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Valuing a diversity of ecosystem services: the way forward to protect strategic groundwater resources for the future?

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Abstract

This paper demonstrates the usefulness of valuing a diversity of ecosystem services for groundwater protection. It argues that improving the understanding of local stakeholders regarding the benefits that strategic groundwater preservation for future generations can bring to their territories is a relevant mean to enhance their support towards groundwater conservation. We develop and test a systemic approach based on local data collection, cost-based monetary valuation methods and stakeholder involvement. The paper reports on empirical work conducted in a strategic groundwater area located in Southern France, that could be of interest in the future to supply the growing population of coastal urban areas. We characterize, quantify and valuate in monetary terms nine ecosystem services. We then analyze the perception of the proposed approach, ecosystem services and associated monetary values by organising a workshop involving 25 local stakeholders. Overall, participants validate the operational feasibility and the relevance of the approach for raising awareness and bridging the gap between environmental issues, which can be effective triggers to the implementation of protection action. Yet, monetary valuation provides only partial insights into the overall value of the benefits of protecting the strategic groundwater area, and would improve from being articulated with socio-cultural valuation methods.

Keywords: groundwater protection, drinking water safeguard zones, ecosystem services, monetary valuation.

1. Introduction

Providing almost half of drinking water worldwide, groundwater resources are of primary importance for human consumption (Smith et al. 2016). The availability of good-quality groundwater is a major concern for the estimated 2.5 billion people that rely solely on groundwater to satisfy their daily water needs (WWAP 2015). Yet, over the long term, the ability of groundwater resources to fulfil these needs is likely to be compromised by projected global changes. Demographic growth will increase global demand for freshwater. Meanwhile, continued urbanization, unsustainable agricultural practices and climate changes are expected to reduce groundwater recharge and jeopardize water quality (Jiménez Cisneros et al. 2014; MEDDE 2013), increasing thereby the vulnerability of entire water supply systems.

Since the 1960s, awareness has progressively risen among land managers and policy makers regarding the vulnerability of communities to groundwater resource pollution and depletion, stressing the need to secure current and future water supply. In many countries, this led to establish drinking water protection areas (DWPA) designed to improve the quality of groundwater resources currently used for drinking water supply. Following the requirements of the European Water Framework Directive (article 7.1), French water agencies have recently included the establishment of drinking water safeguard zones (DWSZ) in their river basin management plans. Compared to standard DWPA, the newly established DWSZ cover strategic good-quality groundwater resources with a high productive potential that are located close to future high-consumption areas. These resources are used or not for human consumption, but they are of great interest for future drinking water supply. For local water managers, the objective is not to restore good-quality but to guarantee that in the future, land-uses and management practices will remain compatible with the maintenance of a good-quality groundwater resource.

Currently in France**,** there is no clear view on the policy instruments that will support the protection of the dozens of recently delineated DWSZ. A large range of policy instruments has already been implemented to protect groundwater resources used for drinking water production: e.g., legal instruments for public land control and land use regulation (Blanchard et al. 2015; Pivot and Aznar 2000), water related agri-environmental measures, or voluntary agreements (Barraqué and Viavattene 2009). However, most of them are not legally enforceable in case of unused strategic groundwater whose potential exploitation could benefit future generations. Due to the non-binding nature of these zones, the effective protection of DWSZ may face several challenges in practice (Hérivaux and Grémont, 2015). First, benefits of groundwater protection policies for drinking water are only likely to materialize in the long term, and their beneficiaries are hardly aware of their

existence, while protection costs are immediate, tangible, and affect well-organized vested interest groups (e.g. businesses, farmers). Thus, land managers struggle to advocate for protection policies when they are faced with competing development projects likely to bring, over the short term, new markets and employment to local economies. Second, because they are legally responsible for continuity of water supply, water services tend to prefer engineered solutions (e.g. treatment plants, network interconnections) whose effects are easily monitored, to groundwater protection policies whose effectiveness and time delay may be highly uncertain. Finally, the lack of coercive groundwater protection measures for unused strategic groundwater and the relative small amounts of available public financial resources dedicated to their preservation, which do not outweigh the costs of most required land-use changes, provide little incentive for stakeholders to implement ambitious policies. We argue that one powerful lever to overcome these barriers is to enhance the support of local stakeholders, by improving their understanding of the economic benefits that groundwater preservation can bring to their territories.

This paper first introduces the shortcomings of conventional economic approaches for assessing the overall long term economic benefits of preserving strategic groundwater resources. It proposes a systemic approach accounting for the diversity of ecosystem services provided by DWSZ, based on local data collection, cost-based monetary valuation and stakeholders involvement. It then investigates the operational feasibility of the approach through a case study located in Southern France and demonstrates its relevance for raising awareness and knowledge of the economic benefits provided by DWSZ protection.

2. Shortcomings of conventional economic valuation of the benefits of DWSZ protection

Two types of monetary valuation methods are commonly used to assess the economic benefits of groundwater protection: the avoidance-cost method and the contingent valuation method. However, both face limitations for assessing the long-term benefits of DWSZ protection. The avoidance cost method (e.g., see Abdalla 1994; Rinaudo et al. 2005) consists of assessing the costs of averting and defensive actions undertaken by economic agents to cope with groundwater degradation (e.g., closing and relocating wells, building water treatment plants, purchasing bottled water), considering that these costs would be *avoided* if the resource was not degraded. Comparing these avoided costs to the costs of protection policies can typically help strengthen the rationale for groundwater protection on DWSZ characterized by a low ratio of protection costs over avoided costs. Since protection costs depend upon the surface of the protected area and avoided costs depend upon the abstracted volume of water, the cost of watershed protection can be more easily justified in watersheds where $S \times C_P < V \times C_A$, that is when $V/S > C_P/C_A$, where S the surface of the protected area (ha), C_P, the protection costs (€/ha/year),

V the abstracted volume (m^3/year), and C_A, the avoided costs (€/m^3). To illustrate this point, Figure 1 depicts the abstracted volumes and surfaces of 178 DWSZ recently delineated in France. We distinguish DWSZ that are already considered as strategic for current use, from DWSZ deemed strategic for future use. From there, let us draw two lines based on the following orders of magnitude taken from the literature: avoided treatment costs ranging between 0.46 and 0.80 € per abstracted cubic meter[1] and protection costs ranging between 125 and 250 €/ha/year[2]. Avoided costs may be sufficient to justify by themselves the protection costs of 79% of the DWSZ, which are already used for drinking water. On the other hand, avoidance costs can hardly be used to justify the protection of 74% of the DWSZ delineated for future use, and characterized by low V/S ratios, as future drinking water abstraction are typically unknown.

