New methodological perspectives on the valuation of ecosystem services: toward a dynamic-integrated valuation approach[1]

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Abstract:

The main objective of this paper is to present what is considered as methodological perspectives in the field of valuation of ecosystem services. The contributions presented here are based on the general assumption that if, on the one hand, we can recognize the inadequacy of the isolated use of the valuation methods, on the other we assume that efforts to refine and expand the scope of ecosystem services valuation should consider the progress already made, not ignoring altogether methods already used. Based on the stance that there should be a joining of efforts to improve the accuracy of ecosystem services valuation and starting from the assumption that the complexity and uncertainty surrounding ecosystem services require a trans-disciplinary analysis, the contribution beckons an approach referred to here as dynamic-integrated. It is dynamic because it considers the trajectory of ecosystem services over time in terms of its main drivers of change (land use dynamic, for example), and integrated in that it takes into account not just the economic values but other dimensions of ecosystem services values.

Keywords: ecosystem services valuation, dynamic-integrated approach, ecological-economic modeling.

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Introduction

Ecosystem services are the basic interface between natural capital and human welfare. They are the direct and indirect benefits generated from the complex interactions between the components of natural capital. The water and climate regulation, erosion control, protection against disturbances, aesthetic pleasures, etc, are some of the examples of services provided by ecosystems. Despite its importance, the traditional market approaches do not take these ecosystems into account in economic transactions, because they are given for "free" or as "gifts" of nature. The fact that they are not priced like other goods or services discourages their preservation, leading to overexploitation and, often, to their total loss.
In Economics, one of the forms developed for addressing the issue of natural capital management is the valuation of ecosystem services, which consists in assigning economic values to the benefits provided by ecosystems through techniques anchored in the neoclassical paradigm. However, severe criticism towards valuation, resulting mainly from the field of Ecological Economics, has already been widely publicized.

Thus a process of valuation of ecosystem services based on neoclassical assumptions is to be viewed as inadequate and efforts are needed in order to improve it. The problem is that, on one hand, the valuation of ecosystem services is necessary for the management of natural capital and preservation of its services, on the other hand, the criticisms addressed to it and already accepted by critical literature impose a demand for concrete propositions for its refinement. Therefore the main objective of this paper is to propose a new approach to the valuation of ecosystem services from an ecological-economic context. This approach is referred to as dynamic-integrated and has as its main characteristic the use of ecological-economic modeling as a necessary operational tool for understanding the interfaces between ecological and economic systems.

The first section of the article deals with some basic assumptions of the ecosystem services valuation. Then, the second describes the dynamic-integrated approach, presenting its main characteristics and showing it as a new methodological approach to the refinement of the ecosystem services valuation. The third section describes the tool of ecological-economic modeling and presents a first example of its use for the valuation of soil ecosystem services.

1. Ecosystem services valuation: some theoretical assumptions

The interest for the ecosystem services valuation has grown considerably lately. The economic science, concerned with ecosystems and their services, has directed, regardless the theoretical perspective, a great deal of efforts to the assignment of economic values concerning ecosystem services. However, the use of neoclassical tools in studies of economic valuation of ecosystem services is rather predominant. This is due mainly to the fact that heterodox currents - such as the Ecological Economics - have little contributed to this theme (Amazon, 2009), although this topic has frequently been in the center of their research agendas.

It is said that the environmental values perceived by society are part of a broader structure valuation, since the society does not take into consideration only the economic values linked to certain flows of the ecosystem services. Value is understood as a broader set of "human values historically determined that govern and organize the relationships in a given society" (Amazon, 2009, p. 185). Some of these values are related to markets and trading - giving the idea of economic values - and others are linked to ideas of moral and ethical order (the value of human life, human rights, solidarity) which are known as non-economical values. Therefore a broader perspective of value carries economical and non-economical values.

In the current sense, value can also be understood as the expression of the magnitude by which a given good or service contributes to a certain pre-established objective (Bingham et al., 1995, Bockstael et al., 2000, Costanza, 2000). Intuitively, for instance, it can be said that a pound of apples is valuable, precisely, because it may well serve to the objective of appeasing a person's hunger. Thus, if the ecosystem services contribute to the most important objective of maintaining life conditions, their values are positive. If the Ecological Economics is built on the integration of ecological sustainability, social justice and economic efficiency, a scheme for a valuation policy of ecosystem services must deal with these three objectives coherently.

Indeed, as stated by Costanza (2003), besides the traditional target of economic efficiency, a broader set of objectives must be incorporated in the ecosystem services valuation. That is because the valuation process based only on the economic efficiency and its individual-driven ultimate usage does not necessarily lead to ecological sustainability and social justice (Bishop, 1993).

Economic science has long expressed the idea of value through prices, but that does not really reflect the idea of importance. That is, for instance, the classic paradox between water and diamond. Within the neoclassical theory, which is based on subjective value theory, market prices are those which balance the quantity supplied and demanded, reflecting the value attributed to certain goods by its marginal buyer (Heal, 2000). However, in the case of complex systems, as the ecosystems, whose functioning is not fully understood, the marginal valuation becomes inappropriate (Farley, 2008a, 2008b), whereas small changes or interventions in an ecosystem can lead to non-marginal changes which - in some cases - may mean disruption of the processes that generate ecosystem services. Furthermore, the valuation process will always be wrapped up in uncertainty and inevitably will involve a certain degree of subjectivity and normative evaluations by the one who defines the valuation problem.

