Looking into Pandora's Box: ecosystem disservices assessment and correlations with ecosystem services

C.S. Campagne, P.K. Roche, J.M. Salles

VERSION AUTEUR. A citer : Campagne C.S, Roche P.K., Salles J-M. (2018) Looking into Pandora's Box: ecosystem disservices assessment and correlations with ecosystem services. *Ecosystem Services* 30, 126–136. https://doi:10.1016/j.ecoser.2018.02.005

Looking into Pandora's Box: Ecosystem disservices assessment and correlations with ecosystem services

Carole Sylvie CAMPAGNE[1], Philip ROCHE[1] and Jean-Michel SALLES[2]

[1] Irstea*, UR RECOVER, 3275 route de Cézanne, CS 40061,13182 Aix-en-Provence Cedex 5, France.*
E-mail: sylvie.campagne@irstea.fr, philip.roche@irstea.fr

[2] CNRS, *LAMETA and CEE-M, 2 place Viala, 34060 Montpellier, France.*
E-mail: jean-michel.salles@supagro.inra.fr

Corresponding author

Carole Sylvie CAMPAGNE, Irstea*, UR RECOVER, 3275 route de Cézanne, CS 40061,13182 Aix-en-Provence Cedex 5, France.* E-mail: sylvie.campagne@irstea.fr Phone: +33 4 42 66 69 81

Abstract

The concept of ecosystem disservices (EDS) has received much less attention than the concept of ecosystem services (ES). Using an expert-based matrix approach, we assessed the capacity of ecosystem types of the Scarpe-Escaut Regional Natural Park (France) to provide ES and generate EDS. The matrix is a look-up table that provide for each ecosystem types a score expressing its ES capacity. Our results point to a lower capacity of the considered ecosystems to provide EDS than ES. On average the EDS scores were 60% lower than the ES scores. Of EDS, those linked to human health are the most critical, with higher capacity scores and higher expert' confidence scores than other EDS than those linked with economic or ecological impacts. We analysed correlations between ES and EDS, the presence of strong and significant positive correlations suggests that the same ecosystem characteristics, ecological functions or species groups may generate both ES and EDS. We emphasise that it is important to evaluate both EDS and ES to implement management of the ecosystems, while respecting the functioning of the ecosystems, to develop positive effects while limiting negative ones.

Abbreviations:

ES, ecosystem service; ET, ecosystem types; EDS, ecosystem disservices; RNP, Regional Natural Park; SE-RNP, Scarpe-Escaut RNP; Conf. Score, Confidence scores

1. Introduction

The positive contributions of ecosystems to human life and well-being are well-attested, but we cannot ignore negative effects arising from characteristics of ecosystems that are economically or socially harmful, or that endanger health or are even life-threatening (Dunn 2010; Lele et al., 2013; Stoll et al., 2015). Although the use of the ecosystem services concept has expanded considerably over the last decade, it is generally not combined with actual consideration of the negative aspects of the natural environment (Schaubroeck, 2017). Although some authors even advocate that the current ecosystem service consideration equilibrate the age-old practice that nature is accounted only for costs (Shapiro and Baldi, 2014). A quick search on Scopus (in July 2017) returned 126 papers on EDS ("article and review", "all year", "ecosystem* disservice") and 21,248 papers on ES ("article and review", "all year", "ecosystem service"), this means that only 0.6% of published studies focused on EDS. However, there has been an increase in the number of papers since 2009 on the adverse effects of ecosystems, reflecting its increasing recognition (Von Döhren and Haase, 2015). Negative or dangerous effects of ecosystems are recognised (Kareiva et al., 2007).

The concept of ecosystem disservices (hereafter EDS) has generated debate in the last few years (Barot et al., 2017; Lyytimäki, 2014a; Lyytimäki et al., 2008; Schaubroeck, 2017; Shapiro and Baldi, 2014; Villa et al., 2014). The EDS concept and its assessment have been challenged because they may be perceived as sending a "wrong message", and so may hamper conservation efforts through induced misconceptions (Villa et al., 2014). As discussed by Lyytimäki (2014a), Von Döhren and Haase (2015) and Shackleton et al. (2016), the concept of EDS has varied over time, and so there is a wide range of other definitions, such as "functions or properties of ecosystems that cause effects that are perceived as harmful, unpleasant or unwanted" (Lyytimäki, 2014b), or "negative ecological effects or impacts have been described as harmful consequences of ecological change or as deficient ecosystem services caused, for example, by the loss of biodiversity" (Von Döhren and Haase, 2015). The disservices were also considered under different names related to their impacts (plagues, pests, floods, diseases…) since the dawn of civilization (Shapiro and Baldi, 2014).

Mirroring the definition of ecosystem services (ES), "the goods or services provided by ecosystems that directly or indirectly benefit humans" (MEA, 2005), ecosystem disservices (EDS) can be defined as "the ecosystem-generated functions, processes and attributes that result in perceived or actual negative impacts on human well-being" (Shackleton et al., 2016).

In the papers published on EDS, several characteristics of the concept can be set out. For present purposes, we will first make a non-exhaustive description of the EDS concept. As presented in Fig. 1,

(a) An EDS can be triggered as an indirect effect of management (orange dotted arrow) by impaired ecosystem functioning. Nuisances resulting from side effects of management practices are considered as negative externalities, but the response of ecosystems to management practices can induce negative effects on the human well-being, and so are considered as EDS (Barot et al., 2017; Lyytimäki, 2014b; Shackleton et al., 2016). For example, health problems resulting from pesticide spraying are negative externalities of agricultural ecosystems management (direct effect of management), whereas resistant weed invasion following pesticide spraying is a management-induced EDS (indirect effect of management, Barot et al., 2017; Lyytimäki, 2014b).

(b) An EDS can be the reverse of an ES, i.e. a "*negative provision*" (green box). It is the opposite of an existing ES, as it is negatively perceived and/or can generate costs (mainly concerning regulation services). For example, greenhouse gas sequestration is an ES in the CICES (Common International Classification of Ecosystem Services, Haines-Young and Potschin, 2013; Hof et al., 2011), yet some ecosystems generate net emissions of greenhouse gases such as CO_2, CH_4 or N_20 (Burgin et al., 2013): it is thus the balance between the production and sequestration of greenhouse gases that ultimately defines whether the ecosystem provides an ES or an EDS.

(c) An EDS can be directly related to ecological characteristics or functions (red dashed arrow). Some EDS are linked to specific species, such as species that harm human health (pathogens, parasites), species that cause pest damage (Lele et al., 2013) or animal attacks (Dunn, 2010).

(d) An effect can be regarded as either an ES or an EDS depending on the point of view of the individuals or societal groups considered, but also depending on space and time (blue double line, Rasmussen et al,. 2017, Saunders & Luck, 2016; Shackleton et al., 2016; Vaz et al., 2017). The same function or species can even be perceived as providing simultaneously both ecosystem services and disservices by the same individual or different ones (Lele et al., 2013). For example, hedges can be used to block out a view: some individuals will consider this positive, while others will consider it a nuisance.

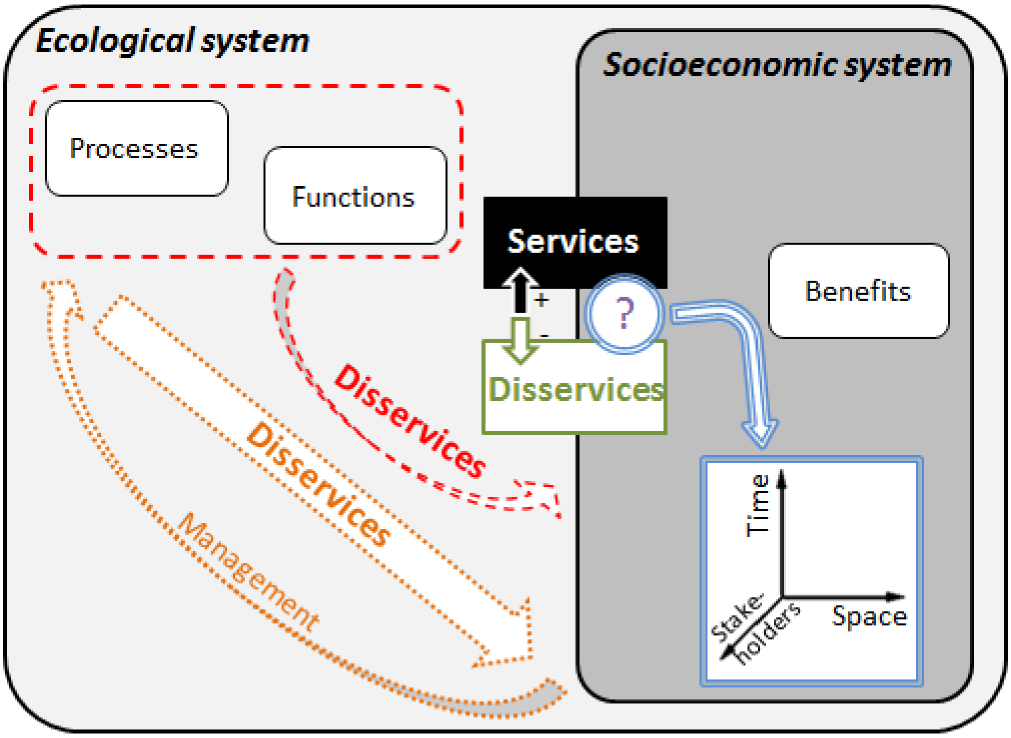

Fig. 1. Distinction between EDS resulting from the ecosystems management (orange dotted arrow); EDS from ecological processes and/or functions (red dashed arrow); EDS as a "negative provision" of ES (green box) and depending on the point of view of individual or societal groups, space and time, effects of the same ecosystem can be considered as either ES or EDS (blue double line)

The diversity of methods that can be used for assessing EDS is as broad as those used to assess ES. They include EDS assessments based on interviews and discourse analysis (Fischer & Eastwood, 2016), with newspaper text analyses (Lyytimäki, 2014b; Kopperoinen et al., 2014), with a quantitative evaluation (Dobbs et al., 2014) and with monetary valuation (Schaubroeck et al., 2016). EDS and ES are mostly assessed separately on specific ecosystems, e.g. on urban ecosystems (Lyytimäki et al., 2008), on urban forests (Dobbs et al., 2014; Escobedo et al., 2011), on agroecosystems (Sabatier et al., 2013), or on ranch lands (Swain et al., 2013). Kopperoinen et al. (2014) assess "according to how favourable or harmful the areas represented by them are in potentially providing each ES" with a scale from "3 = Very favourable" to "−3 = Very harmful", and so assess an EDS as a negatively provided ES.

In our study, to use the metaphor of Shackleton et al. (2016), we unpacked and looked into the Pandora's Box of EDS: we set out to evaluate the capacity of ecosystems to provide ES and generate EDS using an expert-based scoring approach (Campagne et al., 2017), the capacity matrix approach (explained in the next section).

