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Economics & Management

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Keywords: ecosystem services, input-output model, monetary valuation, ecological-economic interactions, limits of monetary values.

CEB Working Paper N° 13/018
2013

Université Libre de Bruxelles - Solvay Brussels School of Economics and Management
Centre Emile Bernheim
ULB CP114/03 50, avenue F.D. Roosevelt 1050 Brussels BELGIUM
e-mail: ceb@admin.ulb.ac.be Tel. : +32 (0)2/650.48.64 Fax : +32 (0)2/650.41.88

A guiding framework for ecosystem services monetization in ecological-economic modeling

Mateo Cordier [a, b, d *], José A. Pérez Agúndez [c], Walter Hecq [d] and Bertrand Hamaide [e]

[a] Recherches en Economie-Ecologique, Eco-innovation et ingénierie du Développement Soutenable, Université de Versailles Saint-Quentin-en-Yvelines (REEDS-UVSQ), France.
[b] Centre Européen Arctique, Université de Versailles Saint-Quentin-en-Yvelines (CEARC-UVSQ), France.
[c] Unité d'économie maritime, Institut Français de Recherche pour l'Exploitation de la Mer (UEM-Ifremer), Plouzane, France.
[d] Centre d'Etudes Economiques et Sociales de l'Environnement, Centre Emile Bernheim, Université Libre de Bruxelles, (CEESE-CEB-ULB), Brussels, Belgium.
[e] Centre de Recherche en Economie, Facultés universitaires Saint-Louis (CEREC-FUSL), Brussels, Belgium.

Abstract

Monetary valuation techniques are often used for evaluating the effect of a change in ecosystem services on components of human wellbeing, even though they face several problems such as poor scientific knowledge on ecological-economic interactions, difficulty for monetary valuation techniques to consider the effect of intermediate ecosystem services on final ones, cognitive limitations of individuals, right-based responses made by individuals instead of consequentialism-based ones,… Considering those limits, this paper proposes an alternative approach for reconciling monetary valuation techniques with methods that address ecosystem-economy interactions. To achieve this goal, we develop a guiding framework that limits the use of monetary valuation to real market simulations. Simulations of scenarios of environmental measures are carried out with a hybrid ecological-economic input-output model. The guiding framework ensures that monetary valuation techniques contribute to the understanding of the impact of economic activities on changes in ecosystems services and the feedback impact of these changes on economic activities. The framework operates according to a double dichotomy: intermediate/final ecosystem services and direct/indirect monetary valuation techniques. One advantage of our guiding framework is to consider the importance of intermediate ecosystem services even if they cannot be monetized. This seems very relevant since intermediate services condition the existence of all other ecosystem services that ensure benefits to human life and economic activities. Our guiding framework may give natural scientists a better understanding of how to take advantage of economics in analyzing the impacts of interactions between the economy and the ecosystem.

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Cordier, M., Pérez Agúndez, J. A., Hecq W., and Hamaide, B., 2014. A guiding framework for ecosystem services monetization in ecological-economic modeling. Ecosystem Services 8 (2014) 86–96.
URL: http://www.sciencedirect.com/science/article/pii/S2212041614000230

[*] Corresponding author: **Mateo Cordier.** Postal address: CEARC-UVSQ, Mateo Cordier, 11 Boulevard d'Alembert, 78280 Guyancourt Cedex, France. Tel.: +33 1 80 28 54 96,. E-mail : mateo.cordier@uvsq.fr ; mcordier@ulb.ac.be

1. Introduction

The ecosystem services paradigm[1] favors a better apprehension of interactions between the functioning of parts of ecosystems and components of human wellbeing such as leisure time, health, education, income, purchasing power, etc. (Fisher et al., 2009 ; MA, 2005; Carpenter et al., 2006; Sachs and Reid, 2006). It focuses on preserving the ecosystem as a whole rather than on managing specific natural resources and uses. As a result, it provides a policy shift from previous resource-centered and species-centered visions of environmental preservation towards a new environmental policy vision based on the preservation of ecological functions and ecosystem services.

Monetary valuation techniques are often used for evaluating the effect of a change in ecosystem services on components of human wellbeing as they are a way to guide trade-offs in decision-making processes (Wincler, 2006). Such evaluations are however difficult to undertake for various reasons, among which limited scientific knowledge about ecosystems. It is indeed complex to apprehend interactions between ecological functionalities and the production of ecosystem services used by humans (Daily *et al.*, 2009; Polasky *et al.*, 2011). This may explain why ecosystem services are often underestimated. Another problem is that monetary valuation techniques (e.g. Costanza *et al.*, 1997; de Groot *et al.*, 2002) are generally micro-specific (i.e. analytic) rather than systemic (Ackerman, 2004; Venkatachalam, 2007). These techniques have difficulties in assessing interactions between intermediate ecosystem services and final ecosystem services whereas those interactions are at the source of every benefit obtained by humans from final ecosystem services. This drawback contributes to explaining why environmental agencies do not exclusively use monetary techniques during the decision-making process of a potential environmental project. An additional difficulty relates to human cognitive limitations occurring in monetary techniques such as stated preference approaches, largely applied for assessing non-market environmental values. Most individuals would have problems weighing up complex or unfamiliar environmental issues with global effects occurring over a long period of time and/or large geographical scales (Markandya *et al.*, 2005; O'Connor, 2000; Ashford, 1981). That can partly explain the price differential between environmental intention and action (Rowlands *et al.*, 2003). A further reason explaining why it is sometimes hard to measure the effect of a change in ecosystem services on components of human wellbeing with monetary valuations techniques is that economic theory of decision-making assumes a preference utilitarian philosophy so that individuals determine whether an action is right or wrong on the basis of its consequences. However, many individuals, when they express their willingness to pay (WTP), do not express their appreciation of the estimated consequences of an environmental policy (consequentialism-based respondents) although they are well explained to individuals before starting the questionnaire (Spash *et al.*, 2009)[2]. This questions the capacity of monetary valuation techniques

[1] See definitions of the concept of ecosystem service in MA (2005), Costanza *et al.* (1997), Daily (1997), Boyd and Banzhaf (2007) and Fisher *et al.* (2009).

[2] Many individuals are rather expressing an ethical position based on existence right (right-based respondents) for species, for natural habitats or for humans without considering the consequences of modifications of causal relations between human activities and those habitats or species that provide ecosystem services. Right-based

based on stated preference methods to correctly assess the economic value of changes caused by economic activities to ecosystem services and subsequent consequences for the part of human wellbeing they satisfy.

Although monetary valuation of ecosystem services suffers from several limits such as those mentioned above, this paper proposes a guiding framework for integrating monetary values into a larger approach based on the study of interactions between the ecosystem and the part of human wellbeing that depends on the economy. For achieving this goal, the guiding framework is built in a manner that limits the use of monetary valuation to real market simulations. Those market simulations, in which monetary values are inserted, are carried out inside a hybrid Input-Output (I-O) model (Daly, 1968; Isard, 1968) that focuses on crossed interactions between components of the ecosystem and the economy.

