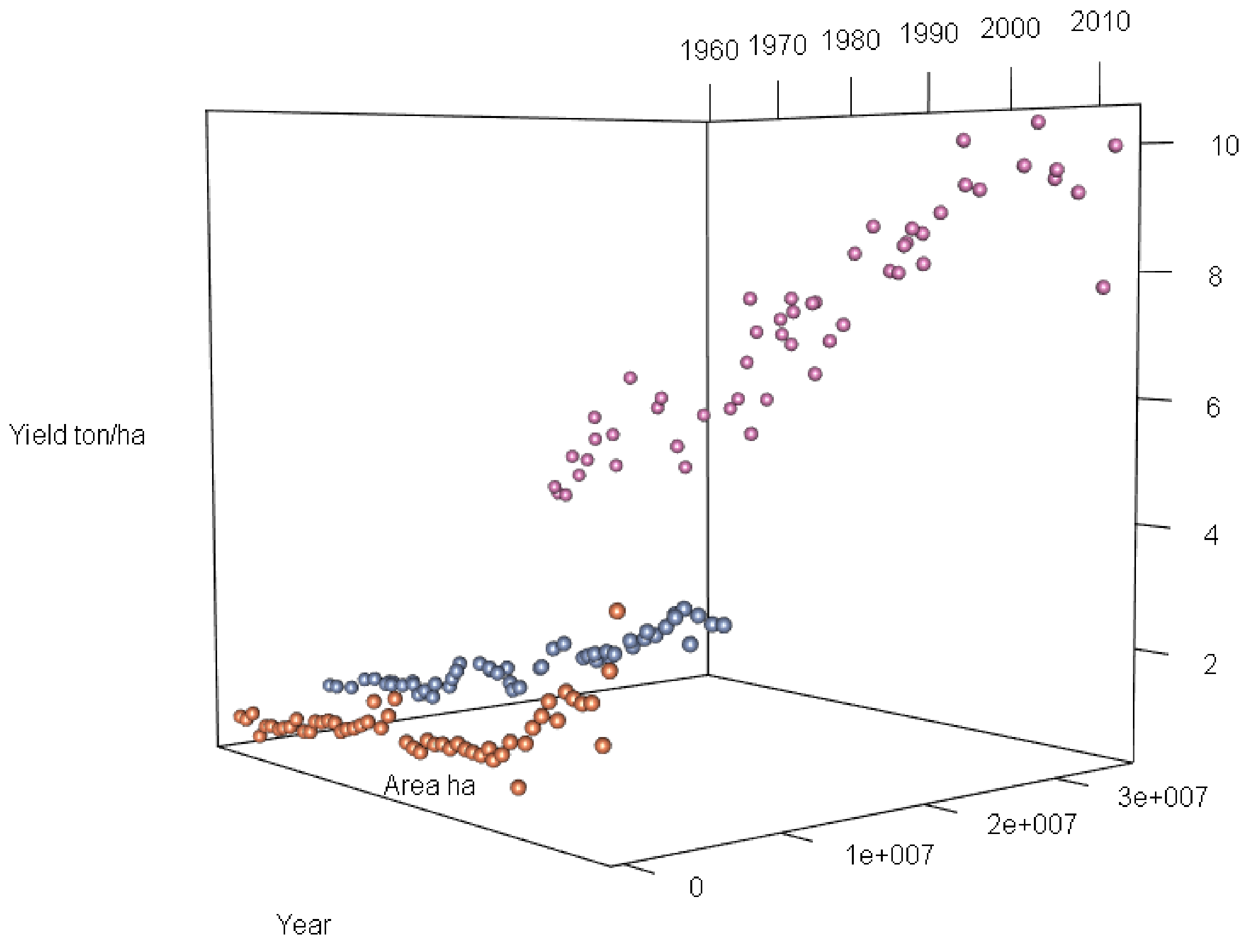

Figure 2: Planted surface and average yield of maize per year in the three countries; blue: Mexico; orange: Ecuador; pink: United States.

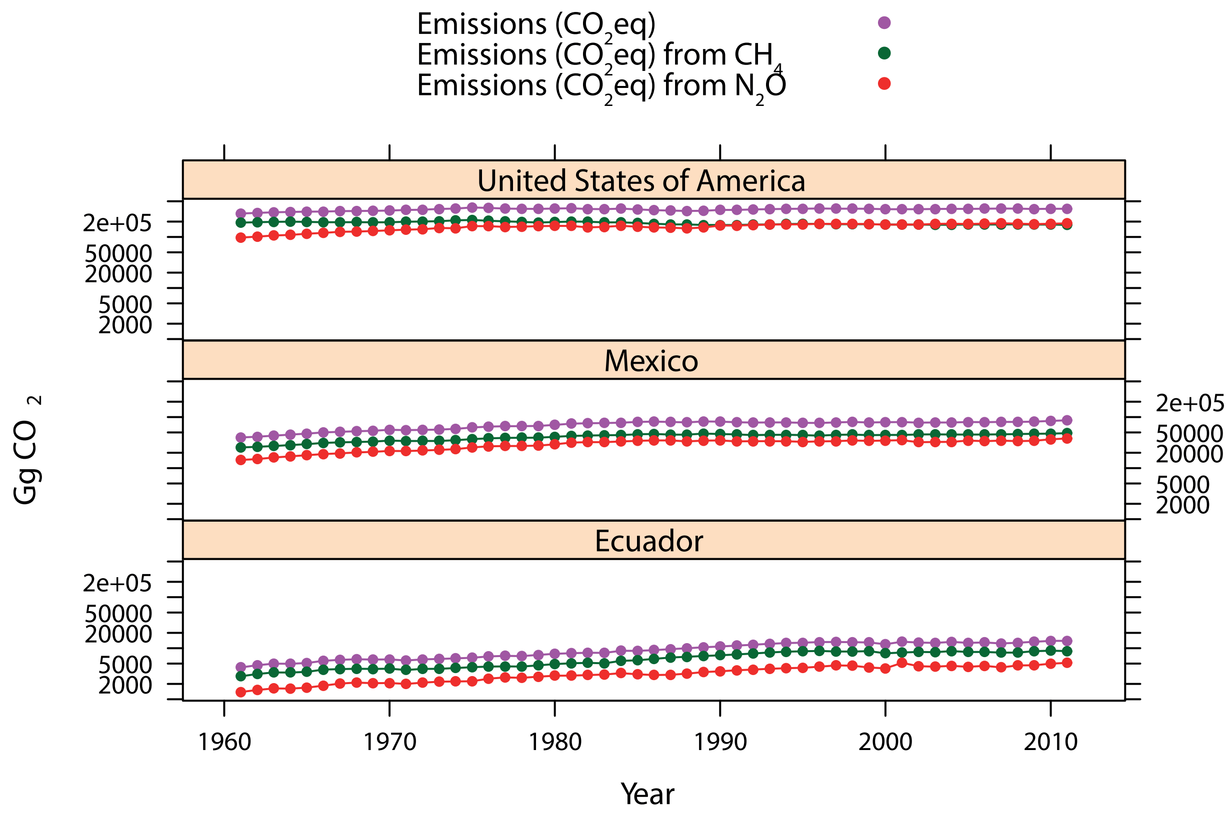

Figure 3: Total agricultural greenhouse gases emissions per year.

of negative externalities or "disservices" (39) to the environment, such as loss of habitat for conserving biodiversity, nutrient runoff, sedimentation of waterways, pesticide poisoning and other non-target species and emissions of greenhouse gases and pollutants (17, 49). Moreover, the intensity of agricultural production and management practices affect both the quantity and quality of water in an agricultural landscape. Therefore, agriculture is often considered a hurdle to conservation. However, appropriate management can lessen many of the negative impacts of agriculture, while largely maintaining provisioning services. In order to do so in paramount to incorporate such externalities into the costs of production in order to incentivize the mitigation of these negative environmental consequences of agricultural practices.

The case for the evaluation of ecosystem services is thus a particularly pertinent one, as agriculture is essentially a man-made ecosystem but, at the same time, the natural ecosystem provide services benefits that do not accrue from the provision of food and other products. While the knowledge regarding agriculture's harmful environmental impacts is extensive (6, 43), many of the other benefits, as well as the degree to which agricultural ecosystems are linked to one another and to unmanaged areas of the surrounding landscape are understudied. Recently, the alteration of the flow of ecosystem services that are mediated by biodiversity has attracted increasing attention (44, 38, 45).

The Economic valuation of ecosystem services.

The assessment of ecosystem services provided by agro ecosystems requires carrying out an economic valuation of the environment and biodiversity related services and amenities. In the past two decades years, an extensive body of literature has emerged estimating these economic values (37, 24, 33, 6) because market prices either do not exist or are difficult to measure for most environmental goods and services. The goal of economic valuation is to impute a value (usually in monetary terms) for these environment related services and amenities. In the past decade, advances in valuation techniques have increased the kind of environmental costs and benefits that can be monetized. In general, valuation involves quantifying or expressing human preferences for environmental services and amenities in monetary terms. Currently, there is an extensive body of literature on environmental valuation studies, usually applied at the local or regional level, to estimate values of forests, coastal and marine areas, protected natural areas, species, plants and genetic resources, greenbelt areas and a whole range of other environmental habitats. The Economic value of a good or service is related to benefit that accrues to the individual from its use/consumption and is expressed by economic agents through their willingness to pay. While this may be determined by the objective (e.g. physical or ecological) properties of the asset, the willingness to pay depends greatly on the socio-economic context in which valuation takes place – on human preferences, institutions, culture and so on (37, 6).

Justifying The Economic valuation of ES.

Is there a need to value ecosystem services and biodiversity? Economics is about de choices that agents make when facing among different alternatives. Ecological habitats offer a wide variety of ecosystem services required for society's well-being. Markets, however, currently only give information about the value of a few ecosystem services that are either directly, or indirectly, priced and incorporated in transactions as commodities or services. Therefore, the ability of markets to provide a thorough valuation of the ecological processes is quite limited (44). Moreover, there are information failures due to the complexity of quantifying most ecosystem services in terms that are comparable with services from human-made assets (16). From this perspective, the logic behind ecosystem valuation is to simplify the complexities of socio-ecological relationships, make explicit how human decisions would affect ecosystem service values, and to express these value changes in units (e.g., monetary) that allow for their incorporation in public decision-making processes. Economic decisions are based on the changes to human welfare caused by small (or marginal) modifications to ecological habitats. Therefore, the economic value of environmental services is anthropocentric and subjective and depends on the context and state of what is being valued (45).

Capturing the economic value of ecosystem services.

The Millennium Ecosystem Assessment (44) divided ecosystem services into four categories: supporting, provisioning, regulation and cultural services. Similarly, (19) also divided ecosystem services into four categories: regulation, habitat, production and information. In relation to economic valuation, the literature classifies these services first according to whether they provide value from its use or not, and the type of value they provide (37).

For the past three decades, Economists have designed different methodologies in order to elicit monetary values for the environment and use them as the common unit of comparison, thus making it simpler for everyone, from farmers to politicians, to understand the value of a service, because most people use currency as a form of exchange (16, 37, 19).

Figure 4: link between ES to human welfare.

Economic decisions are based on the changes to human welfare caused by small (or marginal) modifications to ecological habitats. Therefore, the economic value of environmental services is anthropocentric and subjective and depends on the context and state of what is being valued (44). In order to capture the importance of ecosystems services and to incorporate them in economic and other policy decision-making, is necessary to establish the link between a given ecosystem and its goods and services, and how these are valued by individuals. Ecosystems and their functions and processes provide outputs of goods and services, which generate benefits and can be measured as increases in human well being. This analysis does not measure the absolute value of human life and the role of ecosystems in its provision, but about the marginal value of ecosystem functions, goods and services and trade-offs between the alternative uses (including conservation) of these.

Total economic value (TEV).

A paramount concept of environmental economics is total economic value (TEV), which offers a useful framework for analysis. The total economic value provides a comprehensive measure of the economic value of any environmental good or service. It classifies ecosystem values into use and non-use values, and further sub-classifications can be used if needed. Whereas use values are based on actual use of the environment, non-use values are values that are not associated with actual use, or even an option to use, an ecosystem or its services. Thus, total economic value is the sum of all the relevant use and non-use values for a good or service (23).

Use value.

Involves some interaction with the resource, either directly or indirectly:

Direct use value. involves human interaction with the ecosystem itself rather than via the services it provides. It may be consumptive or extractive use, such as fisheries or timber, or it may be non-consumptive, as with some recreational and educational activities.