Our main aim is to evaluate the importance of ecosystem disservices and compare them with the capacity of ecosystem to provide services for a large set of different ecosystems in the Park.

Here we analyse the results from an assessment of both ES and EDS carried out using the same protocol. Besides gauging how important were the capacities of EDS and ES, we also looked at the correlations between them.

2. Materials and Methods

2.1 Case Study Site

The Scarpe-Escaut Regional Natural Park (RNP, http://www.RNP-scarpe-escaut.fr/en) is a protected area in northern France (Fig. 2), near the Belgian border. It covers over 430 km^2, is crossed by the Scarpe and Escaut rivers, and includes 55 towns and villages. It is the oldest of the 51 French Regional Natural Parks. With its Belgian neighbour, the Plaines de l'Escaut Natural Park, it forms the Hainaut cross-border Nature Park, the largest such park in Europe. The Scarpe-Escaut RNP (SE-RNP) mainly covers the wet lowland plain around the Scarpe and Escaut rivers. As a peri-urban area, urban pressure is high (use of space) in a landscape formed by a mosaic of agricultural and natural environments (crops, grasslands, woodlands, marshes, ponds, etc.) and urbanized areas (SE-RNP and Hauts-de-France Region, 2010). Natural ecosystems are mainly wetlands, grasslands and forests (Maresca, et al., 2014). Wetlands have been considered an unattractive landscape by the local population for aesthetics, recreation activities but more generally as linked to negative perception, and wet meadows have been declining under urban pressure, or exploited as profitable sites for agricultural production such as livestock and as landscaped recreational ponds (SE-RNP and Hauts-de-France Region, 2010). Despite their local importance as an ecosystem providing many ES, current perceptions of wetlands are either negative, for certain local stakeholders, or inexistent for the wider community, (SE-RNP and Hauts-de-France Region, 2010; Morère and Glon, 2016). This perception deficit prompted a study of the ES provided by the wetland types in 2015. A new wetlands assessment was also needed for a revision of the strategy for the development and management of water resources (called SAGE in France) and to apply for RAMSAR certification (http://www.ramsar.org/). In 2015 the capacity matrix approach was thus applied on wetlands, and after positive local feedback from participants and the Park authorities, in 2016 the method was applied to all land cover types in an exhaustive spatial assessment (Campagne et al., 2017). In addition, in 2015 some participants faulted the lack of consideration of EDS, and expressed that from their points of view, EDS were as important as ES in analysing human-environment interactions. The same opinions were voiced in Ango et al. (2014). Thus in 2016 an assessment of EDS was added for the first time.

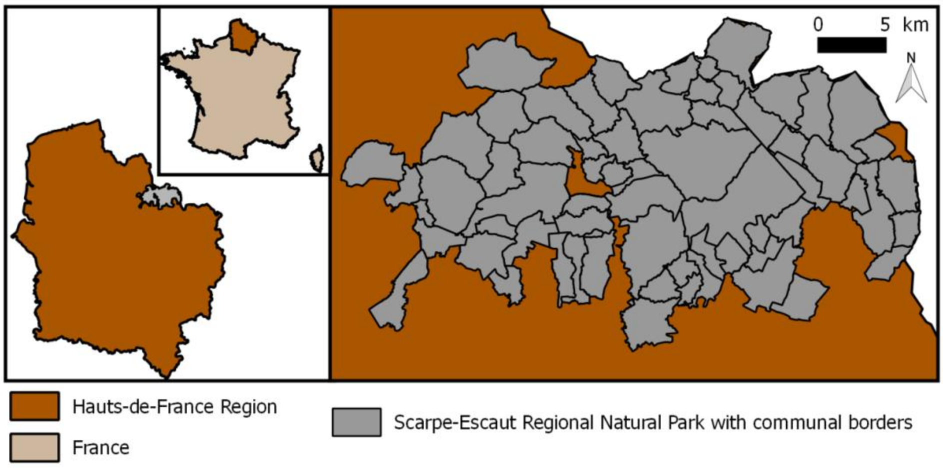

Fig. 2. Localisation of the Scarpe-Escaut Regional Natural Park

2.2 Ecosystem Services and Disservices evaluation method

It is possible to estimate the biophysical capacity, economic or social value of ecosystem services and disservices of different ecosystem types by knowledge or preference elicitation methods based on individual interviews and/or collective deliberative workshops. This is the case for the widely-used multi-criteria approaches, ranking methods, and life satisfaction approaches, and also for other less frequently used methods, such as the Q method (Rodriguez-Vargas and Marburg, 2011), or the Delphi prospective approaches (Martin et al., 2012).

The method used in our study is a knowledge elicitation protocol aiming to evaluate the capacity of different ecosystem types to provide ES and EDS based on a panel of experts. The principal output of this protocol is a capacity matrix linking ecosystem types and ES/EDS. The capacity matrix is a look-up table that links land cover types or ecosystem types to ES (Burkhard et al., 2009). Since the capacity matrix approach was first introduced by Burkhard et al. in 2009, the use of semi-quantitative scoring of ES potential has been developed and applied in many case studies (e.g. Hermann et al., 2013; Kroll et al., 2012; Stoll et al., 2014; Vihervaara et al., 2010; etc.), in many countries (e.g. in Austria and Hungary by Hermann et al., 2014; in China by Cai et al., 2017; in USA by Cotillon, 2013; in Thailand by Kaiser et al., 2013) and at different scales (e.g. local scale in Nedkov et al., 2014; national scale in Depellegrin et al., 2016, and European scale in Stoll et al. 2015). Some limits of this method, as applied in previous studies, have been pointed out in Hou et al. (2012) and Jacobs et al. (2014): poor

methodological transparency, lack of reproducibility and lack of appropriate factoring on uncertainty. In an earlier paper, we addressed several of these limits, we proposed a methodology to consider individual expert scoring and concluded that score variability stabilize when the size of expert panel is higher than 10. We also highlighted the importance of assessing the confidence of the experts as complementary information source regarding scoring reliability (Campagne et al. 2017).
The matrix approach has also the benefit of providing scores on the same (0 - 5) scale for all ecosystem services bypassing a standardization step and allowing a relatively quick assessment of ES capacity for all ecosystem types considered (Vihervaara et al., 2012; Stoll et al., 2014). As a side benefit, the collaborative protocol used also promotes common understanding and territorial vision regarding ES among the experts involved, and good subsequent appropriation of the results by them.

Basically, the method aims to allow each expert involved to provide their best evaluation of the potential of each ecosystem type to provide ES and EDS. Importantly, the ES and EDS scores elicited are not individual preferences, but best-knowledge estimates. Experts use a combination of field observations, formal knowledge and mental models to generate quantitative information (Fazey et al. 2006). The expert knowledge is commonly used as a surrogate of empirical data in many field of ecological research (Drescher et al. 2013).
We define as 'expert' a person with extensive knowledge or skills based on research, experience, or occupation in a particular field. The panel of experts included researchers with expertise in ecology and/or ES, project or site managers, engineers working in environmental or ecological fields, and heads of territorial organizations.
Our protocol for expert knowledge elicitation involved a discussion session with the panel during a workshop where we presented and discussed the list of ecosystem types, ecosystem services and disservices present in the matrix in order to build a common understanding (Fig. 3). The experts were then asked to fill in the capacity matrix individually; scores could be discussed to improve common understanding, but we did not conduct any consensus-building rounds. Finally, individual experts' scores were processed using a bootstrap method to estimate an average mean score and standard errors for each ecosystem type and ES/EDS in order to produce a capacity matrix based on central estimates of ES and EDS capacities for each ecosystem type (Campagne et al., 2017). The matrix for the Scarpe-Escaut RNP (SE-RNP) was completed in 2016 by a panel of 17 experts involved in the participatory method (details of the expert panel are in Appendix 1) and so was based on 17 independent matrices of expert scores and confidence scores.
The capacities of the different ecosystem types (ET) to provide an individual ES were estimated on a 0–5 scale (0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = moderate relevant capacity, 4 = high relevant capacity, and 5 = very high relevant capacity (Burkhard et al. 2009). The EDS were estimated independently of the ES using the same approach and scale (0 = EDS not generated with relevant capacity, to 5 = EDS generated with very high relevant capacity. In what follows, "expert score" refers to the ES and EDS supply capacity score that individual experts provided, and "final score" refers to the mean capacity score computed from all expert scores.
In addition the score for each ES/ET combination, the experts were asked to give a confidence index in their score for each ES and each ET. This confidence index was used to estimate expert confidence in providing the capacity score, and could be used to compute score errors (Campagne et al., 2017). Each expert was asked to state their confidence in their own knowledge on ET and ES using a

confidence score ranging from: 1 = I don't feel comfortable with my score, 2 = I feel fairly comfortable with my score, and 3 = I feel comfortable with my score".

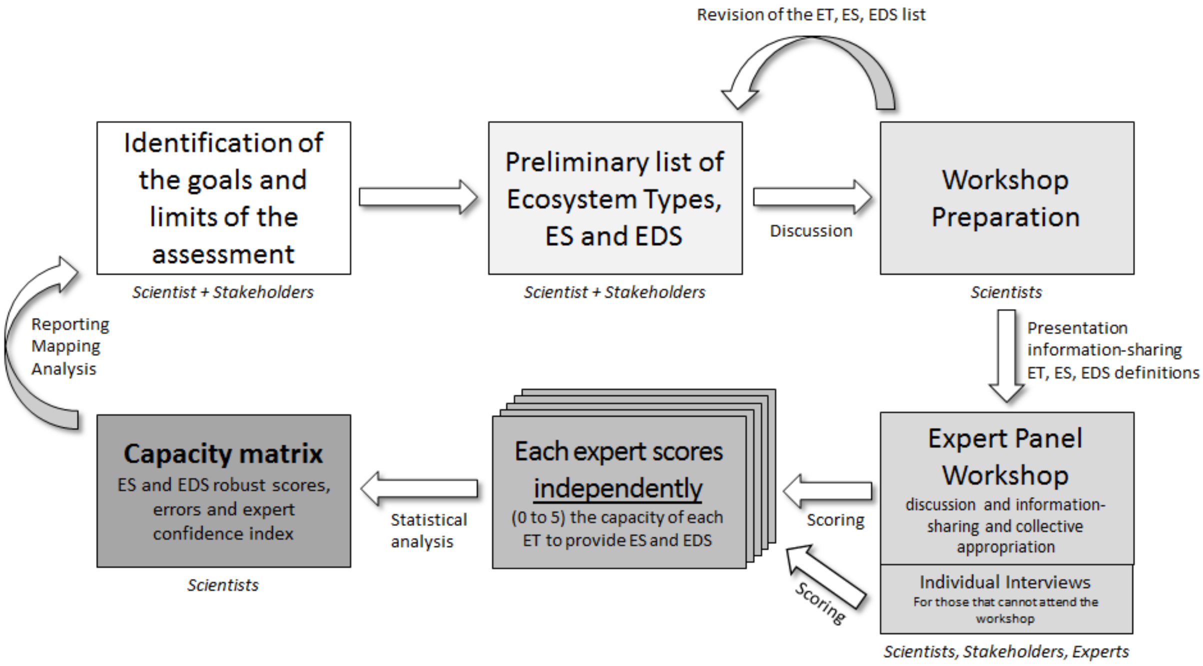

Fig. 3. Methodology for expert-based evaluation of capacity of ecosystem types to supply ecosystem services and ecosystem disservices (see Campagne et al., 2017). ES: Ecosystem services; EDS ecosystem disservices; ET: Ecosystem Types.