The guiding framework ensures that monetary valuation techniques contribute to the understanding of the impact of economic activities on changes in ecosystems services and the feedback impact of these changes on economic activities. It operates according to a double dichotomy: intermediate/final ecosystem services and direct/indirect monetary valuation techniques (see Section 4). One advantage of this guiding framework is to consider the critical importance of intermediate ecosystem services, even if they cannot be monetized, as they condition the existence of all other ecosystem services that benefit human life and economic activities.

The remainder of the paper is organized as follows. Section 2 categorizes ecosystem services into intermediate services, final services and benefits. It explains why our approach limits the use of monetary valuation techniques to benefits produced by final ecosystem services. Section 3 presents the hybrid I-O model. Section 4 describes the guiding framework for the integration of monetization into the I-O model while the last section is devoted to discussion and the conclusion.

2. Monetary valuation techniques and their limits for a full assessment of ecosystem services

One possible approach to measure the impact of changes in ecosystem services on components of human wellbeing is, after specifying spatial and temporal boundaries, to express their value in physical terms and then convert them into monetary units. Various monetary valuation techniques can be used to measure ecosystem services. An overview of these techniques can be found in de Groot *et al.* (2002) who built a table based on a synthesis study published by Costanza *et al.* (1997) from over 100 scientific papers. Although this table offers a good summary to match monetary valuation techniques with the proper category of ecosystem services, it might also be somewhat misleading, as it shows that the diverse techniques are capable of valuing *all* categories of ecosystem services. This appears to be in contradiction with other scientific contributions (Turner *et al.,* 2004 ; Fisher *et al.,* 2009). These contributions suggest that among the four main categories of ecosystem services – the MA classification of supporting, regulating, provisioning

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respondents only value a sub-category (ethical or philosophical services) of the MA category of cultural ecosystem services and they omit the three other categories (provisioning, regulating and supporting services).

and cultural services[3] – the role played by the first two categories inside the ecosystem is not covered by monetary valuation techniques, as they are assumed to be independent of individual preferences. However, monetary valuation techniques are still often used to measure the economic value of supporting and regulating ecosystem services (e.g. the technique of replacement costs for the ecosystem service of hydrological flows regulation). This is probably due to a misunderstanding originating from the fact that the categorization system from the MA and de Groot *et al.* does not dig deep enough into the multiple causality links between ecosystem services occurring inside the ecosystem. It does not show the distinction between final and intermediate ecosystem services: final services generate benefits that can modify human wellbeing whereas intermediate services generate intermediate products that enter the production process of final services.

This distinction between intermediate and final ecosystem services adapted from the categorization system of de Groot *et al.* and the MA is proposed by Fisher *et al.* (2009). It is based on the role of ecosystem services in the simplified causal chain (Table 1) going from the initial ecological structure or process located in step *n-3* in the causal chain (they cover the MA categories of supporting and regulating services) to the end result located in step *n* (i.e. to the benefit to individuals). The initial ecological structure is the natural biotic or abiotic physical support on which an ecological process[4] takes place and includes all components of the physical organization of the environment (e.g. surface waters, forests, sand particles in deserts, marine sediments, etc.).

Ecological structures or processes named 'intermediate services' (Fisher et al., 2009) constitute a preliminary base in the causal chain of ecosystem service supply (Turner, 1999). They generate other intermediate services before generating final services at the next step of the causal chain (cf. scheme of Table 1). Two intermediate services can be distinguished: *i)* intermediate services of first order which are the initial ecological structure or process (e.g. process of primary production of tree biomass in forests) and *ii)* intermediate services of second order which are the function of the ecological process/structure, i.e. the result of interactions between ecological infrastructures and processes that plays a role inside and for the ecosystem (e.g. the function played by trees in structuring forest soils into a "sponge" that retains rain water).

The final service[5] category is more directly related to individual uses (market and non-market uses) and hence to human wellbeing components and economic activities. It includes what is

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[3] **Provisioning services:** provide products obtained from the ecosystem (e.g. food, water, timber, coal, etc.). **Regulating services:** modulation of ecosystem processes in a sense that is advantageous to humans (e.g. climate regulation, water quality regulation, etc.). **Cultural services:** non-material benefits obtained from the ecosystem (e.g. spiritual enrichment, recreational and educational activities, aesthetic landscape, etc.). **Supporting services:** basic ecological structure and processes that ensure the maintenance and the functioning of the ecosystem and hence, the production of all other ecosystem services.

[4] An ecological process is considered to be any causal chain in which a material resource (abiotic or biotic) or energy plays a role in the production of an identifiable end result.

[5] A clear distinction between intermediate and final services is not always possible. An ecosystem service can act as a final one in some cases and as an intermediate one in others (e.g. provision of clean water by a river may be used as a final service for human consumption purposes and/or as an intermediate service that ensures aquatic biodiversity).

often called in literature 'outcome', 'goods' or 'services' that are made available by the ecosystem for potential use by humans (examples of final services: provision of fish resources, of flood-safe lands, of recreational activities in natural areas, etc.). As final services are produced by intermediate services, maintaining the quantity and the quality of intermediate services is necessary for the ecosystem to provide final services, and hence benefits, to humans.

The benefit is the last category of ecosystem services and is defined as the point where a natural component of the ecosystem meets human capital (e.g. knowledge) or technical capital (e.g. equipment, tools, machinery, buildings) to generate a good or a service that directly affects human wellbeing, i.e. individuals' feeling of satisfaction and needs (e.g. needs in recreational activities, economic activities, income production, healthy food resources, etc.). The category of benefits covers goods and services that are effectively used by humans. Similarly to final services, benefits play a role for humans and occur at the interface between the ecosystem and the human or economic system.

Table 1. Classification of ecosystem services: examples of (a) nursery habitats and (b) forest soil cover.

	Intermediate services (ecological structures and processes)		**Final services (goods and services potentially available for human use)**	**Benefits (goods and services effectively used by humans)**
	First order (initial ecosystem structure or process)	**Second order (ecosystem function)**		
	n-3	**n-2**	**n-1**	**n**
(a)	Hydro-sedimentary processes generating the accumulation of fine sediments on seabed located in shallow waters (MA supporting service) →	Formation of mud- and sand-flats used as nursery habitats by juvenile fishes for feeding (MA supporting service) →	Development of fish populations (MA provisioning service) →	Capture of fishes for human consumption
(b)	Process of primary production of trees by photosynthesis and nutrients uptake (MA supporting service) →	Trees structure forest soils into a "sponge" that retains rainwater (MA regulation service of hydrological flows) →	Protection against floods (MA provisioning service of safe lands) →	Decrease in damages caused to human infrastructures (buildings, etc.)

Source: the four categories of ecosystem services are adapted from Fisher *et al.* (2009). Note: the acronym MA written in front of categories of ecosystem services means it pertains to the categorization system of the Millennium Ecosystem Assessment (2005).