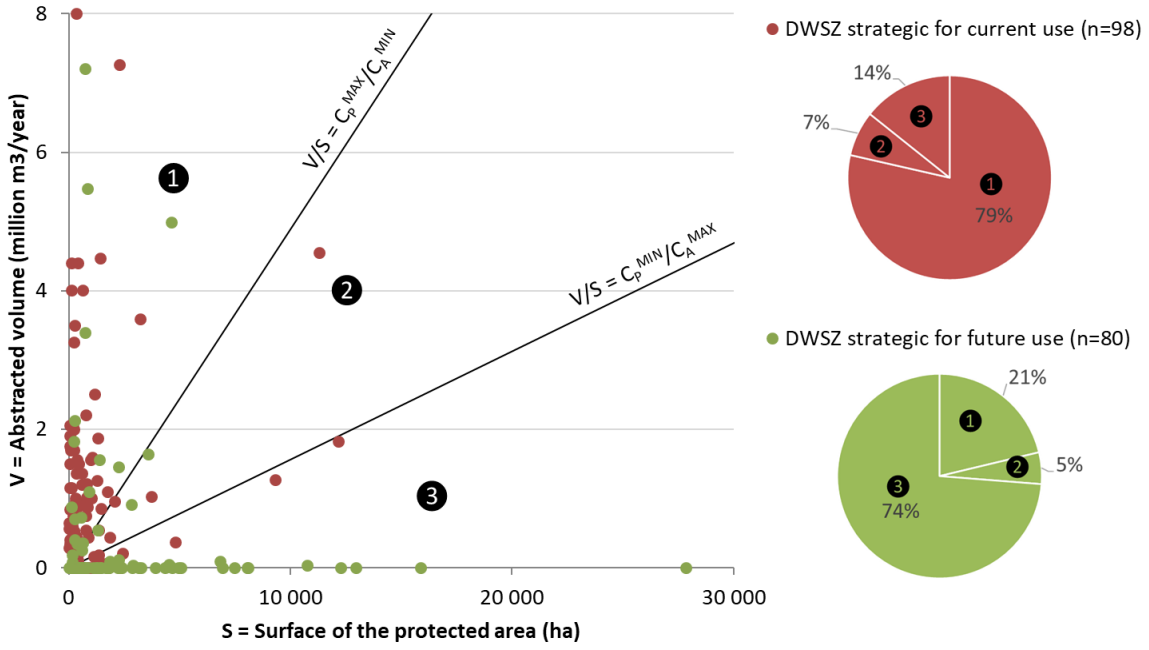


Figure 1. Abstracted volume and surface of 178 DWSZ recently delineated in France. Estimates of the proportion of DWSZ for which protection measures can be economically justified by the avoided treatment costs (❶ and ❷) or not (❸). Considered avoidance costs (C_A) vary between 0.46 and 0.80 €/m^3 produced; protection costs (C_P) vary between 125 and 225 €/ha/year.

[1] In France, Bommelaer and Devaux (2011) estimates that water treatment costs range from 0.40 to 0.60 €/m^3 for the treatment of nitrates and from 0.06 to 0.20 €/m^3 for the treatment of pesticides.

[2] We use here the average drinking water watershed protection costs of the cities of New York and Munich, often used as examples to illustrate that groundwater protection may be cheaper in the long run than curative actions. In New York, the Catskill watershed (518 000 ha) protection program costed the community 1.15 billion € from 1997 to 2007, i.e., 225 €/ha/year (Barraqué and Viavattene 2009; Chichilnisky and Heal 1998; Grolleau and McCann 2012). Similarly, the German city of Munich implemented a preventive program costing 750 000 €/year to protect a 6000 ha watershed for drinking water, i.e., 125 €/ha/year.

Stated preferences methods, such as the contingent valuation method (Poe et al. 2000; Hérivaux and Rinaudo 2016), are alternative conventional approaches used for assessing the benefits of groundwater protection. The contingent valuation method relies on the implementation of surveys to elicit people's willingness to pay for hypothetical environment improvement scenarios. This approach enables to highlight people's preferences towards groundwater protection, and economic values, which are not directly related to the use of groundwater. An abundant literature describes the potential bias associated with the use of the contingent valuation method for valuing environmental goods (Venkatachalam 2004). Hérivaux and Rinaudo (2016) suggest that there are additional problems related to the specific characteristics of groundwater. The first major concern is that respondents may have a very limited knowledge of the environmental asset they are asked to value, especially when they do not use groundwater directly as it is the case for DWSZ strategic for future use. The second limitation is related to embedding effects: people may be unable to assess the benefits derived from the protection of a specific delineated groundwater resource, as (1) groundwater is generally perceived as a uniformly distributed resource and (2) groundwater management actions are expected to bring a wide range of environmental benefits. This casts doubt on the meaning of the individual preferences elicited by the survey. Finally, the avoidance cost and the contingent valuation methods both refer to benefits directly related to groundwater, without considering co-benefits generated by protection policies.

Yet, as DWSZ protection generally consists in maintaining land-uses and activities compatible with good-quality water, the benefits of groundwater protection may go well beyond water security and cover a wide range of co-benefits including protection against erosion, carbon storage, wood production, agricultural production, hunting or fishing (Abell et al. 2017). Current practices of groundwater policy assessments fall short of adequately accounting for these multiple benefits (Bouwma et al. 2018). Against this backdrop, several public policies have highlighted the need to increase sectorial policy integration, including the European Water Blueprint or the global Aichi targets set by the Convention on Biological Diversity (European Commission 2012; CBD 2010). This reinforces the interest of assessing the multiple benefits of groundwater management (Abell et al. 2017; Nel et al. 2017). The ecosystem services valuation framework offers an interesting analytical framework to assess the wide range of benefits provided by groundwater protection. An abundant literature has emerged on ecosystem services characterization and valuation since the Millennium Ecosystem Assessment (Costanza et al. 2017; MEA 2005). While it is common practice to characterize the ecosystem services associated to land-use change scenarios, conservation programs or protected areas (Bateman et al. 2013; Castro et al. 2015; Johnson et al. 2016), economic assessments focusing on ecosystem services provided by groundwater protection remain scarce

(Aguilar et al. 2018) and still mostly focus on water-related services (Brauman et al. 2007; de Groot et al. 2012; Keeler et al. 2012; Nel et al. 2017; Nelson et al. 2015; Vlachopoulou et al. 2014; Wang et al. 2017). Abell et al. (2017) address this gap and explore the co-benefits resulting from source water protection investment (including climate change mitigation and adaptation, biodiversity, and human health and well-being). The recent work of Aguilar et al. (2018) investigates with a discrete choice experiment how population perceives and values different ecosystem services arising from forested watershed ecosystems in the US in general, without referring to any specific watershed. Liquete et al. (2016) highlight the diversity of benefits provided by nature-based solutions for water pollution control through a multi-criteria analysis. The present paper contributes to this emerging trend. It proposes a pragmatic valuation framework enabling to account for the diversity of benefits provided by protecting strategic groundwater resources for the future. We apply this valuation framework to a DWSZ located in southern France.

3. Material and method

3.1. Case study presentation

The DWSZ of the *Contreforts Nord de la Sainte-Baume* is located 40 km from the Mediterranean coast and covers over 7,400 ha dominated by woodlands and semi-natural areas. The karstic aquifer hosts important good-quality groundwater volumes that could supply approximately 4 Mm^3 per year, of which only 1 Mm^3 is currently used for drinking water. This underexploited water resource has been identified by the local French Water Agency as a strategic resource for urban coastal areas where water demand is expected to rise significantly in the coming decades due to both tourism and demographic growth. In a context of increasing tensions over water resources and strong urban development, failing to preserve the watershed would result in land-use shifts likely to affect water quality (e.g. urban sprawl, quarry exploitation). Therefore, preserving current land cover on the DWSZ is a major concern for local authorities.

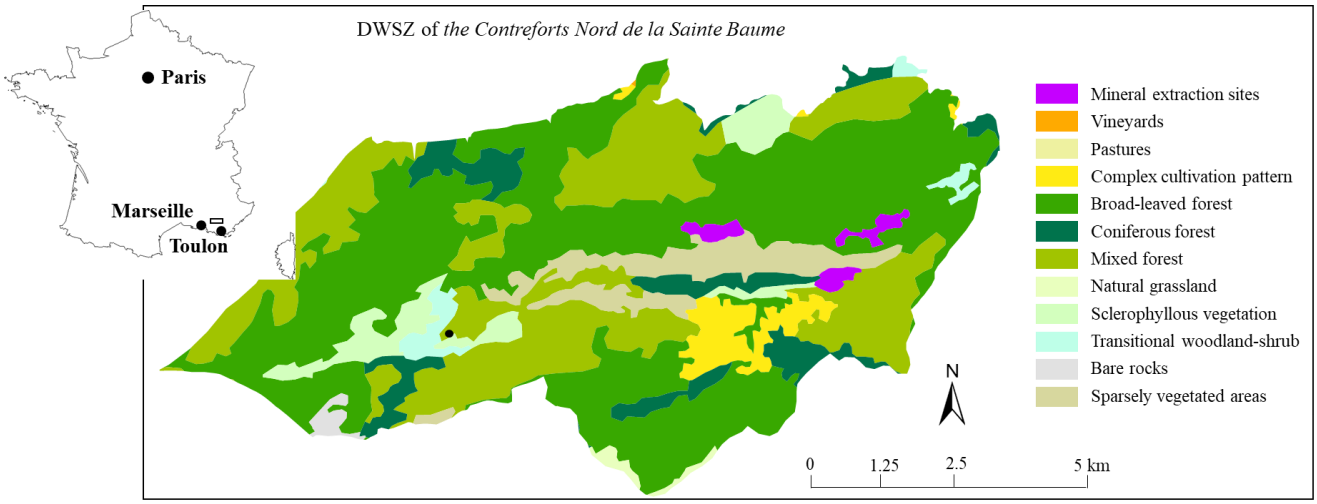


Figure 1. Geographical location and land-cover on the DWSZ (Corine Land Cover)

