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A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions

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ABSTRACT

Despite significant advances in the development of the ecosystem services concept across the science and policy arenas, the valuation of ecosystem services to guide sustainable development remains challenging, especially at a local scale and in data scarce regions. In this paper, we review and compare major past and current valuation approaches and discuss their key strengths and weaknesses for guiding policy decisions. To deal with the complexity of methods used in different valuation approaches, our review uses multiple entry points: data *vs* simulation, habitat *vs* system *vs* place-based, specific *vs* entire portfolio, local *vs* regional scale, and monetary *vs* non-monetary. We find that although most valuation approaches are useful to explain ecosystem services at a macro/system level, an application of locally relevant valuation approaches, which allows for a more integrated valuation relevant to decision making is still hindered by data-scarcity. The advent of spatially explicit policy support systems shows particular promise to make the best use of available data and simulations. Data collection remains crucial for the local scale and in data scarce regions. Leveraging citizen science-based data and knowledge co-generation may support the integrated valuation, while at the same time making the valuation process more inclusive, replicable and policy-oriented.

1. Introduction

The definition and classification of Ecosystem Services is still debated (see *e.g.*, Daily, 1997; de Groot et al., 2002; Millennium Ecosystem Assessment (MA), 2005; Kremen, 2005; Boyd and Banzhaf, 2007; Wallace, 2008; Fisher et al., 2009; TEEB, 2010). But over the last decade and a half, the concept has gained considerable attraction across science and policy arenas, especially on how the ecosystem services can be defined, valued and integrated into conservation and sustainable development agendas (Daily et al., 2009; de Groot et al., 2010 and Laurans et al., 2013). In this paper, we define integrated valuation of ecosystem services at the local scale as the detailed understanding of how ecosystem services provide benefits to human wellbeing, their quantitative measurements (including spatial mapping and modelling), trade-offs analysis and the use of knowledge in planning and decision making.

The value of ecosystem services is now widely acknowledged for their positive role in economic, environmental and social well-being - the three main pillars of sustainable development (UN, 2002; UNDESA, 2015). As such, the concept is becoming a major driving force for natural resources management and human wellbeing (see, TEEB, 2010; Diaz et al., 2015). It has been linked to policy and decision making as an innovative strategy for the improved management of land, water and living resources that can promote conservation and at the same time fostering human well-being (Tallis et al., 2008; Daily et al., 2009; Haines-Young and Potschin, 2010). However, the operationalization of the concept has often remained elusive, especially for an integrated valuation of available services at local and in data scarce regions. Scientific advances related to ecosystem services production functions, services flow and trade-offs among multiple ecosystem services are increasingly important for the practical implementation of the concept into conservation and sustainable development projects (Tallis et al., 2008, Daily et al., 2009 and Ash et al., 2010).

The valuation of ecosystem services (both quantitative and qualitative) and their integration into policy and decision making practices has been a matter of debate ever since the concept first emerged in the early 1990s (Daily, 1997; de Groot et al., 2002; Brauman et al., 2007; Daily et al., 2009, de Groot et al., 2010; Guerry et al., 2015). An

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appropriate analytical framework is required to bridge natural science, economics, conservation and development, and public and private policies (Braat and de Groot, 2012). The integration of different valuation approaches, especially quantitative measurements of services production, distribution and consumption, should be closely aligned with social and economic valuation approaches. Successful operationalization of the concept may need integration of appropriate valuation techniques relevant to policy and decision making practices.

In this paper, we present a review of key ecosystem services frameworks combined with a comparative analysis of selected peer-reviewed and grey literature to explore how different valuation approaches have been used to improve policy and decision making. The selection of ecosystem services valuation approaches is based on their applications for improving our understanding of services through quantitative and qualitative assessments. We discuss on how they can contribute to an integrated valuation of ecosystem services at local and data scarce regions. Subsequently, we assess selected spatially explicit policy support systems by analysing their capabilities to support integrated valuation. The selection of six policy support systems is based on their direct and/or potential roles in different valuation approaches (see in Section 4). As the paper aims to identify appropriate valuation approaches for the local and data scarce environments, we concentrate on the main gaps and how they can be addressed and making the valuation practices more inclusive and policy relevant.

First, we focus on how the natural capital and ecosystem services frameworks have been evolved over the recent years as a major alternative approach to enhance conservation activities and sustainable development. Next, we present a comparative analysis of different valuation approaches along different axes of variability: data *vs* simulation, habitat *vs* system *vs* place-based, specific *vs* entire portfolio, local *vs* regional, and monetary *vs* non-monetary (including cultural and aesthetic) valuation approaches. Then, we discuss different spatial-based policy support systems as a platform for combining more than one of these approaches and compare the strengths and weaknesses of their application at a local scale and in data scarce regions. Lastly, we discuss major challenges in the use of different valuation approaches and highlight the need for an integrated approach with the application of locally relevant data and knowledge co-generation practice to make the ecosystem services valuation more effective in policy and decision making.