In the categorization detailed above, it clearly appears that the category named 'benefits' is the only one that directly affects human wellbeing, needs and activities. As a result, it seems reasonable to assume that this category is the only one that depends on individual preferences and feelings of satisfaction expressed by individuals. Hence, since individual preferences and satisfaction are the basis of monetary valuation, the category of benefits is the only one that should be valued in monetary units.

Similarly, Turner *et al.* (2004) suggest that the valuation of intermediate services is not included in the total economic value (TEV). Gren *et al.* (1994) assert that intermediate services (which they call 'primary value' or 'glue value') "hold everything together" while the secondary value – final services in terms of Table 1 and provisional and cultural services in MA wording – are those ecosystem services that benefit humans directly.

Besides the fact that intermediate services can be considered as independent of individual preferences, two reasons explain why the methodological approach developed in this paper does not enable intermediate services to be monetized.

The first reason concerns the physical nature of the interaction between intermediate and final services. Our aim consists in studying interactions between the various categories of ecosystem services and the subsequent interactions with the economy (e.g. causal chains of Table 1). The analysis of interaction relationships between ecosystem services is a key contribution to better apprehending the ecosystem's functioning and its indirect effects – or feedback impacts – on human activities (de Groot *et al.,* 2002; Carpentier, 1994). Indeed, a change in the supply of an intermediate service may induce an alteration of final services and therefore impact economic activities through the benefits category. Given their physical nature, any modification of intermediate services and their impacts on the provision of final services must be measured in physical units (while economic activities and the related income and consumption can be measured in monetary units). The omission of this causal chain, when using solely monetary units might lead to underestimate the importance of the ecosystem on human wellbeing and their components related to economic activities (income generated, purchasing power, employment, GDP, etc.) and consequently, to increase misunderstanding in decision-making processes.

Secondly, monetization delivers values that express individual preferences. Yet, as stated in the introduction, many individuals, expressing their willingness to pay (WTP) with stated preference techniques (constructed market), may not express their appreciation of the estimated consequences of an environmental policy (consequentialism-based respondents). Therefore, results from stated preferences methods may not always provide reliable information on the consequence of restoration or degradation of intermediate ecosystem services on final services. And revealed preference methods (surrogate market) are also of little help in considering intermediate services since the WTP is obtained from real markets (e.g. real estate or transport market). As a result, changes in prices on surrogate markets are often due to modifications of final services (the only category, with benefits, that directly affects human activities), not intermediate ones.

The hybrid I-O model presented in the next Section proposes an alternative approach in which monetary and physical evaluations are combined into a multidimensional framework for assessing the impacts of intermediate service changes on final services. It enables various ecological policy scenarios to be assessed and compared with each other so that stakeholders can choose the scenario that best suits their needs, desires and projects.

The use of an I-O model gives another reason to base our approach on real market transactions. I-O tables rely on the System of National Accounts. Yet, "In the accounts, cost calculations are based on observed practices, not on individual preferences" (Weber, 2011). This is in line with the EU Regulation (Official Journal of the European Union, 2012) on the International Financial Reporting Standards (IFRS). It states that the evaluation of firms' financial performances must "maximize the use of relevant observable inputs [market data] and minimize the use of unobservable inputs [non market data]". Hence, the aim of this paper is to simulate real impacts, or when impossible, to simulate scenarios with WTP values converted as a tax value to approach a real transaction.

3. Hybrid I-O models for the analysis of ecological-economic processes and trade-offs

The previous section stressed that when used alone, monetizing techniques have difficulties in providing the understanding of ecological-economic processes and trade-offs driven by intermediate services. However, they could be helpful if they were included inside a guiding framework. This framework should *i*) clearly differentiate the ecosystem services that are effectively measured by monetizing techniques from those that are not, *ii*) rely on monetizing techniques to assess benefits only ("benefits" as defined in Section 2) and *iii*) ensure that what cannot be measured in monetary units is assessed in physical units by other techniques. This section proposes to build an ecological-economic model that is able to shelter such a guiding framework (presented in Section 4).

The model consists in a hybrid I-O model that enables monetary units to be used together with physical units and delivers results in both units, such as those found in Leontief (1970), Victor (1972), McDonald (2005), Lixon *et al.* (2008), Miller and Blair (2009) and others. Exogenous equations are coupled to the I-O model for non-linear interactions. This model is chosen because of its capacity to integrate multi-dimensional and multi-criteria issues and because of its capacity to support decision-making processes in a context of complexity and uncertainty. More precisely, the integration of ecosystem services to hybrid I-O models is driven by the following properties:

- *Systemic properties:* because of the complex interactions between the economy and the ecosystem and their related impacts, decision-making should be supported by a systemic vision that considers those impacts (to be expressed either in monetary or physical units) for various categories of stakeholders. I-O models enable such an analysis as they offer a systemic vision of the economic system and can analytically assess direct and indirect effects of ecosystem modifications on various economic sectors (i.e. stakeholders from the production side of the economy).

- *Trade-offs assessment:* I-O models cover all productive sectors of the economy. This property enables the quantification of trade-offs between diverse economic and environmental goals or even between several economic activities. This is interesting for multi-criteria, multi-stakeholder, multi-scenario participative methods since one of their objectives is precisely to make trade-offs in a complex situation clear and apparent to decision-makers and other categories of stakeholders if environmental policies are to be operational (Munda et al., 1994; van den Bergh and Nijkamp, 1991). Moreover, those participative methods are a useful tool for decision-making in complex and uncertain issues (Giampietro *et al.*, 2006; Funtowicz and Ravetz, 1994; Ravetz, 2006) and uncertainty is the rule rather than an exception for environmental issues (Munda *et al.*, 1994; Refsgaard, 2006; Stirling, 2001; Giampietro *et al.*, 2006).

- *Distributional properties:* I-O approaches enable assessments of how costs and benefits related to management measures can be distributed between stakeholders (i.e. consumers as a whole and the various categories of economic sectors). First, I-O equations can be used to calculate a fair cost allocation rule prorated to direct and indirect responsibilities of each sector in environmental degradation (through the inverse Leontief matrix that singles out direct and indirect consumption of intermediate inputs responsible for environmental degradation). Second, I-O data allow the cost allocation rule to be based not only on responsibility but also on financial capacity. The assessment of cost and benefit distribution with hybrid I-O models (combined with exogenous equations) is also possible for ecosystem services that are not monetarily valued. That is the case of a wide range of ecological processes occurring inside the ecosystem (namely intermediate services of first and second order) and that do not directly affect the economy but are nevertheless important to consider (e.g. regulating ecosystem services which have no direct link with the economic systems but are essential for preserving human life and activities (MA, 2005)).

The integration of ecosystem services into a hybrid I-O model requires analyzing ecological processes in four steps. The first one consists in identifying ecosystem services at stake as well as the causality chains in which they are involved. This is achieved through the categorization method presented in Table 1 that divides ecosystem services into four categories: intermediate services of first and second order, final services and benefits.