3.2. Overview of the methodological framework

The methodological framework consists in assessing the ecosystem services provided by the DWSZ in order to highlight the multiple benefits stemming from maintaining the area in its current state. In line with the Common International Classification of Ecosystem Services (CICES), we classified ecosystem services into three categories: (i) *provisioning services* that encompass all nutritional, material and energetic outputs from ecosystems from which goods and products are derived (i.e. agricultural and wood production), (ii) *regulating services* that cover all the ways in which ecosystems can mediate or moderate the ambient environment in which people live or upon which they depend (i.e. carbon sequestration and storage, water cycle regulation and flood protection), and (iii) *cultural services* that include all the non-material characteristics of ecosystems that affect the physical, mental or intellectual well-being of people (i.e. hunting, fishing, hiking and speleology) (Haines-Young and Potschin 2018). This classification attempts to describe ecosystem outputs as they directly affect human well-being. As a result, it sets aside supporting services such as biodiversity that are considered as intermediate services that people do not directly use or consume but that contribute to ecological processes and structures without which the provision of other ecosystem services would not be possible (Fisher et al. 2009; Wallace 2007).

Our approach follows three main steps: (1) identification of the set of ecosystem services provided by the DWSZ, (2) characterization and monetary valuation of these ecosystem services, and (3) organization of a workshop gathering local stakeholders in order to present and debate the results of the assessment.

3.3. Identification of ecosystem services

Based on the available literature (e.g. urban planning management plans, water utility technical reports) and GIS data (e.g. Corine Land Cover, National Institute of Geographic and Forest Information, agricultural census), a set of ecosystem services likely to be provided by the DWSZ has been identified. Landowners, land users, managers and beneficiaries of these services have been characterized. This first step was completed when necessary with telephone interviews with local stakeholders. It enabled pre-identifying 13 ecosystem services typically provided by the land cover types currently found on the DWSZ as well as the stakeholders involved in their provision.

A series of face-to-face interviews was then carried out with these stakeholders in order to (i) validate the set of ecosystem services provided by the DWSZ and (ii) collect the bio-physical and economic data necessary for the assessment. Interviewed stakeholders included local policy-makers, land managers, state representatives, environmental associations and water utilities. Out of the 13 pre-identified ecosystem services, nine were selected following the interviews. The remaining services were excluded from the assessment due to missing data.

3.4. Characterization and valuation of ecosystem services

The information gathered was used to quantify ecosystem services using both bio-physical and socio-economic indicators (e.g. tons of carbon captured, volume of abstracted water). Indicators were then translated into monetary units using mostly price and cost-based monetary valuation techniques (e.g. market prices, replacement costs, avoidance costs). When uncertainties were high, several assessment methods were used to produce a range of benefits. This resulted in estimating an order of magnitude of the minimum economic value of the ecosystem services provided by the DWSZ that reflects the overall benefits of preserving the DWSZ.

The following paragraphs describe the methodology used to assess each individual ecosystem service. Unless otherwise specified, all economic values are expressed in $€_{2013}$ and all data refer to the reference year 2010.

Wood production

Woodlands cover 83% of the area, comprising 4 075 ha of broadleaf trees and 2 028 ha of coniferous trees. Because of low-productivity forests and unorganized supply chains, sylviculture brings little revenues to local economies. Accounting for forest proprietorship and related management practices, we estimated that only 67% of woodlands are exploited for wood production on the DWSZ (OFME 2003), according to a selective harvesting that is based on annual growth rates of trees and maintains forest canopy structure. The economic

value of wood production was estimated using the market price method that consisted of valuing wood production according to the market price of standing wood, taking into account that market prices vary according to the final use (fuel, construction, furniture), and that the final use, in turn, depend upon tree species. According to local stakeholders, in the region, broadleaf wood is mainly dedicated to firewood for a stumpage price for tree stands (without exploitation costs) of 10-35€/m^3. As for coniferous wood, it is delivered to the paper industry for a price of 10-15€/m^3. Other outlets for conifers include wood energy and pallet production, for stumpage prices of respectively 12€/m^3 and 100-130€/m^3. Due to higher market prices, revenues from broadleaf species are therefore higher than revenues from conifers. However, annual growth rates of trees are lower for broadleaf species (1.3-1.5 m^3/ha/year) than for conifer species (3m^3/ha/year) (National Forest Office).

Agricultural production

Agricultural lands account for 3% of the area. Production activities are essentially dedicated to mixed crop-livestock farming, with 25 ha devoted to fruits and vegetables, 362 ha of grassland used for extensive goat and cattle grazing (99 livestock units), and 93 beehives producing on average 3 tons of honey per year. The economic value of agricultural production was estimated using the market-based method. Revenues from beekeeping production were estimated using the average gross operating profit per hives in France (103 €/hive), taking into account the relative yield differential between the French average (24 kg/hive) and local production (32 kg/hive) (Union of French Apiculture). Livestock production was estimated using the mean gross operating profit per livestock unit (LU) in the region for goat farming (Agreste) and cattle farming (Institut de l'Elevage 2012). As for the economic value of land cultivation, it was assessed using mean gross operating profits in *Provence-Alpes-Cote-d'Azur*, per hectare, per year, and per type of culture (719 €/ha/yr for fruits, 7 985 €/ha/yr for vegetables and 9 938 €/ha/yr for horticulture) (French agricultural census).

Carbon sequestration and storage

Forests and grasslands contribute significantly to climate regulation (IPCC 2014). On the one hand, they absorb carbon-containing atmospheric compounds during photosynthesis. The absorbed carbon is stored within soil (in organic form) and biomass (both above-ground such as in leaves or branches, and below-ground such as in roots). On the other hand, they release carbon dioxide through respiration, combustion and decomposition. The difference between the amounts of carbon absorbed – which depend upon vegetation growth – and released – which depend upon harvests and tree mortality – is the *annual carbon sequestration*, expressed in t-eqCO_2/year. On the long run, the total amount of carbon sequestrated over the ecosystem lifetime is the *carbon storage*,

expressed in t-eqCO_2. On the DWSZ, most of the carbon is sequestrated and stored in soils and biomass by forests that account for 83 % of the area.

The annual carbon sequestration of forests was estimated using two indicators of the net annual growth rate of trees provided by the National Forest Office (local average) and the National Institute of Geographic and Forest Information (regional average). Net growth of trees was then combined with carbon sequestration coefficients per tree species in France (Loustau 2004). For grasslands, a similar approach was adopted based on national carbon sequestration coefficients (Puydarrieux and Devaux 2013).

The amount of carbon that is stored over the long run varies according to the relative share of carbon that is stored above and below ground. For forests, the volume of standing timber was estimated based on a regional average (Institut Forestier National 2012). Two hypotheses were then formulated in line with recent literature. First, we considered that 2/3 of the carbon stored was stored below ground (in biomass and soils) against only 1/3 stored above ground (Dupouey et al. 2002). Second, we considered that respectively 3/4 and 1/4 of below and above ground carbon were stored over the long term (Chevassus-au-Louis 2009). For grasslands, carbon stored in above-ground biomass was considered negligible (Puydarrieux and Devaux 2013). Long-term carbon storage by grasslands was therefore estimated using coefficients representing the average amount of carbon stored in soils by south eastern grasslands of France over the long-term (Arrouays et al. 2002).