Although market prices are not equivalent to values, whose meaning goes beyond the economic sphere, the economic valuation works primarily with market prices, showing a partial, anthropocentric and utilitarian bias, emphasizing only the economic dimension of the values associated with the ecosystems. However, despite not being taken into account by the valuation current practice, the non-economic values have important interaction with the economic variables, since the search for these values permeates the economic dimension in a way that is far from neutral in their relationships (Amazon, 2009). The great valuation challenge turns to be, therefore, the attempt of the inclusion of non-economic values related to ecosystem services, so that the valuation becomes more extensive and comprehensive.

Besides including such non-economic values, especially the ones related to moral, ethical and cultural issues, a wide valuation ranking should also bring up considerations about the complexity of ecosystem processes and their interactions with human variables.

In a critical perspective on the valuation of ecosystem services, González (2004) raises some interesting points. Firstly, the author reminds that the economic valuation standard, besides simplifying the dimension of values, does not consider the social differences in the demand and, because of that, does not consider the social or distributive justice issues. That is, the current valuation practices aggregate the derived utilities without taking into account the differences in the agent endowments.

Secondly, González (2004) mentions the lack of questioning on the methodological stiffness that underlies the valuation exercises. Although valuation studies have been published in renowned journals, those that make use of this current paradigm are not questioned regarding the robustness of valuation models, although the potential bias has widely been discussed in review literature. Moreover, González (2004) emphasizes that the valuation current practice reinforces the generalization of results on the macro level, while overlooking the importance of contextual information.

As to its nature, Azqueta & Sotelsek (2007) draw the attention to the fact that the valuation currently practiced fits in the context of the Environment Impact Assessment (EIA), in a microeconomic perspective. However, there is a demand for valuation of ecosystem services that considers all natural capital in a macroeconomic environment. That is, from an individual valuation, the authors advocate a change to a broader valuation platform, which takes all natural capital into account.

The value of every capital stock is given by its current value of future income flows. Whereas ecosystems are stocks of natural capital, their value can also be defined by the present value discounted from future income flows (natural), and, in the case of ecosystems, such flows are equivalent to ecosystem services (Daily et al., 2000, Bockstael et al., 2000). The exercise of valuing ecosystems (or natural capital) means, therefore, to assign the value of services generated by natural capital, considering the dynamics and interdependence of ecological processes.

Hein et al. (2006) provide a framework for ecosystem services valuation, which consists of five steps: i. specification of the boundaries of the system to be valued; ii. ecosystem services evaluation in biophysical terms, iii. valuation by using monetary references or other indicators, iv. Aggregation or comparison of different values, and v. analysis of scales and stakeholders involved.

In the first step, the valuation object has to be clearly defined. In other words, it is necessary to have a spatial resolution of the ecosystem under consideration. The second step suggests that prior to being valued, ecosystem services should be evaluated in biophysical terms. Regarding provision services, for instance, this step involves the quantification in physical units of the flow of goods from the ecosystem. For regulating services, such quantification requires a spatially explicit analysis of the biophysical impacts that a particular service has on the local environment or adjacent ecosystems. For cultural services the evaluation involves identifying the number of people who benefit from a particular service and type of interaction they have with the ecosystem.

Concerning the third step, the values of the ecosystem services depend on the stakeholders involved. In fact, there is a mutual and dynamic relationship between stakeholders and ecosystem services, since services offered by a given ecosystem determine the relevant stakeholders and on the other hand, the stakeholders determine the relevant ecosystem services.

The fourth step involves the aggregation and/or comparison of values obtained in the previous step. If all values are expressed in monetary terms, they can be added together and the sum will indicate the value of the ecosystem in question. Even if not all values are expressed in monetary terms, one can use a multi criteria evaluation, in which a specific stakeholder is required to assign relative weights to different sets of indicators (monetary and nonmonetary), enabling the comparison. It is expected that different groups of stakeholders have different perspectives on the importance of different types of values (Hein et al., 2006).

Finally, the fifth step is an explicit consideration on the adequate scales (ecological and institutional) which are relevant to ecosystem services and their beneficiaries. The evaluation of the scales and stakeholders involved increases the applicability of the ecosystem services valuation to support the decision-making process. The consideration of scales and stakeholders can identify potential conflicts in environmental management, mainly between local stakeholders and stakeholders in larger institutional scales[7] (Hein et al., 2006).

Regarding the valuation process in *stricto sensu*, this is usually done through valuation techniques that use some of the neoclassical economics assumptions on the economic agent's behavior. As an example there is the assumption of substantive rationality, which assumes that the agent is able to understand all the variables that are at stake and to assess potential losses in terms of welfare due to environmental degradation.

One must also consider that the current valuation practice does not incorporate the issue of the complexities involved and does not deal with the interdependency between the

[7] One must not forget inter-generational conflicts either, which involve future stakeholders.

components of natural capital. Furthermore, the valuation itself brings an ethical conflict, because when it allocates resources that are the common heritage of all present and future society it attaches greater weight to the preferences of agents with higher incomes. Consequently, it does not incorporate and ignore the ecological and social values of ecosystem services.

2. The dynamic-integrated approach for ecosystem services valuation

A dynamic-integrated approach must, firstly, incorporate in its scope the values derived from the flows of ecosystem services whose derived from their environmental and social dimensions. Secondly, the dynamic-integrated approach must recognize that the values of ecosystem services are inextricably linked to their physical, chemical and biological functions within an ecosystem in general (Costanza et al. 1989).

In the dynamic-integrated approach the reductionism inherent in the conventional economic view is avoided and follows the steps proposed in Hein et al (2006). Ecosystems as a whole are taken into account in valuation studies, in an explicit recognition of the interaction between environment and economic performance through the assessment of services rendered by ecosystems to societies and of the impacts that human activities have upon their conditions (*Vaze et al*., 2006). There are several dimensions of ecosystem services valuation to be considered and they should be taken into account in the elaboration process of public policies and of decision making which involves the use of ecosystems.