The second step quantifies the physical parameters involved in the supply of each of the four categories of ecosystem services. These physical parameters represent the flows of matter and energy occurring at four interfaces: economy/economy (arrows 7 to 9 in Figure 1), economy/ecosystem (arrows 1 and 2), ecosystem/ecosystem (arrows 3 to 4) and ecosystem/economy (arrows 5 and 6).

The third step aims at representing physical parameters inside the architecture of a hybrid I-O model such as the one conceived by Daly (1968), Isard (1968) or Cordier (2011) and that represents the four interface flows mentioned above. There is nevertheless an important difference between the model presented here and those from Isard and Daly. We have added equations exogenous to the I-O table as well as expert opinions. This makes the hybrid I-O model capable of considering non-linear relationships (see the fourth step below).

The fourth step consists in quantifying the relationships between the four categories of interface flows (when they are quantifiable). If those relations are linear, I-O tables offer a simple and satisfactory solution to represent them through the calculation of technical coefficients for ecological inputs and outputs (e.g. Jin et al., 2003). However, when the relations are non-linear, I-O equations are not sufficient anymore. Our approach relies on other techniques (detailed in Figure 1) to take into account non-linear relationships, which allows intermediate services to be integrated into the I-O model and therefore enables estimation of their interaction with final services, benefits and in the end their feedback impact on the economy. Daly (1968) built a conceptual I-O model that considered ecological processes occurring inside the ecosystem (i.e. the intermediate services). Isard (1968) even succeeded in developing an operational version of that model. However, the application of the model was limited because at the time, environmental data needed to simulate the part of ecological flows that occur exclusively inside the ecosystem between interfaces of two environmental compartments were very scarce. In addition, because equations were included inside the I-O table, only linear relationships could be considered. This is the reason why Victor (1972) and Leontief (1970) discarded such considerations in their I-O model. Our approach enables the reintroduction into I-O modeling of ecological processes that are internal to the ecosystem, i.e. intermediate services.

Figure 1 offers a schematic example showing how intermediate services and their indirect feedback impact on the economy can be introduced into I-O modeling. The impact of the economy on fish nurseries (a marine natural habitat) is used as an illustration. Quantification is made possible by the following techniques, combined with hybrid I-O modeling (numbers correspond to those shown in the Figure):

(1) Exogenous equations calculating the evolution of the stock of intermediate service of first order due to the activity of Economic sectors – in the illustrative example, they are extrapolated from past trends.

(2) Expert opinions adjusting results from the exogenous equations[6].

(3) Exogenous equations calculating the evolution of intermediate services of second order due to changes in those of first order (e.g. equations calculating the link between the evolution of marine habitats and the size of the marine population of fish juveniles).

(4) Exogenous equations calculating the evolution of final services due to changes in intermediate services of second order (e.g. fish population equations calculating the quantity of adult fish based on the variation of the population of juvenile fish computed in (3)).

(5) Economic statistics on the use of final services (e.g. fishing statistics giving the percentage of fish caught in the total fish population of the study area).

(6) Prices from real markets, constructed and surrogate markets (e.g. market prices of fish caught and sold on real market by the fishing sector).

(7) I-O equations calculating the direct economic impact in the fishing sector and the indirect economic impacts on all other sectors that supply the fishing sector with intermediate goods and services.

(8) Cost and consumption data integrated in I-O tables (e.g. cost of restoration of marine habitats, subsequent decrease in salaries and employment and effect on final household consumption).

(9) I-O equations calculating the indirect impact of data integrated in I-O tables in step (8) (e.g. calculation of the impact of final household consumption on all productive sectors of the economy).

Exogenous equations and expert corrections enable us to take into account the idea of Isard (1968) that flows occurring inside the ecosystem (i.e. interactions between intermediate services

[6] Note that, even though it is not mentioned in Figure 1, all results from exogenous equations and expert opinions are subject to a sensitivity analysis based on observed data to make sure that they are consistent. If they are not, it is a signal that equations and/or expert opinions must be refined and that further analysis is necessary.

of first and second orders as well as between the latter and final services) should also be included in ecological-economic models. This idea had been rejected by Victor (1972) and then suggested again by Carpentier (1994), although, to our knowledge, not implemented up to now (except for linear interactions such as in trophic chains – see an application in Jin *et al.* (2003)).

Figure 1 shows that there are two stages at which monetary units can be inserted into a hybrid I-O model to represent ecosystem services: *i*) when using market prices and prices from constructed and surrogate markets (arrow 6) and *ii*) when simulating various scenarios of destruction or restoration of intermediate services of first order (arrow 8). The next Section presents the guiding framework that details how these monetary units can be inserted inside a hybrid I-O model without eclipsing the interesting advantages of physical units advocated in Section 2.

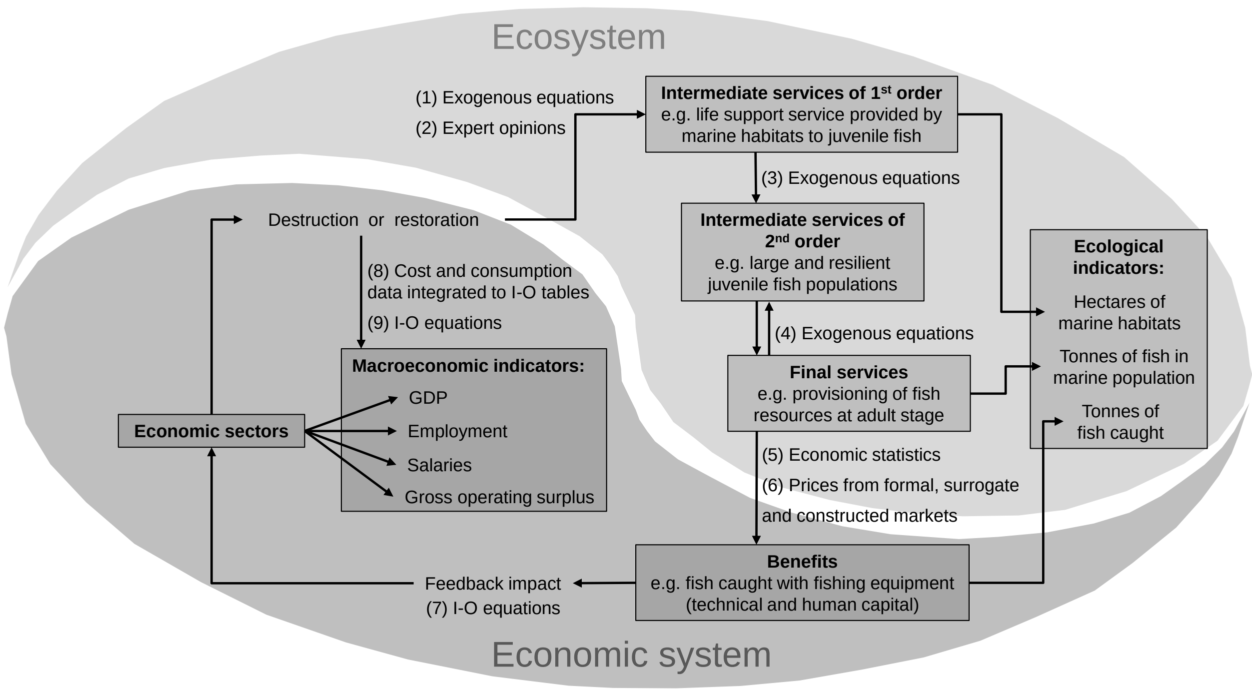

Figure 1. Quantification of relationships between the four categories of ecosystem services: intermediate services of first and second order, final services and benefits.