Finally, two valuation methods were used to assess the economic value of carbon sequestration and long-term carbon storage. The market price method valued each ton of sequestrated and stored carbon at the average spot prices of CO_2 Emission Allowances on the EU Emission Trading System (i.e. 13€/teqCO_2 in 2010). As for the social cost of carbon method, it valued carbon sequestration and storage at the marginal global damage costs of carbon emissions, that is the net present value of climate change long-term impacts of one additional ton of carbon emitted today (Watkiss and Hope 2011). It was assessed using the shadow value of carbon estimated in France by the Quinet commission to 32€/teqCO_2 in 2010, increasing at a 5.8% annual rate so as to reach 100 €/teqCO_2 in 2030 (Quinet 2008). For long-term carbon storage, a discount rate of 2.5% was used over a 30 year time period (Quinet 2013).

Flood protection

The main flood-related risk on the DWSZ pertains to overflows of the Caramy River. Located at the head of the river, the DWSZ contributes to flood protection since it is mostly covered by non-artificialized areas (croplands,

grasslands, forests) that store large volumes of water underground, reducing thereby runoffs and associated flooding. Two methods are commonly used to assess the economic benefits of flood protection. The avoidance cost method (Ninan and Inoue 2013) estimates the damage costs of past events but requires historical data that was not available in our case study. An alternative method is the replacement cost method that consists of estimating the volume of water stored by current land cover in order to assess the mean annual cost of an alternative water storage facility. According to local hydrogeologists, the available water storage capacity in the limestone soils of the DWSZ ranges from 50 to 150 m^3/ha. The alternative water storage facility is assumed to be a dam that would be constructed on the Caramy River and whose construction and operation costs were estimated using the mean costs of five different dams built in France during the past 40 years (Bouscasse et al. 2012). A discount rate of 2.5% was used over a 100 years lifetime.

Water cycle regulation

The approach adopted to assess the water cycle regulation service consisted of assessing the benefits associated with maintaining in its current state a land cover capable of recharging the aquifer (quantity) as well as filtering and purifying the water during its transfer to the aquifer (quality). The beneficiaries of this service are residential users whose drinking water is currently extracted from the aquifer. Benefits were estimated by comparing the current situation with a situation that would require resorting either to another resource for drinking water supply, or to a water treatment facility. Two valuation methods were used: the avoided costs of water treatment and the avoided costs of a network interconnection with an alternative resource. The avoided costs of water treatment were estimated based on the mean cost of water treatment in France (0.46-0.8 €/m^3 depending on treatment types) (Bommelaer and Devaux 2011). According to local stakeholders, since the DWSZ is already crossed by a large water pipe that transports surface water from the Verdon River to the coast (i.e. the *Canal de Provence*), a straightforward alternative if the aquifer was no longer able to provide enough good-quality water would be to resort to the water provided by the *Canal de Provence*. Considering that the costs of connecting to this pipe are negligible, the avoided costs of interconnecting with an alternative resource were estimated by directly comparing water prices for consumers that are currently supplied by the aquifer with those that are currently supplied by the *Canal de Provence*. The assessment was undertaken taking into account differences in water utility management (direct public management or public service concession). All assessments accounted for technical efficiencies of local drinking water networks.

Fishing

Fishing is practiced for recreational purposes, mainly on the Caramy and Issole Rivers that are fed partly by the DWSZ groundwater. Through their role in low water replenishment, groundwater resources contribute significantly to the sustainability of the surrounding environment which favors fish species development and related fishing activities. We assume that groundwater degradation would strongly compromise these activities. According to local angling associations, 2,332 anglers are regularly practicing on the DWSZ. The market value of the benefits driven from recreational fishing is estimated based on fishing-related expenditures incurred by anglers (Toivonen et al. 2004). Details of expenditures were gathered from six local angling associations. They depend on the type of fishing permit subscribed (e.g. adult, child, woman, annual, daily) whose cost varies from 5 to 69€/year, the share of members actually practicing on the DWSZ (the area covered by each association being larger than the DWSZ) and additional expenditures for equipment, food and transportation, estimated in the region to 273 €/angler/year according to a survey carried out in 2012 by the Departmental Angling Federation.

Hunting

Big-game hunting is practiced during shooting parties for recreational purposes. According to local hunting associations, about 400 hunters are regularly practicing on the DWSZ. Related expenditures are used to assess the market value of hunting activities. They include a national hunting license (300€/year), hunting rights delivered by local hunting societies whose prices range from 70€/year for local residents to 120€/year for non-residents, and additional expenditures for hunting dogs, equipment, food and transportation (1,200 €/hunter/year).

Speleology

The DWSZ attracts speleologists drawn by its numerous cavities (mainly caves and abysses), as well as two local remarkable sites. Speleological activities have strong links with scientific research activities in hydrogeology aiming at better understanding the functioning of karst aquifers. Approximately 50 speleologists are regularly practicing on the DWSZ (1 to 3 trips per month). Expenditures include the annual membership to the National Federation of Speleology (115€/member/year), the membership to a local association (5 to 30€/member/year) and additional expenses for equipment (1,000€/member renewed every 5 years) and food (5 €/trip).

Nature walks and cultural heritage

Although located in the vicinity of the Sainte-Baume national forest, the DWSZ lacks infrastructures to attract overnight visitors (one museum, three hiking trails, one bed and breakfast, one restaurant and two bars). Visitors are mainly local day-tripper practicing nature walks through the forest. In the absence of accurate visitor counting, the frequentation of the DWSZ has been estimated by applying a mean visitor rate to the 3,600 ha of public forests that are accessible to visitors. Two hypotheses were used. The mean visitor rate of forests in France (58 visitors/ha/year) (Chevassus-au-Louis 2009) was first used, resulting in an estimated 212 000 visitors/year on the DWSZ. This rate was then halved in order to account for the existence of substitutes (Gomez-Baggethun and Barton 2013) and the relative smaller attractiveness of the DWSZ compared to most French forests, resulting in an estimated 106 000 visitors/year on the DWSZ.

Two economic valuation methods were then applied. First, the results of a survey of visitor expenditures carried out on local day-trippers in a remarkable site located nearby (estimated to 6.5 €/visitor by Réseau des Grands Sites de France, 2010) were used to assess the expenditures of hikers on the DWSZ. It was then compared to the results of a larger survey undertaken in France to assess travel costs incurred by forest walkers (estimated to 7.5€/visitor by (IFEN 2005).

3.5. Stakeholder workshop

Finally, we organized a half-day workshop in November 2016 in order to present and put into debate the results of the assessment. The workshop gathered 25 local stakeholders (including municipalities, environmental associations, state representatives, water agency, and land managers). The participation of stakeholders having a good local knowledge was important to validate the data and assumptions, and to debate the results of the monetary valuation with their own perception of the ecosystem services. We were particularly interested in understanding how participants perceived the overall framework for ecosystem services valuation and the ability of the proposed approach to facilitate the protection of DWSZ.

The workshop followed four main sessions, with alternating periods of presentation, completion of individual questionnaires and collective debates. First, we presented issues related to the protection of the DWSZ both in and around the study area, the objective of the workshop and the global methodological framework. Participants were then asked to fill out their individual questionnaire with information about their level of knowledge regarding the DWSZ and the concept of ecosystem services. They also had to identify, from a general reference list, the services they perceived as likely to be provided by the study area. Then, the 13 ecosystem services identified as relevant for valuation were presented and characterized. Again, participants were asked to rate the

13 services according to their level of presence (from 1 to 5) and the importance of their preservation (from 1 to 5). Thirdly, we detailed the valuation of nine ecosystem services, in terms of data and methods. Participants could then compare and debate the results of the economic assessment in light of their own perceptions. After the concluding session, participants were asked to express themselves about the relevance and the potential facilitating role of the proposed valuation approach to protect DWSZ, its level of complexity, and the step at which the approach is the most useful. The three first degrees of ecosystem services assessment and appropriation proposed by Ten Brink (2011) were used to delineate each step: 1° identification, 2° characterization / quantification, 3° monetary valuation.