The traditional approaches for the valuation of ecosystem services emphasize either the economic system or the ecosystems, and do not consider the inter-relationships between the two systems and the ethic and normative aspects of ecosystem services valuation. Furthermore such approaches are static or almost static, and do not follow the trajectories of the valuation of ecosystem service associated with the evolution of structures and ecosystem processes in function of their main drivers of change (Winkler, 2006).

Given the insufficient treatment of each approach and the reductionism inherent in the attempts of isolated disciplines to deal with ecosystem valuation (Costanza et al., 1993), it is urgent to adopt an approach that takes into account ecosystems, economy and society in which the main feature is the ecological-economic modeling of these three subsystems, explicitly considering the dynamics of change in the ecosystem services valuation in light of the interdependencies between different parts of the models and their different spatial and temporal scales.

The integration of several approaches means the emergence of a new trans-disciplinary paradigm valuation, in which the objectives of ecological sustainability, distributive justice and economic efficiency are taken into account (Costanza, 2001). This seems the most coherent with the principles and with the pre-analytical view of Ecological Economics.

In the dynamic-integrated valuation, the contributions of social sciences (mainly economics), and the natural sciences (especially, biology and ecology) are put together in an attempt to build economic and ecological models. The ultimate objective is to provide a holistic approach to the treatment of ecosystems, their services and their contribution to human welfare, as well as to consider the various feedback effects found between ecosystems and economic systems (Robinson, 1991; Harris, 2002). Unlike the approaches such as EIA (Environment Impact Assessment), the dynamic-integrated approach treats ecosystems as internal elements for the analysis, making it more dynamic and thus promoting the knowledge of the impacts of environmental changes on the results of human activities, and of the effects those activities have on future changes in ecosystems (feedbacks), which makes this approach provide a more thorough and comprehensive analysis.

The limited knowledge of individual disciplines in integrated approaches has led to simplification, reductionism and difficulties in dealing with the complexity of ecological and economic systems. The different disciplines have different idiosyncrasies and the challenge lies in building a common language capable of aggregating the isolated views. In the case of ecosystem service valuation, the knowledge of ecological processes becomes a prerequisite for understanding the dynamics triggered by human interventions in ecosystems. From these changes, valuation schemes can be used to overcome the limitations imposed by economic and ecological approaches in which the values of ecosystem services are represented not only by values based on the individual preferences, but in values based on a common value system whose foundations are similar to socio-cultural valuation.

Besides considering the ecological dynamics, a real integrated-dynamic evaluation must also include the views that different groups have over different ecosystem service categories and their cultural and ethical dimensions. Just to expand the valuation scenario, incorporating aspects of ecological and biophysical dimensions is not enough. It is vital to acknowledge that human beings have a bounded rationality and it is necessary to reflect upon social order questions, by introducing in the debate questions about the sustainable ecological scale, the risks of irreversible losses and ecosystem's resilience.

By aiming at the integration of the ecological and economic systems, the dynamic-integrated approach must rely on the help of ecological-economic models, that is, as a broader paradigm of ecosystem services valuation, which assumes that the allocation of ecosystem services values should not be restricted to the application of valuation methods and neither to a mono-disciplinary effort.

The dynamic-integrated approach presupposes the use of economic-ecological modeling as an operational tool. The economic-ecological modeling immediate goal is the representation of the interactions between the ecosystems and human activity, illustrating how anthropic actions modify the ecosystems and how different ecosystem configurations contribute to human welfare (Bockstael et al., 1995). The importance of considering the underlying dynamics to ecological-economic systems is due to the fact that one can organize/separate stock and flow variables in order to avoid possible double counting in the process of ecosystem service valuation (Turner et al., 1998). Furthermore, to incorporate aspects of ecological and economic dynamics extends the range of ecosystem services, making the valuation process become more accurate.

3. Using the modeling tool to value ecosystem services

3.1 The ecological-economic modeling

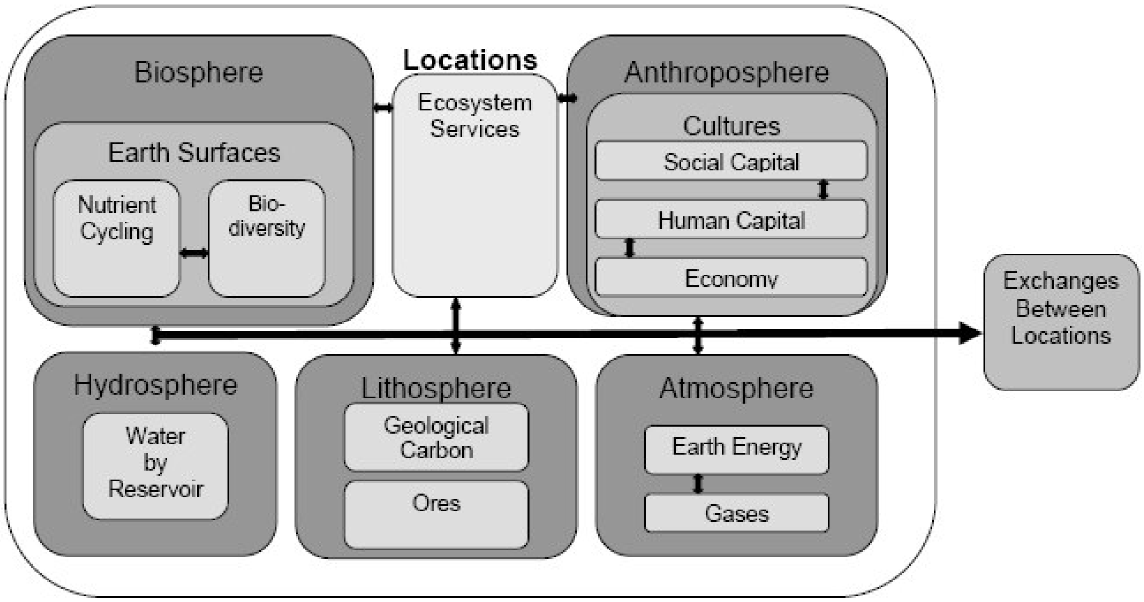
The use of ecological-economic models for dealing with issues concerning ecosystems and their services is still quite restricted. However many efforts have been directed to this area, since the interest in ecosystem services has been increasing.