Indirect use value. Is derived from services provided by the ecosystem. This might, for example, include the removal of nutrients, providing cleaner water to those downstream, the prevention of downstream flooding and diseases and provision of information.

Option value. Is associated with benefit an individual derives from ensuring that ecosystem services will be available for his or her own use in the future. In this sense it is a form of use value, although it can be regarded as a form of insurance to provide for possible future use (often associated with the potential of genetic information inherent in biodiversity to be used for research, e.g. pharmaceuticals).

Non-use value. Is associated with benefits derived simply from the knowledge that the ecosystem is maintained. By definition, it is not associated with any use of the resource or tangible benefit derived from it, although users of a resource might also attribute non-use value to it. It can be split into two basic components:

1. Existence value: is derived simply from the satisfaction of knowing that ecosystems continue to exist, whether or not this might also benefit others (also associated with 'intrinsic value').
2. Bequest value: is associated with the knowledge that ecosystems and their services will be passed on to descendants to maintain the opportunity for them to enjoy it in the future.

TEV is an expression of the preferences of individuals, just like the price they pay from consuming service goods and services that are provided in markets expresses the minimum willingness to pay for the benefits they obtain from their consumption. Most environmental resources are not traded in actual markets,

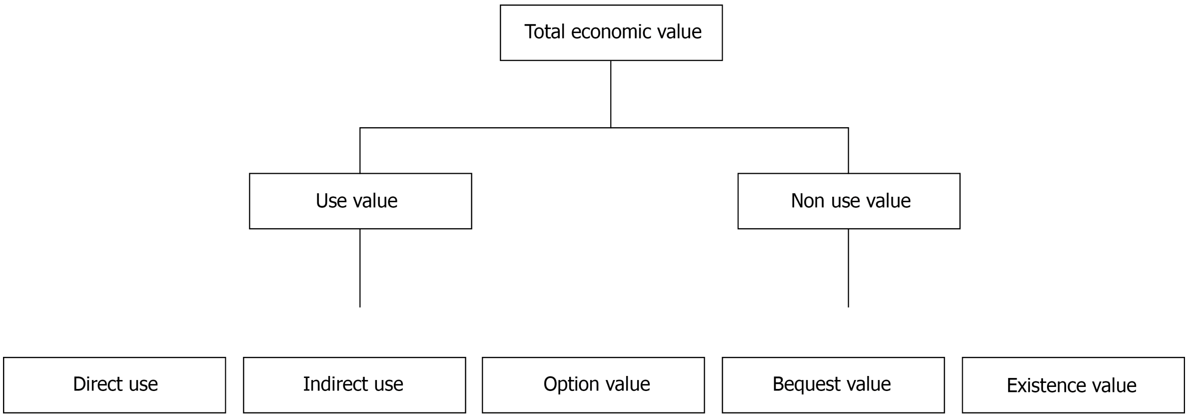

Figure 5: Total economic value.

therefore, such behavioural and market price information are missing. In such situations, the methods of economic environmental valuation provide several tools that may be employed to estimate these 'non-market' or 'external' benefits. What these techniques have in common is that they express economic value in units of money or proxies. This has the advantage of allowing the non-market benefits of ecosystem goods and services to be compared with financial gains from their use. The economic literature using these techniques is vast. Regardless of whether all components of TEV can be expressed in monetary terms for a given ecosystem good or service, the concept is useful in gathering the necessary information for more sustainable decision-making.

Services provided by agro-ecosystems.

This section focuses on the indirect use values of the agro-ecosystem services given the familiarity and abundance of data about the agro-ecosystem goods. The estimates of economic value reviewed concentrate on linking the ecosystem services as inputs to agricultural outputs which are not directly marketed.

Pest and disease control.

The loss of plant diversity that accompanies agricultural landscapes usually causes loss of diversity but an increase in pest species. The usual solution to this issue is the application of pesticides, of which 2.5 million tonnes are applied annually to crops worldwide. In contrast, more diversified and less intensive agro-ecosystems retain natural pest control by supporting a greater number and diversity of predators and parasites that attack herbivorous pest species (23).

Soil processes.

The organic component of soils provides a critical service in maintaining soil structure, facilitating water storage and retention, reducing erosion and providing the organic matter from which nutrients are released. Conversion of tropical forests to agriculture can result in substantial losses of soil organic matter by as much as 50% within five. Soil communities from agricultural systems have been shown to be substantially poorer in abundance and diversity than the soil communities of natural systems from which they are derived Degradation of the soil community occurs by removal and burning of the surface vegetation, tillage and substantial decrease in organic inputs into the soil among other factors.

Soil condition is a key measure of the long-term productive capacity of an agro-ecosystem. Both natural weathering and human management affect soil quality, and maintaining soil quality requires that soil-degrading and soil-conserving processes be balanced (23).

Pollination.

Pollination of crops is considered an ecosystem service of large economic value and crucial importance. Forests and woodlands particularly have been noted to provide shelter, nest-sites, water, larval food plants and floral resources for an immense number of pollinators ranging from tiny insects to birds and bats, and decline in pollinators has been attributed to the spread of intensive farming in developed nations and the clearance of natural vegetation, particularly forests, in tropical countries (23).

Nutrient cycling.

Nutrient supply by ecological systems is largely derived from the soil organic matter which is mediated by soil nutrient cycling organisms. In agro-ecosystems this process is disrupted due to the removal of nutrient through the harvesting process. The degradation of nutrient cycling services normally provided by an intact and diverse soil biota results in an estimated loss through leaching of 40 to 60% of nitrogen applied as inorganic fertiliser with severe downstream effects (Eftec, 2005). Water quality and quantity Agriculture consumes a large proportion of freshwater, with about 70% used for irrigation alone. Sedimentation and leaching of agrochemicals or manure may threaten water quality. Agriculture may thus negatively impact both the quantity and quality of available water (23).

Carbon storage.

Carbon in the form of soil organic matter (SOM) is of fundamental importance to the fertility of agro-ecosystems. SOM levels and their stability over time are key indicators of long-term soil quality and fertility, affecting water retention, cultivation, and the richness of soil biota and nutrients. When converted to agriculture, lands typically lose a significant proportion of their SOM. Carbon in soil and vegetation is also important to the global carbon cycle, accounting for 26-28% of carbon stored in terrestrial ecosystems. Land use changes and land management practices emit an estimated 1.6 GtC to the atmosphere annually, or about 20% of human-induced greenhouse gas emissions (IPCC, 2000).

Economic Valuation Methods for Environmental Services.

In the past three decades, diverse methodologies that make possible to elicit and express in monetary terms the economic values of ES have been designed. This makes it simpler to understand the value of a service, because most people use money as a form of exchange Within the TEV framework, values are elicited, when possible, from market transactions related directly to the ecosystem services. In the absence of this type of information, price information must be derived from proxy market transactions, those that are associated indirectly with the good to be valued. In the case when there is no price information on ecosystem services, hypothetical markets may be created in order to elicit values. These situations correspond to a common categorization of the available techniques used to value ecosystem services:

Group	Service	Direct Use	Indirect Use	Option Value	Non-Use value
Provisioning	Food, fibre and fuel Fresh water supply	X	NA	X	NA
Regulating	Water regulation carbon storage nutrient recycling	NA	X	X	NA
Cultural	Cultural heritage Recreation and tourism Aesthetic values	X	NA	X	X
Supporting*	Primary production Nutrient cycling Soil formation				

Table 1: Valuing ecosystem services through the TEV framework; *Supporting services are values through the other categories of ecosystem services.

(1) direct market valuation approaches, (2) revealed preference approaches and (3) stated preferences approaches (45).

There are two approaches to measure the benefits of environmental quality. They differ with regard to the types of values estimated, the type of data they require, and whether there are markets or proxy markets where these goods/services (G/S) are exchanged. Each approach includes several methods:

1. Direct market approach. Approaches values are derived, if available, from information of individual behaviour provided by market transactions relating directly to the ecosystem service 2.
2. Revealed preference approach. Infer the value of environmental goods from other transactions in real markets.
3. Stated preference techniques. Ask individuals hypothetical questions about their willingness to pay due to the lack of markets for this G/S.

	Goods and services	Local	Regional	Global
Direct use	Plants/food	X	X	X
	Livestock/food	X	X	X
	Visual amenity of agricultural landscapes	X	X	
Indirect use	Pest and disease control	X	X	
	Soil nutrient cycling	X	X	
	Maintenance of soil structure and porosity	X	X	
	Maintenance of soil fertility	X	X	
	Pollination	X	X	
	Nutrient cycling	X		
	Water quality and quantity	X		
	Carbon Storage			X
	Genetic Diversity	X	X	X
Option	Future direct and indirect uses of above goods and services	X	X	X
Non-use	Traditional / cultural knowledge & traditions	X	X	X

Table 2: Total economic value of agro-ecosystem goods and services; adapted from Eftec (2005).

Direct Market Approach.

When ES are traded in markets, their value can be estimated by the consumer and producer surplus generated by their market prices. Direct market valuation approaches tend to be separated into three different types (i) market price- based, (ii) cost-based, and (iii) production functions based. Their main strength is that they rely on actual data from current markets and therefore, reflect real preferences or costs to economic agents (45).

Market price-based techniques elicit the economic value of ecosystem products or services that are available to buy or sell in markets. The market price method can be used to value changes in either the quantity or quality of ES. The standard method for measuring the use value of resources traded in the marketplace is the estimation of consumer and producer surpluses using market price and quantity data. The total net economic benefit, or economic surplus, is the sum of consumer surplus and producer surplus.

Cost-based approaches techniques are based on estimates of the costs that would be incurred to substitute ecosystem services. Different techniques exist, including, (i) the avoided cost method, which elicits the value using the costs that would have been incurred if the ecosystem services is absent, (ii) replacement cost method, which estimates the costs incurred by replacing ecosystem services with man-made technologies, and (ii) mitigation or restoration cost method, which uses the cost of mitigating the effects caused by to the loss of ecosystem services or the cost of getting those services restored as a proxy for its value (45).

Production function-based approaches (PF) estimate how much a given ecosystem service is responsible for the provision of another good or service which is traded on an existing market.

Limitations of direct market valuation approaches. Direct market valuation approaches rely primarily on production or cost data, which are generally easier to obtain than the type of data required determining the demand for ecosystem services. However, when applied to ecosystem service valuation, these approaches have important limitations. These are mainly due to ecosystem services not having markets or markets being distorted. If markets are absent either for the ecosystem or for the goods and services that are indirectly related, then the data needed for these approaches are not available. In addition, there may be cases where markets do exist but are distorted (in the presence of subsidies or market failure for example), thus prices will not express properly the preferences or costs and the elicited values of ecosystem services will be biased. In addition, the complexity in defining ecosystem services may generate double-counting in the valuation estimates.

Revealed Preferences Approach.

Many ecosystem services cannot be directly obtained through markets. Revealed preference techniques are based on the observation of individual choices in existing markets that are related to the ecosystem service that is subject of valuation. In this case it is said that economic agents "reveal" their preferences through their choices. The two main methods within this approach are:

Hedonic Pricing Method. This method may elicit the value of ecosystem services that have an impact on market prices. It regularly is applied using changes in housing or land prices derived from the change of their environmental attributes (proximity to environmental amenities, noise, pollution, among others). The hedonic pricing method is most often used to value environmental amenities that affect the price of housing properties. The basic assumption of this method is that the price of marketed goods is derived from its attributes or the services it provides. For instance, the price of a house depends on its characteristics (like size, location, proximity to schools, amenities, air and noise pollution). Consequently, it is possible to value the individual attributes of a good by analysing how the price that people are willing to pay for it changes when some or all of these attributes are modified.

Travel Cost Method. This method is used to estimate the use values associated with ecosystems services that are used for recreation. The method can be used to estimate the economic benefits or costs resulting from i) changes in access costs for a recreational site, ii) changes in environmental quality at a recreational site iii) Disappearance of an existing recreational site, iv) creation of a new recreational site. The basic assumption of the travel cost method is that the expenses that agents incur to visit a site (time and transportation costs) represent a minimum willingness to pay to access the site. Consequently, the economic value of the site can be elicited using the number of trips that agents make at different travel costs. This is analogous to estimating peoples' willingness to pay for a marketed good based on the quantity demanded at different prices.

Limitations. The main disadvantages of these methods are: i) their failure to estimate non-use values and, ii) the sensibility of the elicited values on the specification of the relationship between the environmental good and the proxy marketed good. In addition, due to their dependency in actual data on market prices, the estimation elicited by revealed preferences methods might be biased when markets are distorted (in the presence of subsidies or market failure for example). Hence, in order to perform an unbiased elicitation, it is necessary to gather appropriate data on each transaction, use large data sets, and carry out sophisticated econometric analysis. Revealed preference approaches, therefore, tend to be costly and time-consuming (45).