2.3 ET, ES and EDS lists

ET, ES and EDS lists were at the SE-RNP scale and adapted to the local context, because ES and EDS have a strong "spatial, temporal and socio-economic context-dependency" (Vaz et al., 2017). ET typology corresponded to land cover types in the ARCH map (www.archnature.fr), yielding 33 ET: 6 aquatic, 13 agriculture, 7 forest and 7 urban (detailed in Table 2). We considered provisioning services, regulating services, cultural services (details in Table 3 and Appendix 2 and 3) and EDS (detailed in Table 1). For provisioning services and regulating services, the list was based on the CICES V4.3 (Haines-Young and Potschin, 2013), and definitions and examples (e.g. indicators) were adapted to local contexts by local managers. Local adaptations were preferred in order to promote understanding and above all to increase the involvement of the local experts and the future users of the results. Cultural services were listed and defined using an adaptation of the CICES, because the CICES classification for cultural services was perceived as too complex and ill-suited to local stakeholders. The list of EDS was drawn from a review of the EDS scientific literature (e.g. Ango et al., 2014; Dobbs et al., 2014; Lyytimäki, 2014b; Shapiro and Baldi, 2014; Von Döhren and Hasse, 2015), and meetings were held with local managers in order to adapt it to the local specific context. The 6 EDS, presented in Table 1, were identified as those most relevant to the local context by the local experts involved in the participatory scoring. This capacity matrix counted 25 ES (9 provisioning services, 11 regulating services and 5 cultural services) and 6 EDS. The total dataset comprised 33 ET x (25 ES + 6 EDS) x 17 experts.

Table 1. Definition of Ecosystem Disservices assessment in the Scarpe-Escaut Regional Natural Park (Type of direct negative impacts is based on Von Dohren and Hasse, 2015)

Type of direct negative impacts	EDS		Definition
Health impacts	Wild animal attacks	EDS1	Capacity of ecosystem to shelter species harmful to humans through bites and attacks by insects or other wildlife.
	Plant allergies or poisoning	EDS2	Capacity of ecosystem to shelter species harmful to humans due to their release of allergenic pollen and spores, their toxicity or irritant properties.
	Disease transmission	EDS3	Capacity of ecosystem to be a reservoir for disease vectors: Lyme disease, leptospirosis, hantavirus, etc.
Economic impacts	Damage to infrastructure	EDS4	Capacity of ecosystem and species to cause damage to infrastructure: dwellings and properties, cables, sidewalks, roads.
	Pest damage to agriculture	EDS5	Capacity of ecosystem to shelter species causing damage to human activities such as on agricultural or agroforestry environments
Ecological impacts	Carbon release	EDS6	Capacity of ecosystem to release carbon dioxide, methane and other greenhouse gases

2.4 Statistical analysis

Since normality cannot be assumed for the ES and EDS scores, we used the Kruskal-Wallis test for EDS score differences between the broad ecosystem types. The Kruskal-Wallis test is a widely-used non-parametric test suitable for comparing ordinal and ranked variables between several samples.

The box plots for the EDS scores were produced using median and interquartile ranges. The box and whisker plots and Kruskal-Wallis tests and Mann-Whitney pairwise comparison test with a Bonferroni correction were done using Past3 software (Hammer et al. 2001)

The correlation analysis between ES and EDS was carried out using Spearman's rho statistic to evaluate the degree of correlation between two variables linked monotonically but not necessarily linearly. Alternatively, the Kendall tau correlation statistic could have been used, but both provided the same significance patterns. The Spearman correlation matrix was computed using R software (R Development Core Team, 2017) version 4.0-2 and the 'Hmisc' package. A Bonferroni correction has been used for correcting for repeated correlation tests risk inflation.

3. Results

3.1 EDS profiles

The capacity of ecosystems to generate EDS was estimated to be low to moderate. The mean of all the EDS scores was 1.36 (median 1.16), and the means for the broad ecosystem types ranged between 1.25 and 1.65 (Table 2). Health impacts EDS (EDS1, EDS2 and EDS3) had higher scores than Economic impacts EDS (EDS4 and EDS5) and Ecological impacts EDS (EDS6) (Table 2). A Kruskal-Wallis test and Mann-Whitney pairwise comparison test with a Bonferroni correction were significant between EDS1, EDS2, EDS3 and EDS4, EDS5, EDS6 (pBonf.Corr < 0.001). There were no significant differences between EDS1, EDS2 and EDS3, or between EDS4, EDS5 and EDS6. The highest score was EDS of Ecological impacts (EDS6 Carbon release) in "Towns, villages and industrial sites" with 4.20.

We found that EDS1 (Wild animal attacks) and EDS3 (Disease transmission) had similar patterns, with most of the capacity associated with aquatic and forest ecosystems, and low capacity in urban. EDS4 (Damage to infrastructures) was clearly associated with aquatic ecosystems, while EDS5 (Pest damage to agriculture) was more evenly spread in the different groups. EDS6 (Carbon release) was clearly associated with urban ecosystems (Fig. 4).

Forests were considered to generate more EDS than other broad ecosystem types, with a mean of 1.65 (median = 1.37, Kruskal-Wallis $H = 8.97$, $p = 0.03$), particularly for EDS1, EDS2, EDS3 and EDS5. Aquatic ecosystems had high scores for EDS1 (Wild animal attacks) and EDS3 (Disease transmission). Agricultural ecosystems had high scores in Health impacts EDS2 and EDS3. Urban ecosystems had the highest score for EDS6 (Carbon release) and the lowest scores for Health Impacts (Fig. 4).

Besides differences between broad ecosystem types, we found large differences in EDS scores between ecosystem types belonging to the same broad category, for example, EDS2 (Plant allergies and poisoning) in Urban ecosystem had scores ranging from 0.19 in Active quarries to 3.06 in Urban parks and large gardens (Table 2).

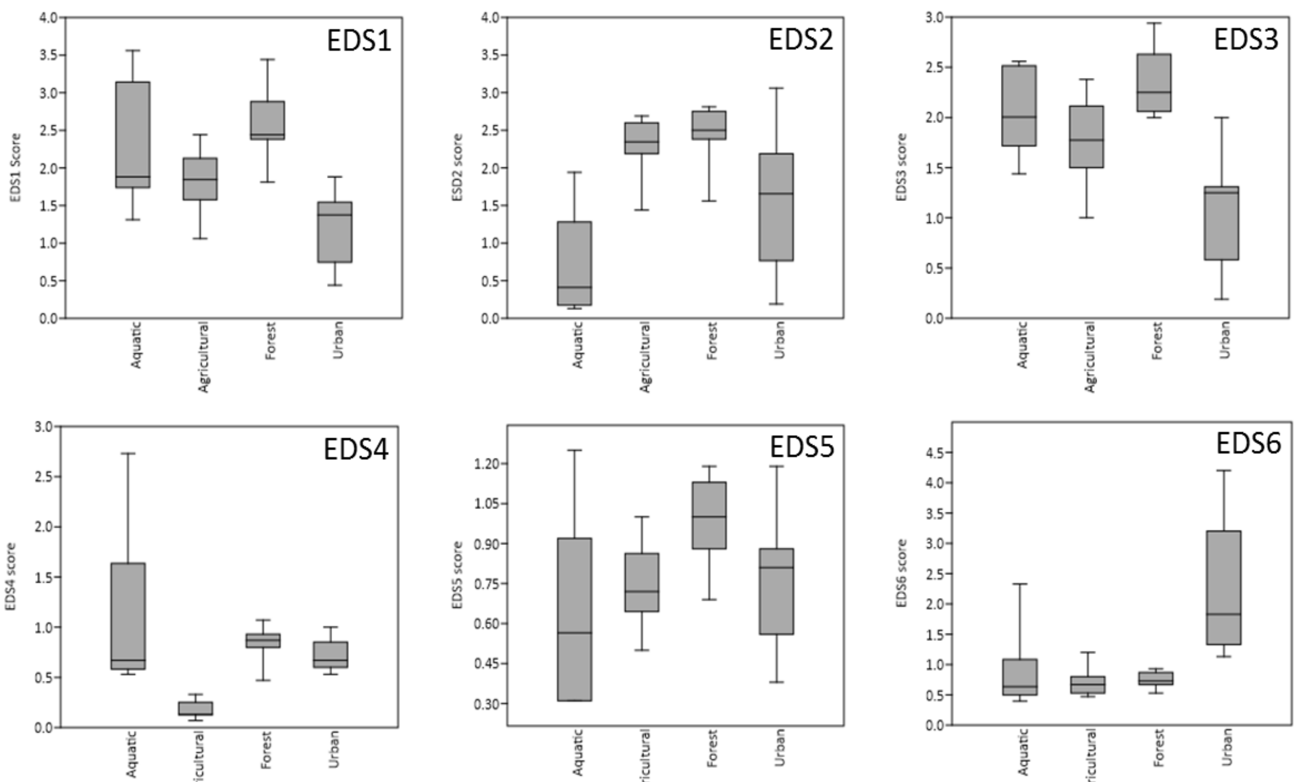

Fig. 4. Box and whisker plots of the EDS scores grouped by broad ecosystem type: EDS1 (Wild animal attacks), EDS2 (Plant allergies and poisoning), EDS3 (Disease transmission), EDS4 (Damage to infrastructures), EDS5 (Pest damage to agriculture), EDS6 (Carbon release)

Table 2. Capacity matrix of ecosystem disservices on the Scarpe-Escaut Regional Natural Park (Type of negative effects is based on Von Dohren and Hasse, 2015)