4. The guiding framework

The reason for integrating monetary values to the hybrid I-O model is to assess the economic impact of a variation in the supply of an ecosystem service on production sectors and final demand. This differs from other I-O approaches, such as those developed by Cumberland (1966), Hannon (2001) and Grêt-Regamey and Kytzia (2007) who assess the impact of a variation in the supply of an ecosystem service on satisfaction feelings expressed by individuals (through a measure of individual preferences) as is usually the case in conventional cost-benefit analysis.

4.1. First dichotomy: monetization criteria of ecosystem services

The guiding framework, illustrated in Figure 2, allows monetary valuation techniques to be inserted into an ecological-economic I-O model, but prevents them overshadowing the existence and the role of intermediate services as well as their interactions with other ecosystem service categories (see Section 2). The framework is based on the partition of ecosystem services detailed in Table 1 and operates according to a double dichotomy: intermediate/final services and direct/indirect monetary valuation approaches.

The first dichotomy operates a clear distinction between ecosystem services that may or may not be monetized based on 3 criteria:

- First decisional criterion: is the ecological process or structure considered an ecosystem service? According to the definitions given in MA (2005), Costanza *et al.* (1997), Daily (1997), Boyd and Banzhaf (2007) and Fisher *et al.* (2009), if the ecological process does not bring about any benefit either directly or indirectly, it is not an ecosystem service, and the ecological-economic analysis of ecosystem services does not apply (cf. Figure 2). On the contrary, if it does bring about a benefit either directly or indirectly, the second decisional criterion is used to identify whether a monetary valuation is appropriate.

- Second decisional criterion: is the ecological process or structure considered an intermediate or final service? It is considered an intermediate service if it relates to a process or a structure of the ecosystem that participates in the generation of either an intermediate service of second order or a final service; in that case, evaluation should be expressed in physical units (Section 2) that can be entered into the hybrid I-O model as a parameter. It is considered a final service if individuals may obtain a direct benefit from a source of matter or energy taken from the ecosystem via a human or a technical capital (knowledge or know-how, equipment, tools, infrastructures, etc.).

- Third criteria: even though final services are assessed in physical units, the benefits they generate can be expressed both in physical and monetary units and hence monetary valuation techniques should apply; consequently, the last decisional criterion questions whether the monetary value to be entered in the I-O model is calculated from a direct or an indirect approach.

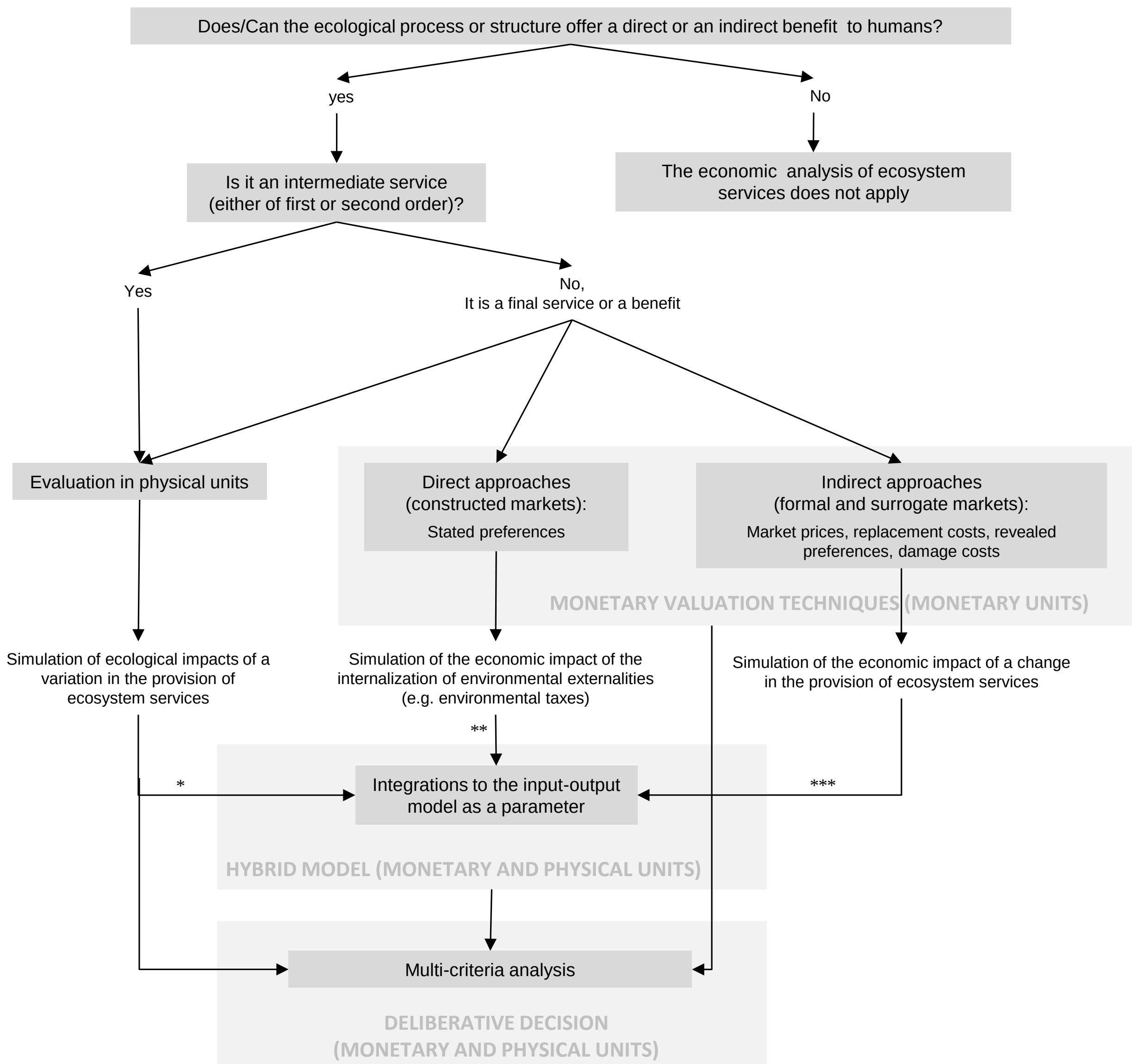

Figure 2. Guiding framework for the integration of monetary valuation techniques to a hybrid I-O model for the study of ecosystem-economy interactions

Note on parameter inserted into the hybrid model:
* Changes in matter or energy flows (involved in ecological impacts) at the interface between the ecosystem and the economy (in both directions) caused by economic activities on ecosystem services (km^2, t, kW, etc.).
** Hypothetical tax inserted into the model to simulate the economic impact of environmental measures on disposable income, the subsequent effect on final consumption by households and, in the end, the direct and indirect economic impacts on the production of economic goods and services by economic sectors (€).
*** Final demand (household consumption, investments, exportations, etc.) or intermediate demand of inputs are modified in the model to simulate direct and indirect economic impacts of a variation in the provision of ecosystem services on the production of economic goods and services by economic sectors (€).