Stated Preferences Approach.

Many ecosystem services are neither traded nor related to any marketed goods. Thus, is not possible to elicit values through an agent's behaviour. Stated preference approaches simulate a market and demand for ecosystem services by carrying out surveys on hypothetical settings related to the provision of ecosystem services and asking stakeholders to directly state their valuation or willingness to pay, rather than observe actual choices. Alternatively, people can be asked to make trade-offs among different alternatives, from which their willingness to pay can be estimated. These methods can be used to estimate both use and non-use values of ES (45).

The main types of stated preference techniques are:

Contingent Valuation Method (CVM). This method is used to elicit economic values for all types of ecosystem and environmental services and can be applied to estimate both use and non-use values. It is also the most contentious of the non-market valuation methods. It involves directly asking people, in a survey, how much they would be willing to pay for specific environmental services. In some cases, people are asked for the amount of compensation they would be willing to accept to give up specific environmental services. It is called "contingent" valuation, because people are asked to state their willingness to pay, contingent on a specific hypothetical scenario and description of the environmental service.

Contingent Choice Method. This method can be used to elicit economic values for virtually any ecosystem or environmental service and non-use as well as use values. It is also a conjectural method as it requires agents to make choose between alternatives based on hypothetical scenarios. However, it differs from contingent valuation because it does not directly ask people to state their values in monetary terms. Instead, values are inferred from the hypothetical choices or trade-offs that people make. This analysis of trade-offs among scenarios with different characteristics makes contingent choice very well suited to inform policy decisions. In addition, contingent choice results may also be used to simply rank options, without including monetary values.

Limitations of stated preference approaches. The hypothetical nature of the scenarios these methods use to elicit value has raised numerous questions regarding their validity. The main issue is whether respondents hypothetical answers correspond to their actual behaviour if they were faced with these choices in real life. Another important problem is the "embedding", "part-whole bias" or "insensitivity to scope" problem (2, 45).

Literature review

The literature published on this subject was investigated through a search in the Web of Science. Using the search terms in tittle: agriculture AND ecosystem AND services, 23 out of 38 peer reviewed papers were selected and in-

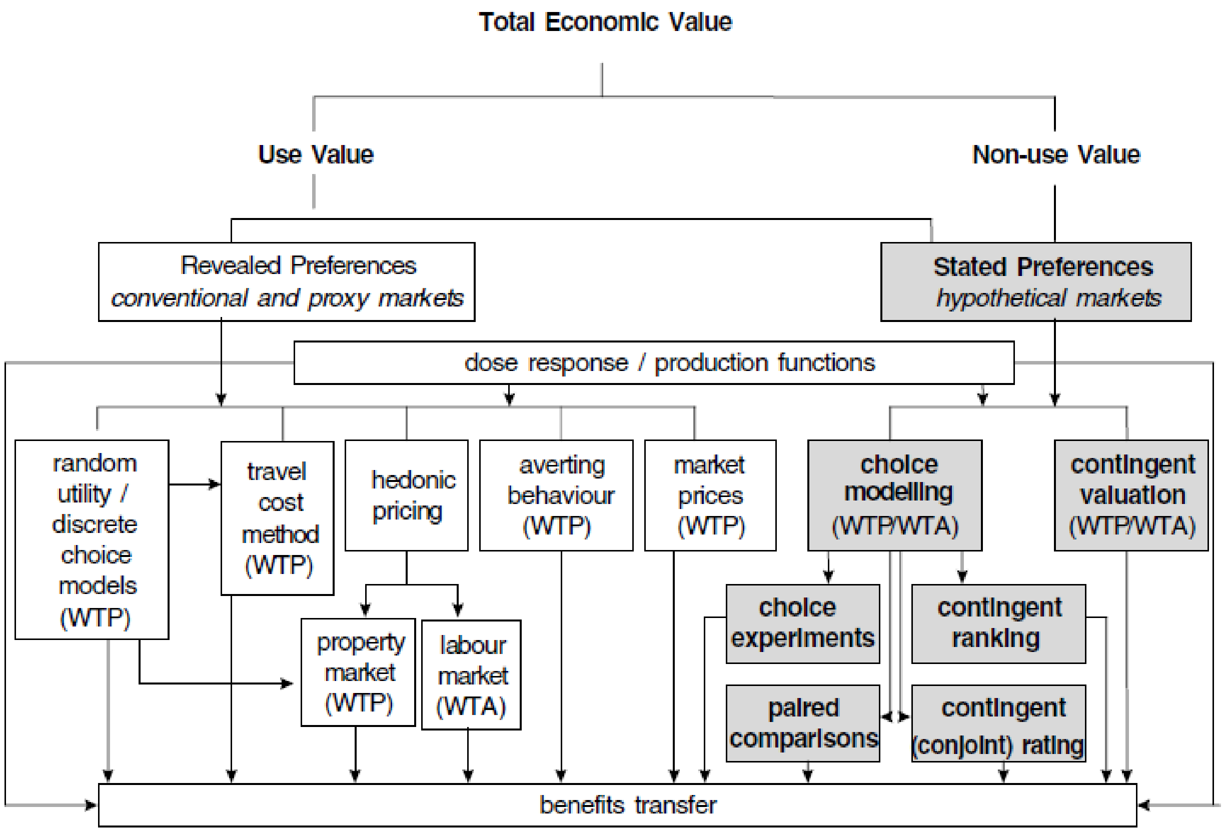

Figure 6: Total economic value and valuation techniques. Source

corporated into a relational database.

Ecosystem service studies vary widely in focal services, geographic extent, and in methods for defining and measuring services (48). Not surprisingly, during the process of populating the tables, it was found that not all the literature uses an uniform ES taxonomy, many studies does not declare explicitly the category and/or the services assessed, and the great majority lack of a proper statement of the components of ES delivery (i.e. capacity, pressures, demand, and flow (48)). Therefore a significant level of interpretation was required in order to adapt, as much as possible, the collected information to the TEEB framework.

The majority of studies (10) assesses only one category of ES; only three include three categories. Although the studies focus on agriculture, only nine specifies the crop type with which the ES are accrued. 15 studies have a theoretical approach while the remaining eight are applied.

Due to the variety of terms used in the studies' titles, the scope of this search is very limited; therefore an *ad hoc* search was conducted in order to include many other relevant papers that were left out by this approach (see table 4).

Case Studies with one valuation method.

Ecosystem service studies are well represented in the literature (for a comprehensive review, see (9) and (15)) However, there are only a select few articles that attempted to value at least one component of ecosystem services in agro-ecosystems using original data and one of the economic valuation methods reviewed above. The table provides a summary of some relevant examples of case studies for each of the methodologies discussed above.

Direct Market Approach.

Production function and input cost. (31) elicited the value of the service of pest regulation. They calculated the lost value of natural biocontrol services

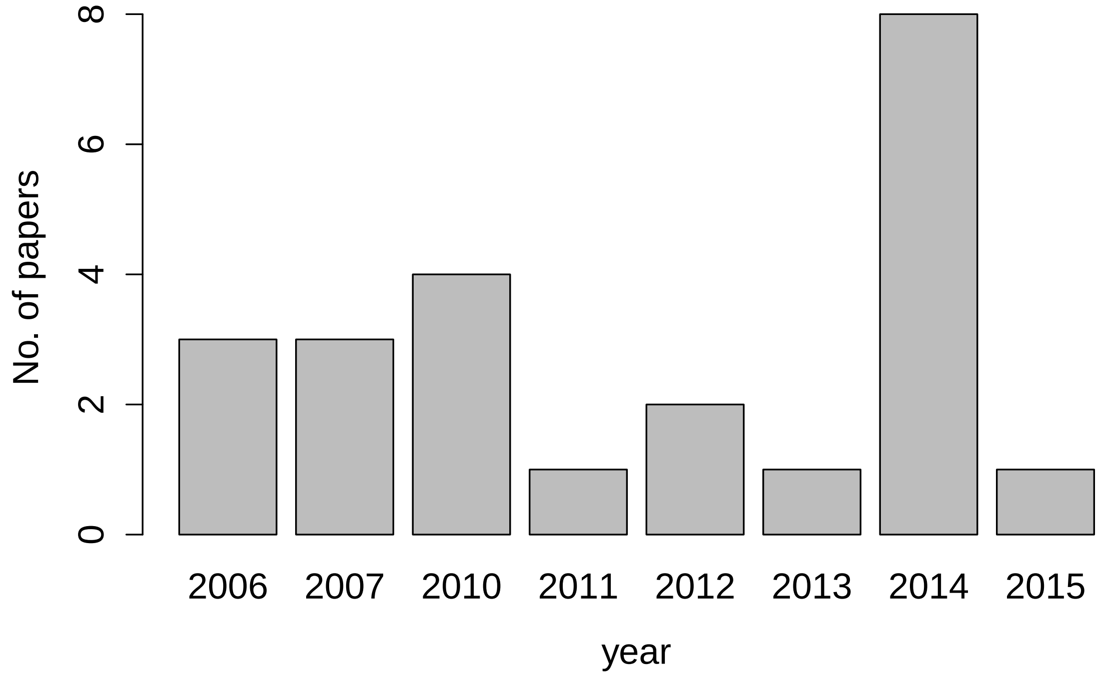

Figure 7: Number of papers published per year.

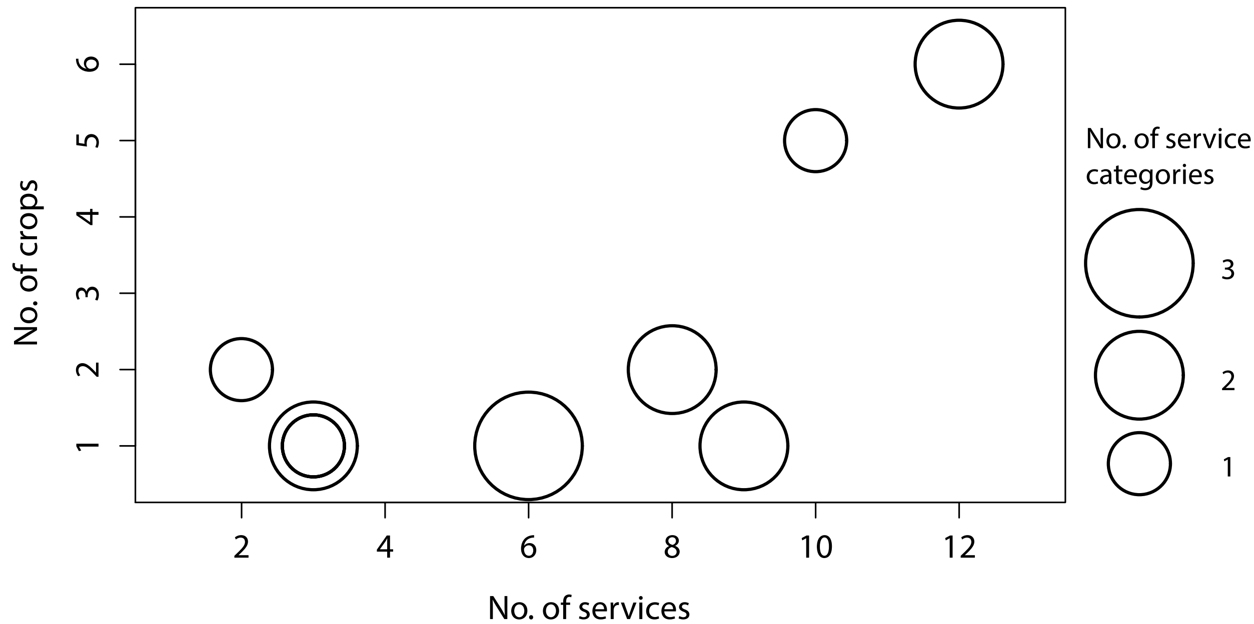

Figure 8: Number of ES categories, ES and crops assessed by papers which explicitly indicate crop type.