		Health impacts			Economic impacts		Ecological impacts
		Wild animal attacks EDS1	Plant allergies or poisoning EDS2	Disease transmission EDS3	Damage to infrastructure EDS4	Pest damage to agriculture EDS5	Carbon release EDS6
Aquatic ecosystems		**2.25**	**0.69**	**2.05**	**1.08**	**0.64**	**0.87**
Freshwater	**ET1**	3.00	0.38	2.50	1.27	0.81	0.67
Bottom or shores of unvegetated water bodies	**ET2**	1.88	0.19	1.88	0.67	0.31	0.53
Aquatic vegetation	**ET3**	1.88	1.06	2.13	0.67	0.44	0.67
Running water	**ET4**	1.31	0.13	1.44	2.73	1.25	0.40
Submerged vegetation	**ET5**	1.88	0.44	1.81	0.60	0.31	0.60
Low marshes, transition bogs, springs	**ET6**	3.56	1.94	2.56	0.53	0.69	2.33
Agricultural ecosystems		**1.82**	**2.30**	**1.76**	**0.18**	**0.74**	**0.69**
Steppes and dry calcareous grasslands	**ET7**	1.94	2.25	1.81	0.20	0.81	0.67
Grasslands containing heavy metals	**ET8**	1.33	2.07	1.80	0.33	1.00	0.53
Acidic grasslands and fossil dunes	**ET9**	1.94	2.31	1.88	0.13	0.69	0.47
Wet margins with tall grass/weed	**ET10**	2.44	2.69	2.38	0.13	0.75	0.80
Wet meadows	**ET11**	2.19	2.63	2.19	0.13	0.50	0.87
Water's edge vegetation	**ET12**	2.38	2.38	2.25	0.27	0.56	0.80
Mesophilic grasslands	**ET13**	1.94	2.50	1.75	0.13	0.63	0.60
Fodder grasslands	**ET14**	1.63	2.63	1.50	0.13	0.69	0.47
Improved grasslands	**ET15**	1.56	2.19	1.38	0.13	0.69	0.73
Crops	**ET16**	1.06	1.44	1.00	0.33	1.00	1.20
Grass strips	**ET17**	1.75	2.38	1.69	0.13	0.75	0.53
Orchards	**ET18**	1.69	2.19	1.50	0.07	0.88	0.67
Forest ecosystems		**2.54**	**2.45**	**2.34**	**0.84**	**0.98**	**0.76**
Moors	**ET19**	2.44	2.50	2.25	0.47	0.88	0.53
Thickets	**ET20**	2.38	2.44	2.25	0.87	0.94	0.73
Deciduous Forests	**ET21**	2.88	2.81	2.63	0.93	1.00	0.73
Riparian forests, wet forests and wet thickets	**ET22**	3.44	2.75	2.94	0.80	1.06	0.93
Deciduous plantations	**ET23**	2.50	2.38	2.25	0.87	1.19	0.87
Conifer plantations	**ET24**	1.81	1.56	2.00	0.87	1.13	0.87
Hedgerows. tree alignments	**ET25**	2.38	2.69	2.06	1.07	0.69	0.67
Urban ecosystems		**1.25**	**1.55**	**1.11**	**0.72**	**0.76**	**2.24**
Urban parks and large gardens	**ET26**	1.50	3.06	1.25	0.87	0.38	1.33
Towns, villages and industrial sites	**ET27**	1.31	2.25	1.31	0.67	0.56	4.20
Active quarries	**ET28**	0.44	0.19	0.19	1.00	0.88	3.00
Abandoned quarries	**ET29**	1.56	1.56	1.31	0.53	0.56	1.13
Slag heaps	**ET30**	1.44	2.00	1.25	0.60	0.81	1.53
Railway and roadside fallows	**ET31**	1.31	1.75	1.19	0.80	1.19	2.13
Industrial water bodies	**ET32**	1.88	0.81	2.00	0.60	0.88	1.33
Road and rail networks	**ET33**	0.56	0.75	0.38	0.67	0.81	3.27
All ecosystem types		**1.91**	**1.88**	**1.77**	**0.61**	**0.78**	**1.12**

3.2 Comparing ES and EDS scores

The different broad ecosystem types had very different ES and EDS bundles (Fig.5). Forest ecosystems were assigned the highest capacity to provide both ES and EDS, while urban ecosystems had the lowest (Fig. 5). Aquatic and agricultural ecosystems had high ES scores and variable EDS scores. The agricultural ecosystem's relatively low average score of Provisioning services (1.6) resulted from the specialisation of agricultural systems. Crops had high plant food scores and low animal food scores. Meadows and grasslands displayed the reverse pattern. When averaging precise ES into a broad ES category this resulted in a low mean. We found that EDS (Carbon release) was particularly high for urban areas, but other ecosystem service and ecosystem disservice scores were low. This score is questionable since many carbon emissions result from the use of fossil fuels, and thus may not be considered as a direct ecosystem disservice.

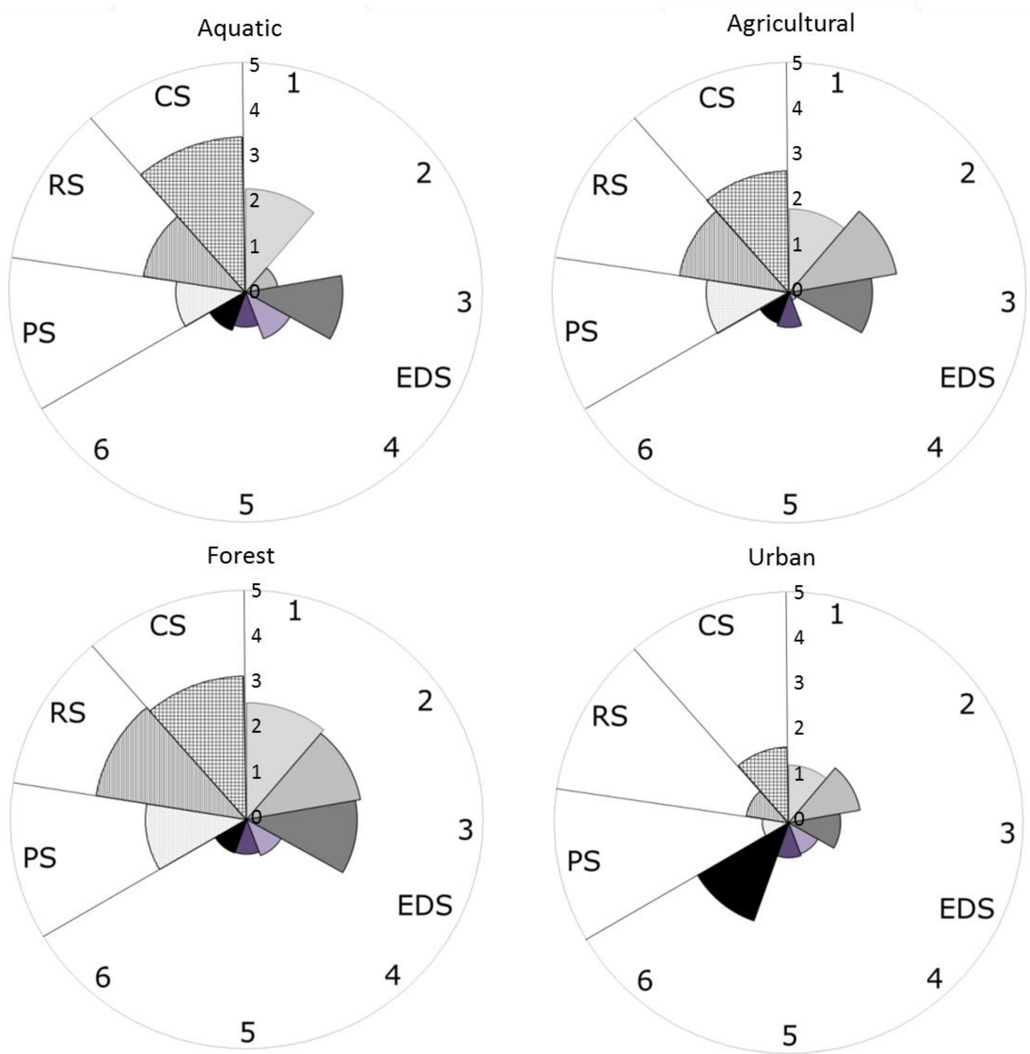

Fig. 5. Bundles of the capacity of the four broad ecosystem types to generate EDS and ES types: EDS1 (Wild animal attacks), EDS2 (Plant allergies and poisoning), EDS3 (Disease transmission), EDS4 (Damage to infrastructure), EDS5 (Pest damage to agriculture), EDS6 (Carbon release), PS (Provisioning Services), RS (Regulating Services) and CS (Cultural Services). The wedges in the chart are same-shaped; their length (radius) indicates the capacity of the ecosystem type to generate ES and EDS.

3.3 Confidence scores

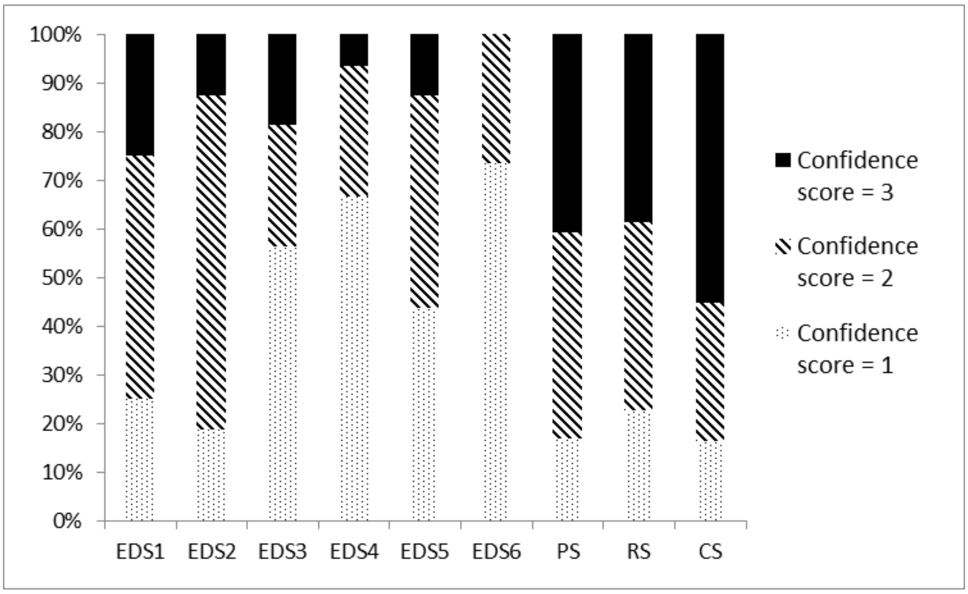

Fig. 6. Percentage of the three different confidence scores for each EDS and each ES type: EDS1 (Wild animal attacks), EDS2 (Plant allergies and poisoning), EDS3 (Disease transmission), EDS4 (Damage to infrastructures), EDS5 (Pest damage to agriculture), EDS6 (Carbon release), PS (Provisioning Services), RS (Regulating Services) and CS (Cultural Services). Confidence score is expressed to high (=3) to low (=1)

There is a significant difference in profile of Confidence score (Conf. Score) frequencies between the EDS and the ES (Chi-squared Test = 75.34, df = 16, $p < 0.001$). The percentage of low confidence (Conf. Score = 1) was higher for ES than for EDS (Fig. 6). In the chi-squared test, the contributions of EDS4 and EDS6 were particularly high (34% of the chi-squared value). For EDS4 (Damage to infrastructure) to EDS6 (Carbon release), a high proportion (>40%) of the participants felt "uncomfortable with their scores" (Conf. Score = 1). EDS1 (Wild animal attacks) and EDS2 (Plant allergies and poisoning) had confidence score profiles similar to those of ES (Fig. 6).