4.2. Second dichotomy: operational processes for integrating monetized ecosystem services into the hybrid I-O model

The second dichotomy (Figure 2) suggests two possibilities to integrate monetary values into the hybrid I-O model depending on whether the monetary technique is a direct approach (constructed markets such as contingent valuation, etc.) or an indirect approach (formal market and surrogate markets like hedonic pricing, travel cost, replacement costs, etc.).

Results from direct approaches may be inserted into the I-O model to simulate the impact of environmental measures on disposable income and, therefore, on final household consumption. This is carried out by inserting the monetary values in the form of a hypothetical tax in the line of value added and the column of final demand, both located in the use table of the I-O model (Table 2). This allows us to simulate the direct and indirect impacts of internalizing an externality on the economic system in the case where individuals would actually pay the amount they stated in the contingent valuation or the choice experiment, which reduces household consumption as illustrated in equation (1):

$$f_{i,k=1}^{t_n} = f_{i,k=1}^{t_0}\left(1 - e_i\frac{([Y_{t_0}] - WTP)}{[Y_{t_0}]}\right) \quad , \qquad (1)$$

where $f_{i,k=1}^{t_0}$ is an element of matrix $\mathbf{F}$ representing the consumption of commodity *i* by households (k = 1) before (i.e. in t_0) individuals would pay the WTP they declared in contingent valuation or choice experiment and $f_{i,k=1}^{t_n}$ represents the same but after (i.e. in t_n) individuals would pay the WTP; Y_{t_0} is the income available for final consumption of all individuals before paying the WTP (which is aggregated across all inhabitants of the study zone) and e_i is the income-elasticity of demand for commodity *i*.

The impact on final demand would be a reallocation of household consumption from various economic goods and services to services of environmental preservation. To take that impact into account, we have modified the initial household consumption ($f_{i,k=1}^{t_0}$) prorated to the income variation due to environmental restoration and preservation costs, assuming that households purchase commodities in proportion to their income. To calculate the income available for final consumption (Y_{t_0}), we subtracted taxes on incomes, savings and social contributions from compensation of employees and added the share of the gross operating surplus, which is paid to shareholders in the form of dividends.

In addition, if environmental restoration or preservation activities require investments, column *k* corresponding to gross fixed capital formation in the matrix $\mathbf{F}$ of final demand is modified to take into account the positive effect of such investments (Ψ_i) on economic activities. This is illustrated in equation (2):

$$f_{i,k=4}^{t_n} = f_{i,k=4}^{t_0} + \Psi_i \quad , \qquad (2)$$

where $f_{i,k=4}^{t_0}$ is an element of matrix $\mathbf{F}$ (see equation (6)) that represents expenses in investments (gross fixed capital formation).

If the amount stated by individuals in direct approaches turns out to be insufficient, a part of the costs of environmental restoration may also be borne by economic sectors in application of the

Polluter Pays Principle. We assume that half the cost is paid through a reduction of benefits (gross operating surplus: GOS_j) and the other half by a reduction of employment or salaries[7]. The variation in gross operating surplus has an impact on the final consumption of households that benefit from dividend incomes. The same occurs with the variation in salaries of employees. The impact on final household consumption is then calculated by modifying equation (1) as follows:

$$f_{i,k=1}^{t_n} = f_{i,k=1}^{t_0}\left(1 - e_i\frac{\left([Y_{t_0}] - WTP - \Psi_i\left(\frac{1}{2}\sum_j \theta_j\frac{Shares_j}{GOS_j} + \frac{1}{2}\sum_j \theta_j\right)\right)}{[Y_{t_0}]}\right), \qquad (3)$$

where Ψ_i is, as above, the investment cost in environmental restoration or preservation; θ_j is the share[8] of the investment cost in environmental restoration or preservation borne by each sector *j*; $\sum_j \theta_j \frac{Shares_j}{GOS_j}$ is the sum across all economic sectors *j* of the proportion of the gross operating surplus distributed to shareholders (once multiplied by Ψ_i, it represents the part of the household incomes earned from dividends ($Shares_j$) that contributes to environmental restoration or preservation costs) and the last term $\frac{1}{2}\sum_j \theta_j$ is the part of environmental restoration or preservation costs that companies bear by reducing employments or household incomes (most of the time it is not a reduction but a limitation of job creation or of salary increases).
Hence, we assume that the increase in production costs, caused by environmental restoration or preservation costs, leads to a decrease in the gross operating surplus and salaries, rather than to a price increase. This might be a correct assumption for studies at regional levels and for goods and services for which geographical location is not important (the price of such goods and services is influenced by national or international dynamics rather than regional ones). Another option would be to consider solely an increase in sales prices. In that case, an I-O price model should be used (see below the example for hedonic prices in equations (4) to (7)).

Results coming from indirect approaches, or monetization techniques based on formal and surrogate markets, are integrated into the hybrid I-O model to simulate the impact of a change in the provision of ecosystem services on the production of economic goods and services by economic sectors. The I-O model allows us to measure the direct and indirect effect of this change on the whole economic system through the links that connect an economic sector to its suppliers in raw material and semi-finished goods and services as well as to final consumers. This is carried out by the integration of monetary values, which measure the change in the provision of

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[7] Both coefficients $\frac{1}{2}$ have been set arbitrarily; they consist in simulating the case where half of the restoration or preservation cost (Ψ_i) would be subtracted from the household incomes and the other half from the gross operating surplus (GOS_j), i.e. companies' benefits.

[8] The value of the percentage θ_j for each sector depends on the cost allocation rule decided. It can be subject to discussions. A possible option is to decide it with stakeholders inside a participative decision process

an ecosystem service, inside the matrix $\mathbf{F}$ of final demand (household consumption or investments) or the matrix $\mathbf{B}$ of intermediate inputs.