Table 1. Main caracteristics of the ecosystem services assessment

Ecosystem services	**Valuation methods**	**Indicators**	**Sources** (data scale)
Wood production	Market prices	Surfaces per type of tree species	Corine Land Cover (1)
		Proprietorship of parcels	National Forest Office (2)
		Share of woodlands exploited for wood production per type of proprietorship	Observatory of the Mediterranean Forest (3)
		Annual growth rates of trees	National Forest Office (2)
		Stumpage price for tree stands per outlets	Centers of Forests Property (1,2)
Agricultural production	Market prices	Surfaces per type of agricultural activities	Corine Land Cover (1) / Chamber of Agriculture (1)
		Yields per hives	Chamber of Agriculture (1)
		Income of beekeeping production	Union of French Apiculture (4)
		Gross operating profits	Agricultural census (1) / French Livestock Institute (3)
Carbon sequestration and storage	Market prices Social cost of carbon	Woodlands and grasslands surfaces	Corine Land Cover(1)
		Net annual growth rate of trees	National Forest Office (2) / National Institute of Geographic and Forest Information (3)
		Carbon sequestration coefficients	Loustau (2004) (4) / Puydarrieux and Devaux (2013) (4)
		Share of carbon stored above and below ground	Dupouey et al. (1999) (4)
		Share of carbon stored over the long-term	Chevassus-au-Louis (2009) (4)
		Prices of CO_2 Emission Allowances	European Energy Exchange AG (4)
		Social cost of carbon reference value	Quinet (2008) (4)
Flood protection	Replacement cost	Non-artificialized areas	Corine Land Cover (1)
		Available water storage capacity	BRGM (2)
		Mean cost of dams	Bouscasse et al. (2012) (4)
Water cycle regulation	Avoided costs of water treatment Avoided costs of an interconnection	Volume abstracted for drinking water supply	Water utilities (1)
		Mean cost of water treatment	Bommelaer and Devaux (2011) (4)
		Water prices	Water utilities (1)
Fishing	Spending of practitioners	Number of practitioners	Angling Associations (1)
		Expenditures of practitioners	Angling Associations (1)
Hunting	Spending of practitioners	Number of practitioners	Hunting Societies (1)
		Expenditures of practitioners	Hunting Societies (1)
Speleology	Spending of practitioners	Number of practitioners	Federation of Speleology (1)

Ecosystem services	**Valuation methods**	**Indicators**	**Sources** (data scale)
		Expenditures of practitioners	Federation of Speleology (1)
Nature walks and cultural heritage	Benefit transfer from visitor spending Benefit transfer from the travel cost method	Number of practitioners Expenditures of practitioners Travel expenditures of practitioners	Chevassus-au-Louis (2009) (4) Réseau des Grands Sites de France (2010) (5) IFEN (2005) (5)

1 – DWSZ data. 2 – Local expert knowledge. 3 – Regional data. 4 – National data. 5 – Benefit transfer.

4. Results and discussion

The benefits of DWSZ protection

The overall economic benefits of preserving the DWSZ are estimated to range from 2.6 to 5 million €/year, that is between 350 and 685 €/ha/year (see Hérivaux and Grémont 2015 for a detailed presentation of the calculations). Although estimated benefits vary by a factor of two according to valuation methods and hypotheses, this estimation provides an order of magnitude of the benefits that society draws from maintaining the DWSZ in its current state of preservation. Table 2 displays economic values per ecosystem service. Results show that two thirds of these benefits pertain to cultural services. As for the benefits provided by water cycle regulation, they contribute only to 10% of the overall benefits. This means that economic rationales focusing solely on the water-related services provided by the DWSZ would largely underestimate the overall benefits of preserving the area. They would also ignore the multiple hidden beneficiaries of groundwater preservation that go beyond drinking water users and encompass local forest walkers, anglers, speleologists, hunters, foresters, farmers, local inhabitants and businesses, reaching even the world's population through carbon sequestration. These estimates should however be interpreted with caution. Indeed, several services were not taken into account in the monetary valuation due to missing data. Moreover, cost-based monetary methods typically exclude some paramount benefits, such as positive health effects and social welfare related to non-use values.

Table 2. Economic values of the ecosystem services associated to preserving the DWSZ

Ecosystem services	**Economic value (k€/year)**		**Economic value per hectare (€/ha/year)**		**Mean contribution (%)**
	Min	**Max**	**Min**	**Max**	
Provisioning services	***224***	***414***	***30***	***56***	***8%***
Wood production	103	103	14	14	3%
Agricultural production	120	311	16	42	6%
Regulating services	***486***	***1 620***	***66***	***220***	***27%***
Carbon sequestration and storage	274	1 038	37	141	17%
Flood protection	3	32	<1	4	0%
Water cycle regulation	208	551	28	75	10%
Cultural services	***1 934***	***3 044***	***258***	***406***	***64%***
Hunting	656	744	89	101	18%
Fishing	514	785	66	100	17%
Nature walks and cultural heritage	743	1 487	101	201	29%
Speleology	20	28	3	4	1%
Total	**2 643**	**5 078**	**354**	**682**	**100%**

These benefits can be compared to the costs of DWSZ protection that can be captured using either the cost of agri-environmental measures or the opportunity cost of urban development. The cost of the French agri-environment climate scheme for the conservation of grasslands and pastoral systems range between 58 and 116 €/ha/year (MAAF 2015). This cost is higher than the benefits provided by the water cycle regulation service alone. These estimates can also be balanced with the opportunity costs of urban development, which are the benefits that local communities would have to forgo in order to preserve the DWSZ. Due to demographic growth, the next best land-use alternative in the Sainte-Baume area is urban development. Net revenues from urbanization depend upon the market value of the real estate on the DWSZ, which can be roughly approximated using the price difference between woodland and building land in the area (McDonald 2015). According to local estimates (EPTB[3], SAFER[4]), the mean value of woodland is about 340 times lower than the mean value of building land. Considering that the rental value of building land is 5% (Sutton and Anderson 2016), the net annual revenues from converting woodland to building land are estimated to 70 k€/ha/year. With an annual rate of urbanization ranging between 2 and 5.2%[5], urban areas within the DWSZ are expected to expand on an area of 123 to 214 ha up to 2030. This would result in an increase of the land value ranging from 2.6 to 9 M€/year (i.e. between 350 and 1220€/ha/year on average on the DWSZ). This cost - that can be used as an indicator of the protection cost – is significantly higher than the benefits provided by the water cycle regulation alone. Such results tend to confirm that when resources are not or only little used for human consumption, results obtained with conventional approaches focusing mainly on water-related benefits are not likely to outweigh the costs of groundwater protection. However, when expanding the range of benefits so as to account for all the co-benefits of DWSZ protection, findings may be reversed (Figure 2).