To explore the association patterns between EDS and ES, a Spearman's rho correlation matrix were computed (Table 3). The Health-Related EDS were the most closely correlated with a wide range of ES and between them (Table 3). EDS1 (Wild animal attacks) was significantly ($p < 0.05$) correlated with all ES, with highly significant ($p < 0.01$) correlations with RS9 (Storm protection), RS11 (Nuisance control), PS3 (Wild plants and fungi), PS4 (Wild animal provisioning services), and with CS1 (Emblematic) and CS2 (Existence). EDS2 (Plant allergies and poisoning) was significantly correlated with 17 ES out of 26, and highly significantly correlated with 2 ES (RS2 Erosion control and PS7 Secondary resources). ED3 (Disease transmission) was significantly correlated with 19 ES out of 26, and highly significantly correlated with 4 ES (RS3 Pest control, RS11 Nuisance control, PS4 Wild animal attacks and CS1 Emblematic). EDS4 (Damage to Infrastructure) was significantly and negatively correlated with only 2 ES (PS2 Reared animals and PS7 Secondary resources). EDS5 (Pest damage to agriculture) was not correlated to any ES. EDS6 (Carbon release) was negatively correlated with 10 ES and highly significantly with PS2 (Reared animals).

3.4 ES and EDS correlations

Table 3. Spearman correlation matrix (significant correlations in bold, cell colour light grey $p < 0.05$; dark grey $p < 0.01$)

	Health			Economical		Ecological	Regulating Services (RS)											Provisioning Services (PS)									Cultural Services (CS)				
	Wild animal attacks	Plants and their pollens can cause allergies or poisoning	Disease transmission	Damage on infrastructures	Pest damages to agriculture	Carbon release	Atmospheric composition and climate regulation	Disease control	Pest control	Maintaining nursery populations and habitats	Pollination and Seed dispersal	Maintenance water quality	Maintenance soil quality/ Land/soil formation and composition	Mass stabilisation and control of erosion rates	Protection against storms	Protection against floods	Limitations of noise pollutions and odour and visual nuisances	Cultivated crops (including seaweed farming)	Reared animals and animals from aquaculture	Wild plants, algae, fungi and their outputs	Wild animals and their outputs	Drinking water	Materials and fibres	Secondary resources / Outputs from domestic food used for no human comsuption	Genetic materials	Biomass-based energy sources	Emblematic and symbolic	Existence and bequest	Aesthetic	Physical and experien-tial interactions	Knowledge, scientific and educational
	EDS1	EDS2	EDS3	EDS4	EDS5	EDS6	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10	RS11	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	CS1	CS2	CS3	CS4	CS5
EDS1		**0.46**	**0.95**	0.01	-0.05	-0.22	**0.83**	**0.82**	**0.74**	**0.81**	**0.55**	**0.77**	**0.82**	**0.79**	**0.61**	**0.82**	**0.66**	**0.10**	**0.38**	**0.67**	**0.64**	**0.70**	**0.44**	**0.35**	**0.81**	**0.48**	**0.62**	**0.59**	**0.69**	**0.47**	**0.56**
EDS2			**0.38**	-0.24	-0.07	-0.08	**0.47**	**0.65**	**0.73**	0.30	**0.83**	**0.26**	**0.77**	**0.73**	**0.79**	**0.39**	**0.71**	0.32	0.25	**0.79**	0.25	0.09	**0.48**	**0.61**	**0.49**	**0.63**	0.31	**0.37**	**0.36**	**0.35**	0.25
EDS3				0.09	0.04	-0.24	**0.84**	**0.78**	**0.70**	**0.80**	**0.47**	**0.78**	**0.77**	**0.76**	**0.57**	**0.81**	**0.67**	0.03	0.28	**0.56**	**0.60**	**0.70**	**0.40**	0.21	**0.75**	**0.41**	**0.60**	**0.54**	**0.68**	**0.43**	**0.57**
EDS4					0.33	0.25	0.15	-0.17	-0.19	0.06	-0.32	0.02	-0.18	-0.13	-0.02	-0.07	0.04	-0.01	**-0.42**	-0.18	0.13	0.12	0.06	**-0.50**	-0.17	-0.02	0.05	0.00	0.06	0.26	0.02
EDS5					0.33	0.25	0.05	-0.04	0.06	-0.15	0.10	-0.23	0.01	0.03	0.11	-0.18	0.14	-0.09	-0.19	0.04	0.00	-0.16	0.23	-0.02	-0.10	0.30	0.01	-0.07	-0.09	0.01	-0.05
EDS6						0.08	-0.23	-0.32	**-0.45**	-0.31	-0.23	**-0.38**	-0.33	**-0.36**	-0.03	-0.33	-0.21	-0.26	**-0.61**	-0.25	**-0.56**	**-0.36**	0.15	-0.31	**-0.42**	0.00	**-0.36**	-0.26	**-0.38**	-0.14	**-0.35**

To explore the association patterns between EDS and ES, a Spearman's rho correlation matrix were computed (Table 3). The Health-Related EDS were the most closely correlated with a wide range of ES and between them (Table 3). EDS1 (Wild animal attacks) was significantly ($p < 0.05$) correlated with all ES, with highly significant ($p < 0.01$) correlations with RS9 (Storm protection), RS11 (Nuisance control), PS3 (Wild plants and fungi), PS4 (Wild animal provisioning services), and with CS1 (Emblematic) and CS2 (Existence). EDS2 (Plant allergies and poisoning) was significantly correlated with 17 ES out of 26, and highly significantly correlated with 2 ES (RS2 Erosion control and PS7 Secondary resources). ED3 (Disease transmission) was significantly correlated with 19 ES out of 26, and highly significantly correlated with 4 ES (RS3 Pest control, RS11 Nuisance control, PS4 Wild animal attacks and CS1 Emblematic). EDS4 (Damage to Infrastructure) was significantly and negatively correlated with only 2 ES (PS2 Reared animals and PS7 Secondary resources). EDS5 (Pest damage to agriculture) was not correlated to any ES. EDS6 (Carbon release) was negatively correlated with 10 ES and highly significantly with PS2 (Reared animals).

4. Discussion

Our study set out to evaluate the ecosystem disservices (EDS) in the Scarpe-Escaut Regional Natural Park and to compare them with the capacity of ecosystem services (ES) using an expert-based methodology.

EDS were acknowledged in the Park, but were estimated to be less important than the ES. At the design stage of the study, our exchanges with the local stakeholders (park managers) allowed to identify 6 key ES for the territory. This figure can be compared to the 25 ES previously at a similar stage for the same territory. Similarly, Lugnot and Martin (2013) in Swedish agrosystems found that farmers identified an average 2.25 EDS for 13.12 ES (8 farmers interviewed, 18 EDS cited and 105 ES).

Our results show a general pattern of lower capacity of ecosystems to generate EDS compared with ES. Even though the measurement scales are not commensurable, we see that when we consider the scores associated with EDS and ES, in our study on average the EDS scores were 60% lower than the ES scores. If we consider not the average scores but the sum of ES and EDS scores, then the EDS scores are 17% of the ES scores. For the urban areas EDS had scores higher than ES, but this is due to the very low level of ES associated with urban areas, rather than very high levels of EDS. Some studies evaluating ES and EDS also found lower estimates for EDS than for ES. We can cite Ninan and Kontoleon (2016), who used a monetary valuation approach in Indian agricultural ecosystems. Their results indicated that the EDS score was close to 10% of the ES score. Klimas et al. (2016), using a biophysical approach in urban forests, found that EDS (Carbon emission) was 9.3% of ES (Carbon sequestration).

Besides the valuation of ES and EDS capacity by the expert panel, we analysed an index rating the experts' confidence in their scores. The EDS with the lowest confidence scores were related to Economic impacts and Agricultural impacts, and the EDS related to human health had higher confidence scores. The two EDS linked to economic impacts, EDS4 (Damage to infrastructure and EDS5 (Pest damage to agriculture), mostly concerned maintenance of municipal roads and infrastructure, and to a lesser extent maintenance of private properties and the agricultural sector. Carbon release had the lowest confidence score. From experts' remarks, it seems to be mostly unknown, in contrast to the capacity to sequester carbon. This implies that for a better reliability of some EDS scores, better knowledge of the Economic and Agricultural disservices needs to be considered by extending the expert panel.

In a third step, we looked for correlations between ES and EDS. We found some expected positive and significant correlations: EDS2 (Plant allergies or poisoning) and RS5 (Pollination and seed dispersal); EDS3 (Disease transmission) and RS2 (Disease control), and EDS3 (Disease transmission) and RS3 (Pest control). We also observed positive and significant to highly significant positive correlation patterns between ES and EDS related to health impacts. Based on the scores, EDS1 (Wild animal attacks), EDS2 (Plant allergies or poisoning) and EDS3 (Disease transmission) are strongly related to the capacity of an ecosystem to provide ecosystem services. This shows that the same ecosystem characteristics, functions or species groups can generate both positive and negative effects. For instance, some insect species can bite and be dangerous to human health, while others pollinate or control crop pests. Surprisingly, some expected correlations were not significant, such as EDS5 (Pest damage to agriculture) and RS3 (Pest control).

Further analyses and interviews would be needed to interpret these findings. Moreover, these correlations and lacks thereof have to be considered in the light of their low confidence scores. In an urban area of Melbourne, Dobbs et al. (2014) observed correlations between ES and EDS, such as Forest productivity and Infrastructure damage, or Climate mitigation and Allergens. These correlation patterns implied that management practices or policies aiming to promote ES were very likely to also increase EDS potentially affecting human health.

As a first integration of EDS on the capacity matrix, we acknowledge the limits of this approach expressed in particular in Hou et al. (2012), Jacobs et al. (2014) and Campagne et al. (2017). Scores are based on experts' knowledge and perceptions, and the ES and EDS scores should be considered as semi-quantitative or ordinal estimates of ecosystem capacity. However, the scoring approach has several qualities: it is integrative and provides estimates on a similar scale. Quantitative data very often raise the problem of comparability of ES/EDS potentials using different metrics. It could be argued that the possibilities of biophysical quantification of ecosystem services are still limited and, above all, that the results are expressed in different units that make their aggregation difficult and somehow meaningless. Expert knowledge based estimates might therefore be an efficient way to obtain an comprehensive measurement. As stated by Drescher et al. (2013) given that a rigorous method is used and that explicit steps in the process are followed, the use of expert knowledge in research can be as equally valid as the use of empirical data.