An example of integration of results coming from indirect approaches is given in Table 2 for the technique of hedonic prices. This technique is integrated into the I-O model in order to estimate the impact of a change in the provision of ecosystem services on prices of economic commodities. Based on the I-O model described above, new equations are built to obtain an I-O price model (cost push). This model is based on normalised prices in which the output from sector *j* is defined as one Euro's worth of good *j*. Its unit price is by definition 1. The model is calibrated to a row vector (P) of unit prices (p_j). It can be used to calculate relative price changes subject to an exogenous factor price increase, for instance an increase in the price of houses due to higher demand for real estate goods; this higher demand being generated by a change in the provision of ecosystem services (e.g. restoration program of natural habitats that improves landscape beauty and enhances recreational activities). Let W be a row vector made of w_j's (the value added coefficients per money unit of output) and A be a matrix whose elements a_{ij} are technical coefficients calculated from an *industry-by-industry*[9] I-O model made of *n* sectors producing outputs in row and *m* sectors consuming these outputs as intermediate inputs in columns; then we can write the following equation (Leontief, 1974; Miller and Blair, 2009):

$$\begin{cases} p_1 - a_{11}p_1 - a_{21}p_2 - \square - a_{n1}\,p_m = w_1 \\ p_2 - a_{12}p_1 - a_{22}p_2 - \square - a_{n2}\,p_m = w_2 \\ \quad \dots \quad \dots \quad \dots \quad \dots \\ p_m - a_{1m}p_1 - a_{2m}p_2 - \square - a_{nm}\,p_m = w_m \end{cases} \quad \text{with } i = 1, \dots, n \text{ and } j = 1, .., m\,, \qquad (4)$$

Equation (4) is based on the principle that the price of a commodity *i* must be just sufficient to cover – after the payment of intermediate inputs ($a_{ij}p_j$) to other sectors – the value added, i.e. the payment of primary inputs: labour, gross operating surplus (benefits) and taxes. This equation requires that an increase in the price of real estate goods due to natural habitat restoration programs automatically leads to a decrease in the value added of the other sectors using such goods as intermediate inputs (e.g. rent of buildings).

However, it might be possible that these other sectors would not allow a decrease in their value added and would therefore increase the prices of the economic commodities they produce (e.g. if natural habitat restoration brings about an increase in rental prices in a region, lawyers renting an office in that region might increase the price of their services in order to offset the rise in their rent). In order to consider this possibility, equation (4) can be rewritten in matrix algebra,

$$[I - A^T]P^T = W^T\,, \qquad (5)$$

and by rearranging (5), price modifications can be calculated as follows:

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[9] All equations presented below regarding the I-O price model do also apply for *commodity-by-industry* I-O models as the one presented in Table 2. The only difference is that in Equation (5), the term $[I - A^T]$ is calculated as follows $\left[\left(\mathbf{I} - \mathbf{D}^{\mathbf{T}}\mathbf{B}^{\mathbf{d}}\right)^{-1}\mathbf{D}^{\mathbf{T}}\right]^T$ (transposed term from Equation (7)).

$$P^T = [I - A^T]^{-1} W^T, \quad (6)$$

where I is the unit matrix, P^T and W^T are column vectors generated by a transposition of the row vectors P and W. The matrix A^T is the transpose of matrix A. Its technical coefficients a_{ij} can be calculated from the Supply Table (see table from Cordier *et al.*, 2011) and the Use Table (Table 2) after a transformation of the *commodity-by-industry* format into an *industry-by-industry* format.
Relative price changes caused by an exogenous factor such as the impact of the restoration of natural habitats on the increase in the price of real estate goods can be calculated as follows. The difference between the new price (after restoration) and the old price (before restoration) is estimated by the hedonic price technique. This difference is added to the value added w_j corresponding to the real estate sector inside the matrix W^T of equation (6) (and more specifically to the part of the value added corresponding to gross operating surplus because it is a pure benefit for the real estate sector).

The last step consists in translating the effect of price increases (calculated by P^T in equation 6) on final demand with the use of coefficients of price elasticity of demand found in the economic literature for each good and service. The subsequent modification of final demand would then be inserted in matrix $\mathbf{F}$ and the impact on the total output produced per economic sector in the area studied would be calculated via equation (7). This equation is the central equation of I-O models built on *commodity-by-industry* tables (Table 2). From this equation, the economic components of the wellbeing measured by employment and GDP can be calculated for the whole economy of the study area as well as for each economic sector (see detailed mathematical developments in Victor, 1972). This gives a useful picture of the macro-economy and the meso-economy of the study area.

$$g^T = \left[\left(\mathbf{I} - \mathbf{D}^{\mathbf{T}}\mathbf{B}^{d}\right)^{-1}\mathbf{D}^{\mathbf{T}}\right]\mathbf{F}^{d}\ \mathbf{i}, \quad (7)$$

where $\mathbf{I}$ is the $n \times m$ identity matrix ; $\mathbf{D}$ is a $n \times m$ matrix of technical coefficients named *commodity output proportion*; $\mathbf{B}$ is a $n \times m$ matrix of *input technical coefficients* b_{ij}; $\mathbf{i}$ is a unity column vector $1 \times n$ (not to be mistaken for *i* that symbolises commodities), $\mathbf{D}^{\mathbf{T}}$ is the matrix of the *commodity output proportions* d_{ij}, which are technical coefficients defined under the *industry-based technology* assumption. Both technical coefficients $\mathbf{B}$ and $\mathbf{D}$ are calculated respectively on the basis of the supply matrix V (see Cordier *et al.*, 2011) and the use matrix U (Table 2), as in Lixon *et al.* (2008). Exponent d shows that in matrix $\mathbf{B}$, consumption concerns intermediate inputs used inside the study area, which have been domestically produced in the study area. Exponent *d* shows the same for matrix $\mathbf{F}$ except that in addition to final outputs consumed inside the study area by domestic final demand, exports are also included in the matrix (i.e. final outputs consumed abroad by foreigners).

Table 2. Use table of the hybrid I-O model applied to nurseries (marine habitats) of the Seine estuary.

		Economic sectors (j = 1, …, m)	Final demand (k=1, …, p)	Ecosystem	Total
Economic commodities (M€) (i = 1, …, n)		**U** u_{ij}	**F** f_{ik}		q_i
Imports (M€)		m_j			$\sum_{j=1}^{m+p} m_j$
Primary inputs (value added: benefits (GOS), wages and salaries, net taxes) (M€) (z = 1, …,t)		**W** W_{zj}			$\sum_{j=1}^{m} y_{zj}$
Total (M€)		g_j	μ_k		$\sum_{j=1}^{m}(g_j) + \sum_{k=1}^{p}(\mu_k)$
Ecological commodities	Nursery (km²)	r^N		$(e^N)^{Seine}$	$r^N + (e^N)^{Seine}$
	Fish (t)	r_j^S		$(e^S)^{Seine}$	$\sum_{j=1}^{m+p} r_j^S + (e^S)^{Seine}$

Arrow labels in the table: I-O price model; Proportional modification

a. ⋯⋯▶ Integration of hedonic prices (indirect approach) to model the impact of the restoration of natural habitat (Nursery) on final demand.

b. - - -▶ Integration of prices from direct approach (contingent valuation, choice experiment) to model the effect of a new environmental tax set at the WTP value for the restoration of natural habitats (Nursery).

c. - - -▶ Integration of prices from direct approach (contingent valuation, choice experiment): the modification consists in taking the share of the cost of restoration of natural habitats (Nursery) that exceeds the amount declared by individuals in direct approaches (b) and subtracting them from the benefits (GOS: Gross Operating Surplus) produced and the salaries paid by economic sectors.