Service	Papers	Theo.	App.	Indicators	Crops
Cultural					
Agricultural heritage	1	0	1	0	1
Recreation	2	1	1	0	1
Provisioning					
Fibre	2	1	1	1	0
Food	7	3	4	4	4
Fuel	2	1	1	1	0
water quality	2	1	1	2	0
Regulating					
Biological control	10	7	3	2	7
Carbon sequestration	8	4	4	2	11
Climate regulation	2	1	1	1	1
Emission of greenhouse gases	3	2	1	1	1
Erosion prevention	1	1	0	0	0
Filtering of contaminants	1	0	1	0	1
Filtering of nutrients	1	0	1	0	1
Flood control	2	1	1	1	1
Nutrient cycling	1	1	0	0	2
Pollination	7	7	0	0	0
Recycling	1	0	1	1	0
Soil structure and fertility	6	5	1	1	1
Waste water treatment	2	0	2	1	2
Water avalilability	4	3	1	0	1
Water quality	5	5	0	0	2
Supporting					
Diversity	5	4	1	1	8
Habitat provision	2	1	1	1	0

Table 3: Summary of the studies included.

based on predicted soybean yield loss and associated increased insecticide costs. They estimated impacts both on farmers who follow integrated pest management (IPM) to guide insecticide sprays and on the roughly 1% of farmers who rely entirely on natural biocontrol. Depending on whether the soybean price was the 1996–2007 median or the higher post 2007 level, the reduced value of biocontrol services to soybeans due to the 19% increase in corn acreage was estimated to be $18–25/ha for IPM farmers and $110–199/ha for natural biocontrol farmers.

Revealed Preferences Approach.

Hedonic Pricing Method.

Ma, S., and S. Swinton. 2011. Valuation of ecosystem services from rural landscapes using agricultural land prices. Ecological Economics 70:1649–1659.

A study by Ma and Swinton (2011) (32) measured the value of land-based ecosystem services in in south-western Michigan using a hedonic model of land prices in four counties (Allegan, Barry, Kalamazoo, and Eaton). Their model included variables describing attributes of both the natural and man-made environments and split these into traits that affect both the production value of the land and its consumption value (e.g., residential and recreational attributes). To capture the effect of surrounding ecosystems, the study analyzed spatial data on the proportions of land cover in a 1.5 km radius around property parcels. The study inferred ecosystem service values from the influence that particular landscape features had on agricultural land prices. Their results shown that the price of land parcel increased by 3% in response to a rise of 1% of the proportion of wetlands within the 1.5 km radius of surrounding land, suggesting that land markets place value on certain ecosystem services of wetlands. Similarly, a 1% increase in surrounding conservation rose up parcel prices by 2%. In addition, parcel prices rose by 6% for each kilometre closer to a river, suggesting that recreation and crop irrigation are valued traits. These findings suggest that recreational and production-supporting services tend to make the largest contributions to land values. In addition, they noted that some ecosystem services are unlikely to be incorporated by land prices, either because landowners are unaware of their value or because the benefits are dispersed to areas external to the parcel. Moreover, it seems that land prices do not reflect benefits that are largely realized outside the parcel, such as greenhouse gas mitigation or habitat for large wildlife.

Travel Cost Method.

Knoche, S., and F. Lupi. 2007. Valuing deer hunting ecosystem services from farm landscapes.Ecological Economics 64:313–320.

A study by Knoche and Lupi (2007) (28) elicited the value of Michigan's agricultural land as wildlife by a travel cost analysis of deer hunting in the state. The authors used data on the cost of hunting trips to calculate how much hunters are willing to pay for various attributes of the hunting experience and found that hunters were effectively paying $39 per acre for access to 10% of the private agricultural land in the southern Lower Peninsula of Michigan. This represents 7% of the per-acre market value of farm products in the area in 2004, a significant value. By providing a varied landscape with abundant food, agriculture enhances the habitat for deer. This study estimated that in a non-agricultural landscape that supported only half as many deer, the annual value to hunters would decline by $15 million.

Stated Preferences Approach

Contingent valuation.

Chen, H. 2010. Ecosystem services from low input cropping systems and the public's willingness to pay for them. Thesis, Michigan State University, East Lansing, Michigan, USA.

A study by Chen (2010) (13) elicited whether residents in Michigan where willing to pay to compensate corn and soybean farmers in Michigan to change their cropping practices so as to generate more ecosystem services. Under the hypothetical scenario, farmers would expand both the complexity of management practices and the acreage generating enhanced ecosystem services in the form of reduced numbers of eutrophic lakes and reduced greenhouse gas emissions.

A key complexity facing this research was bringing together the supply and demand for ES. First, the supply units need to be converted from all land area under a given practice to land area under changed management that provides additional ecosystem services as resident taxpayers would expect to pay for increases in ecosystem services, not just to express gratitude to environmentally minded farmers who were already providing those services.

Therefore, the land area under stewardship practices offered by farmers was meticulously recalculated to ensure that it refers to practices that bring additional ecosystem services. In addition, given that some ecosystem services like climate regulation, water quality regulation, nutrient cycling, and pest population regulation are meaningful opaque to the general public. (13) developed a graphical model of how agricultural practices generate intermediate environmental changes that lead to the ecosystem services experienced by the general public.

Based on the literature and pre-tests of the questionnaire, the research focused on two high-profile endpoints: the proportion of eutrophic lakes and percentage of progress toward international goals for abatement of climate change. The survey population were all residents of the state of Michigan. The 2009 Michigan Environmental Survey went to 6000 Michigan households stratified by population in each county to cover the full geographic extent of the state; the final response rate was 41%. Respondents were first presented with information about climate change and eutrophication of lakes, along with the links between land management practices and changes in those outcomes. Householders were then presented with three land stewardship programs, with each proposing to make different changes in (i) the number of lakes with excess nutrient levels and (ii) the percentage change in greenhouse gas emissions that scientists estimate is needed to slow global warming. For each of three programs, respondents were asked:

"Would you vote for program (Y) if it increased income taxes and your share of the increased tax was $X per year?"

The questionnaire was mailed in 14 versions, varying the tax rate ($X), the levels of eutrophic lakes and greenhouse gas abatement, and whether the recipients of the program payments were described as farmers or land managers. The results found significant public willingness to finance policies that would pay land managers for changed practices to mitigate lake eutrophication, but less support for financing mitigation of global warming. The overall mean marginal willingness to pay of Michigan residents was $175 per household per year to reduce the number of eutrophic lakes by 170 and to reduce greenhouse gas emissions by 0.52% of their 2000 levels. They did not care whether the funds for changed land management went to farmers or other land managers. Support for cleaner lakes was clear-cut. Respondents were willing to pay $0.45 per eutrophic lake per household per year, or $1.7 million annually per eutrophic lake, based on the 3.8 million households in Michigan. Most households were unwilling to pay for reduced greenhouse gas emissions. This finding was due, in part, to the fact that 60% of households were unconcerned about climate change. But the unwillingness to pay may also have resulted from the smallness of the potential emission reductions—just 0 to 1.2%—based on the crop systems proposed in the 2008 Crop Management and Environmental Stewardship Survey. Ordinarily, economists expect that people will pay more to buy more. But statistical tests showed that willingness to pay was unaffected by the level of proposed reduction in greenhouse gas emissions. Hence, overall mean willingness to pay for reduced emissions was zero. Among the 40% of households that were concerned about climate change, however, the mean household would pay $141 per year for a 1% reduction, compared to year 2000 greenhouse gas emission levels. Scaling up to the 1.52 million Michigan households that were concerned about climate change, this would amount to $214 million annually for a 1% reduction in greenhouse gas emissions, compared to the year 2000 level.

Contingent Choice Method.

Bernués A, Rodríguez-Ortega T, Ripoll-Bosch R, Alfnes F (2014) Socio-Cultural and Economic Valuation of Ecosystem Services Provided by Mediterranean Mountain Agroecosystems. PLoS ONE 9(7).

A study by Bernués, *et al.* (2014) (11), aimed to elucidate the socio-cultural and economic value of a number of ecosystem services delivered by mountain in Euro-Mediterranean regions. The authors combined deliberative (focus groups) and a choice modeling method to, first, identify the perceptions of farmers and other citizens on the most important ecosystem services and, second, to value these in economic terms according to the willingness to pay of the local (residents of the study area) and general (region where the study area is located) populations. Cultural services (particularly the aesthetic and recreational values of the landscape), supporting services (biodiversity maintenance) and some regulating services (particularly fire risk prevention) were clearly recognized by both farmers and citizens, with different degrees of importance according to their particular interests and objectives.

The authors designed a Choice Experiment survey where individuals were asked to choose between policy scenarios in a series of choice sets. Each choice set includes three alternative policy scenarios defined by attributes cultural landscape, preservation of biodiversity, prevention of wild forest fires, and provision of local quality food products. Each attribute had three levels and annual cost have five levels. In the analyses all ES variables are treated as categorical variables, while the annual cost is treated as a continuous variable. Because each attribute (ES) corresponds to a different component of the TEV and all attributes are evaluated simultaneously, the sum of the WTP values obtained in the analysis can be considered the TEV of Mediterranean mountain agro-ecosystems.

Respondents were asked to choose their most preferred policy scenario among three alternatives presented in the choice set. One of the alternatives was fixed (status quo situation) and corresponded to the current policy scenario. The other two alternatives were referred to as policy A and B and represented different combinations of attribute levels The attribute levels were defined in biophysical terms according to contrasting policy scenarios called `liberalization' and `targeted support'. The liberalization policy scenario assumes a reduction of support of both EU and national agro-environmental schemes. The targeted support policy scenario involves additional funding to agro-environmental schemes, which are specifically designed to deliver public goods. Thirty choice sets divided in six blocks were obtained, i.e., each respondent made five choices.

The results shown that prevention of forest fires (≈50% of total willingness to pay) was valued by the general population as a key ecosystem service delivered by these agro-ecosystems, followed by the production of specific quality products linked to the territory (≈20%), biodiversity (≈20%) and cultural landscapes (≈10%). The value given by local residents to the last two ecosystem services differed considerably (≈10 and ≈25% for biodiversity and cultural landscape, respectively). The Total Economic Value of mountain agro-ecosystems was 120 euros / person / year, three times the current level of support of agro-environmental policies.

Case studies with more than one valuation method.

Münier, B.; Birr-Pedersen, K. & Schou, J. Combined ecological and economic modeling in agricultural land use scenarios Ecological Modelling, Elsevier, 2004, 174, 5-18.

Abstract.

This paper presents a modeling framework for integrated economic and ecological evaluation of governmental agricultural policy at a local level. Using a spatially explicit approach helps to clarify and assess interrelations between physio-geographical conditions, biodiversity, land use and economy. This paper therefore, addresses the consequences of changes in agricultural production with respect to ecology, environment and economy. Ecological effects are assessed in terms of type, area and fragmentation of biotopes at landscape level. Assessment is based upon the output of a spatial detailed Biotope Landscape Model, describing the distribution of plant communities and nature types in Danish (semi-) natural terrestrial biotopes. In addition an agro-economic model, assessing the costs of agricultural land use changes at the farm level, has been implemented. Input and output of the economic model has been linked to the GIS-based Biotope Landscape Model, allowing scenario definition and integrated evaluation of results, including their spatial representation. The present situation has been modeled as a base line

scenario. Afterwards, three scenarios aiming at more extensive agricultural production have been selected so they reflect different ecological or economic priorities. Results show economic as well as ecological consequences, compared to the present situation.

Model structure.

The modeling approach described in this paper integrates spatial and non-spatial information from agricultural databases, land use and ownership and physical settings within a common framework. Geo-referenced nation-wide agricultural databases provide data on land use and livestock husbandry for each farm in the study area, which are used to derive economic output in terms of gross output and the economic rent. This allows mapping of the spatial variation of the economic output on farm level, by which opportunity costs can be estimated in terms of reduced agricultural production caused by area-specific changes in land use. Knowing the ecological requirements of terrestrial plant communities, the expected distribution of (semi) natural vegetation can be derived from maps on land use and abiotic settings, e.g. grazing, hay cutting, soil types, soil moisture and geomorphology. Resulting maps of vegetation types are analyzed to reveal changes in fragmentation of the entire landscape as well as key types of vegetation. Scenarios highlighting economic as well as ecological outcomes imposed by agri-environmental policies and different policy objectives and instruments may be appraised and compared against each other using the combined ecological and economic model. Scenario definition may use spatial and non-spatial regulations, i.e. subsidies, taxes, area reservations and others.

Study area.