2. Evolution of ecosystem services frameworks and persistent challenges for local level integrated valuation

Soon after the emergence of the ecosystem services concept as a way to redefine the role of ecosystem services in conservation and sustainable development, different frameworks have emerged to systematize this new knowledge and to guide policy and decision making practices. The Millennium Ecosystem Assessment (MA) was the first major international effort to explore the linkages between ecosystem services and human well-being. The MA framework was designed to understand the current state of major ecosystem services, trends in their production and flows, as well as major pressures and threats, management decisions and policy formulations (MA, 2005). The concept has been widely accepted among scientific and policy communities, and as a result of this, new approaches have been developed to value the services and thus better integration of the concept in research, conservation and development sectors (Daily and Matson, 2008), However, some policies and practices in water and land resources management that intended to improve ecosystem services and human well-being are based on untested assumptions and sparse information (Carpenter et al., 2009; Yang et al., 2013). This is particularly the case at local scale and where data are scarce. A concrete step towards local scale integrated valuation is clearly needed to improve the knowledge of ecosystem services and their integration into decision making.

Since the MA, different alternative frameworks have been developed to make the ecosystem services concept more relevant to policy and decision making processes. In response to the lack of economic perspective of biodiversity loss and ecosystem degradation in the MA framework, The Economics of Ecosystems and Biodiversity (TEEB) came into effect emphasizing more on joint efforts of ecologists and economists in ecosystem services valuation (TEEB, 2010). It has been strongly argued that any ecosystem services valuation should begin with the detailed understanding of biophysical generation of services to provide solid ecological underpinning to the economic valuation (de Groot et al., 2010). It is important to combine both ecological and economic perspectives in a collaborative way, so any trade-offs reflected at individual and societal choices are better understood at policy and decision making levels (Polasky and Segerson, 2009). Such linkages have been highlighted in the TEEB framework for mainstreaming the valuation of ecosystem services into local, national and international planning processes (TEEB, 2011 and 2012). The framework also intends to inform conventional economic policy about its impact on ecosystem health and biodiversity. It also makes a distinction between services and benefits and explicitly acknowledges that services can benefit people in multiple and indirect ways (TEEB, 2010). Although the framework looks at conservation and sustainable development through a strongly economic lens, the integration of the framework into policy and decision making mechanisms has been slow. Often the strong lack of locally relevant data is the main bottleneck for a successful integration of framework into policy and decision making processes.

To strengthen further the role of biodiversity and ecosystem services in human wellbeing and to promote sustainable development, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) came into effect with comprehensive interlinkages among diverse scientific disciplines, stakeholder interests and knowledge systems (Diaz et al., 2015). The framework focuses on co-construction of integrative knowledge which could be useful for wider research and knowledge-policy communities including the valuation of ecosystem services. The framework also focuses on the central role that institutions, governance and decision-making can play towards the better realization of nature's services in improving human welfare. It links multiple knowledge systems to ensure nature conservation and sustainable use of biodiversity for greater benefit to humanity. Although the IPBES framework is very useful to characterize the role of nature's benefits in enhancing human wellbeing, the framework is primarily focused at regional and international scales. There is no clear recognition of integrated valuation of services at local scale which could eventually create a functioning science-policy interface for higher level. In addition, the framework has an exclusive focus on living resources such as biodiversity and ecological functioning and how that produces ecosystem goods and services to people. Not incorporating non-living natural capitals such as water, soil and minerals resources could eventually make the framework less relevant to policy and decision making. The framework, while concentrating on ecological functioning of biodiversity and ecosystem services, does not explicitly recognize the crucial role of non-living resources in human wellbeing. Without proper consideration of these different elements of natural capital and ecosystem services, the framework could rather be reduced to an effort to understand ecological functioning and nature's intrinsic values but may not support the integrated valuation of services to influence decision making.

In conclusion, the reviewed ecosystem services frameworks are useful to increase the understanding of natural capital and ecosystem services, their stocks & flows and linkages (direct and indirect) between them and human well-being. Some frameworks have also raised the need for integrated valuation of services relevant to policy and decision making. However, they are too focused on assessing ecosystem services at regional and global significance of ecosystem services. At the local scale, the dynamic nature of ecosystems and ecological functioning may create a big impact on ecosystem services, for example a marginal change in hydrological characteristics could have a significant impact on agricultural production. Considering the local contexts of ecosystem services, any valuation cannot be policy relevant without integrating locally relevant data and knowledge alongside the application of appropriate scientific and socio-ecological approaches. In the next section, we develop a methodology to assess different valuation approaches in relation to above ecosystem services frameworks and to understand how these different approaches could be useful to develop integrated valuation for the local scale in data scarce regions.

3. A methodology for comparing valuation approaches

As reviewed in the previous section, a persisting challenge remains to value services in an integrated manner, especially at a local scale and in data scarce regions. Although a wide range of valuation approaches have been developed, most of them are designed to address specific policy questions and their capabilities to improve our understanding of ecosystem services is often limited by the complex nature of local environments and their inter-linkages with various disciplines mainly natural, social and economic characteristics. Some policies and practices intended to improve ecosystem services and human well-being are based on untested assumptions and sparse information. A meaningful valuation mechanism is crucial to local and data scarce environments where a limited data and information exists to explain the characteristics and quantitative assessment of services. It is therefore paramount to assess the strengths and weaknesses of existing valuation approaches in order to derive an integrated valuation approach. To address this issue, we apply a comparative analysis of selected published papers on multiple dimensions of evaluation: *i.e.* data *vs* simulation-based evaluation, habitat *vs* system-based *vs* place-based approaches, specific *vs* entire portfolio-based approaches, local *vs* regional approaches, and monetary *vs* non-monetary valuation approaches.