Boumans et al. (2002) give an example of the application of ecological-economic models for the valuation of ecosystem service. The authors used the Global Unified Metamodel of the Biosphere (GUMBO) to estimate the general value of ecosystem services, whose total was found to be 4.5 times bigger than the Gross World Product for the year 2000. The tool aims at modeling the dynamic and complex links between social, economic and biophysical systems in a global scale, by focusing on ecosystem services and on their contribution to human welfare.

The model GUMBO has been considered a unique model in a global scale, since ecosystem services are its main focus. Its structure was built up in such a way that the changes in their flows affect economic production and social welfare directly. This allows the model to calculate dynamic changes in the values of ecosystem services, which are based on its marginal contribution related to other inputs used in production and welfare. Both socioeconomic and ecological changes are endogenous to the model, which emphasize its interactions and feedbacks, differentiating it from other models that limit ecological and/or economic changes to scenarios exogenously determined. Furthermore, the model includes the four types of capital (natural, social, human and manufactured) as state variables and factors of production, sorting them out into material and transformation factors (material cause and efficient cause, respectively) and allowing limited marginal substitution between factors of production (Boumans et al., 2002).

The importance of the GUMBO model lies in the fact that it is the basis of recent efforts to build ecological-economic models for the assessment of ecosystem services. Built on the GUMBO model, the Multiscale Integrated Models of Ecosystem Services (MIMES) was developed by the same researchers and its conceptual structure can be seen in Figure 1. It aims at putting together a number of computational models to integrate the understanding of the functions and ecosystem services and their interactions with human welfare in a range of different spatial scales. In addition, the project that led to the MIMES also seeks the development and application of new valuation techniques adapted to ecosystem services and their integration with the modeling work (Boumans & Costanza, 2007).

Figure 1: MIMES General Conceptual
Structure



Source: Boumans & Costanza (2007, p. 105).

The MIMES' structure follows the original GUMBO's components, consisting of the five spheres and also including natural, human, social and manufactured capital. The advance on the previous version is the concept of "locations", which allows spatial dynamics and which is not found at GUMBO. Ecosystem services are the interface between the spheres of natural capital and the anthroposphere, where they are evaluated according to their contribution to economic production and human well-being. The MIMES' structure can be used to represent a spatially-explicit model (multiple "locations"), where the exchange between the locations can be coded to represent not only the flow of water, air and individuals, but also the spread of species (Boumans & Costanza, 2007).

The most visible difference between the GUMBO and the MIMES models is the use of different software platforms. While the former used STELLA, the latter uses the platform SIMILE[8]. The purpose of this change was to improve the presentation of diagrammatic models and to clarify the interactions between the various subsystems analyzed. Besides that, the latter

[8] For further details see: www.simulistics.com.

(MIMES) allows input from the geographic information system (GIS). One may also work with models based on cell grid or polygons. The polygon-based model may or may not coincide with geopolitical boundaries (municipalities within a watershed, for example).

Unlike its predecessor, MIMES is spatially explicit and scalable. Each "location" contains a percentage of the land surface in terms of biomes and ecosystem types. Each area related to each biome can change in response to several drivers such as population and economic growth, changes in temperature and precipitation, and other variables relevant to the area studied.

The multi-scale feature of the MIMES model represents a breakthrough for the ecological-economic models, since different users can use it in different scales (world scale for the entire terrestrial ecosystem, or regional scales for watersheds, for instance) with the same multi-location structure. This demonstrates a great flexibility of the tool, which can be used not only to determine the world dynamics of ecosystem services, but also to assist the assessment process (and evaluation) of ecosystem services at local and regional scale.

So far, the main limitation to apply the MIMES model concerns the large volume of information required and the great computational effort required to run all its components simultaneously. However, there is still the possibility to analyze the different components of the model separately.

3.2 An initial application of the modeling tool to value soil ecosystem services

One of the advantages of the tool ecological-economic modeling tool is the possibility to capture the impact of degradation vectors on a bundle of ecosystem services. Taking the case of soil erosion[9], for example, it is possible to assess the impacts that this phenomenon has on the ecosystem services offered by the soil. So the valuation of its damage in terms of lost of ecosystem services flows becomes more comprehensive[10]. The economic costs of erosion-

[9] See Pimentel et al. (1995) for more details about environmental and economic costs of soil erosion.