In other words, for objects as heterogeneous as ecosystem services whose commonality lies in the benefits they represent for human populations, assessment and valuation cannot always be separated. Indeed, it would have been interesting to be able to compare the results of expert judgments about the biophysical capacity with an economic valuation of the considered disservices. Comparing expert judgments with the aggregated measure of perceptions that is the foundation of economic assessments, could have shed some perspective on the differences between the perception of experts and those of a wider population. But we did not realize such an economic valuation and the rare works in the literature did not allow to feed such an analysis from benefit transfers. Moreover, although some services can be economically evaluated with some accuracy or at least estimated within a reasonable range (e.g. there are many estimations of the costs of disease outbreaks, cost of purifying water, value of crops or forest products) and some ES / EDS can certainly be measured in rigorous, quantitative ways, such as carbon sequestration / emission, evaluation techniques are of little relevance to estimate a wide variety of services simultaneously and comparing measurements made with different methods is really tricky. Spangenberg and Settele (2010) even consider that despite an illusion of precision given by the rigorous methods used, the economic evaluation of services is based on conventional premises that preclude any claim to "objectively" calculating their score. The intrinsic complexities of estimating scores linked to ES or EDS, particularly those that cannot be easily quantified (some regulation services and most cultural services) question the reliability of many biophysical or economic valuation approaches (Aldred, 2006). In the case of economic valuation, the question of the value of services raises many problems (for a recent synthesis, see Rey-Valette et al., 2017), such as the perception and identification of services by social actors or the measure of option and non-use values.

Further analyses will be needed to test the comparability of scores from different ES or EDS, and especially the comparability of expert-based assessment scores with quantitative biophysical estimates or economic values. The scientific literature on the cost of ecosystem disservice is very limited. This is not surprising given that the literature on ecosystem disservices is itself limited, and the few articles that deal with the subject do not focus particularly on economic aspects, and when they do, only describe costs in qualitative terms (Escobedo et al., 2011; Lyytimäki and Sipilä, 2009;

Zhang et al., 2007). Some evidence can be found in the literature regarding the EDS1 (Animal attacks), EDS2 (Plant allergies and poisoning) and EDS3 (Disease transmission) in medical and epidemiological studies. Notably, tick bites are associated with the transmission of several bacteria and viruses, and particularly Lyme borreliosis. The ticks (*Ixodes ricinus*) involved in this disease are significantly more abundant in deciduous forests, thickets and dense vegetation that shelter rodents and other mammal hosts (Lindgren and Jaenson, 2006), and where the highest scores for EDS1 are observed.

We conclude by agreeing that though not common practice (Von Döhren & Haase, 2015), ecosystem services assessments should consider both ecosystem services and disservices (Lyytimäki, 2014a; Ango et al., 2014; Méral and Pesche, 2015; Vaz et al., 2017), since identifying EDS would allow managers and stakeholders to explicitly address, manage and eventually mitigate some of the negative effects of ecosystem processes (Barot et al., 2017; Maestre Andrés et al., 2012), to understand the interrelated dynamics, and thereby to increase the analytical depth and policy-making relevance of the assessments (Lyytimäki, 2014a).

5. Conclusion

In our study, the expert knowledge elicitation method used enabled us to assess both ecosystem services and disservices amounts for a large number of different ecosystem types. Our results indicate a lower potential of the Scarpe-Escaut Regional National Park ecosystems to produce ecosystem disservices compared with ecosystem services. Although ecosystem disservices are acknowledged, they can be considered less important than the services, both in quantity (scores) and in variety (number of disservices).

We interpreted the significant positive correlations observed between ecosystem services and health disservices as resulting from similar ecosystem characteristics, functions and/or species groups that can generate both positive and negative effects. As a consequence, management or policies options aiming to promote some ecosystem services will very likely result in increases in some ecosystem disservices as well. This highlights the importance of ecosystem services assessments that are not limited to the positive aspects only.

Moreover, considering ecosystem disservices with the general framework of ecosystem services is also a way to gain a better understanding of our natural environment, integrate our dependence on it, and thereby improve the perception of positive services. The participants in the evaluation acknowledged the importance of being able to express negative impacts of ecosystems and species in addition to recognising their benefits. We emphasise that it is important to evaluate both ecosystem disservices and ecosystem services to implement management of the ecosystems, while respecting the functioning of the ecosystems, to develop positive effects while limiting negative ones.

Finally, whatever progress can be made in the evaluation of disservices, damage will always be more perceived by certain categories of agents than by others, depending on their exposure and sensitivity.

References

Aldred, J. (2006). Incommensurability and monetary valuation. *Land economics*, 82(2), 141-161.

Ango, T.G., Börjeson, L., Senbeta, F., & Hylander, K. (2014). Balancing ecosystem services and disservices: smallholder farmers' use and management of forest and trees in an agricultural landscape in southwestern Ethiopia. *Ecology and Society,* 19(1), 30.

Barot, S., Yé, L., Abbadie, L., Blouin, M., & Frascaria, N. (2017). Ecosystem services must tackle anthropized ecosystems and ecological engineering. *Ecological Engineering*, 99(February), 486–495. doi.org/10.1016/j.ecoleng.2016.11.071

Burgin, A.J., Lazar, J.G., Groffman, P.M., Gold, A. J., & Kellogg, D.Q. (2013). Balancing nitrogen retention ecosystem services and greenhouse gas disservices at the landscape scale. *Ecological Engineering*, 56, 26–35. doi.org/10.1016/j.ecoleng.2012.05.003

Burkhard, B., Kroll, F., & Müller, F. (2009). Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. *Landscape Online*, 15(1), 1–22. doi.org/10.3097/LO.200915

Cai, W., Gibbs, D., Zhang, L., Ferrier, G., & Cai, Y. (2017). Identifying hotspots and management of critical ecosystem services in rapidly urbanizing Yangtze River Delta Region, China. Journal of Environmental Management, 191, 258–267. doi.org/10.1016/j.jenvman.2017.01.003

Campagne, C.S., Roche, P., Gosselin, F., Tschanz, L., & Tatoni, T. (2017). Expert-based ecosystem services capacity matrices: Dealing with scoring variability. *Ecological Indicators*, 79, 63–72. doi.org/10.1016/j.ecolind.2017.03.043

Cotillon, S. (2013). Impacts of Land Cover Changes on Ecosystem Services Delivery in the Black Hills Ecoregion from 1950 to 2010. Theses and Dissertations. 1145. http://openprairie.sdstate.edu/etd/1145

Depellegrin, D., Pereira, P., Misiunė, I., & Egarter-Vigl, L. (2016). Mapping ecosystem services potential in Lithuania. International Journal of Sustainable Development & World Ecology, 4509(February), 1–15. doi.org/10.1080/13504509.2016.1146176

Drescher, M., Perera, A.H., Johnson, C.J., Buse, L.J., Drew, C.A., Burgman, M.A., (2013). Toward rigorous use of expert knowledge in ecological research. *Ecosphere* 4, 1–26.

Dobbs, C., Kendal, D., & Nitschke, C.R. (2014). Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics. *Ecological Indicators*, 43, 44–55. doi.org/10.1016/j.ecolind.2014.02.007

Dunn, R.R. (2010). Global Mapping of Ecosystem Disservices: The Unspoken Reality that Nature Sometimes Kills us. *Biotropica*, 42(5), 555–557. doi.org/10.1111/j.1744-7429.2010.00698.x

Escobedo, F.J., Kroeger, T., & Wagner, J. E. (2011). Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environmental Pollution*, 159(8–9), 2078–2087. doi.org/10.1016/j.envpol.2011.01.010

Fazey, I., Fazey, J. A., Salisbury, J. G., Lindenmayer, D. B., & Dovers, S. (2006). The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation,* 33, 1–10.

Fischer, A., & Eastwood, A. (2016). Coproduction of ecosystem services as human-nature interactions-An analytical framework. *Land Use Policy*, 52. doi.org/10.1016/j.landusepol.2015.12.004

Haines-Young, R., & Potschin, M., (2013). CICES V4.3 – Report Prepared Following Consultation on CICES Version 4, August-December 2012. EEA Framework Contract No EEA/IEA/09/003.

Hammer, Ø., Harper, D.A.T., & P. D. Ryan. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4(1): 9pp

Hermann, A., Kuttner, M., Hainz-Renetzeder, C., Konkoly-Gyuró, É., Tirászi, Á., Brandenburg, C., Allex, B., Ziener, K., Wrbka, T., 2014. Assessment framework for landscape services in European cultural landscapes: An Austrian Hungarian case study. Ecol. Indic. 37, 229–240. doi:10.1016/j.ecolind.2013.01.019

Hof, C., Araújo, M.B., Jetz, W., & Rahbek, C. (2011). Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature*, (September), 1–17. doi.org/10.1038/nature10650

Hou, Y., Burkhard, B., & Müller, F. (2012). Uncertainties in landscape analysis and ecosystem service assessment. *Journal of Environmental Management*, 127, S117-31. doi.org/10.1016/j.jenvman.2012.12.002

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., & Schneiders, A. (2014). "The Matrix Reloaded": A review of expert knowledge use for mapping ecosystem services. *Ecological Modelling*, 295, 21–30. doi.org/10.1016/j.ecolmodel.2014.08.024

Kaiser, G., Burkhard, B., Römer, H., Sangkaew, S., Graterol, R., Haitook, T., Sterr, H., Sakuna-Schwartz, D., 2013. Mapping tsunami impacts on land cover and related ecosystem service supply in Phang Nga, Thailand. Nat. Hazards Earth Syst. Sci. 13, 3095–3111. doi:10.5194/nhess-13-3095-2013

Kareiva, P., Watts, S., McDonald, R., & Boucher, T. (2007). Domesticated nature: shaping landscapes and ecosystems for human welfare. *Science*, 316(5833), 1866-1869.

Klimas, C., Williams, A., Hoff, M., Lawrence, B., Thompson, J., & Montgomery, J. (2016). Valuing ecosystem services and disservices across heterogeneous green spaces. *Sustainability* (Switzerland), 8(9), 1–21. doi.org/10.3390/su8090853

Kopperoinen, L., Itkonen, P., & Niemelä, J. (2014). Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: An insight into a new place-based methodology. *Landscape Ecology*, 29(8). doi.org/10.1007/s10980-014-0014-2

Kroll, F., Müller, F., Haase, D., & Fohrer, N. (2012). Rural–urban gradient analysis of ecosystem services supply and demand dynamics. Land Use Policy, 29(3), 521–535. doi.org/10.1016/j.landusepol.2011.07.008

Lele, S., Springate-Baginski, O., Lakerveld, R., Deb, D., & Dash, P. (2013). Ecosystem Services: Origins, Contributions, Pitfalls, and Alternatives. *Conservation and Society*, 11(4), 343. doi.org/10.4103/0972-4923.125752

Lindgren, E., & Jaenson, T.G.T. (2006). Lyme borreliosis in Europe: influences of climate and climate change, epidemiology, ecology and adaptation measures. World Health Organization, 35.