3.1. *Data* vs *simulation-based approaches*

An appropriate level of data and information is vital for understanding and quantifying natural capital and ecosystem services and how their functioning can create services to humanity's wellbeing. Recent advancement in data collection are constantly generating new information about various environmental data with direct relevance to decision making. For example, data monitored at a rainfall station contain information about local hydrology and potential water availability at local scale. Similarly, data collected for livestock and agricultural production can indicate the production trend of these key ecosystem services benefits. But, the key question is whether such data are relevant to local scale valuation of services, and if not, how to generate locally relevant data for data scarce environments. Nowadays, *in situ* data can be complemented with remotely sensed data to create regional or global inventories and derived products, such as the WorldClim monthly meteorological data (Hijmans et al., 2005), land cover (Ramankutty et al., 2008), vegetation cover (Sexton et al., 2013) and Protected Areas database (WDPA, 2015). Although these types of datasets contain information on the distribution of key environmental properties, most of them tend to have lower level of accuracy and/or high uncertainties at local scale, which need to be taken into account when used for decision making.

More recently, simulation of environmental data is playing an increasingly important role in ecosystem services valuation, especially to understand the biophysical generation of services, their trends of production in a historical perspective as well as spatial and temporal scales. Simulation (*i.e.* the estimation of environmental variables through advanced computer-based modelling) can help with quantifying ecosystem services where direct observations are scarce or absent. Simulation-based valuation approaches are becoming useful to link where the services are produced and where they are consumed, and for exploring non-existing scenarios such as future climate and land use change. In many cases, simulation is a necessary method to quantify certain ecosystem services as direct measurements are difficult, such as measuring evapotranspiration rates, water balance at a certain geographical scale with the help of relevant hydro-meteorological data (Mulligan, 2013), and mapping/modelling of ecosystem services at landscape scale (Nelson and Daily, 2010). These approaches are increasingly used in ecosystem services valuation practices (see, Egoh et al., 2008; Nelson et al., 2009; Kienast et al., 2009).

Because simulations themselves are strongly reliant on input data into models, probably no clear distinction can be made between data based and simulation based evaluation practices. Indeed, many observations are themselves already the result of a complex processing flow. For instance, stream flow is almost never measured directly, but instead relies upon a stage – discharge model to convert water level into discharge (Beven et al., 2012). Such procedures inevitably introduce errors and uncertainties, which need to be taken into account when simulations are used to inform decision-making on ecosystem services. At the same time, simulation becomes ever more prominent, because of the need to go beyond the point or plot scale and simulate data and information at the policy-relevant scales such as site, basin or administrative region. Especially in data scarce regions, the simulation of environmental properties can be an important step towards integrated valuation of intended ecosystem services, as it allows quick identification of areas of high uncertainty and priority data collection needs for generating more robust simulations. While integrated valuation also requires relevant data from social system, it is also crucial to incorporate them into simulation practices.

Both data and simulation based approaches are highly relevant to MA's conceptual framework in which current trends and future state of services rely on a different sets of data and their simulated projections. In the case of TEEB framework, which is based on ecological functioning as well as social, economic and cultural values of services, both approaches could generate useful results for decision making. Since the IPBES framework links nature's services to human wellbeing, the simulation based approaches could support integrated valuation of services.

3.2. *Habitat* vs *system-based* vs *place-based approaches*

A habitat approach focuses on the valuation of ecosystem services provided by specific habitat units (Potschin and Haines-Young, 2013). This approach can be illustrated by the outcomes of several pilot study sites that looked at the prospect of making an assessment of intended ecosystem services at wider scale (Haines-Young and Potschin, 2008). The habitat approach is useful in identifying the unique roles of habitats that can generate service provisions and their multifunctional characteristics. For example, the valuation of ecosystem services provided by coastal habitats (Barbier et al., 2008) and wetland habitats (Ghermandi et al., 2009; Maltby, 2009) can be directly useful to improve the management of ecosystem services of these ecosystems, A habitat-based valuation approach may have a high degree of transferability to data sparse areas with similar habitat classifications or functions.

Although the habitat-based approach can explain the characteristics of intended ecosystem services at habitat scale, the approach deals very little with the flow of services from sources to beneficiaries because this tends to occur across habitats boundaries. The distribution of ecosystem services benefits is crucial for designing intervention measures. To overcome this gap, the system perspective can assess the chains of ecological processes that eventually give rise to ecosystem services goods and benefits (Potschin and Haines-Young, 2013). Quantifying biodiversity loss effect (on ecosystem functioning, change in provision of ecosystem services and consequences to human well-being are some of the examples of a system based approach (Balvanera et al., 2006). The system-based approach is useful to understand the ecosystem services functioning at a larger geographical scale, but that may make it difficult at the local scale, where the area of interest could be significantly smaller than the large system boundary.

Lastly, the place-based approach is also a common approach in ecosystem services valuation. Haines-Young and Potschin (2008) estimated ecosystem services of some selected areas in England. Costanza et al. (2006) estimated the values of natural capitals and ecosystem services provided by New Jersey State which might be useful for resources management at the state level. Similarly, there are several cases where researchers and development experts value certain ecosystem services at appropriate geographical scales such as river catchments and mountain and valleys (Hein et al., 2006 and Nelson et al., 2009). Since most policies and decisions are linked to place based perspective, the approach supports the generation of evidence for the value of services and how production and delivery may be improved for specific areas.