Applications of the modeling frameworks are demonstrated in a study area located within the two municipalities Bjerringbro and Hvorslev in the centre of the peninsula of Jutland (Denmark). The two municipalities cover 425 km 2 of which almost 3/4 is agricultural land. All types of agricultural production are found in the area ranging from intensive pig and cash crop production, organic dairy farming to part time agriculture. The total number of farms in 1997 was 878 with an average farm size of 36.3 ha, which is 15% smaller than the average farm size in the whole of Denmark. Agricultural land use area sums at 13.911 ha, shared between cash crops (59% of the area) and roughage (41% of the area). Livestock hold consists of ruminants (mainly cows), pigs and poultry. An economic model is used for estimating the economic output from each farm based on information on land use (crop types), livestock husbandry and the main soil type of the farm. The information of land use and livestock husbandry on each farm is combined with a Farm Account Database holding data on average economic output from each production activity taken from the Danish Institute of Agricultural and Fisheries Economics. From this, coefficients for economic rent per hectare and per animal have been calculated. In this way the information on production structure on each farm is utilised in order to reflect as much as possible of the spatial variations. In the present study, the economic output is expressed using the profit, which is identical to the economic rent of crop production and of husbandry. The economic rent is what remains when all costs, including labour and capital costs except the capital costs of owning soil, are subtracted. To illustrate the effects of different policy strategies three different scenarios for converting a subset of 550 ha to extensive pasture have been evaluated: 1. In the first scenario the least costly areas are chosen without setting any ecological restrictions (referred to as Low cost). 2. The second scenario has the same condition, but selects only farms with more than 20 ha of marginal areas, presupposing that larger semi-natural areas may alter the ecological benefits (Low cost, >20 ha). 3. The third scenario emphasises more connectivity among (semi-) natural areas in the landscape. It ranks farms according to the largest share of their fields sharing edges with existing (semi-) natural open areas, regardless of the costs involved (Close to nature). The portion of shared edges has been derived in the GID from a map on land cover and a map allocating fields to each individual farm. In all scenarios, fields outside the predefined marginal areas may also be affected. Farms having more than 75% of their farmland converted will change the entire farm to grazing pasture

Results of economic modeling.

The average costs of converting 550 ha under the Low cost scenario (scenario 1) make up DKK 1500 per hectare. This is more than DKK 3000 less than the average cost of DKK 4800 for converting all 4313 ha of potential new pasture in the study area The costs increase by more than 25% by imposing the restriction that the pasture of each farm should be at least 20 ha (scenario 2: Low cost, >20 ha). Appointing areas close to existing (semi-) natural areas and regardless of costs involved (scenario 3: Close to nature) is much more expensive, with 3400 DKK per hectare per year on average. However, this is still approximately 30% cheaper (in terms of DKK per hectare) than average conversion costs of all potential pasture, probably because the new pasture is placed close to existing pasture and potentially located on marginal or less productive areas.

The loss of economic rent per hectare for each individual farm in all three scenarios was elicited. The most flexible Low cost scenario has least costs with most farms placed between 1000 and 2000 DKK per hectare per year. Putting other constraints in means higher costs per hectare, as the Low cost, >20 ha scenario shows higher costs at each farm selected. This is even more obvious in the Close to nature scenario using only an ecological criterion for ranking the individual farms. Here, no criterion for minimising the costs is given and thus the scenario affects some of the farms with a very high economic rent per hectare.

Rasul, G. & others Ecosystem services and agricultural land-use practices: a case study of the Chittagong Hill Tracts of Bangladesh Sustainability: Science, Practice & Policy, NBII, 2009, 5, 15-27.

Abstract.

This article estimates, using non-market valuation techniques, the value of environmental services associated with four agricultural land-use systems in the Chittagong Hill Tracts of Bangladesh and compares their relative profitability from private and social perspectives. The financial analysis reveals that annual cash crops are the most profitable short term land use and agroforestry is the least profitable, with horticulture and farm forestry providing benefits intermediate between these two systems. However, the relatively larger returns

from annual cash cropping lead to higher environmental costs such as soil erosion, forfeited carbon sequestration, and biodiversity loss. When the environmental costs are taken into account, annual cash crops appear to be the most costly land-use system, with agroforestry and farm forestry becoming more profitable. The findings demonstrate the trade-offs and synergies between relatively more environmentally sustainable and harmful land-use practices. Financial incentives to encourage more prudent agricultural activities are needed to transform trade-offs into synergies.

Study Area.

The study is conducted in the CHT region located in the southeastern part of Bangladesh and coveringthree hill districts—Rangamanti, Bandarban, and Khagrachari With an area of 5,089 square miles, CHT covers about one-tenth of the Bangladeshi territory and is surrounded by India in the north and east, Myanmar in the southeast, the Chittagong district in the west, and Cox's Bazar in the southwest. This area is geographically and culturally distinct from the rest of the country and is inhabited by a variety of tribal ethnic groups.

This study is based on both primary and secondary data. Primary data were assembled through a household survey, focus groups, key informant interviews, and case studies. The research was carried out in two stages in two representative sub districts, namely Bandarban Sadar and Alikadam in the Bandarban district. Initial information on farmers'socioeconomic conditions, land-use practices, land-management activities, farming systems, employment, income, and personal experiences in the four different land-use types was collected from 304 randomly sampled farm households using a standard questionnaire. This phase was followed by the collection of additional information on more specific land-use practices such as area under cultivation, volumes and prices of inputs and outputs, and land management activities and time spent on each activity.

Data were collected through detailed interviews administered to a random sample of farm households that had participated in the first stage of research. The information provided by individual farmers was verified through focus groups and interviews with key informants, agricultural extension agents, forestry officials, local non-governmental organization workers, and, particularly, land-user groups through focus-group discussions.

Estimation of Financial Costs and Benefits The various land-use systems each have different production cycles. For annual crops, the production cycle is one year, horticulture is five to six years, and farm forestry is twelve years. To compare the costs and benefits of land-use systems, a twelve-year time horizon was considered in an analysis based on inputs, outputs, and farm-gate prices of produce.5 To facilitate the comparison, all costs and benefits were brought to present value by using a discounting method. The opportunity cost of labor in the study area varies by gender and season. Following the prevailing wage-labor rates, US$1.57 (Taka 90) and US$1.05 (Taka 60) were considered to be the daily *per capita* opportunity costs of adult male and female workers, respectively6 The national interest rate for agricultural credit is 11% and farmers incur additional administrative costs of about 1% to secure credit. A discount rate of 12% was considered to reflect the cost of capital.

Estimation of Environmental Services Agricultural land use can generate both positive and negative externalities. The common positive externalities are soil and water conservation, carbon sequestration, biodiversity protection, and scenic beauty. Negative externalities are soil erosion, land degradation, biodiversity loss, carbon emissions, and water-quality. As the externalities vary from one land use to another estimates were made of the value of carbon sequestration and biodiversity protection and the cost of soil erosion associated with each land-use system.

Estimation of Soil Erosion Soil erosion has both on site and off site effects. The on site effects include soil-nutrient depletion and deterioration in the physical and biological structure of the soil that cannot be easily replenished in the short term Since no other data were available to capture the on site and off site effects of soil erosion, only the cost of nutrient depletion was considered. Estimation of Carbon Sequestration and Biodiversity Services. Separate indices were developed for the carbon sequestration and biodiversity-protection benefits of each land-use system and then aggregated. This study uses US$45 per point of environmental services, with 25% of the value discounted on the basis that some of the products and biomass will be used by the farm households themselves for fuel, fodder, and other subsistence. purposes. This adjustment yields US$33.75 point/ha for environmental services, reflecting the sum of the carbon-sequestration and biodiversity-protection services.

Results.

The economic analysis (including environmental costs) to estimate the discounted costs and benefits of products produced under the four land-use systems demonstrates that when the social costs and benefits of soil conservation, carbon sequestration, and biodiversity protection are taken into account, that more sustainable land-use practices are, ultimately, more profitable.

Sandhu, H.; Wratten, S.; Costanza, R.; Pretty, J.; Porter, J. R. & Reganold, J. Significance and value of non-traded ecosystem services on farmland PeerJ, PeerJ Inc., 2015, 3, e762.

Abstract.

This study explores the potential economic value of two key ES in agriculture—the biological control of insect pests by soil-surface predators and the mineralisation of plant nutrients (nitrogen in this case). First the above two key ES were assess using field experiments in ten conventional and ten organic fields in New Zealand and then calculate the effect of organic and conventional practices on the delivery of the two key ES from arable fields under four crop types: peas, beans, barley and wheat. They conclude by discussing the potential relative magnitude of these ES in temperate arable areas in 110 countries in 15 global regions as one plausible scenario.

Data A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research, Lincoln, New Zealand, and OPENZ (Organic Products Exporters of New Zealand; provided the contacts for all organic farmers. The latter were contacted first by sending a letter, followed by a telephone call and a meeting to collect detailed information about the farming practices, such as crop rotations and the crops grown, as well as soil type. Ten organic fields were selected from the above totals. Subsequently, conventional arable farmers within 5 km of the selected organic farms were contacted. These were selected within this radius because they were growing similar crops on similar soil types. These farmers were practising high-input intensive mixed farming, which included arable crops. Each field pair consisted of two fields, one organic and one conventional, and although not directly adjacent to each other, fields chosen in each pair had the same microclimate, soil type and crop type and rotation. The 10 organic/conventional field pairs had the following crops: two organic/conventional field pairs growing peas (*Pisum sativum*), two field pairs with beans (*Phaseolus vulgaris*), three field pairs in barley (*Hordeum vulgare*) and three more in wheat (*Triticum aestivum*). The mean field area of organic fields was 10.3 ha (range 8–14 ha) and conventional fields was 10.4 ha (range 7–15 ha).

Methods.

The authors quantified the economic value of two key but contrasting ES (biological control of pests and nitrogen mineralisation) provided by non-traded non-crop species in ten organic and ten conventional arable fields in Field trials conducted from 2004–2006 in 20 arable fields spread across the province of Canterbury, the main arable area of New Zealand, comprising 125,000 ha of arable land using field experiments. The arable crops grown, same for each organic and conventional pair,were peas (*Pisum sativum*), beans (*Phaseolus vulgaris*), barley (*Hordeum vulgare*),and wheat (*Triticum aestivum*).

Results.

The study found that organic farming systems depended on fewer external inputs and produced outputs of energy and crop dry matter generally less than but sometimes similar to those of their conventional counterparts. The economic values of the two selected ES were greater for the organic systems in all four crops, ranging from US$ 68–200 ha/yr for biological control of pests and from US$ 110–425 ha/yr for N mineralisation in the organic systems versus US$0 ha/yr for biological control of pests and from US$ 60–244 ha/yr for N mineralisation in the conventional systems.

The total economic value (including market and non-market components) was significantly greater in organic systems, ranging from US$ 1750–4536 ha/yr, with US$ 1585–2560 ha/yr in the conventional systems. The non-market component of the economic value in organic fields was also significantly higher than those in conventional fields.

de Lange, W. J. & van Wilgen, B. W. An economic assessment of the contribution of biological control to the management of invasive alien plants and to the protection of ecosystem services in South Africa Biological Invasions, Springer, 2010, 12, 4113-4124.

Abstract.

This study is a first attempt at a holistic economic evaluation of South African endeavours to manage invasive alien plants using biological control. Their focus was on the delivery of ecosystem services from habitats that are invaded by groups of weeds, rather than by each individual weed species. The study elicited the net present value of the weed biological control efforts, and derived benefit:cost ratios by comparing this value (a cost) to the estimated value of ecosystem services protected by weed biological control. The authors identified four major functional groupings of invading alien plants, and assessed their impact on water resources, grazing and biodiversity. They estimated the area that remained free of invasions due to all historic control efforts in South Africa, and the proportion that remained free of invasion as a result of biological control (which was initiated in 1913). The estimated value of potential ecosystem services amounted to 152 billion South African Rands (ZAR – presently, about US$ 21 billion) annually. Although an estimated ZAR 6.5 billion was lost every year due to invading alien plants, this would have amounted to an estimated additional ZAR 41.7 billion had no control been carried out, and 5 - 75% of this protection was due to biological control. The benefit:cost ratios ranged from 50:1 for invasive sub-tropical shrubs to 3726:1 for invasive Australian trees.

Methods.

Selection of species The study focused on four groups of invasive alien plant species: Fire-adapted Trees, Perennial invasive Australian trees, Invasive succulents (cacti) and Subtropical shrubs that invade particular ecosystems, where they create a suite of similar problems. Groups were based on the premise that if one such species were to be removed from the ecosystem concerned (for example by means of effective integrated control), one of the others may simply replace it, with no benefit being gained from the control effort. By using a group approach, questions about the relative contribution of biological control to the alleviation of problems can be addressed more holistically.