Lugnot, M., & Martin, G. (2013). Biodiversity provides ecosystem services: Scientific results versus stakeholders' knowledge. *Regional Environmental Change*, 13(6), 1145–1155. doi.org/10.1007/s10113-013-0426-6

Lyytimäki, J. (2014a). Bad nature: Newspaper representations of ecosystem disservices*. Urban Forestry and Urban Greening,* 13(3), 418–424. doi.org/10.1016/j.ufug.2014.04.005

Lyytimäki, J. (2014b). Ecosystem disservices: Embrace the catchword. *Ecosystem Services*, 12(October 2014), 2212. doi.org/10.1016/j.ecoser.2014.11.008

Lyytimäki, J., & Sipilä, M. (2009). Hopping on one leg – The challenge of ecosystem disservices for urban green management. *Urban Forestry & Urban Greening*, 8(4), 309-315.

Lyytimäki, J., Petersen, L. K., Normander, B., & Bezák, P. (2008). Nature as a nuisance? Ecosystem services and disservices to urban lifestyle. *Environmental Sciences*, 5(3), 161-172.

Maestre Andrés, S., Calvet Mir, L., van den Bergh, J.C.J.M., Ring, I., & Verburg, P.H. (2012). Ineffective biodiversity policy due to five rebound effects. Ecosystem Services, 1(1), 101–110. doi.org/10.1016/j.ecoser.2012.07.003

Maresca, B., Vandebroucke, S., Mercurio, G., Brice, L., Petit, O., Calvo-Mendieta, I., Carnoye, L., Maillefert, M., Masson, E., Julliard, R., Schwartz, A., Tesnière, C., & Duhayon G., (2014) Les Services Écosystémiques du parc naturel régional Scarpe-Escaut : Évaluation et approche Prospective (SESEEP), CRÉDOC, MESHS, MNHN, SE-RNP, 59p.

Martin, T.G., Burgman, M.A., Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., & Mengersen, K., (2012). Eliciting expert knowledge in conservation science. *Conserv. Biol*. 26 (1), 29–38.

Méral, P., & Pesche D. (2015). Préface; In R. Muradian, Les services écosystémiques. Repenser les relations nature et société, Ed. Quae (Nature et Société), Paris, 298p.

Millennium Ecosystem Assessment MEA, (2005). Ecosystem and Human Well-Being, General Synthesis. Island Press, Washington D.C.

Morère, L., & Glon, E. (2016). Les défis de la gouvernance pour concilier protection et valorisation territoriales d'une ressource. Le cas du programme « Agriculture et zones humides » du Parc naturel régional Scarpe-Escaut. Développement durable et territoires - Économie, géographie, politique, droit, sociologie, 7(3), 23p.

Nedkov, S., Gikov, A., Nikolova, M., Dimitrov, P., & Gachev, E. (2014). Mapping Ecosystem Services Supply in Mountain Areas: a Case Study of Seven Rila Lakes, Bulgaria. 5th International Conference on Cartography and GIS, June 15-21, 2014 Riviera, Bulgaria, (JUNE).

Ninan, K.N., & Kontoleon, A. (2016). Valuing forest ecosystem services and disservices - Case study of a protected area in India. *Ecosystem Services*, 20, 1–14. doi.org/10.1016/j.ecoser.2016.05.001

R Development Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing URL: https://www.R-project.org/.

Rasmussen, L.V., Christensen, A.E., Danielsen, F., Dawson, N., Martin, A., Mertz, O., Sikor, T., Thongmanivong, S., & Xaydongvanh, P., (2017). From food to pest: Conversion factors determine switches between ecosystem services and disservices. Ambio 46, 173–183. doi:10.1007/s13280-016-0813-6

Rey-Valette H., Mathé, S., & Salles, J.-M. (2017). An assessment method of ecosystem services based on stakeholders perceptions: the Rapid Ecosystem Services Participatory Appraisal (RESPA). *Ecosystem Services*, available online on August 11.

Rodríguez-Vargas, A. & Marburg, P., (2011). A Deliberative Economics of Ecosystems and Biodiversity. 9th Conference of European Society for Ecological Economics ''Advancing Ecological Economics: Theory and Practice" Istanbul, Jun 14–17, 2011.

Sabatier, R., Meyer, K., Wiegand, K., & Clough, Y. (2013). Non-linear effects of pesticide application on biodiversity-driven ecosystem services and disservices in a cacao agroecosystem: A modeling study. *Basic and Applied Ecology*, 14(2), 115–125. doi.org/10.1016/j.baae.2012.12.006

Saunders, M.E., & Luck, G.W. (2016). Limitations of the ecosystem services versus disservices dichotomy. *Conservation Biology*, 30(6), 1363–1365. doi.org/10.1111/cobi.12740

Scarpe Escaut Regional Natural Park & Hauts-de-France Region (historically Nord-Pas-de-Calais Region), (2010) Charte 2010-2022. 129p. (available online http://www.pnr-scarpe-escaut.fr/sites/default/files/charte_pnrse_definitive_bdef.pdf)

Schaubroeck, T. (2017). A need for equal consideration of ecosystem disservices and services when valuing nature; countering arguments against disservices. *Ecosystem Services*, 26, 95–97. doi.org/10.1016/j.ecoser.2017.06.009

Schaubroeck, T., Deckmyn, G., Giot, O., Campioli, M., Vanpoucke, C., Dewulf, J., Verheyen, K., Rugani, B., Achten, W.M.J., & Muys, B., (2016). Environmental impact assessment and monetary ecosystem service valuation of an ecosystem under different future environmental change and management scenarios; a case study of a Scots pine forest. J. Environ. Manage. doi:10.1016/j.jenvman.2016.03.005

Shackleton, C.M., Ruwanza, S., Sinasson Sanni, G.K., Bennett, S., De Lacy, P., Modipa, R., Mtati, N., Sachikonye, M., Thondhlana, G., 2016. Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing. Ecosystems 19, 587–600. doi:10.1007/s10021-015-9952-z

Shapiro, J., & Baldi, A.(2014). Accurate accounting: How to balance ecosystem services and disservices. *Ecosystem Services*, 7, 201–202. doi.org/10.1016/j.ecoser.2014.01.002

Spangenberg, J. H., & Settele, J. (2010). Precisely incorrect? Monetising the value of ecosystem services. *Ecological Complexity*, 7(3), 327-337.

Stoll, S., Frenzel, M., Burkhard, B., Adamescu, M., Augustaitis, A., Baeßler, C., Bonet, F.J., Carranza, M.L., Cazacu, C., Cosor, G.L., Díaz-Delgado, R., Grandin, U., Haase, P., Hämäläinen, H., Loke, R., Müller, J., Stanisci, A., Staszewski, T., Müller, F., 2015. Assessment of ecosystem integrity and service gradients across Europe using the LTER Europe network. Ecol. Modell. 295, 13. doi:10.1016/j.ecolmodel.2014.06.019

Swain, H.M., Boughton, E.H., Bohlen, P.J., & Lollis, L.O. (2013). Trade-Offs Among Ecosystem Services and Disservices on a Florida Ranch. *Rangelands*, 35(5), 75–87. doi.org/10.2111/RANGELANDS-D-13-00053.1

Vaz, A.S., Kueffer, C., Kull, C.A., Richardson, D.M., Vicente, J.R., Kühn, I., Schröter, M., Hauck, J., Bonn, A., Honrado, J.P., 2017. Integrating ecosystem services and disservices: insights from plant invasions. Ecosyst. Serv. 23, 94–107. doi:10.1016/j.ecoser.2016.11.017

Vihervaara, P., Kumpula, T., Tanskanen, A., & Burkhard, B. (2010). Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity, 7(3), 410–420. doi.org/10.1016/j.ecocom.2009.12.002

Villa, F., Bagstad, K.J., Voigt, B., Johnson, G.W., Athanasiadis, I.N., & Balbi, S. (2014). The misconception of ecosystem disservices: How a catchy term may yield the wrong messages for science and society. *Ecosystem Services*, 10, 52–53. doi.org/10.1016/j.ecoser.2014.09.003

Von Döhren, P., & Haase, D. (2015). Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators*, 52, 490–497. doi.org/10.1016/j.ecolind.2014.12.027

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., & Swinton, S.M. (2007). Ecosystem services and dis-services to agriculture. *Ecological Economics*, 64(2), 253-260.

Supplementary data

Appendix 1. Details of the expert panel

Our aim was to produce estimates of the biophysical capacity of an ecosystem to provide ES. We restricted the panel of eligible experts to those having both local and global ecological knowledge of the area in order to take into account all major ecosystem types and all major activities applied there. We generally tried to follow the recommendations of Jacobs et al. (2014) on forming a relevant sample of experts with specific affinity to their territory. The experts considered included researchers with expertise in ecology and/or ES, project or site managers, technicians working in environmental or ecological fields, and heads of territorial organizations such as the water agency, regional chamber of agriculture, regional professional centre for forest owners, regional environmental science council, regional conservatories of natural areas, national botanical conservatory, local or regional departments of environmental affairs. The departmental hunting and fishing federation was also represented, along with associations for environmental protection and naturalists.

Of the 17 participants involved: 11 were men, 5 researchers or PhD students and the other 12 were engineers working at different hierarchical levels. For their ecological knowledge we considered the field of their work: 59% were multidisciplinary, 18% were botanists, 12% were specialists in aquatic ecosystems, 6% in agricultural ecosystems and 6% in forest ecosystems.

For each of the ES assessments, the participants were invited to a workshop dedicated to filling out capacity matrix scores. Any participant who was unable to attend the workshop was interviewed individually. During the workshop and the personal interviews, participants were informed about the state of the art in ES, the study, the methods, and the list of ES and ET. We took time to discuss and clarify all the definitions involved in the matrix and the scoring. We proposed completing the matrix in columns, and giving a score by comparing the different ES capacities of each ET. Our experience showed that this was an effective way to fill in the matrix. The workshops lasted one day, with the morning session dedicated to presenting all the definitions, and the afternoon left for participants to fill in the matrices and discuss their understanding of the scorings. In both situations (workshop or personal interviews), we let people give their own score independently. The difference between the two approaches lies in the dialogue initiated in the workshop after the scoring, where everyone was given time to voice their chosen score and open a dialogue on any divergences. At the beginning of the workshop, we defined and specified the rules of dialogue: freedom of speech and to voice divergent opinions, and the possibility of constructive criticism.