These three different approaches apply different valuation techniques (depending on the types of services to be assessed) and accordingly they influence decision making processes (Potschin and Haines-Young, 2013). For conservation management, habitat approach might be useful to better inform about biodiversity and ecosystem services of the area. Similarly, the system based assessment would improve the knowledge about the production of services, their flow and consumption. For example, it might be useful to characterize the biophysical generation of hydrological services and their flow from the source of production to beneficiaries. Finally, the place based approach is also useful to decision makers as most decisions are made at administrative region scale.

Although these different approaches are useful in different conditions, it would be practical if they are applied in a complementary way to value the ecosystem services more relevant to policy and decision making process (Haines-Young and Potschin, 2008). For example, habitat or place based ecosystem valuation could inform decision makers about a bundle of services. Biodiversity richness, water and landscape may provide completely different sets of services to humanity and that can be better understood by habitat, system or placed based approaches. Despite the complementary nature of three-way valuation approaches, without sufficient data, it might still not answer key questions at decision making levels with a high level of confidence. Such assessment can be more practical to data scarce regions if we integrate locally relevant data co-generation methodologies. Although the major frameworks have highlighted the importance of ecosystem services generated by habitats, system-based (such as ecological functioning) and place-based services, there is no direct relation to different methodological approaches to value services generated at local and data scarce regions.

3.3. *Specific* vs *entire portfolio based approaches*

The selection of valuation approaches depends on the types of ecosystem services that we intend to value at particular scale and specific context. Some valuation techniques are designed to value certain services such as water or carbon related services while some other approaches are developed for the valuation of the bundle of services. For example, WaterWorld approach is a spatially explicit modelling tool to estimate water related services such as water balance and quality (for *e.g*., sedimentation and human footprint) to support land and water resources based policies (Mulligan, 2013). Similarly, the Water Evaluation and Planning (WEAP) approach is developed to support integrated water resources management at different geographical scales (Sieber and Purkey, 2011). These approaches are specific to water related ecosystem services and their valuation. Since the hydrologic characteristics are highly dynamic both spatial and temporal scale, their successful use in integrated valuation depends on locally relevant data and knowledge.

Where there is a need for detailed valuation of different ecosystem services, the portfolio based approaches are designed to address such policy questions. The portfolio based valuation approach is useful to measure a range of services provided by the specific location. The valuation methods proposed in the InVEST (Tallis et al., 2013) and Costing Nature (Mulligan et al., 2010) tools are widely used for the valuation of a number of ecosystem services such as water, biodiversity and carbon. To achieve integrated valuation, a portfolio-based approach would be ideal, yet it again requires scientific data and knowledge that are often sparsely available at different geographical scales.

Since the lack of sufficient data is a major challenge for remote and data scarce regions, the outcomes of these approaches may not be comprehensive to support decision making. Application of participatory data and knowledge co-generation techniques could improve the valuation of specific as well as the bundle of ecosystem services. All ecosystem services frameworks require both specific and portfolio-based valuation approaches in order to value individual as well as the bundle of services. The choice of approaches is dependent on individual policy questions.

3.4. *Local* vs *regional approaches*

The geographical scale is a common classification for ecosystem services monitoring and valuation processes. There is a clear distinction within this classification - the approaches focused at local scale (which tend to be much more rigorous in terms of valuation) and the approach that are designed to assess services of much wider geographical scales at regional, national and international scales. A geographical approach has been advocated to characterize the structure and the dynamics of service providing units (Potschin and Haines-Young, 2011). Given its nature, it seems more straightforward to scale this approach to the local level.

The spatial scale of ecosystem services valuation methods can be divided into two major categories. First, the broad-scale assessment of multiple services which extrapolate a few estimates of ecosystem services values based on major natural capitals and ecosystem services, to entire regions or the entire planet (for e.g., Costanza et al., 1997; Troy and Wilson, 2006; MA, 2005; Rockström et al., 1999). Although the large scale assessment is useful for awareness raising to support conservation and sustainable development agenda in international scale, such a broad scale assessment of ecosystem services may have incorrectly assumed that every piece of land has equal value of assessed services (regardless of their variability in biophysical properties quality, rarity, spatial configuration, size, proximity to population centres or the prevailing social practices and values) (Nelson et al., 2009). Second, local scale assessment is usually focused on a single service in a small area where researchers carefully model the ecological production function to determine how provision of that service depends on local ecological variables (for *e.g*., Ricketts et al., 2004). Some of these production function approaches also use market prices and non-market valuation methods to estimate the economic value of the services and how that value changes under different ecological conditions (Nelson et al., 2009). Using plausible scenarios for land use change may help to understand the changing prospects of services in the most likely management conditions (see, Nelson et al., 2009; Nelson and Daily, 2010; Pandeya and Mulligan, 2013). Although these methods are superior to the broad scale assessment, such studies may lack both the scope (the number of services) and the scale (geographical and temporal) to be relevant for decision making processes that consider trade-offs between multiple services and occur over multiple scales. Furthermore, a local valuation approach necessitates local data (*e.g*. local market prices).