Costs of biological control research We identified all of the biological control agents that had been investigated for each of the target weed species in each group of weeds and estimated the approximate annual research costs related to exploration, to research on safety-screening and other pre-release preliminaries in the laboratory, and as appropriate, to the costs of actual releases, redistribution, monitoring and impact-evaluation of the individual biological control agents in the field. Data on the magnitude of ecosystems services, and the current estimated reductions in the magnitude of these services due to invasive alien plants were used as a basis for estimating the value of biological control. These data were provided for five major terrestrial biomes in South Africa: fynbos (Mediterranean shrublands); grassland; savanna and thicket; Nama karoo (arid shrublands); and succulent karoo. For each biome, we used the estimates of annual flows of benefits for three major ecosystem services as a basis for estimating monetary values. The services were the provision of water; the provision of grazing for livestock and biodiversity (a biodiversity intactness index). An estimate of the unit price of water in both in its and un-serviced forms was used. They also used a weighted average price for livestock in South Africa as a basis for quantifying the impact of invasions on livestock numbers in monetary terms. The unit pricing of biodiversity was based on numerous studies that have attempted to place a monetary value on the ecosystem services derived from biodiversity.

Contribution of biological control to reducing impacts on ecosystem services Three estimates of the value of ecosystem services were available at the start of this study. These were (i) the value that could be expected from ecosystems that were unaffected by alien plants; (ii) the current values, which reflect the extent of invasion as well as the contribution of past control efforts; and (iii) the future value when invasive alien plants occupy all of the available suitable habitat.

Benefit:cost estimation and sensitivity analyses.

A benefit:cost ratio (the value of ecosystem services protected compared to the cost of biological control research) was estimated for each group of weeds. Net present values for ecosystem services were estimates from future annual benefit flows, discounted at 8% over 140 years.The estimated net present value of protected benefits attributable to biological control ranged from ZAR 840 million in the case of fire-adapted trees to ZAR 104 billion in the case of invasive Australian trees The benefit:cost ratios associated with the four groups were all positive, and ranged from 50:1 in the case of subtropical shrubs to 3726:1 in the case of invasive Australian trees. Moreover, the estimated annual value of ecosystem services (in million ZAR) derived from five terrestrial ecosystems in South Africa under three different scenarios: no invasion (152271) , at current levels of infestation with invasive alien plants (145705), estimates of the value saved due to invasive alien plant control efforts in the past (41690) was estimated.

Dominati, E.; Mackay, A.; Green, S. & Patterson, M. A soil change-based methodology for the quantification and valuation of ecosystem services from agro-ecosystems: A case study of pastoral agriculture in New Zealand Ecological Economics, Elsevier, 2014, 100, 119-129.

Abstract.

This paper tests the steps required to transform a theoretical natural capital/ecosystem service framework for soils into an operational model. Each of the services provided by a volcanic soil under a pastoral dairy use are quantified and valued. The six guiding principles underpinning the method developed include differentiating soil services from supporting processes; identifying key soil properties and processes behind each service; distinguishing natural capital from added/built capital; identifying how external drivers affect natural capital stocks; analysing the impact of degradation processes on soil properties and basing the economic valuation on measured proxies. Proxies to quantify ecosystem services focus on the part played by soil in generating each service. This new approach highlights the importance of soil change in quantifying services, and goes beyond simply determining the status of soil natural capital. The total value of the ecosystem services provided by a volcanic soil under dairy in the Waikato region in New Zealand was estimated at $16,390/ha/year on average over 35 consecutive years. The services with the highest value were the filtering of nutrients and contaminants (58–63% of total value), followed by the provision of food and then flood mitigation. Regulating services had an economic value 2.5 times more important than provisioning services.

Methods.

This study, elicited the quantification and economic valuation of the contribution of soils to the delivery of provisioning and regulating services provided under a dairy operation (cultural services required different valuation techniques than those used for the provisioning and regulating services. This is why they were not considered as part of this study). Provisioning Services Provision of Food Quantity and Quality. In a grazed pasture, the provision of food is embodied by pasture growth and quality, which are supported by natural capital stocks including soil physical structure, available water capacity and nutrient status. To quantify the amount of food grown, the contribution of soil natural capital stocks must be distinguished from added capital inputs. In the system studied here, the contribution of the added capital inputs is limited to fertiliser. This needs to be subtracted from total pasture production to calculate the contribution from the soil natural capital stocks. A measure of the service was defined as the total yield per year, measured or modeled, minus the contribution from N and P fertilisers.

Provision of Support for Human Infrastructures and Animals. It is a critical service often overlooked. Soils form the physical basis on which infrastructure, humans and animals stand. The resilience and intactness of soil structure drives the provision of all services.. A proxy to measure the service was defined here as the number of days during the wet period (May to October) when soil water content (SWC) is below a value half way between field capacity (FC) and saturation. This measure of the service represents the days when the soil provides adequate support to animals. Filtering of Nutrients and Contaminants. Soil acts as a filtering agent through which water passes before entering water bodies including ground water and rivers. In dairy-grazed systems, materials like animal dung and urine, farm dairy effluent, fertiliser and pesticide are applied to pastures and soils. These materials contain nutrients (including nitrogen (N) and phosphorus (P) in different forms), organic matter, pathogens, endocrine-disrupting chemicals and heavy metals.

Nitrogen and P are key plant nutrients added through fertilisers in most production systems. However, they can pose a potential threat to surface and ground water quality if lost in excessive amounts. The filtering of nutrients and contaminants depends on natural capital stocks including available anion storage capacity, cation exchange capacity, soil texture and structure, and soil water content. Nutrients. A measure of the filtering of nutrient service is the amount of nutrients locked into the exchange sites. It was defined here as the difference between maximum nutrients potentially lost if soil had no exchange surfaces retaining nutrients and actual loss.

Contaminants. The filtering of contaminants, including pathogens,pesticides and endocrine-disruptingchemicals was not quantified directly, but by assessing the risk of these contaminants being lost in run-off in the days following deposition or application on pasture. This measure of the service represents the fraction of the water contaminated during those 5 days that does not run-off, but is absorbed and filtered.

Detoxification and Recycling of Wastes. Animal dung and urine, effluent from the dairy shed, standoff-pad, effluent pond and composts are applied to pasture soils in New Zealand dairy systems. They contain organic and chemical compounds that are potentially harmful to the environment as well as living organisms (pathogens such as viruses, bacteria, or parasites). The ability of soils to deactivate non-organic contaminants (detoxification) and biologically degrade organic wastes constitutes an ecosystem service linked directly to human health. It is a service in itself, separate from the filtering of nutrients and contaminants or the provision of nutrients to plants. This service was quantified here indirectly by following soil water content at grazing, as a proxy for microbial activity and waste decomposition potential. Ideal conditions for optimum decomposition of wastes by soil fauna were associated with soil water content between permanent wilting point and field capacity. The service was defined as the total amount of dung deposited and decomposed during ideal conditions per year.

Carbon Storage and Greenhouse Gas Regulation. The C storage service was defined as the annual net C flow into soil, not C stock as only a net accumulation of C represents a service. The method used to quantify N_2O emissions from the studied soil includes both the IPCC and model outputs from SPASMO. The N_2O regulation service was quantified as the difference between the maximum potential N_2O emissions that could occur if the soil was always wet (SWC N FC) and the actual emissions. Methane (CH_4) oxidation regulation by soil biota is an ecosystem service only if the soil is a net sink of CH_4. Methane oxidation was quantified by following daily soil water content outputs from the model. For soil water content below field capacity, it was assumed that the studied soil could oxidise2 g CH_4–C/ha/day, and if soil water content was above field capacity, it was assumed that the Horotiu soil could oxidise 1.3 g CH_4–C/ha/day.

Regulation of Pest and Disease Populations. The natural capital stocks behind this service include soil biodiversity, soil structure and water). In this case study, two common pasture pests porina caterpillars (*Wiseana sp.*) and grass grubs (*Costelytra zealandica*) were examined and the service was quantified indirectly by following soil water content and macroporosity model outputs and determining the number of days unfavourable for pest development per year.

Economic Valuation of Soil Services Neoclassical economic valuation techniques, including market prices, productivity change, defensive expenditure, replacement cost and provision cost were chosen to value the soil ecosystem services. All the results are averages over 35 consecutive years of modeled data. The total value of the ecosystem services provided by a volcanic soil under a dairy use was estimated at $16,390/ha/year, ranging from a low of $12,207 to $22,282 over the 35 consecutive years considered, which is partly due to climate variation Valuation of Provisioning Services The sustainable pasture yield from soil natural capital (kg DM/ha/year) was converted to milk solids using a conversion factor (15 kg DM/kg MS) and then valued using the price of milk solids (NZ$6.87/kg MS, Nov 2012). Food quality was valued using a replacement cost method, where the value of the service was defined as the cost associated with avoiding trace-element deficiencies if the soil was deficient in all four major trace (NZ$38/ha/year).

The provision of support to human infrastructures was valued using the annualised construction costs and maintenance costs of farm tracks. The value of the service was defined as the difference between the maximum cost of building foundations (for a very low bulk density soil) and the actual cost of the foundation for the chosen soil. The provision of support to animals was valued using the costs construction and maintenance of a standoff. A discount rate of 10% was used to annualise the construction costs of farm tracks and stand-off pad.

Valuation of Regulating Services Regulating services are typically non-marketed, therefore, their valuation is more challenging. Flood mitigation was valued using the costs associated with building a water-retention dam on-farm, to substitute for the water retention capacity of the. The filtering N or P was valued by using the costs of existing mitigation techniques for limiting the loss of these two nutrients. The cost of the mitigation, applied to the measure of the service, was used as a proxy for the value of the service.

The filtering of contaminants was valued using as proxy the costs of building an artificial wetland to decontaminate runoff water before it reaches water. The annualised construction and maintenance costs of a constructed wetland were used as a proxy for the value of the filtering of contaminants. A similar approach was also used to value the recycling of waste. If soil biota were unable to decompose and recycle waste, an alternate solution would be to use an effluent treatment pond to degrade wastesand fertigation to return nutrients to pasture. The amount of dung deposited on the soil and decomposed fully was converted to the volume of effluent that would have to be treated in a treatment pond if the soil wasn't providing the service. Annualised construction and maintenance costs of the effluent pond and fertigation system were used as a proxy for the value of the service. The C market price (NZ$13/t CO_2) was used to value carbon storage and greenhouse gas regulation from soils The measures of net C flows, N_2O regulation and CH_4 oxidation services were converted to CO_2 equivalents, and multiplied by the market price of CO_2.

The regulation of pest and disease populations in soils was only partially valued using a provision cost method, by limiting the analysis to the regulation of two major pasture pests. The cost of applying insecticides to regulate pest population in a well-established pasture was used to calculate the value of the service. For each of the two pasture pests, the value of the service was defined as the difference between the cost of insecticide application for initial infestation rates in a new pasture, compared with the actual cost of the insecticide application at the infestation rate determined following SWC and macroporosity for an established pasture with built up pathogens. This value represents the current level of pest regulation provided by the soil.

Results.

All the results presented here are averages over 35 consecutive years of modeled data. The total value of the ecosystem services provided by a volcanic soil under a dairy use was estimated at $16,390/ha/year, ranging from a low of $12,207 to $22,282 over the 35 consecutive years considered, which is partly due to climate variation. The services with the highest value were the filtering of nutrients and contaminants (58–63% of total value), followed by the provision of food (28–32%) and then flood mitigation (6.6–7.1%) Regulating services had an economic value 2.5 times more important than provisioning services. The legume based pasture yield sustained by the natural capital stocks of the Horotiu silt loam averaged 10.4 t DM/ha/year, 63% of total pasture produced when fertilised with N and P fertilisers. This translates when grazed by a milking cow and converted to milk to an average value for the provision of food from soil natural capital of $4,757/ha/year. The trace element requirements of the pasture and lactating dairy cows, met by the weathering of the Horotiu silt loam natural capital stocks, have an annual value of NZ $38/ha/year.

The provision of support for human infrastructures, here farm-tracks, was worth $17/ha/year. The Horotiu silt loam also provided support for animals on average 78% (142 days) of the days between May and October over the 35 years modeled. This translates into a value of $112/ha/year. The provision of support to animals is not often considered by farmers when purchasing dairy land, but a well-drained and structured soil, providing good support year round can reduce not only the cost of production, but also the exposure of the business to unpredictable climatic conditions. At a different scale (landscape, catchment, and region) the shape of a landscape and the position of soil types in this landscape would have to be considered when quantifying the service. The approach used to value the flood mitigation service had a focus of limiting the flood risk at a farm scale. On average the maximum amount of water stored by the soil in seven consecutive days was 102 mm/ha/year, translating into a flood mitigation value of$1,196/ha/year, when using an on-farm retention dam infrastructure cost. Shifting the quantification and valuation of that service.