Legend:
U : use matrix, **F** : matrix of final demand, **W** : matrix of primary inputs (covers all categories of value added: benefits (gross operating surplus), wages and salaries, net taxes), g_j : row vector of total output per sector *j*, q_i : column vector of the total demand per commodity *i*, m_j : row vector of interregional and international imports, μ_k : row vector of total input consumed per category of final demand, r_j^S : quantity of fish consumed by sector *j* or final demand *k* in the Seine estuary, r^N : total amount of nursery areas destroyed by all economic sectors, $(e^N)^{Seine}$: nursery surface that can be used by the ecosystem of the Seine estuary, $(e^S)^{Seine}$: tonnage of fish that can be used by the ecosystem of the Seine estuary.

5. Discussion and conclusion

This paper proposes an alternative approach for reconciling monetary valuation techniques with methods that address ecosystem-economy interactions. To achieve this goal, we develop a guiding framework that limits the use of monetary valuation to real market simulations. Simulations of scenarios of environmental measures are carried out with a hybrid ecological-economic input-output model (Figure 1 and Table 2). The guiding framework ensures that monetary valuation techniques contribute to the understanding of the impact of economic activities on changes in ecosystems services and the feedback impact of these changes on economic activities. The framework operates according to a double dichotomy: intermediate/final ecosystem services and direct/indirect monetary valuation techniques (Figure 2).

The first dichotomy of the guiding framework establishes that benefits generated by final ecosystem services are measured by monetary valuation techniques while intermediate ecosystem services are measured in physical units. The advantages of this choice are summarized in Table 3. However, papers such as Hannon (2001) and Grêt-Regamey and Kytzia (2007) show that our position is not one shared by all economists. Our guiding framework uses results from monetary valuation techniques to assess the economic impact of a variation in the supply of an ecosystem service on production sectors and final demand while both authors mentioned above use them to assess the impact of a variation in the supply of an ecosystem service on feeling of satisfaction expressed by individuals in direct and indirect monetary approaches used in environmental economics.

Individual satisfaction may be due to benefits obtained from a final service such as recreational fishing activities in estuaries with higher fish resources due to restoration of natural marine habitats. In this case there is no opposition between our approach (Figure 2) and the monetary valuation of benefits obtained from final ecosystem services since uses of final ecosystem services by individuals can have an impact on the production of economic sectors and final demand, which is precisely what we want to measure in our approach, i.e. impacts on real markets.

Nevertheless, individual satisfaction may also be due to indirect uses of some ecosystem services (Section 2). Indirect uses typically cover intermediate services since this category of ecosystem services is not provided directly to individuals. In that case, individuals' preferences and satisfaction are due to their knowledge of the importance of intermediate services for the generation of the final service they use directly. This explains why a monetary value based on the degree of satisfaction of individuals regarding a change in intermediate ecosystem services does not cover impacts on the production of economic sectors and final demand. For that reason, our methodology does not favor monetary valuation of intermediate ecosystem services.

To monetize benefits generated by final ecosystem services (with the exclusion of intermediate services), the second dichotomy of the guiding framework (Figure 2) frames the integration of results from monetary valuation techniques to hybrid I-O models as well as the integration of results from natural sciences in physical units. Our framework allows three categories of impacts to be considered: *i)* ecological impact of economic activities on alterations of ecosystem services, *ii*) subsequent feed-back impacts of these alterations on economic production and final demand, and *iii)* economic impacts of environmental measures aimed at internalizing an externality (Table 3).

Another advantage of our guiding framework is to consider the importance of intermediate ecosystem services even if they cannot be monetized. This is essential since intermediate services condition the existence of all other ecosystem services that benefit human life and economic activities.

Hence, the framework developed in this paper clearly shows what category of ecosystem services monetary valuations do and do not measure (Figure 2, Tables 1 and 3). Even though this guiding framework remains largely theoretical at this stage, the clear distinction between the various categories of ecosystem services and the resulting monetization preferences may give natural scientists a better understanding of how to take advantage of economics when analyzing the impacts of interactions between the economy and the ecosystem.

Table 3. Differences between our methodological approach (hybrid I-O model) and purely monetary approaches.

<table>
<tr><th>Our methodological approach:
Hybrid I-O models</th><th>Monetary approaches:
Monetary valuation techniques and monetary I-O models*</th></tr>
<tr><td colspan="2">Cover the impacts on the category of ecosystem services of benefit**, i.e. the impacts on human wellbeing in terms of satisfaction of needs and desires for goods (e.g. fish) and services (e.g. recreational activities) (Section 2).</td></tr>
<tr><td>Cover intermediate ecosystem services per se (in physical units) and their indirect impact on economic activities*** (Section 2).</td><td>Cover intermediate service categories in terms of their impact on feeling of satisfaction expressed by individuals**** (Section 2):
- for simple ecological issues, the feeling of satisfaction results from the indirect provision by intermediate services (through final services they produce) of a precise amount of goods (e.g. fish) and services (e.g. recreational activities) that satisfy individuals' needs and desires,
- for complex ecological issues, the feeling of satisfaction results from knowing that intermediate services are important for the ecosystem to be able to provide goods and services (benefits) but without being able to weigh up the amount provided.</td></tr>
<tr><td>Integration of monetary value inside a hybrid I-O model to assess:
- direct and indirect economic impacts of a change in the provision of ecosystem services on the production of economic goods and services by economic sectors (Section 4.2).
- direct and indirect economic impacts of an environmental measure aimed at internalizing an externality(Section 4.2).</td><td>Integration of monetary value inside a monetary I-O model to assess:
- direct and indirect impact of a change in the provision of ecosystem services on the feeling of satisfaction expressed by individuals**** (Section 4).</td></tr>
</table>

* Examples of monetary I-O models can be found in Hannon (2001) and Grêt-Regamey and Kytzia (2007). ** The benefit, as defined in Section 2, is the last category of ecosystem services in Fisher *et al.* (2009) and is defined as the point where a natural component of the ecosystem meets human capital (e.g. knowledge) or technical capital (e.g. equipment, tools, machinery, buildings) to generate a good or a service that directly affects human wellbeing. The category of benefits covers goods and services that are effectively used by humans. *** Through a measure of their interactions with final services. **** Through a measure of individual preferences in monetary units.

Acknowledgements

We are grateful to Kate Weir for checking the English. Her help is always appreciated.

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