To integrate natural capitals and ecosystem services concept into policy processes, a combined approach of both small-scale rigorous analysis and the broad scale assessment is essential (see, Jackson et al., 2005; Naidoo and Ricketts, 2006; Egoh et al., 2008). Quantifying ecosystem services in a spatially explicit manner, and analysing trade-offs between them can help to make natural resource decisions more effective, efficient and defensible (Nelson et al., 2009). Using mapping and modelling tools may be a better option for the regional/watershed scale modelling but at a local level a combination of different approaches is important to quantify the available natural capitals and ecosystem services relevant to policy and decision making. Evidence also suggests that integrated valuation is more practical at local scale to capture the diversity of natural capitals and their services to people.

Most existing frameworks are focused at regional scales and there is limited focus at local scale valuation. The MA framework was largely based on the regional and global scale assessment of services. Although the TEEB framework is based on biophysical metrics to underpin ecological and economic valuations, there is no clear focus on how to address such valuation at local scale in data scarce regions. Therefore, while there is a need for an integrated valuation, it should be a balance approach that could address local scale valuation practices.

3.5. *Monetary* vs *non-monetary (ecological and cultural) approaches*

The monetary valuation of ecosystem services has a direct influence in policy and decision making since the approach can provide an easily comprehensible measure of how ecosystem services could be linked to human well-being. The focus of monetary valuation of ecosystem services has attracted political support for conservation but it also initiated a neoclassical paradigm to address environmental issues (Gomez-Baggethun et al., 2010). Although a number of studies have emphasized that the idea of monetary and non-monetary valuation processes is limiting our understanding of ecosystem services (Christie et al., 2012), it can help to internalize so-called externalities such as impacts and side effects so that they can be accounted into decision making processes. However, the use of economic valuation approach is somehow deficient to capture the actual values of ecosystem services into decision making (Laurans and Mermet, 2014). The economic valuation of nature can only be acceptable when management of ecosystems develops synergies between ecosystem services and biodiversity conservation, which can create improved environmental and socioeconomic conditions (Adams, 2014). A debate on economic valuation of ecosystem services is always critical depending on the types of services we value and the context of their uses at policy and decision making.

The economic valuation is generally divided into use and non-use values, each subsequently disaggregated into different value categories that are generally added up to the so-called Total Economic Value (TEV) framework (TEEB, 2010). The TEV framework is a widely used monetary valuation approach that views ecosystem goods and services as the flows of benefits from nature to humans. Values are assessed through the ways in which ecosystem services support people's own consumption (use values) and provide intangible human benefits (non-use values). Use values can be divided into direct use values and indirect use values. On the one hand, the direct use values can be further divided into extractive uses such as water, cereals and fisheries and non-extractive values such as eco-tourism and recreation. On the other hand, indirect use values result from the regulatory or supporting ecological processes that contribute to the ecosystem services giving rise to benefits, for example, improved forest coverage in tropical land can lead to increased water availability in the downstream areas (Bruijnzeel, 1990; Bruijnzeel et al., 2006).

For the elicitation of different value types, a range of monetary valuation techniques have been developed and increasingly refined to estimate the economic values of intended ecosystem services. Economic values are estimated based on either market transaction values of intended ecosystem services or in absence of such values, with the help of some kind of parallel market transactions that are associated indirectly with the ecosystem services to be valued or value estimation based on consumers' willingness to pay for the ecosystem services goods and services. Contingent valuation and choice modelling methods are also widely used to estimate the economic value of ecosystem services (Hanley et al., 2001). The above economic valuation methods come under one of the following three approaches - direct market valuation approaches; revealed preference approaches and stated preferences approaches. Values from original valuation study sites are sometimes applied to other sites/situations through 'benefit transfer' techniques (Barton, 2002). However, the practice of benefit transfer is highly contested from the 'value heterogeneity' perspective because the analyst performing the transfer makes assumptions about the decision context itself (unit value transfer), or the significant variables of the decision (benefit function transfer) being the same at all the sites values are transferred to. The requirements of benefit transfer are also the interest of ecosystem services mapping, which often extrapolate value estimates from specific study locations to a region.

It has always been a major challenge for environmental/ecological economists to put price (monetary value) on many natural capital and ecosystem services (Spangenberg and Settele, 2010). To understand the values of biodiversity, landscape beauty, cultural heritages and regulatory services of water and air, we need a robust non-monetary valuation method which can address specific contexts at local level. Non-monetary valuation usually expresses an explicit distinction from the valuation methods as it examines the importance of natural capital and ecosystem services (including cognitive, emotional, and ethical arguments), preferences, needs, or demands expressed by people towards nature (de Groot et al., 2010; Chan et al., 2012; Gomez-Sal et al., 2003). It offers alternatives and solutions to some of the methodological difficulties and limitations of monetary valuation (Baveye et al., 2013). Despite the growing number of scientific papers on non-monetary methods, non-monetary valuation methods have yet to be a formalized methodological approaches in ecosystem services valuation.

The non-monetary valuation methods cover a broad set of approaches that emphasize stakeholder participation in expressing individual, as well as group perceptions as part of the valuation process. The framework often applies coarse and arbitrary indicators and often produces results that are difficult to operationalize. The non-monetary valuation thus needs clear terminology and the delineation of the boundaries of this methodological framework (Kelemen et al., 2014). Understanding non-monetary values such as cultural and spiritual values of ecosystem services needs a different approach including identification of such services. In this context, developing the applicability of non-monetary methods to real world policies is paramount.