[3] http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/enquete-prix-terrains-batir-eptb.html

[4] http://www.safer.fr/indicateur-2016-marche-forets-france.asp

[5] Mean rate of urbanization experienced from 1990 to 2012 by municipalities with less than 3% of urban areas in 1990 and respectively located in the outer suburbs of Marseille and Toulon coastal metropolis

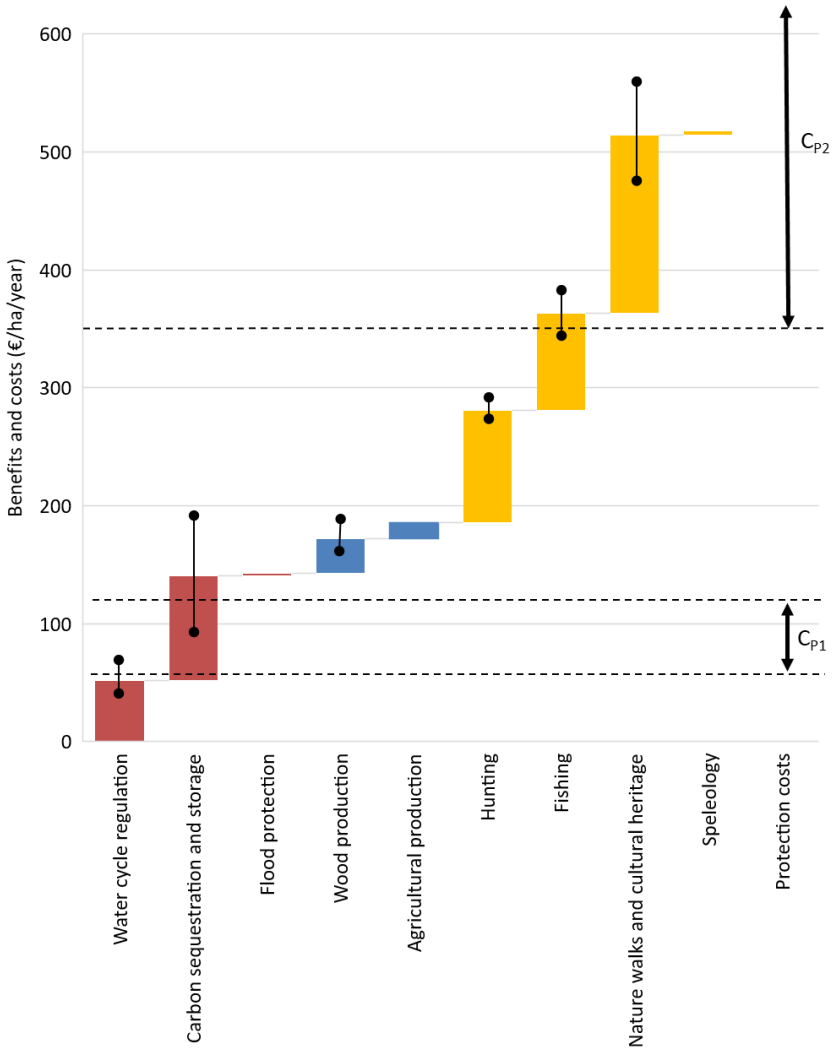


Figure 2. Estimated cumulative benefits and comparison with the cost of DWSZ protection. CP1: Cost for the conservation of grassland and pastoral systems, CP2: Opportunity cost of urban development (up to 1220 €/ha/year)

Informative use of monetary valuation

We presented these results to local stakeholders during a workshop. Overall, participants confirmed the relevance of the proposed approach for highlighting the benefits of protecting DWSZ. A majority considered that the approach could help raising awareness on the protection of DWSZ (86%), bring together stakeholders with different interests (84%), bridge the gap between environmental issues (76%), and help implementing protection actions (62%)[6].

[6] Participants were asked to rate on an individual questionnaire the potential role of the proposed approach for four issues (from 1: not at all to 5 totally). Percentages represent the number of participants (out of 21) answering 4 or 5.

When asked to choose the step at which the approach is the most useful, all participants expressed that the identification of ecosystem services alone was not sufficient. Most participants considered the characterisation and monetary valuation steps as the most useful (29% and 43% respectively, with an additional 10% of participants that could not choose between these two steps). Such results are in line with Costanza et al. (2017) who state *"The decisions we make as a society about ecosystems imply valuations (although not necessarily expressed in monetary terms)"*. Interestingly, 19% of the participants highlighted that the monetary valuation step by itself was not sufficient. They argued that the approach should go further. For instance, they recommended using the methodological framework to compare the benefits resulting from different future land-use scenarios in order to help selecting and implementing protection actions.

Yet, participants also emphasized the limitations of monetary valuation. In particular, the results of the questionnaire enabled pinpointing differences between (a) stakeholders' awareness of the ecosystem services provided by the DWSZ, (b) the importance they attach to their conservation, and (c) the value captured by the monetary valuation (Figure 3). The divergence between perceptions and monetary values results from two sets of explanations. First, due to missing data, only nine of the thirteen ecosystem services that were initially identified by stakeholders were eventually assessed. As a result, the values of some services identified as very important by stakeholders (harvestable wild products, erosion control, aesthetic amenities and education and research) are not included in the overall economic estimate. Thus, it should be noted that the results of the monetary assessment provide only partial insights into the overall value of the benefits of protecting the DWSZ. Monetary results would benefit from being completed by additional valuation for the missing services. Second, participants generally granted high and relatively homogeneous scores to the levels of presence and the importance of services, in comparison with the range of monetary values. As a result, some services with low monetary estimates are considered as very present on the study area and important to protect (e.g., flood protection, speleology). Such differences may be interpreted as knowledge gap and thus call for information and awareness campaigns. This can also reflect that stakeholders struggle to discriminate between ecosystem services when judgments are based on own perceptions, hence the need for scientifically grounded tools and assessment methods enabling to compare services based on objective criteria. They also reveal that the proposed monetary valuation does not account for some very important socio-cultural preferences, such as social welfare related to non-use values. Such results highlight that monetary valuation is only part of the way, and that *"valuation approaches that target single value-types, be it economic, ecological or socio-cultural values, can only represent part of the society and its worldviews, interests and preferences"* (Jacobs et al. 2018). They claim for articulating

monetary valuation with socio-cultural valuation methods (Martin-Lopez et al. 2012; 2014), in order to better elicit stakeholders' preferences.

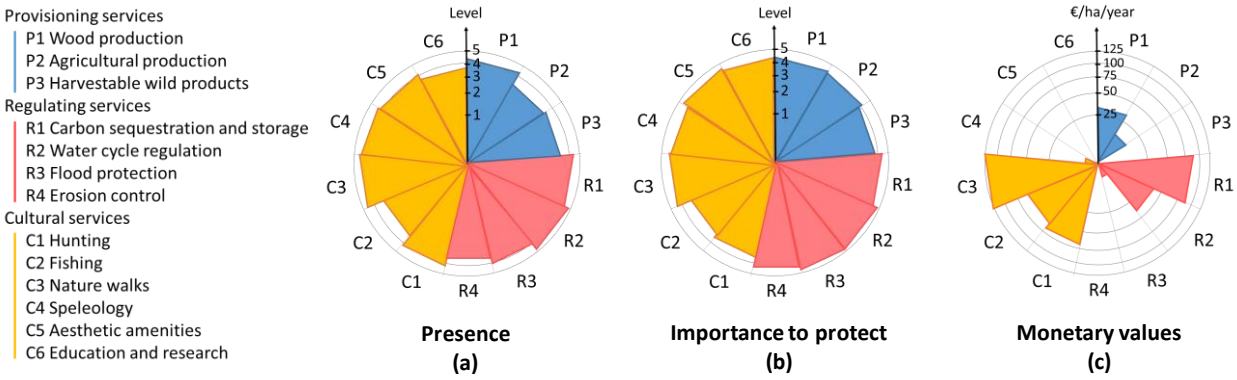


Figure 3. Assessment of (a) the level of presence, (b) the importance to protect and (c) the monetary values of 13 services identified on the DWSZ. Note: (a) average presence level based on the answers of 22 workshop participants (from 1: not at all to 5: very present); (b) average importance to protect level based on the answers of 22 workshop participants (from 1: not at all to 5: very important); (c) only nine services (out of 13) were monetary assessed; values are depicted on a different scale (from 0 to 125 €/ha/year).

5. Conclusion and perspectives

The valuation of ecosystem services can have many potential uses, at multiple time and space scales, from simply raising awareness to detailed analysis of various policy choices and scenarios (Costanza et al. 2017). This article demonstrates the relevance of valuing a diversity of ecosystem services for raising awareness on the need to protect strategic groundwater resources at local scale, especially when stakeholders are involved in the assessment process. It proposes a promising approach to enhance the protection of DWSZ for the future, especially when conventional economic approaches face limitations. It highlights that any relevant rationale aiming at highlighting the interest of preserving good-quality groundwater resources should bring to light the multiple co-benefits provided by maintaining in good condition existing ecosystems. Although monetary valuation provides only partial insights, it may be sufficient to tip the balance in favor of conservation. Results also suggest that monetary valuation would benefit from being combined with other valuation methods to assess the full set of values related to ecosystem services (Costanza et al. 2017; Jacobs et al. 2018; Kenter 2016).