[10] According to Kremen (2005), the biophysical measurement of ecological processes and their role in the generation of ecosystem services has been neglected in most analyses. The elucidation of the relationships suggested is presented as an important research agenda, because the lack of information and the uncertainties about how services are generated from ecosystem functions restrict more accurate analyses about the quantification of

degraded soil have been usually calculated through the nutrient replacement cost. This is based on the reductionist assumption that the market value of the lost nutrients replaced by industrial fertilizers is a good estimate of the economic costs of erosion. In these situations, only the service of soil natural fertilization[11] is valued, whereas all the other benefits provided by the soil as water regulation and storage, production of organic matter, among others are not considered. Without a modeling tool, it is impossible to consider all these variables, stemming from multiple and often interrelated ecosystem functions, as well as their respective sustainability parameters with their nonlinear thresholds. Even when there is only one ecosystem variable, this tool is useful, because ecological models often show their spatial distribution, as in the case of the sub-models of MIMES.

The service of water regulation is affected by erosion to the extent that this erosion has a negative impact on soil structure, which becomes more compressed and with less infiltration capacity and hydraulic conductivity. As a result, there is an increase in the surface runoff.

Gately (2008, p.41) conceives water regulation as the process of hydrological abstraction that can be universally measured as far as volume of regulated waters is concerned. The concept of runoff is directly related to the definition presented above, and, most of the times, the stronger the runoff, the bigger the discharge into rivers/water bodies and the lower the recharge of aquifers, thus reducing the flows of water regulation. In addition, the surface runoff is related to the capacity of water purification of the ecosystems, since the larger the volume of water, the greater quantities of pollutants being discharged into the water system.

Surface runoff means the water flow that occurs when the volume from rainfall exceeds the infiltration capacity of the soil. That depends on several physical and meteorological factors such as soil type and intensity of rainfall, as well as anthropogenic factors, such as the characteristics of the land cover. Sartori (2004, p. 1) states that "surface runoff is one of the phases of the hydrological cycle and its study is of great importance due to the dimensions of engineering works and agricultural management. Its quantification is a complex task and depends on several factors, which are added to parameters or variables in runoff models."

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ecosystem services flows on the basis of anthropic interventions. The proposal of integration of various models through spatially-explicit computational simulations makes the MIMES model a promising tool to bridge this gap.

[11]There are several studies that used the method of nutrient replacement cost to calculate the economic cost of erosion. This is the case of Andrade (2010), who recognizes the inadequacy of this technique and proposes the use of the modeling tool together, whose presentation will be described below.

Variations in the pattern of surface runoff in a particular area can be a proxy for variations in the flow of water regulation service. It is considered that the greater the magnitude of the first variable, the lower the amount of regulated water. In this case, the amount of lost water increases, which generates economic impacts such as loss of crop productivity due to the reduced amount of water available.

Using the "curve number" model ("CN model"), which is part of the MIMES structure, one can estimate the volume of water converted into surface runoff. This procedure was adopted to estimate the trajectory of the water regulation service in the town of Araras, São Paulo State (SP), Southeastern Brazil, in 2007. The CN model, originally developed for the Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA)[12], was used to complement the calculations of the economic cost of erosion made by Andrade (2010)[13] and to illustrate the potential of the modeling tool to make the results of the assessment process more accurate.

Figure 2 below shows the model's diagram used to calculate the flows of the water regulation services in Araras-SP, whose original conception is that of CN model mentioned above. The first step for the use of this model was to estimate the values of the CN parameter (curve number) for nine categories of land use in Araras-SP. Details of the calculations can be checked in Andrade (2010).

In Araras-SP, the diagram presented in the figure was built based on cells (cell grid), with the total amount of 104 lines and 106 columns, at a resolution of 300 m^2 [14]. The map was obtained at the Geoprocessing Laboratory of the Agricultural Institute of Campinas (IAC).

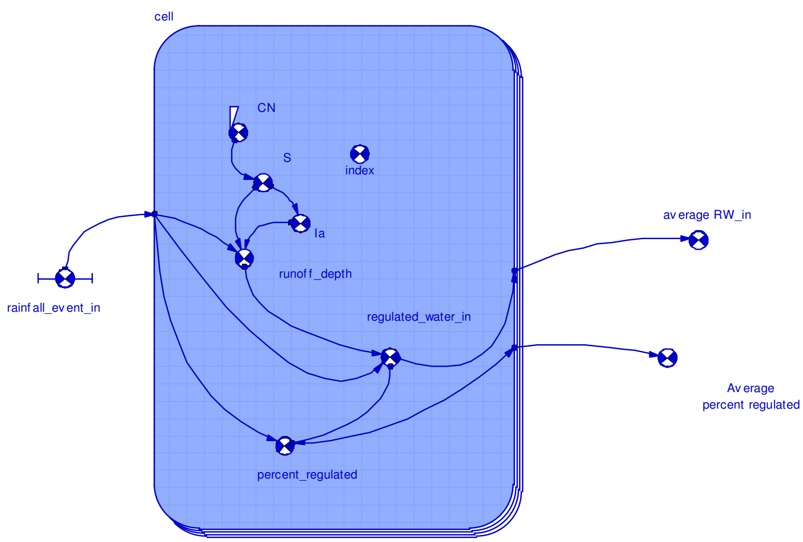
The sub-models represented above are equivalent to each unit of area, whose objects are modeled by the relationships suggested in the diagram. It is as if the map of the town was divided into several squares, in which the behavior of each one is given by the model. The model inputs are the estimated data for the CN parameter, calculated based on a combination of categories of land use and soil type, and information on precipitation, whose results can be seen in Andrade (2010) ("rainfall_event_in" and "CN" variables). The parameters *Ia* and *S* represent,

[12] The description of CN model can be found, among others in USBR (1977), Sartori (2004) and Gately (2008).
[13] The average cost of nutrient replacement in Araras-SP was U$ 14.02/hectare in 2007 and the total cost was US$ 854,174.58. The exchange rate used was US$1.00 = R$ 1.77050 (R$= reais, the Brazilian currency).
[14] The number of area units (lines and columns) is defined by the user according to the resolution used. However, a high resolution model can represent a great computational effort, which may not be always available.

respectively, the initial hydrologic abstraction and the maximum retention potential, both influencing the volume of surface runoff.