Nahuelhual, L.; Carmona, A.; Laterra, P.; Barrena, J. & Aguayo, M. A mapping approach to assess intangible cultural ecosystem services: The case of agriculture heritage in Southern Chile Ecological Indicators, Elsevier, 2014, 40, 90-101.

Abstract.

A GIS-based methodological framework was developed and applied to map agricultural heritage (AH), understood as a non-divisible combination of three cultural services (dimensions, D): the heritage value associated to a culturally significant species (i.e. Chiloé native potato) (D1); the traditional systems of knowledge of AH keepers (D2); and the social relations among them (D3).

The final aim of the study was to provide indicators of the "final" service (AHI, measured in a 0–100 point scale) and its benefits (AHB, measured in US$/ha), capable to display areas where high value farmland was located.

Study area.

The study area was the municipality of Ancud, which is located in the norther nportion of Chiloé Island in the Chiloé Archipelago in southern in southern Chile. It is also part of the Valdivian Temperate Rainforest Ecoregion.The municipality covers a territory of 172,400 ha, of which less than 1% is classified as urban. Of this total area 11,776 ha are protected by Chiloé National Park. The remainder of the rural territory is comprised of 2770 farms, with an area that ranges between 0.03 ha and 4658 ha.

Methods.

The mapping framework comprised two major stages which were the spatial representation of AH as a "final"ecosystem service (steps 1–5) and the spatial representation of the economic benefits that people derived from AH (step 6), A GIS-based methodological framework was developed and applied to map agricultural heritage (AH), understood as a non-divisible combination of three cultural services (dimensions, D): the heritage value associated to a culturally significant species (i.e. Chiloé native potato) (D1); the traditional systems of knowledge of AH keepers (D2); and the social relations among them (D3). The final aim of the study was to provide indicators of the "final" service (AHi, measured in a 0–100 point scale) and its benefits (AHB, measured in US$/ha), capable to display areas where high value farmland was located. AHB reflected society's willingness to pay for the nonmaterial benefits of AH conservation. Since these benefits "propagate" across space extending from local to unknown and distant beneficiaries, and the aim was to identify the most valuable areas for their capacity to satisfy a potential demand, AHB was spatialized following the approach of "ascribing" the potential benefits to their "point of provision".

Results.

The estimation of non-use benefits of AH relied on data previously gathered through a Contingent Valuation (CV) survey applied in person in January of 2012 in the cities of Castro and Ancudin the Los Lagos administrative region (where Chiloé Island is located), the city of Valdivia which is the capital of the Los Ríos administrative region (379 km distance from Chiloé) and Santiago Metropolitan region which is the country's capital (1198 km distance from Chiloé). The value used in this study was the average WTP for the entire sample (627 people) which was equal to US$50.54/person/year. Multiplying this individual value by the working population of the three regions (N = 2,370,538 people) and adjusting for hypothetical bias a final aggregate benefit of US$39,935,664 was obtained, which can be interpreted as the non-use economic value people place on the AH conservation in Chiloé. This value was adjusted to represent the value of AH conservation only in Ancud, using as criteria the proportion of keepers that conserve native potato only in this municipality respect to the total, which produced a benefit of US$149,758. The indicator of benefits reached a maximum value of US$10.64/ha and a minimum of US$0.18/ha, with an average of US$3.8/ha and a standard deviation of US$3.2. Most farmland reached values of Ahi between 46 and 66, which corresponded to economic values between US$6.6/ha and US$8.6/ha.

Brady, M. V.; Hedlund, K.; Cong, R.-G.; Hemerik, L.; Hotes, S.; Machado, S.; Mattsson, L.; Schulz, E. & Thomsen, I. K. Valuing Supporting Soil Ecosystem Services in Agriculture: a Natural Capital Approach.

Abstract.

This study presented a method for valuing changes in supporting soil ecosystem services and associated soil natural capital—the value of the stock of soil organisms—in agriculture, based on resultant changes in future farm income streams. We assume that a relative change in soil organic carbon (SOC) concentration is correlated with changes in soil biodiversity and the generation of supporting ecosystem services. To quantify the effects of changes in supporting services on agricultural productivity, we fitted production functions to

data from long-term field experiments in Europe and the USA. The different agricultural treatments at each site resulted in significant changes in SOC concentrations over time. Declines in associated services are shown to reduce both maximum yield and fertilizer-use efficiency in the future. The average depreciation of soil natural capital, for a 1% relative reduction in SOC concentration, was 144 €/ha (SD 47 €/ha) when discounting future values to their current value at 3%; the variation was explained by site specific factors and the current SOC concentration. Moreover, the results show that soil ecosystem services cannot be fully replaced by purchased inputs, they are imperfect substitutes.

Methods.

Inferring the value of soil natural capital Their approach to valuing supporting ecosystem services followed from Envelope Theorems in mathematics that describe how the optimal value of the decision-maker's objective function (in a parameterized optimization problem) changes as one of the parameters. By analyzing the effect of a small change in soil natural capital on maximal future farm income streams they infer its value to the farmer (its marginal user cost) based on economic theory for valuing unpriced but scarce inputs. Fundamentally, the valuation is based on a crop production function that quantifies changes in yield and the minimum fertilizer input needed to achieve a particular yield for different stocks of soil natural capital. They estimated production functions using balanced panel data sets on wheat yield, fertilizer input and SOC concentration generated from long-term agricultural field controlled experiments in four representative arable cropping regions in Europe and North America. To value changes in soil natural capital the best estimated production function for each site was integrated with an economic optimization model that describes the farmers' decision problem with a suitable behavioural goal (i.e., income maximization). They subsequently used observed market prices (objective values) of the provisioning ecosystem service (wheat) and man-made inputs (mineral fertilizer) to infer the contribution of supporting ecosystem services to annual farm income streams; and subsequently value changes in soil natural capital in present value calculations (for different ranges of the necessarily subjective discount rate).

Results

The results shown that the present value of the change in future profits brought about by a change in soil natural capital (SOC) is calculated for different values of the discount rate δ (1.4–28%). The range of the marginal value of soil natural capital at each site was affected strongly by the discount rates applied where 1.4–3% can be regarded as a standard interval for public investments and 3–7% is more reflective of affluent farmers, while higher discount rates are likely among farmers who treat their land as just another investment or cannot afford the short-term costs of soil conservation measures. When future profits are discounted at 1.4%, a 1% relative reduction in SOC depreciates the value of soil natural capital by, on average, €263/ha (SD €194/ha), whereas an extreme rate of 28% implies a loss of only €17/ha (SD €12/ha).

Baskaran, R.; Cullen, R. & Colombo, S. Estimating values of environmental impacts of dairy farming in New Zealand New Zealand Journal of Agricultural Research, Taylor & Francis, 2009, 52, 377-389.

Abstract.

This paper provides a case study of the intensification of dairy farming in New Zealand and its detrimental environmental impacts such as nitrate leaching to streams and rivers, methane gas emissions, demands for surface and groundwater for irrigation and reduced variety in pastoral landscapes.. The study uses choice modeling method, in particular Mixed Logit model, to evaluate these relative values (willingness to pay), incorporating sources of preference heterogeneity (both observed and unobserved heterogeneity) within a sampled population to estimates the relative values (i.e., marginal willingness-to-pay (WTP)) held by society in order to reduce these detrimental environmental impacts (i.e. for improvements in ecosystem service quality). The estimated values are marginal WTP annually for a period of 5 years for a change (improvement) in the environmental attributes described assuming all other attribute levels (except those under consideration) are held constant.

Methods.

The authors designed a Choice Experiment survey where individuals were asked to choose between policy scenarios in a series of choice sets. Each choice set includes three policy scenarios defined (two alternatives and the status quo) by the levels of methane gas emissions from dairy farms, the amount of nitrate leaching to surface and ground water, the amount of water used for irrigation on dairy farms, and the diversity of scenery in dairy landscapes. The cost attribute was defined as an additional annual payment to the regional council responsible for the management of the environment over the next 5 years. 72 choice sets which were then allocated into eight sets of nine choices each. each respondent was presented with nine choice sets and was asked to choose among the status quo (current condition) and two improved environmental management alternatives. During November to December 2005 a pre-survey card, survey booklet, cover letter, and a reminder post-survey card were mailed to 504 Canterbury region respondents selected from the New Zealand electoral roll using a random sampling design. The study received 155 completed questionnaire responses and had an overall effective response rate of 31%.

Results.

The results shown that, on average, respondents are willing to pay NZ 7.67 for a 10% reduction in methane emissions and NZ 13.92 for a 30% reduction. The average WTP for a 10% reduction of nitrate leaching was NZ 19.52 and for a 30% reduction 27.40. With respect to the water usage attribute, the average WT were NZ 17.88 and NZ 23.58 for, respectively a a 10% and 30% reduction. Finally the average WTP for improved dairy landscape (30% more variation in scenic views) was $14.35 per household.

YongPing, W.; White, R.; KeLin, H.; DeLi, C.; Davidson, B.; Gilkes, R. & others Valuing environmental externalities associated with oasis farming in Alxa, China. Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010. Division Symposium 3.2 Nutrient best management practices, 2010, 309-311.

Abstract.

This study investigated physical measurements of environmental externalities for maize cropping in oasis farming, north-western China, and the monetary value of these environmental externalities, based on integrated process-based biophysical and economic modeling.

Methods.

Left Banner in Alxa was chosen to represent the physical and socio-economic conditions for maize cropping in oasis farming of north-western China. Left Banner is located in the west of Alxa.

In terms of the main consequences of intensive maize cropping in oasis farming, the authors focused on three environmental externalities: groundwater depletion, groundwater pollution related to nitrate leaching, and nitrous oxide (N_2O) emission. The physical dimensions of environmental externalities were simulated by process-based biophysical modeling. The model simulated the key processes of crop growth within the water and nitrogen cycles. Groundwater depletion is calculated as the difference between irrigation applied and drainage during the growth period of maize. Nitrate leaching was obtained from modeling. When the nitrate concentration in drainage meets the water quality standard of 10 mg N/L, groundwater pollution related to nitrate leaching is considered to be zero. N_2O emission was directly obtained from the modeling.

The restoration cost approach was used to assess the value of environmental externalities from the cropping system. This approach does not actually value the externality, but uses as a proxy the expenditure which society incurs in dealing with that negative externality

Results.

The results showed that current farming practices have caused 7854 Yuan/ha of recharge groundwater cost, 7696 Yuan/ha of water treatment cost and 91 Yuan/ha of nitrous oxide mitigation cost.

Bateman, I. J.; Harwood, A. R.; Abson, D. J.; Andrews, B.; Crowe, A.; Dugdale,

S.; Fezzi, C.; Foden, J.; Hadley, D.; Haines-Young, R. & others Economic analysis for the UK national ecosystem assessment: synthesis and scenario valuation of changes in ecosystem services Environmental and Resource Economics, Springer, 2014, 57, 273-297.

Abstract.

This study combine natural science modeling and valuation techniques to present economic analyses of a variety of land use change scenarios generated for the UK National Ecosystem Assessment. Specifically, the agricultural, greenhouse gas, recreational and urban greenspace impacts of the envisioned land use changes are valued. Particular attention is given to the incorporation of spatial variation in the natural environment and to addressing issues such as biodiversity impacts where reliable values are not available.

Methods.

Examining the consequences of land use change. The paper reports the central economic analysis of potential scenarios (defined and discussed subsequently) undertaken for the UK National Ecosystem Assessment (UK-NEA), The study estimated agricultural food production using market priced goods whose output value varies significantly across locations (due to variation in the natural environment) and across time (due to change in policy, prices, climate, technology, etc.). 6 different scenarios generated for land use futures under the UK-NEA. These scenarios considered the consequences for land use of implementing different policy strategies from the present day forward to 2060. Six basic scenarios were identified each describing the consequences of different policy priorities, named and described as follows: (i) World Markets (WM), where the goal is economic growth and the elimination of trade barriers; (ii) Nature at Work (NW), where ecosystem services are promoted through the creation of multifunctional landscapes; (iii) Go with the Flow (GF), where current trends are assumed to continue, and in which current principles and practices are not radically altered; (iv) Green and Pleasant Land (GPL), where a preservationist attitude to UK ecosystems was taken; (v) Local Stewardship (LS), where society strives to be sustainable within its immediate surroundings;

(vi) National Security (NS), where the emphasis is placed upon increasing UK production and hence self-sufficiency.