Both monetary and non-monetary valuation approaches are hugely important at decision making, and both may be equally practical at local scale, given some investment into knowledge co-generation at the scale of interest. Since the sustainable development is also closely related to economic well-being of people at local scale, it is important to estimate the gains and losses in terms of economic benefits. Similarly, assessing the social and cultural values of natural capital and ecosystem services would improve our understanding on how such values play their role in social well-being. Nevertheless, the economic valuation cannot stand alone as it has to be supported by the metrics of ecosystem services production, delivery and consumption. Thus, it has to be closely integrated with other valuation approaches including biophysical measurement of ecosystem services.

Looking through the lens of ecosystem services frameworks, the TEEB framework has an explicit focus on monetary valuation of services. Although the TEEB framework is based on biophysical metrics to support how services are produced, distributed and consumed, the economic measurements are crucial for supporting decision making. The framework recognizes the crucial role of economic valuation in policy and decision making. Compared to the TEEB framework, the MA and the IPBES are less concerned with the monetary valuation

Table 1
An overview of selected policy support systems for the local scale and in data scarce regions.

No.	Tools, accessibility and key references	Type of model and development stage	Policy implication at local scale	Limitations for data scarce regions
1	Artificial Intelligence for Ecosystem Services (ARIES); Web-based application http://www.ariesonline.org; (Villa et al., 2009, 2014; Bagstad et al., 2011)	An artificial intelligence and semantic modelling platform; Bayesian Network based model; Open source; documented some components of the model	Suitable for ecosystem services assessment, can be integrated into local decision making process such as PES scheme and conservation planning; limited functionality for climate change and land use change scenarios	No datasets provided by default; needs moderate to high level of expert knowledge;
2	WaterWorld model; Web-based application (http://www.policysupport.org/waterworld); (Mulligan and Burke, 2005; Bruijnzeel et al., 2011; Mulligan, 2013)	Detailed and process-based model; raster based modelling system; open source; documented	Used in policy and decision making processes; useful for scenarios analysis for LUCC and climate change; can be integrated into local decision making for water and land management	Linked with 'Simterra' - an online database of hydro-climatic, biophysical and some socio-economic data
3	Integrated valuation of Ecosystem Services and Trade-offs (InVEST); Web-based application (http://www.naturalcapitalproject.org); (Tallis and Polasky, 2009; Daily et al., 2009; Kareiva et al., 2011; Tallis et al., 2013)	An advanced model for quantifying and mapping multiple ecosystem services; open source; documented	Widely used in policy and decision making for water and land resources management; can be integrated into local decision making processes	Limited data availability, needs expert knowledge on GIS techniques; local data required
4	Co$ting Nature Model; Web-based application (http://www.policysupport.org/costingnature); (Mulligan et al., 2010)	Simple modelling tool for a much wider range of ecosystem services; open source; documented	Suitable for ecosystem services based policy and decisions; can be easily integrated into local decision making processes; no scenario analysis for LUCC and climate change;	Linked with 'Simterra' - an online database of hydro-climatic, biophysical and some socio-ec0nomic data, Local data required
5	Water Evaluation and Planning System (WEAP); Web based application (http://www.weap21.org/); (Sieber and Purkey, 2011)	Process based hydrological model with scenario analysis; well documented	Suitable for water resources based policy and decisions; can be integrated into local decision making processes; Limited physical processes for scenario analysis,	substantial data required for detailed hydrological modelling
6	Toolkit for Ecosystem Service Site-based Assessment (TESSA); Web-based platform of different approaches; (Peh et al., 2013)	A collection of models for quantifying and mapping values of multiple ecosystem services; Suitable for landscape based valuation	Suitable for ecosystem services based policy and decision making; can be integrated into local decision making processes	Substantial data are required to assess specific and/or the bundle of services

approaches. Since many decisions are directly influenced by economic values of natural capital and ecosystem services, integrating appropriate monetary (and non-monetary) valuation practices is crucial for integrated valuation of services and thus to support local livelihoods and promote local development.

4. An application to some commonly used policy support systems

Our discussion hitherto highlighted the wide variety of approaches to achieve ecosystem services valuation as guided by different frameworks. Yet, each valuation approach is designed for answering specific questions and looks a problem through a restricted lens instead of the full picture. Robust local scale valuation for policy and decision support seemingly requires a combination of more than one of these approaches, and would remain dependent on the availability of data and knowledge generated at that scale. This leads us to investigate whether spatial policy support systems can serve as an integrator of these various approaches.

Ecosystem services are distributed in space and time, so their values can be better understood by applying spatially explicit valuation methods (*e.g.*, Nelson et al., 2009; Nelson and Daily, 2010; Burkhard et al., 2012; Crossman et al., 2013). Some services such as hydrological and carbon related ecosystem services require mapping and modelling methods to simplify the complex system of biophysical generation of services and their spatial distribution across the landscape. Where data is not adequately produced, the use of spatially explicit policy support systems is immensely useful for decision support (*e.g.*, Mulligan, 2013). The spatial characterization of services from local to regional scales also makes decision support tools more relevant to policy and decision making at local scale that takes into account the multi-scalar properties of ecosystem services production and flows. Given the complexity of ecological systems and human interactions, there is a lot of expectation from spatial-based policy support systems; nevertheless these approaches are typically confined to addressing specific questions in ecosystem services valuation process.