Appendix 2. Details and final scores of the matrix of 2016

The matrix was completed in 2016 and consisted of a panel of 17 experts in the "Scarpe-Escaut" RNP (noted SE-RNP all) intended to be more exhaustive, since it integrated all land cover types:

✓ 25 ES (9 provisioning services, 11 regulation services and 5 cultural services)

Regulation and Maintenance Services (with 3 subdivisions):

- Maintenance of physical, chemical, biological conditions: Atmospheric composition and climate regulation (ES1), Disease control (ES2), Pest control (ES3), Maintaining nursery populations and habitats (ES4), Pollination and Seed dispersal (ES5), Maintenance water quality (ES6), Maintenance soil quality/ Land/soil formation and composition (ES7).
- Regulation of natural risks: Mass stabilisation and control of erosion rates (ES8), Protection against storms (ES9), Protection against floods (ES10)
- Nuisances: Limitations of noise pollutions and odour, and visual nuisances (ES11)

Provisioning Services (with 3 subdivisions):

- Nutrition – Biomass for human consumption: Cultivated crops (including seaweed farming) (ES12), Reared animals and animals from aquaculture (ES13), Wild plants, algae, fungi and their outputs (ES14), Wild animals and their outputs (ES15)
- Freshwater: Drinking water (ES16)
- Raw materials: Materials and fibres (ES17), Secondary resources / Outputs from domestic food used for non-human consumption (ES18), Genetic materials (ES19), Biomass-based energy sources (ES20).

Cultural Services (with 2 subdivisions):

- Representations (subjective point of view): Emblematic and symbolic (ES18), Existence and bequest (ES19), Aesthetic (ES20)
- Use (objective point of view): Physical and experiential interactions (ES21), Knowledge, scientific and educational (ES22)

Accordingly, this total dataset comprised 1023 ES/ET expert scores ($Y_{k,i,o}$) x 25 + 33 confidence scores (respectively $V^{ES}{}_{i,o}$ and $V^{ET}{}_{k,o}$) x 17 experts (*n*). The capacity matrix SE-RNPwet is 33 ET by 25 ES, thus 153 scores in total. Appendix 2 presents the final score by means with parametric approaches $\hat{\mu}^{1}_{k,i}$. The confidence scores of this data set are not used in the paper and so are not presented here.

Appendix 3. The SE-RNP matrix (Campagne, 2016)

	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9	ES10	ES11	ES12	ES13	ES14
ET1	2.8	1.8	2.0	4.2	0.9	3.6	0.9	1.9	0.3	3.8	1.4	0.7	2.7	0.6
ET2	1.6	1.1	1.0	3.1	0.4	2.5	0.7	1.3	0.1	2.9	0.4	0.2	1.7	0.3
ET3	2.5	1.9	1.8	4.6	1.6	4.4	1.5	2.9	0.4	3.1	1.9	0.4	0.9	0.7
ET4	2.1	1.6	1.8	3.5	2.0	3.5	0.5	0.9	0.2	2.4	1.4	0.5	1.9	0.8
ET5	2.4	1.9	1.6	4.4	1.4	4.3	1.6	2.8	0.6	2.9	1.6	0.4	0.6	0.8
ET6	3.7	2.2	1.9	4.5	2.3	4.6	3.1	3.2	1.2	4.5	2.0	0.1	0.9	1.4
ET7	1.8	2.1	2.2	3.9	3.8	1.9	3.2	2.8	0.6	1.7	1.8	0.2	2.2	1.6
ET8	1.5	1.4	1.6	1.9	2.4	0.4	0.9	2.5	0.4	1.9	1.8	-	0.1	0.2
ET9	2.0	1.8	2.0	3.4	3.3	2.2	3.1	2.9	0.9	2.1	1.7	0.2	1.9	1.4
ET10	2.7	2.3	2.5	4.1	3.9	3.6	3.9	3.6	1.1	3.6	2.5	0.1	1.1	1.6
ET11	2.6	2.5	2.6	3.9	4.0	4.1	3.7	3.7	1.0	4.2	2.2	0.8	3.3	2.4
ET12	2.8	2.4	2.4	4.3	3.4	4.3	3.4	3.8	1.3	3.8	2.3	0.3	0.8	1.5
ET13	2.2	2.1	2.1	3.2	3.4	2.9	3.1	3.5	0.8	3.0	1.7	0.5	3.9	2.2
ET14	1.9	2.1	2.2	2.9	2.6	2.4	2.8	3.5	0.9	3.1	1.7	0.7	3.1	1.9
ET15	1.8	1.7	1.7	2.2	1.8	1.6	2.0	3.1	0.8	2.6	1.4	0.6	3.2	1.6
ET16	1.2	1.5	1.1	1.4	1.2	0.3	0.4	0.4	0.3	0.8	0.7	4.9	0.9	0.5
ET17	1.9	1.8	2.2	3.1	3.4	2.9	2.8	3.4	0.9	2.6	1.8	0.5	1.2	1.6
ET18	2.4	1.7	2.1	3.2	3.5	2.0	2.6	3.1	1.9	2.5	2.7	4.9	1.4	1.1
ET19	2.2	2.1	2.8	3.6	3.7	2.6	3.4	3.6	1.4	2.4	2.3	0.3	1.6	2.0
ET20	2.5	2.2	2.8	4.1	3.6	2.7	3.8	4.0	2.5	2.5	2.8	0.4	0.8	2.4
ET21	4.4	2.6	3.1	4.4	3.8	3.5	4.4	4.5	4.1	3.4	4.1	0.4	1.1	3.2
ET22	4.5	2.6	3.1	4.6	3.8	4.1	4.5	4.6	4.1	4.6	4.2	0.4	0.8	2.6
ET23	3.6	1.9	1.9	3.3	2.8	2.9	3.5	3.8	3.1	3.2	3.4	0.6	0.9	2.3
ET24	3.1	1.7	1.5	2.6	2.1	2.1	2.1	3.1	2.9	2.1	3.4	0.4	0.3	1.1
ET25	3.4	2.2	2.5	3.9	3.5	3.4	3.7	4.2	3.8	3.5	3.9	1.3	0.8	2.2
ET26	2.1	1.4	1.6	2.5	2.8	1.7	1.7	1.8	1.7	1.5	2.9	1.2	0.5	0.9
ET27	0.3	0.7	0.9	1.5	0.9	0.1	0.1	-	0.8	0.1	0.1	0.4	0.5	0.4
ET28	0.2	0.7	0.9	1.1	0.6	0.2	-	0.1	0.2	0.5	0.1	0.1	-	0.1
ET29	0.9	0.9	1.1	3.1	2.1	1.2	0.5	0.6	0.3	1.0	1.0	0.1	0.2	0.9
ET30	1.2	1.5	1.5	3.2	2.6	0.8	0.4	0.5	0.9	0.4	1.4	0.3	0.8	1.1
ET31	0.6	1.3	1.2	2.1	2.2	0.4	0.3	0.5	0.3	0.2	0.4	-	0.2	0.5
ET32	0.7	0.9	0.9	1.6	0.9	0.8	0.4	0.5	0.3	1.9	0.4	-	0.1	0.2
ET33	-	0.7	0.6	0.4	1.2	0.1	0.1	0.1	-	0.1	-	-	0.1	0.3

	ES15	ES16	ES17	ES18	ES19	ES20	ES21	ES22	ES23	ES24	ES25
ET1	4.1	3.8	0.4	0.9	2.8	0.4	4.0	3.8	4.4	4.5	4.1
ET2	2.9	3.1	0.3	0.2	1.6	0.1	2.0	2.0	2.5	2.4	2.6
ET3	2.8	1.5	1.0	0.6	2.6	0.6	2.9	2.8	4.1	1.7	3.8
ET4	3.5	3.8	0.3	0.6	2.3	0.3	4.1	3.6	4.4	3.9	4.2
ET5	2.8	1.4	0.8	0.7	2.6	0.3	2.4	2.7	3.5	1.5	3.6
ET6	2.9	3.2	2.1	1.3	3.2	2.3	4.3	4.3	4.6	2.2	4.6
ET7	2.6	1.2	0.8	1.5	3.2	0.8	3.5	3.1	4.1	2.6	4.2
ET8	0.6	0.2	0.3	0.3	1.6	0.3	2.1	2.1	2.5	1.0	3.9
ET9	2.2	0.9	0.6	1.3	2.5	0.8	2.8	3.0	3.2	2.4	3.9
ET10	2.4	1.9	1.4	1.4	2.7	1.1	2.2	2.6	3.4	2.1	3.5
ET11	2.8	2.8	1.8	3.5	3.2	1.3	3.5	3.6	4.1	2.6	3.9
ET12	2.5	1.9	2.4	1.5	2.8	1.3	2.8	3.2	4.2	1.9	3.7
ET13	3.2	1.4	1.7	2.9	2.8	1.5	2.2	2.9	3.2	1.9	3.0
ET14	3.0	1.2	1.6	4.1	2.6	1.8	2.5	2.8	2.9	1.5	2.5
ET15	2.5	0.8	1.4	3.5	2.1	1.4	1.4	1.6	1.8	1.4	1.8
ET16	2.2	0.6	3.4	3.6	1.4	3.3	1.8	2.2	1.6	1.3	1.6
ET17	2.9	1.1	1.1	1.8	2.1	0.9	1.5	1.5	2.3	1.5	2.4
ET18	2.1	1.2	1.3	1.9	2.1	1.6	2.9	3.5	3.7	2.4	3.2
ET19	2.7	1.2	1.6	1.8	2.9	1.8	3.2	3.2	4.2	2.6	3.6
ET20	2.9	1.1	2.1	1.8	2.4	2.4	2.2	2.2	2.8	2.2	2.8
ET21	3.8	2.0	4.1	1.5	3.5	4.4	4.2	4.1	4.6	4.2	4.4
ET22	3.4	2.5	3.7	1.3	3.6	4.1	4.1	4.3	4.8	3.7	4.6
ET23	2.8	1.4	4.1	1.4	1.9	4.3	2.1	2.0	2.4	2.5	2.2
ET24	1.9	1.1	4.2	0.8	1.7	4.3	1.4	1.4	1.9	2.1	1.8
ET25	3.0	1.7	3.1	1.6	2.8	3.8	3.6	3.8	4.1	2.0	3.7
ET26	0.7	0.6	0.8	1.1	1.1	1.3	2.1	2.6	3.4	4.4	2.8
ET27	0.2	0.1	0.3	0.2	0.3	0.2	1.3	2.1	1.7	2.6	2.1
ET28	0.3	0.3	1.8	0.3	0.1	0.1	0.4	0.8	0.3	0.2	1.5
ET29	1.6	1.5	0.7	0.8	1.5	0.8	1.3	1.7	1.6	1.6	2.8
ET30	1.6	0.2	1.8	0.9	1.9	1.3	3.8	3.8	3.1	3.1	4.0
ET31	1.0	0.2	0.6	0.4	0.9	0.9	0.6	0.9	0.5	0.8	1.5
ET32	0.5	1.0	0.3	0.2	0.5	0.1	0.5	0.9	0.5	0.8	1.4
ET33	0.5	-	0.1	-	0.3	0.1	0.1	0.4	0.2	0.3	0.9