Figure 2: Representation of the Water Regulation Model

(component of the MIMES structure)



Based on the precipitation data obtained in data sources in the state of São Paulo, and on the estimates for the CN parameter, it was possible to calculate the surface runoff volume by category of soil in the town of Araras in 2007, data in m³ per hectare/year (Table 1)[15].

According to the type of management considered, the results are consistent with the expectations, since the crops with less adequate practices or that provide less protection to the soil are the ones that had higher runoff volume. But it is necessary to point out that the low runoff volumes for citrus and coffee result from good soil covers. As for annual crops and pasture, one would expect a high runoff, mainly due to the intense use of machinery and cattle trampling, respectively, which decreases soil infiltration.

[15] Only agricultural activities were considered

Table 1: Estimate of the runoff volume according to land use in Araras-SP in 2007.

Use and cover	Surface water runoff ($m^3.ha^{-1}.year^{-1}$)	Total runoff ($m^3.year^{-1}$)
Raw sugarcane	166	42,348,096.68
Burned sugarcane	283	25,713,895.44
Citriculture	10	1,141,773.50
Coffee	6	20,121,79
Yearly cultures – Soy beans+corn	215	3,633,536.18
Pasture	263	3,507,016.56
Riparian forest	31	2,072,015.39
Secondary forest	111	3,333,280.40
Total	**1,084**	**81,769,735.94**

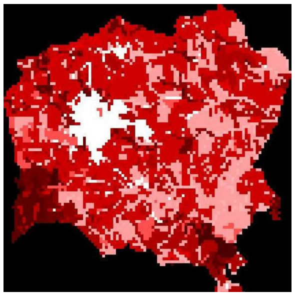
Source: elaborated by the authors.

The secondary forest showed a high runoff due to anthropization. On the other hand, the potential for runoff in riparian vegetation is lower, which is the result already expected for this case. The last column of the table above shows the total runoff volume in the category of land use in the town analyzed. The total runoff volume is approximately 81.8 million m³. If this volume of water could be valued, for example, according to the price of water charged by some Watershed Committees, there would be an indicator of the economic loss caused by the runoff. The committee comprising the Piracicaba, Corumbataí and Jundiaí rivers (also in São Paulo State) estimates the cost in US$ $1,69.10^{-3}$/m³, which generates a total of US$ 13,855.92. This is a relatively low amount due to the small price charged per unit of water volume. However, when considering an arbitrary value of US$ 0.50/m³ for domestic use and charged from the inhabitants of Araras-SP, the total economic loss amounts to US$ 40,884,867.97.

Figure 3 shows spatialized indicators for the CN estimates in the municipality. The lightest area of the figure represents the urban perimeter of Araras, where the CN is estimated close to 100, which means a minimum capacity of water infiltration. Areas with stronger colors are those in which the CN estimate is lower, which means a greater infiltration capacity.

The output data of the model are the volume of regulated water (difference between the precipitated and runoff water volume, the latter given by the variable “runoff_depth ") and represented by the variable “regulated_water_in”. The variables "Average RW_in" and "Average percent regulated" represent, respectively, the average volume of regulated water in mm and percentage, considering all the area units of the model.

Figure 3: Representation of the estimated CN parameter

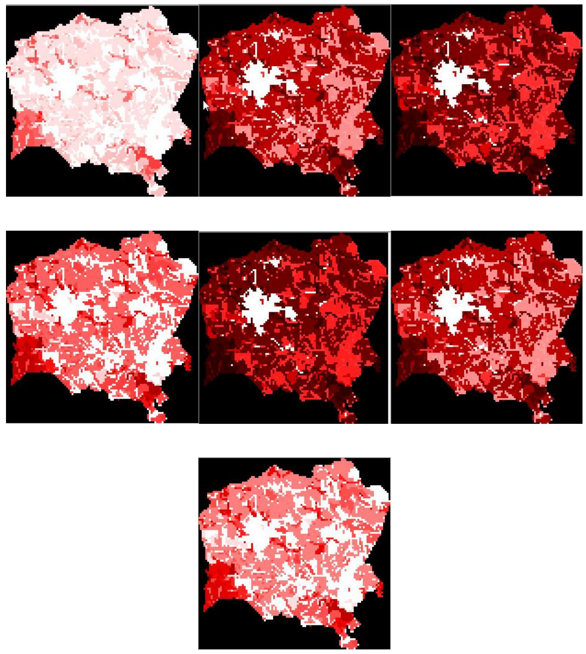


The model shows in a spatial way the regulated water volume (in percentage) for all rainfall events analyzed (Figure 4), based on the partial results (though not calibrated yet). The areas with lighter colors represent those where the percentage of regulated water is low, whereas the areas with stronger colors represent parts of the town with greater capacity for water retention due to the events already analyzed, the previous conditions of humidity and precipitation intensity. It should also be mentioned that the area of the urban perimeter has a scarce capacity to retain water, which results in a low percentage of regulated water.

From the model the average volume of regulated water per event (figure 5) can also be taken as an output variable. Then, figure 6 represents the evolution of the volume of regulated water in Araras-SP from December 31st, 2006 to July 26th, 2007.