From a methodology perspective, this research proposes a low-cost and time-efficient method to assess the overall value of a set of diversified ecosystem services. The valuation methods and level of precision required are appropriate when using the valuation of ecosystem services for raising awareness (Costanza et al. 2017).

They also make a case for costs assessment. Primarily based on local indicators and data, it also allows resorting to expert knowledge or regional and national proxies as surrogates to approximate indicators of ecosystem functions and processes when local information is lacking. This enables locally grounding the assessment within a local context, which contrasts with some WFD economic assessments that are performed mechanically, rarely involve local stakeholders in the process, and as a result, poorly reflect local specificities and concerns of stakeholders (Feuillette et al. 2015). Future methodological perspectives include (1) applying the approach to other DWSZ depicting contrasted land use types (e.g., urban) in order to test its operational relevance in other environmental, economic and socio-cultural contexts, and (2) comparing future alternative land use and management scenarios.

From a policy perspective, the approach sets the basis to construct coalitions between natural resources protection policies. As protecting strategic groundwater resources requires the development of dedicated policy instruments, granting a monetary value to its benefits may help envisaging innovative cross-funding instruments (Abell et al. 2017) and building bridges with the instruments that are currently implemented for biodiversity conservation. This is all the more relevant since such areas are likely to multiply over the next century.

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References

Abdalla CW (1994) Groundwater Values from Avoidance Cost Studies: Implications for Policy and Future Research. American Journal of Agricultural Economics 76:1062-1067

Abell R, Asquith N, Boccaletti G, Bremer L, Chapin E, Erickson-Quiroz A, Higgins J, Johnson J, Kang S, Karres N, Lehner B, McDonald R, Raepple J, Shemie D, Simmons E, Sridhar A, Vigerstøl K, Vogl A, Wood S (2017) Beyond the Source: The Environmental, Economic and Community Benefits of Source Water Protection, The Nature Conservancy, Arlington, VA, USA. Available on https://global.nature.org/content/beyond-the-source?src=r.global.beyondthesource

Aguilar FX, Obeng EA, Cai Z (2018) Water quality improvements elicit consistent willingness-to-pay for the enhancement of forested watershed ecosystem services. Ecosystem Services 30 :158-171. doi:10.1016/j.ecoser.2018.02.012

Arrouays D, Balesdent J, Germon JC, Jayet PA, Soussana JF, Stengel P (2002) Stocker du carbone dans les sols agricoles de France? Synthèse du rapport d'expertise réalisé par l'INRA à la demande du Ministère de l'Ecologie et du Développement Durable.

Barraqué B, Viavattene C (2009) Eau des villes et Eau des champs. Économie rurale 310: 5-21. doi : 10.4000/economierurale.708

Bateman IJ, Harwood AR, Mace GM, Watson RT, Abson DJ, Andrews B, Binner A, Crowe A, Day BH, Dugdale S, Fezzi C, Foden J, Hadley D, Haines-Young R, Hulme M, Kontoleon A, Lovett AA, Munday P, Pascual U, Paterson J, Perino G, Sen A, Siriwardena G, van Soest D, Termansen M (2013) Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. Science 341 (6141): 45-50. doi: 10.1126/science.1234379

Blanchard L, Vira B, Briefer L (2015) The lost narrative: Ecosystem service narratives and the missing Wasatch watershed conservation story. Ecosystem Services 16: 105-111. doi :10.1016/j.ecoser.2015.10.019

Bommelaer O, Devaux J (2011) Coûts des principales pollutions agricoles de l'eau. Etudes et documents n°52:34. Commissariat Général au Développement Durable, Paris

Bouscasse H, Defrance P, Duprez C, Strosser P, Beley Y, Morardet S (2012) Evaluation économique des services rendus par les zones humides. Le cas de la moyenne vallée de l'Oise. Collection « Études et documents » du Service de l'Économie, de l'Évaluation et de l'Intégration du Dé veloppement Durable (SEEIDD) du Commissariat Général au Développement Durable (CGDD), 84p.

Bouwma I, Schleyer C, Primmer E, Winkler KJ, Berry P, Young J, Carmen E, Špulerová J, Bezák P, Preda E, Vadineanu A (2018) Adoption of the ecosystem services concept in EU policies. Ecosystem Services. doi: https://doi.org/10.1016/j.ecoser.2017.02.014

Brauman KA, Daily GC, Duarte TK, Mooney HA (2007) The nature and value of ecosystem services: an overview highlighting hydrologic services. Annual Review of Environment and Resources 32:67-98. doi:10.1146/annurev.energy.32.031306

Castro AJ, Martín-López B, López E, Plieninger T, Alcaraz-Segura D, Vaughn CC, Cabello J (2015) Do protected areas networks ensure the supply of ecosystem services? Spatial patterns of two nature reserve systems in semi-arid Spain. Applied Geography 60:1-9. doi:10.1016/j.apgeog.2015.02.012.

CBD (2010) COP 10 – Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity. Nagoya, Japan 18–29 October 2010. Decision X/2. Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. United Nations Environment Programme. http://www.cbd.int/sp/targets/

Chevassus-au-Louis B (2009) Approche économique de la biodiversité et des services liés aux écosystèmes. Contribution à la décision publique. Série rapports et documents, Centre d'Analyse Stratégique, La documentation française, Paris, 399 p.

Chichilnisky G, Heal G (1998) Economic returns from the biosphere, Nature 391: 629-630. doi:10.1038/35481

Costanza R, de Groot R, Braat L, Kubiszewski I, Fioramonti L, Sutton P, Farber S, Grasso M (2017) Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services 28:1-16. doi:10.1016/j.ecoser.2017.09.008

de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S, Kumar P, McVittie A, Portela R, Rodriguez LC, ten Brink P, van Beukering P (2012) Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1(1): 50-61. doi:10.1016/j.ecoser.2012.07.005

Dupouey JL, Pignard G, Badeau V et al. (2002) Stocks et flux de carbone dans les forêts françaises. Forêt Wallone 57 : 6-19

European Commission (2012) A Blueprint to Safeguard Europe's Water Resources. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0673

Feuillette S, Levrel H, Blanquart S, Gorin O, Monaco G, Penisson B, Robichon S (2015) Évaluation monétaire des services écosystémiques. Un exemple d'usage dans la mise en place d'une politique de l'eau en France. Natures sciences sociétés 23(1): 14-27

Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making. Ecological Economics 68:643-653. doi:10.1016/j.ecolecon.2008.09.014

Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. Ecological Econonomics 86:235-245. doi:10.1016/j.ecolecon.2012.08.019

Grolleau G, McCann LMJ (2012) Designing watershed programs to pay farmers for water quality services: Case studies of Munich and New York City. Ecological Economics 76:87-94. doi :10.1016/j.ecolecon.2012.02.006

Haines-Young R, Potschin MB (2018) Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. Available from www.cices.eu

Hérivaux C, Grémont M (2015) Caractérisation des bénéfices économiques liés à la préservation des eaux souterraines: le cas des zones de sauvegarde pour l'alimentation en eau potable. BRGM/RP-63859-FR: 236. http://infoterre.brgm.fr/rapports/RP-63859-FR

Hérivaux C, Rinaudo JD (2016) Integrated assessment of economic benefits of groundwater improvement with contingent valuation. In: Jakeman A.J., Barreteau O., Hunt R.J., Rinaudo JD., Ross A. (eds) Integrated Groundwater Management. Springer, pp 519-549. doi:10.1007/978-3-319-23576-9_21.