Troy and Wilson (2006) emphasized that spatially explicit units are necessary because supply and demand for many ecosystem services are distributed geographically. For example, water related services distributed not only within the catchment but also far beyond of them. Similarly, the linkages between multiple ecosystem services, their interactions, synergies, trade-offs and tipping points vary in space and time. For data poor regions, an application of spatially based mapping and modelling techniques is essential to organizing existing knowledge and pave the way to a better understanding of ecosystem services in current state as well as in plausible scenarios in future. It is therefore appropriate policy support tools should be at the centre of integrated valuation of ecosystem services, how they function, produce services and flow to the actual beneficiaries (Burkhard et al., 2013).

Although a number of mapping and modelling tools have been developed in recent years to assess ecosystem services at different geographical scales (see, Mulligan et al., 2010; Bagstad et al., 2013), most of them are still in early stages of their development. Some tools are designed to assess a particular set of ecosystem services such as WaterWorld for hydrological ecosystem services (Mulligan, 2013), whereas some tools such as ARIES (Villa et al., 2014), InVEST (Tallis et al., 2013) and Costing Nature (Mulligan et al., 2010) are developed to assess individual as well as a portfolio of ecosystem services and strongly feature a monetary-based assessment. Some of these tools are also capable of assessing current pressures such as land use change impacts and future threats particularly climate change impact which is becoming an increasing concern in policy development. Despite an increased use of spatially explicit policy support systems, inconsistencies in methods and lack of the effective communication about their skills and limitations have been a key issue for policy and decision making levels (Crossman et al., 2013). In this section, we assess a selected number of mapping and modelling tools to illustrate this point, first by analysing their approach dimension(s) and second by identifying their key strengths and weaknesses for applications at local scale and in data scarce regions (Table 1, below).

Most of the spatially explicit policy support systems are now web-based and often freely available for mapping and modelling of different ecosystem services. However, their adopted methodological approach and current development stages vary significantly and that determines which decision support systems are suitable for data scarce regions. More importantly, the availability of data is a critical factor. For example, ARIES is a web-based modelling platform to assess different ecosystem services using a Bayesian network method, which is a systems approach to ES valuation, but the model is not pre-packaged with any datasets and therefore requires significant data collection efforts. InVEST and WaterWorld models are advanced and process-based models set up on a geographical scale to quantify ecosystem services, to visualize the benefits and trade-offs delivered now and in future to support sustainable development goals (Tallis et al., 2013; Mulligan, 2013). WaterWorld is also provided with a number of globally available datasets such as hydro-climatic, biophysical, land cover and some socio-economic datasets. This makes it very promising for data-poor mountains and remote areas, though the limits in accuracy and potential errors in these datasets need to be taken into account, especially in complex regions. In terms of complexity, the tools range from simple mapping tools for analysing the bundle of ecosystem services for conservation and management options such as Co$ting Nature (Mulligan et al., 2010), to complex models such as TESSA, which is a platform of accessible monitoring/modelling tools for identifying and assessing ecosystem services at site scale and comparing them with an alternative land use system (Peh et al., 2013). Although most policy support systems are designed for a more direct connection to policy and local decision making, a substantial amount of locally relevant data is required for local scale mapping and modelling of ecosystem services. Based on key valuation approaches adopted by different policy support systems, we try to assess their role in different valuation approaches (Table 2 below).

The selected policy support systems use different quantitative valuation approaches and all use data and simulation based approaches to characterize ecosystem services. Most of them are also system-based as they try to link how services are produced, flow and consumed. As all models are spatial-based, they are place-based systems and can be used at local to regional scale valuation. However, the data gap is a persistent issue at local scale for them. Models such as WaterWorld, InVEST and WEAP, have a clear focus on valuing specific services such as water related services, while some others such as Costing Nature and TESSA have portfolio based approaches as they are designed to value a bundle of services. Despite efforts made by some approaches to estimate monetary valuation, most policy support system use non-monetary valuation approaches.

Most policy support systems are useful for assessing services at regional and river basin scales (for example, Pandeya and Mulligan, 2013; Malinga et al., 2015; Bark et al., 2016) but have seen limited application for detailed mapping and modelling of ecosystem services at the local scale. This mainly the result of a lack of methodological robustness and data gap at that level. Nevertheless, they can be useful to make "first guesses" in the absence of local scientific knowledge, through the use of knowledge and datasets generated away from the local site. This is particularly the case for spatially explicit systems, which are best placed to incorporated globally available datasets such as maps and satellite products (Vrebos et al., 2015). Such first estimates may then provide a useful baseline to assess the value of new, locally collected data, including potentially the incorporation of situated or local knowledge. This can give rise to a process of co-creation of knowledge through a critical, participatory review of these preliminary estimates by the decision makers and other local stakeholders (Karpouzoglou et al., 2016), who can then make decisions either based on incomplete or uncertain information, or to improve the quality of information by initiating local monitoring (*e.g.*, Buytaert et al., 2014; Buytaert et al., 2016). We further explore this idea in the next section on making integrated valuation work for local scales and in data scarce regions.