According to the proposal made by Hein et al. (2006), a process of ecosystem services valuation should comprise five stages, namely: i. definition of the ecosystem or the region where ecosystem services are valued; ii. biophysical assessment of the ecosystem services contemplated; iii. valuation in the *strict sensu;* iv. aggregation and comparison of different values; v. consideration of appropriate scales from the viewpoint of the stakeholders. In terms of this proposal, when the trajectory of service regulation is analyzed, the model above should be used if the objective is a valuation process which considers the changes in the flows of ecosystem services. This fact shows that the MIMES model and all its components are useful operational tools and that they have great potential to improve the valuation of ecosystem services.

Figure 4: Percentage of regulated water in Araras-SP for the pluviometric events analyzed[16]



The results derived from a model as described above allow the researcher to have deeper knowledge about the "performance" of a particular ecosystem service. From that point on, the *strict sensu* valuation is done based on information obtained from the modeling procedure. In the case of water regulation, for example, an option for this service valuation would be the estimate of productivity loss in agricultural crops due to the loss of water available for the plants, reducing its resistance in times of *veranico*[17]. The irrigation growing cost can also be estimated to compensate for the natural moistening of the soils[18].

[16] The pluviometric events are placed from the left to the right (first day of each event)

[17] Summerlike weather, *veranico* is a dry period within the rainy season. The regulation capacity of the soil water is fundamental for plants during this time interval. If there is loss in the capacity of water infiltration and retention, a lower resistance of crops is expected during *veranico*, which results in the growing costs for irrigation and/or loss of agricultural productivity.

[18] Pimentel et al. (1995) estimated the irrigation additional cost in the EUA of US\$30.ha^{-1}year^{-1}, considering a water loss of 75mm per hectare and an eolian erosion rate of 17tons (t) per hectare a year.

Figure 5: Percentage of regulated water (in mm) in Araras-SP for pluviometric events analyzed[19]

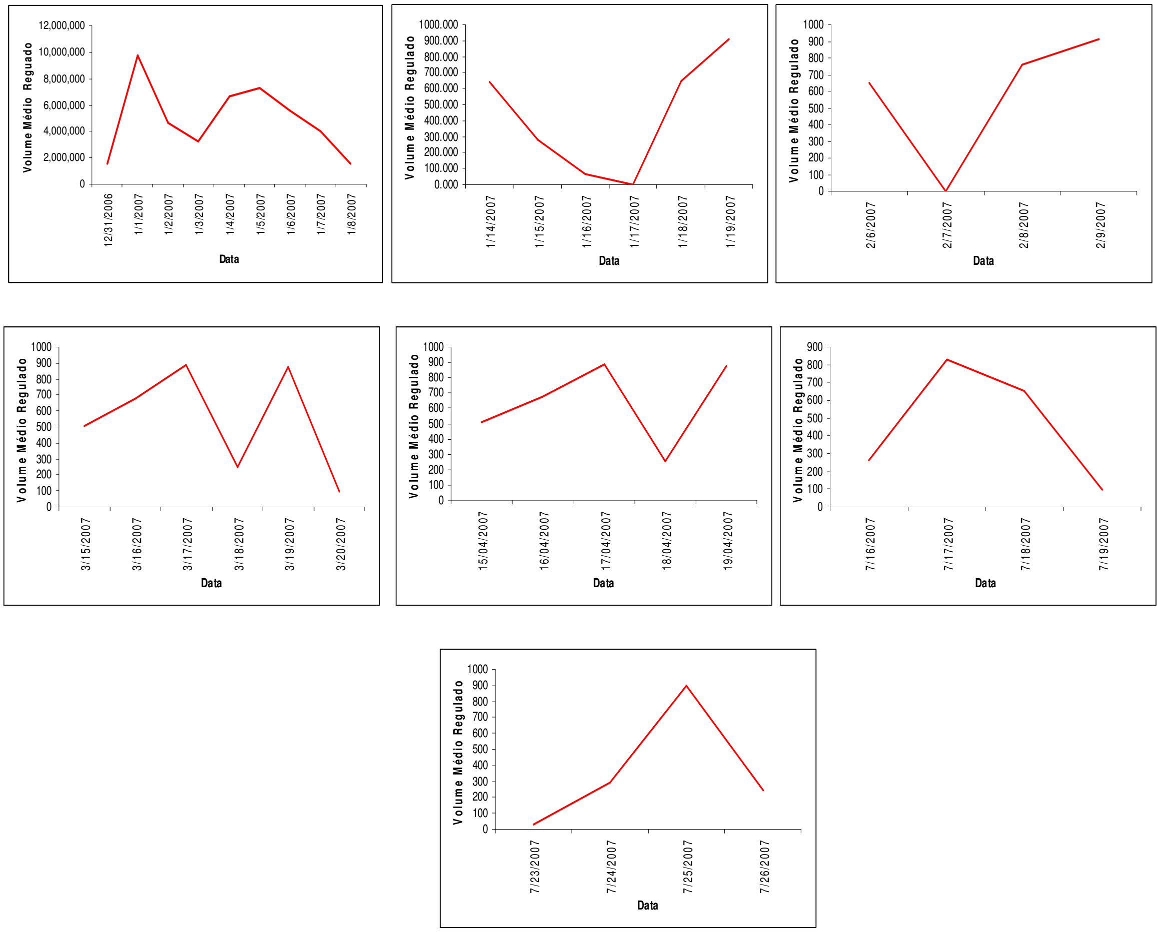
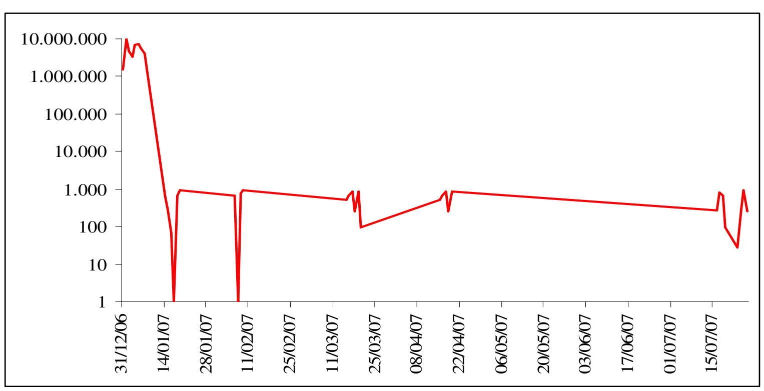