IFEN (2005) Les multiples valeurs de la forêt française, Les données de l'environnement, numéro 105, 4p.

Institut de l'Elevage (2012) Résultats Technico-économiques 2012, Systèmes bovins en PACA et Rhône-Alpes, actualisation 2011.

Institut Forestier National (2012) La forêt en chiffres et en cartes, 2012.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jacobs S, Martín-López B, Barton DN, Dunford R, Harrison PA, Kelemen E, Saarikoski H, Termansen M, García-Llorente M, Gómez-Baggethun E, Kopperoinen L, Luque S, Palomo I, Priess JA, Rusch GM, Tenerelli P, Turkelboom F, Demeyer R, Hauck J, Keune H, Smith R (2018) The means determine the end – Pursuing integrated valuation in practice. Ecosystem Services 29:515-528. doi:10.1016/j.ecoser.2017.07.011

Jimenez Cisneros BE, Oki T, Arnell NW, Benito G, Cogley JG, Doll P, Jiang T, Mwakalila SS (2014) Freshwater resources. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Gimma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds.) Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 229-269

Johnson KA, Dalzell BJ, Donahue M, Gourevitch J, Johnson DL, Karlovits GS, Keeler B, Smith JT (2016) Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. Ecosystem Services 18:175-185. doi: 10.1016/j.ecoser.2016.03.004

Keeler BL, Polasky S, Brauman KA, Johnson KA, Finlay JC, O'Neill A, Kovacs K, Dalzell B (2012) Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proceedings of the National Academy of Sciences of the United States of America. doi: 10.1073/pnas.1215991109

Kenter JO (2016) Editorial: Shared, plural and cultural values. Ecosystem Services 21:175-183. doi:10.1016/j.ecoser.2016.10.010

Liquete C, Udias A, Conte G, Grizzetti B, Masi F (2016) Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. Ecosystem Services 22:392-401. doi:10.1016/j.ecoser.2016.09.011

Loustau (2004) Séquestration du Carbone dans les grands écosystèmes forestiers en France. Quantification, spatialisation, vulnérabilité et impacts de différents scénarios climatiques et sylvicoles. Rapport Final du Projet CARBOFOR, Juin 2004.

MAAF (2015) MAEC systèmes herbagers et pastoraux (logique de maintien de pratiques existantes), Cap sur la PAC 2015-2020, Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, Paris. http://agriculture.gouv.fr/maec-les-nouvelles-mesures-agro-environnementales-et-climatiques-de-la-pac-2015

Martín-López B, Gómez-Baggethun E, García-Llorente M, Montes C (2014) Trade-offs across value-domains in ecosystem services assessment. Ecological Indicators 37:220-228. doi:10.1016/j.ecolind.2013.03.003

Martín-López B, Iniesta-Arandia I, García-Llorente M, Palomo I, Casado-Arzuaga I, Amo DGD et al. (2012) Uncovering Ecosystem Service Bundles through Social Preferences. PLoS ONE, 7(6), e38970. doi: 10.1371/journal.pone.0038970

McDonald RI (2015) The effectiveness of conservation interventions to overcome the urban–environmental paradox. Annals of the New York Academy of Sciences 1355:1-14. doi: 10.1111/nyas.12752

MEA (2005) Millennium Ecological Assessment. Ecosystem and Human Well-being: A framework for Assessment. A Report of the Conceptual Framework Working Group of the Millennium Ecosystem Assessment. Island Press, Washington

MEDDE (2013) Synthèse du projet Explore 2070: Hydrologie souterraine. Ministère de l'Ecologie, du Développement Durable et de l'Energie, Paris. http://www.onema.fr/sites/default/files/pdf/RE_Explore2070_4pages_Eaux_souterraines.pdf

Nel JL, Le Maitre DC, Roux DJ, Colvin C, Smith JS, Smith-Adao LB, Maherry A, Sitas N (2017) Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services. Ecosystem Services 28(B):251-259. doi: 10.1016/j.ecoser.2017.07.013

Nelson NM, Loomis JB, Jakus PM, Kealy MJ, von Stackelburg N, Ostermiller J (2015) Linking ecological data and economics to estimate the total economic value of improving water quality by reducing nutrients. Ecological Economics 118:1-9. doi:10.1016/j.ecolecon.2015.06.013

Ninan KN, Inoue M (2013) Valuing forest ecosystem services: What we know and what we don't. Ecological Economics 93:137-149. doi :10.1016/j.ecolecon.2013.05.005

OFME (2003) Les espaces forestiers en Provence-Alpes-Côte d'Azur, Fiche n°27. Observatoire de la Forêt Méditerranéenne, Gardanne, France.

Pivot J-M, Aznar O (2000) Acquisition foncière et environnement : le cas de la protection d'un captage d'eau potable. Économie rurale 260 :135-141

Poe GL, Boyle KJ, Bergstrom JC (2000) A meta-analysis of contingent values for groundwater quality in the United States. 2000 Annual meeting, July 30-August 2, Tampa, FL 21871, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association)

Puydarrieux P, Devaux J (2013) Quelle évaluation économique pour les services écosystémiques rendus par les prairies en France métropolitaine ? n°89 de la collection "Etudes et documents" du SEEIDD du CGDD, 40p.

Quinet A (2008) La valeur tutélaire du carbone, Série rapports et documents, N°16, Centre d'Analyse Stratégique, La documentation française, Paris, 424p.

Quinet E (2013) L'évaluation socioéconomique des investissements publics, Rapport de la mission présidée par Emile Quinet, Série Rapports et documents, Commissariat général à la stratégie et à la prospective, Paris, 352 p.

Réseau des Grands Sites de France (2010) Evaluation des avantages économiques liés au Grand Site Sainte-Victoire, Réseau des grands sites de France, Paris, 26p.

Rinaudo JD, Arnal C, Blanchin R, Elsass P, Meilhac A, Loubier S (2005) Assessing the cost of groundwater pollution: the case of diffuse agricultural pollution in the Upper Rhine valley aquifer. Water Science and Technology 52:153-162

Smith M, Cross K, Paden M, Laban P (2016) Spring: managing groundwater sustainably. IUCN, Gland, Switzerland. http://dx.doi.org/10.2305/IUCN.CH.2016.WANI.8.en

Sutton PC, Anderson SJ (2016) Holistic valuation of urban ecosystem services in New York City's Central Park. Ecosystem Services 19:87-91. doi: 10.1016/j.ecoser.2016.04.003

ten Brink P (2011) The economics of ecosystems and biodiversity in national and international policy making. Routledge.

Toivonen AL, Roth E, Navrud S, Gudbergsson G, Appelblad H, Bengtsson B, Tuunainen P (2004) The economic value of recreational fisheries in Nordic countries. Fisheries Management and Ecology 11:1-14. doi:10.1046/j.1365-2400.2003.00376.x

Venkatachalam L (2004) The contingent valuation method: a review. Environmental Impact Assessment Review 24(1): 89-124. doi:10.1016/S0195-9255(03)00138-0

Vlachopoulou M, Coughlin D, Forrow D, Kirk S, Logan P, Voulvoulis N (2014) The potential of using the Ecosystem Approach in the implementation of the EU Water Framework Directive. Science of the Total Environment 470–471:684-694. doi:10.1016/j.scitotenv.2013.09.072

Wallace KJ (2007) Classification of ecosystem services: Problems and solutions. Biological Conservation 139 (3-4): 235-246. doi:10.1016/j.biocon.2007.07.015

Wang Y, Atallah S, Shao G (2017) Spatially explicit return on investment to private forest conservation for water purification in Indiana, USA. Ecosystem Services 26:45-57. doi:10.1016/j.ecoser.2017.06.004

Watkiss P, Hope C (2011) Using the social cost of carbon in regulatory deliberations. WIREs Climate Change 2:886-901. doi: 10.1002/wcc.140

WWAP (2015) The United Nations World Water Development Report 2015: Water for a Sustainable World. United Nations World Water Assessment Programme. UNESCO, Paris