5. Towards an integrated approach to value ecosystem services at the local scale and in data scarce regions

Decision makers need detailed information about ecosystem services to make decisions that impact livelihoods and sustainable development at local scale. For instance, mapping ecosystem services at high spatial resolution tends to support land management practices at field to village scales (Malinga et al., 2015). Similarly, understanding temporal variation in ecosystem services also plays an important role (Hein et al., 2016). However, although new data and knowledge is constantly being generated, the degree of uncertainties is often high, and needs to be treated explicitly in policy support systems to support adequate decision making. The previous sections have shown that although different frameworks are emerging to value ecosystem services, there is still a need for a more coherent approach for ecosystem services valuation especially at the local scale and in data scarce regions. Only an integrated approach makes it possible to explore the linkages of the functioning of various ecosystems and their values in terms of biophysical generation, socio-economic and human well-being (Gomez-Baggethun et al., 2014). This is necessary to provide evidence to identify management options that optimise public benefit across the breadth of ecosystem services, avoid potentially significant costs and risks arising from overlooking implications for some services, or expose transparently the social and economic costs implicit in any trade-offs.

Our review indicates that it is unlikely that a single valuation approach will be able to value accurately the variable and contextual nature of ecosystem services in extremely diverse local environments. Different valuation approaches may have specific and complementary roles in integrated valuation of ecosystem services. This is in line with Haines-Young and Potschin (2008) who argue that three different but complementary approaches (such as habitat, system-based and place-based approaches) could make very positive contribution in valuation of biodiversity and ecosystem services. It is therefore a detailed valuation may require a tailored combination of specific approaches to address specific policy and decision related questions. For example, for the evaluation of major hydrological ecosystem services, a spatial analytical approach may be useful to quantify provisioning and regulating services, the aesthetic and cultural values of same water resources require an effective non-monetary valuation approach.

Researchers have too often ignored the fact that the location of ecosystems, their human beneficiaries and the biophysical nature of

Table 2
Classification of different policy support systems and their valuation approaches.

	Data-based	Simulation-based	Habitat-based	System-based	Place-based	Specific-	Portfolio-based	Local	Regional	Monetary	Non-monetary
ARIES	√	√		√	√		√	√	√		√
WaterWorld	√	√		√	√	√		√	√		√
InVEST	√	√	√	√	√	√	√	√	√	√	√
Costing Nature	√	√	√		√		√	√	√	√	√
WEAP	√	√		√	√	√		√	√		√
TESSA	√	√	√	√	√		√	√	√	√	√

ecosystem service flows affect how much of a service is actually used by people (Brauman et al., 2007). Since ecosystem services are spatially explicit, the emergence of tools for systematic mapping and modelling at appropriate scales is therefore very promising (Crossman et al., 2013). A number of GIS based mapping and modelling tools is emerging, which can play important roles in detailed exploration of ecosystem services to support policy and decision making (Maes et al., 2012; Hauck et al., 2013; Mulligan, 2013). Process-based modelling tools to estimate the ecosystem services provided by water and land resources are particularly promising, as their application could make the valuation practices more integrated and facilitate the decision making. However, as data availability of diverse ecosystem services increases over time, and the spatially explicit models themselves also evolve further, it becomes increasingly important to assess accuracy and reliability of mapping and modelling tools for ecosystem services valuation (Schroter et al., 2015).

We identify several pathways for future improvement. First, economic valuation of ecosystem services is fundamental in an integrated valuation (Gomez-Baggethun et al., 2014), however, it should aim at determining services generation and the delivery in biophysical terms, to provide ecological underpinning to the decision making (TEEB, 2010). Making a distinction between functions, services and benefits is important to make ecosystem services valuation more accessible to economic valuation, although no consensus has yet been reached on how to classify ecosystem services. Valuation processes should be guided by the perception of the services providers and beneficiaries - a better way to linking valuation process for payment for ecosystem services mechanism.

In addition, the valuation should be done using alternative but best plausible scenarios – recognizing that both the values of services and the costs of human interventions can be best measured as a function of changes between alternative options. Using scenario analysis is now being recognized as an important part of ecosystem services valuation process to understand the counterfactual evidence (especially in conservation management) in a rapidly changing world. While assessing trade-offs between alternative uses of ecosystems, the total bundle of ecosystem services provided by different conservation and development practices should be included. It is also important for monetary valuation, since scenarios enable analysis of changes in service delivery which are necessary to obtain marginal values. For an integrated valuation in which different scenarios are tested for better understanding of potential changes in ecosystems and resulting ecosystem services, data and knowledge co-generation activities at local level are crucial and they enable the valuation process.

Lastly, valuation can be done in different ways as valuation needs to be driven by local needs, by means of assessing the total contribution that ecosystems make to human well-being, to understand the incentives that individual decision-makers face in managing ecosystems in different ways, and to evaluate the consequences of alternative courses of action. The mapping and modelling scales should be meaningful for policy interventions, inherently acknowledging that both ecological functioning and economic values are contextual, anthropocentric, individual-based and time specific.

In such conditions, inclusive and participatory monitoring of ecosystem services may have a large potential, especially in local and data scarce environments where conventional data and knowledge generation practices may not be sufficient to support policy and decision making, such as remote mountainous areas (Buytaert et al., 2014). Participatory data and knowledge co-generation may not only support a better management of ecosystem services but also their adaptive use for improving local livelihoods (Buytaert et al., 2014, 2016). Participatory approaches and other ways of embedding local knowledge and preferences may also make valuation process more policy oriented. It is paramount, then, that the use of such approaches is explored further as a way to increase the efficiency and local relevance of the generation of actionable knowledge. Finally, embedding aspects of citizen science approaches into ecosystem services valuation may be able to generate locally-relevant evidence to support local decisions.

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