Figure 6: Evolution of the volume of regulated water in Araras-SP from Dec 26th 2006 to July 26th 2007.



[19] The pluviometric events are shown from the left to the right (average regulated volume for each rainfall day)

Regardless how the damage associated with a reduced flow of ecosystem services is valued, the fact is that an assessment process based on modeling results becomes more credible from the stakeholders' point of view. They can also assess the valuation of impacts because the models allow the visualization of the resulting adverse effects by encouraging stakeholders' own assessment of the damages caused by their actions. Thus, by making the ecological interrelationships clearer, models can be used as an integrating source of information for experts and non-experts and in the assessment and valuation of ecosystem services. Moreover, the way models are constructed, taking advantage of the MIMES potential, even the simplified models of an only ecosystem service (such as the one adopted for illustration) makes it possible to spatially know the dynamics of ecosystem services. This is important information, because it can be used as a way of supporting mechanisms to generate incentives for the natural capital preservation.

The exercise conducted here illustrates the potential of the MIMES sub-models to assess the trajectory of the ecosystem services flows. At first, the model led only to the analysis of the water regulation service, but the components present in the MIMES allow the user to model other ecosystem services. The valuation process should always try to integrate other types of models in order to promote the knowledge of dynamics of the largest number of ecosystem services affected by soil degradation.

Concluding Remarks

The main objective of this paper was to contribute to the methodological improvement of the valuation process of ecosystem services. The basic hypothesis adopted was that this one should count on the usage of the tool of ecological-economic modeling as a basic requirement for understanding the ecological dynamics involved and the incorporation of values of other ecosystem services that would not be captured otherwise.

The irrational use of resources from natural capital has led to a steady degradation of ecosystem services flows, which are essential for life support and the human welfare. As science committed to the efficient management of scarce resources, Economics should endeavor theoretical and methodological efforts that provide subsides for the formulation of environmental policies that prevent and/or reverse the current trend of degradation of environmental resources, which are so necessary for human welfare. Its methodology should be reconsidered in order to address the new issue of natural capital as a scarce and limiting factor of economic growth.

In their vast majority ecosystem services are public goods, and so they are not incorporated into traditional economic transactions. This market failure would theoretically be solved as soon as values were assigned to these services so that they could proceed with its efficient allocation. However, the way how these values are attributed - the valuation - is inadequate because it is based on assumptions that ignore the peculiar nature of ecosystem services (complexity, irreversibility, nonlinearity, etc.). In particular, it is worth noticing the assumption that natural capital and manufactured capital are substitutes. This substitutability occurs marginally and primarily in relation to natural capital as source of raw materials. It is practically nonexistent when it comes to natural capital as source of ecosystem services.

To achieve an efficient and prudent management of natural capital resources, the valuation of services rendered by natural capital plays an important role. However, the current practice of ecosystem service valuation suffers from serious limitations, especially with regard to the inconsideration underlying ecological dynamics. It can be said that the biases of the current practice of ecosystem service valuation can be grouped into three main points: i. excessive emphasis on the economic dimension of ecosystem services values and the implicit assumption that preferences are weighted by the purchasing power of the agents; ii. inappropriate assumptions about the behavior of economic agents; iii. disregard for the complexity of ecological processes and their interdependencies.

The junction of the three points listed above backs the main argument defended in this paper: the process ecosystem services valuation must be refined in order to consider the use of tools to help them overcome their limitations. This article tried also to show that the valuation (or evaluation) of ecosystem services should not be restricted only to the mere application of methods but it should rather be a wider process in which economic, ecological and social aspects are considered.

The dynamic-integrated valuation aims at integrating valuation *stricto sensu* to the most general analysis of the changes in the physical flows of ecosystem services and their effects on economic variables. It can be regarded as a distinct valuation paradigm, since it aims not only at economic efficiency and allocation of scarce environmental resources, but also the ecological and social sustainability.

The second part of the paper had as its goal to give greater concreteness to the integrated dynamic valuation proposed. Still preliminary in nature, it aimed at showing that the modeling tool is important for the correct assessment and valuation of ecosystem services. It is configured as an aid in the valuation process, getting its executor to have a better understanding of ecosystem services dynamics affected by the different vectors of environmental degradation.

It is important to say that the primary approach used here has not allowed full exploration of the potential of the modeling tool yet. In building scenarios, for example, it is possible to analyze the trajectory of water regulation service under the assumption that the municipality considered fully comply with the Brazilian environmental legislation (20% of Legal Reserve in Southeastern of Brazil and the maintenance of Areas of Permanent Protection). Another possibility would be to join the model compared to other models within the MIMES structure (Land Use Change Model, for example). The latter, when it analyzes dynamically the evolution of land use in a particular area, allows the user to know the impacts on ecosystem services arising from the expansion/reduction of land uses more or less favorable to the provision of ecosystem services.

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