Each of these scenarios was further modified to allow for the impacts of expected climate change under the low and high emission (respectively the SRES B1 and SRES A1FI) projections in the IPCC Special Report on Emissions Scenarios and subsequently modified under the spatially disaggregated scenarios provided by the United Kingdom Climate Impacts Programme. This provided a high and low emissions variant of each of the scenarios bringing their total number to twelve. These sources provide full details regarding thismodel but in essence, for each location, the analysis works from a profit function and uses duality theory to derive optimal shares of land use foreach of a complete set of agricultural activities. The model is empirically specified to capture both cross-sectional effects (e.g. the influence of location in terms of variation in the physical environment between each area) and temporal change (e.g. variation in prices and policy).

Data for this analysis are drawn from a variety of sources including a panel covering more than 40 years from the Agricultural Census which collects land use shares, livestock numbers and other farm data at a 2×2 km grid (400 ha) basis for the entirety of Great Britain.However, this dataset does not provide profit data. For this reason the empirical focus is restricted to the estimation of land use shares to which farm gross margin (FGM) estimates (obtained from independent sources) can be applied. Farm activity data obtained from the Agricultural Census are combined with annual information on policy (both agricultural and relevant environmental measures), prices, costs and highly detailed data on the geophysical environment (soil characteristics, slope, etc.) and climate. Together this provided over half a million sets of spatially referenced records for the period between 1969 and 2006. Models for optimal land use shares were estimated using techniques which respect the potential for corner solutions (not all farms cultivate all possible crops) and results were tested using out-of-sample, actual versus predicted comparisons.

Results.

All the scenarios were considered under high and then low climate change emission variants. The estimates for agriculture values only considered the value of market priced agriculture WM-H gives one of the highest market price outcomes (second only to NS-H) while both the NW scenarios yield very low rankings (with NW-L being the lowest of all). Clearly if, as an unregulated market would dictate, decisions are dominated by priced outputs then the WM scenarios easily outstrip the NW options. This dominance of market priced values over all others reflects not only real world private sector decisions but also the direction of much historic public sector decision making.

Comments.

All the studies reviewed above belong to the type that generates o collects their own data within a specific geographical area. However, given that the application of these primary evaluation methods is costly both in terms of time and financial resources, an approach who uses primary research, while reducing the use of resources is the benefit transfer approach (included in the lower part of figure 6).

Benefits Transfer Approach (BT).

Benefit transfer may be defined as "a process by which readily available economic valuation evidence is applied in a new context for which valuation is required" (7). This approach is now commonly applied however, there are several guides that cover the practical steps and key aspects of conducting such a study (36, 34, 42, 7).

BT has been used more and more frequently by various bodies and organizations including government agencies to facilitate benefit-cost analysis of public policies and projects affecting natural resources (36). However, the main problem with benefits transfer is its reliability in order to be a valid approach, Most BT guidelines focus on how should value transfer be done taking special consideration on how much additional uncertainty is introduced by benefit transfer, relative to the uncertainty that is inherent in all non-market value estimates (the focus here is in knowing both whether BT is valid in a statistical or theoretical sense, as well as in measuring the potential error that value transfer can introduce) and what level of additional uncertainty (or BT error) is acceptable in a policy analysis (34). If BT is a valid procedure, values could be taken form one study site and applied to new contexts.

Given the specification of the current study it will out of the scope to replicate the sort of studies that generate, or collect *in situ*, their own data. Therefore, the Benefit Transfer Method will be used as an approach to elicit most of the values that accrue form environmental services provided by maize agroecosystems.

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
Münier *et al.*, 2004.	Provisioning.	Food.	Loss of Economic Rent.	Production function.	Three scenarios considered Low cost (LC) Low cost, >20ha (LC > 20) Close to nature (CTN)	Primary. Collected in the study area, located within the two municipalities: Bjerringbro and Hvorslev in the centre of the peninsula of Jutland (Denmark).	Yearly.	DKK/Ha/year	1,500 (LC) 1,900 (LC > 20) 3,400 (CTN)
Rasul, 2009.	Provisioning. Regulating.	Food. Carbon storage. Soil conservation. Biodiv protection.	Net Economic Rent. (NER)	Production function. Avoided costs. Environmental benefit Index.	Only the cost of nutrient depletion was considered. $45 per point of environmental services.	Primary. The Chittagong Hill Tracts (CHT), a hilly region in Bangladesh The research was carried out in two stages in two representative sub-districts namely Bandarban Sadar and Alikadam in the Bandarbandistrict of CHT. Initial information on farmers' socioeconomic conditions, land-use practices, land-management activities, farming systems, employment, income, and personal experiences in the four different land-use types was collected from 304 randomly sampled farm households using a standard questionnaire	Twelve-year time horizon, all costs and benefits were brought to present value	NPV in $	942.5 (NER)
Sandhu *et al.*, 2015.	Provisioning. Regulating.	Food. Carbon storage. Biological control (BC). Soil fertility.	Value of yield. Nitrogen mineralisation.	Production function. Avoided costs.	The ratio of organic matter to nitrogen is 20:1.	Primary *in situ*. Secondary provided by Foundation for Arable Research Lincoln, New Zealand, and OPENZ (Organic Products Exporters of New Zealand).	November 2004 –January 2005.	$/Ha/year	68–200 for BC of pests and 110–425 for N mineralisati on in the

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
									organic systems 0 from BC of pests and from 60–244 for N mineralisation in the conventional systems. 1750–4536 TEV in Organic systems 1585–2560 TEV in the conventional systems
de Lange *et al*., 2010.	Provisioning. Regulating.	Food. Water supply. Biological control.		Avoided cost. TEV.	Rate of discounted at 8%. Three scenarios: pristine un-invaded ecosystems; current levels of infestation; protected by historic control efforts.	Secondary. Estimates of annual flows of benefits for three major ecosystem services from Statistics South Africa.	Annual net present value over the next 140 years.	Million ZAR/year	TEV for each scenario 152271 (W) 145705 (F) 41690
Dominati *et al*., 2010.	Provisioning. Regulating.	Food. Support for human infrastructure. Support for animal. Flood mitigation. Filtering of N.		Market prices. Replacement cost. Replacement cost. Provision cost. Defensive expenditure.		Secondary. New Zealand's National Climate Database.	All the results presented are averages over 35 consecutive years of modelled data.	$/ha/year	4,757 38 17 112 1,196 554

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
		Filtering of P. Filtering of contaminants. Recycling wastes. N_20 Regulation. CH_4 oxidation. Biological control. Population.		Provision cost. Market process. Market prices. Provision cost.					2,924 6,513 78 7.3 0.23 210
Nahuelhuala *et al*., 2014.	Cultural.	Cultural Heritage.	Agricultural Heritage Index.	Contingent valuation.	Agricultural heritage, understood as a non-divisible combination of three cultural services.	Primary.	Not specified.	$/ha	3.8
Brady *et al*., 2015.	Provisioning.	Provision of soil Natural capital.	Soil Organic Carbon.	Production function.	Different values of the discount rate. Where 1.4–3% can be regarded as a standard interval for public investments and 3–7% is more reflective of affluent farmers. The price of winter wheat is assumed to be €0.15 kg-1 and that of nitrogen €1.10 kg-1 based on expected market prices in 2012.	Primary. Long-term field controlled experiments in Europe and the USA.	Net present value over a period of 20 years.	€/ha on average per 1% reduction on SOC	144
Bashkaran *et al*., 2009.	Provisioning. Regulating. Cultural.	Water. Recreation / amenities.	Reduction in emissions of methane (ME) and nitrate leaching (NL). Water usage (WU). Improved dairy landscape.(IDL)	Choice modelling.	Respondents fully understand scenario. Regression model fully specified.	Primary. During November to December 2005 a pre-survey card, survey booklet, cover letter, and a reminder post-survey card were mailed to 504 Canterbury region respondents selected from the New Zealand electoral roll using a random sampling design. The study received 155 completed	Annually for a period of 5 years.	NZ/year/household	7.67 (10% ME) 13.92 (30%ME) 19.52 (10% NL) 27.40 (30% NL) 17.88 (10% WU)

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
						questionnaire responses			23.58 (30% WU) 14.35 (30% IDL)
Wei *et al*., 2010.	Provisioning. Regulating.	Water quantity and quality. Greenhouse gases.	Groundwater depletion (GWD) Groundwater pollution related to nitrate leaching (GWP) . Nitrous oxide (N_2O) emission. (N_2O E)	Mitigation costs.		Simulated by process-based biophysical modelling and applied in Left Banner in Alxa , China	Not specified.	Yuan/ha	7,854 (GWD) 7,696 (GWP) 91 (N_20 E)
Bateman *et al*., 2014.	Provisioning.	Food.	Farm gross margin due to the land use change over 12 scenarios.	Market prices	Linear causality between drivers (policy, market forces, technology, cross sectional and temporal environmental change) and consequent land use change and then on to the various goods associated with that change agricultural food production. 6 scenarios were considered : (i) World Markets (WM), where the goal is economic growth and the elimination of trade barriers; (ii) Nature at Work (NW), where ecosystem services are promoted through the creation of multifunctional landscapes; (iii) Go with the Flow (GF), where current	Secondary. Data for this analysis are drawn from a variety of sources including a panel covering more than 40 years from the Agricultural Census which collects land use shares, livestock numbers and other farm data at a 2×2 km grid (400 ha) basis for the entirety of Great Britain.	The scenarios considered the consequences for land use of implementing different policy strategies from 2010 forward to 2060.	Million GBP	1,030 (VM-h) 490 (VM L) -130 (NW H) -600 (NE L) 690 (GF H) 260 (GF L) -30 (GPL H) -340 (GPL L) 500 (LS H) 410

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
					trends are assumed to continue, and in which current principles and practices are not radically altered; (iv) Green and Pleasant Land (GPL), where a preservationist attitude to UK ecosystems was taken; (v) Local Stewardship (LS), where society strives to be sustainable within its immediate surroundings; (vi) National Security (NS), where the emphasis is placed upon increasing UK production and hence self-sufficiency. Each of these scenarios was further modified to allow for the impacts of expected climate change under the low (L) and high (H) emission projections. .				(LS L) 1400 (NS H) 790 (NS L)
Landis *et al*., 2008.	Regulating	Pest regulation (soy aphid)	Corn area in 1.5-km radius	Production function and input cost	Crop yield response known to proxy variable. Prices 2005–2008	Primary data. 4 states (Iowa, Michigan, Minnesota, and Wisconsin). Secondary data from U.S. Department of Agriculture crop production summary reports.	measured the biocontrol service supplied by natural enemies of the soybean aphid, *A. glycines*, in soybean fields across 2 years.	$ / ha $ / yr	$20–39 (IPM) $70-264 no insecticide.
Ma & Swinton, 2011.	Regulating	Flood regulation, native habitat parcels	Wetland % area in 1.5-km radius of agric. land	Hedonic analysis of land prices	Regression model fully specified	Secondary land transaction and parcel information, including land price, appraised value, sales time,	Five year period 2003-2007	% price change per % change in	2–4% of agric. land price

Author	ES Category	Ecosystem service	Indicator	Valuation method	Key assumptions	Data source	Time frame	Units	Value
						contract type and land class were collected from the County Equalization Office in each of the four counties.–2007.		wetland area	
Knoche & Lupi, 2007.	Cultural	Recreation (hunting).	Hunting access to 10% of agric. land in southern Michigan	Travel cost.	Full accounting of travel costs to hunt; Data: Hunter mail survey, Michigan 2003	The data used in this research was obtained from the 2003. Michigan Deer Hunter Survey, which was distributed via mail to 3000 Michigan residents who purchased a deer hunting license in 2002.	One year 2003	$ / trip / yr	$1.90–2.20
Chen, 2010.	Regulating	Water-quality regulation.	Eutrophic lake number	Contingent valuation.	Respondents fully understand scenario; Regression model fully specified;	Data: Survey Michigan residents, 2009.	One year 2013	$ hhd/lake/ yr kept non-eutrophic	0.45
Bernués *et.al*., 2014.	Cultural Regulating	aesthetic and recreational values of the landscape. Biodiversity maintenance regulating services	quality of rural landscapes (vegetation, land use, form and texture; Preservation of bearded vulture; prevention of forest fires	Choice Experiment.	Respondents fully understand scenario; Regression model fully specified; Data: Survey local population (residents of Sierra y Cañones de Guara Natural Park) and the general population in the region where the park is located (Aragón, Spain).	The survey was designed to collect the responses from the local population (residents in the SCGNP) and the general population in the region where the park is located (Aragon, Spain). For the general population, 402 persons over age 18 were interviewed through a professional online panel representative of the adult population in Aragon(N = 1103864) in June 2013.	One year 200	€ / person / year,	≈120

Table 4. Values of ES in agro-ecosystems.

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