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Quantification of the potential impact of nature conservation on ecosystem services supply in the Flemish Region: A cascade modelling approach

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A B S T R A C T

Ecological networks of protected areas are critical elements to protect biodiversity. To achieve a minimal performance of such networks, measures and investments are necessary for nature restoration and management. The concept of ecosystem service (ES) can provide additional arguments for investments in ecological networks. However, ES delivery processes are embedded in a complex array of ecological processes and there is a need to cope with this complexity in a pragmatic manner. As many assessment studies have already been criticized for using oversimplified indicators, too much pragmatism may foreclose credibility and acceptance of ES assessments. Therefore, a cascade ES modelling approach was developed that incorporated ecological processes, multiple off-site effects, feedbacks and trade-off mechanisms through shared variables. The assessment focused on which services the existing network delivers and how these services are influenced after realization of site specific conservation objectives.

1. Introduction

Rapid urbanization, industrialization, and successive agricultural revolutions cause changes to the Earths land surface with a pace, magnitude and spatial reach that are unprecedented (Foley et al., 2005). These land-use changes result, next to other factors, in continuously rising rates of habitat destruction and species loss (Foley et al., 2005; Lambin et al., 2001). Consequently, conserving biodiversity has become imperative during the last decades, and the need for conservation action is increasingly recognized worldwide (Pullin et al., 2004). Nevertheless, the main conclusion of the Global Biodiversity Outlook 3 report (Secretariat of the CBD) in 2010 was that the target agreed by the world's Governments in 2002, "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth", has not been met [*sic*]".

Within the European Union the Habitat and Bird Directives are the main policy instruments for biodiversity conservation (EC, 1979, 1992). The European Habitats and Birds Directives require the Member States of the European Union to establish a network of protected areas to ensure the long-term survival of species and habitats that are threatened on a European scale (Evans, 2012). In 2015, there were 25,717 protected areas forming the NATURA 2000 network, covering 767,995 km^2 or about 18% of the EU-27 land territory (Kati et al., 2015). Nonetheless, the implementation of appropriate management for NATURA 2000 sites remains a big challenge (Kati et al., 2015). In the Flemish Region (Belgium), negative trends in the conservation status of several species and habitats were observed (RBINS, 2014) and additional measures need to be taken to counter this trend.

For each NATURA 2000 area in the Flemish Region, nature conservation objectives (NCO's) are defined for the habitats and species of European importance (Louette et al., 2015). To achieve the NCOs, measures and investments for nature restoration and

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management will be necessary. This includes land-acquisition, rewetting, top-soil removal, mowing, forest conversion, etc. The high costs that are associated with the NCOs became a subject of debate in the Flemish Region. On the other hand, the realization of the NCOs could also generate additional ecosystem services (ES).

Inspired by international initiatives such as the Millennium Ecosystem Assessment (2005) and the Economics of Ecosystems and Biodiversity (TEEB, 2010), the ES concept has also been put at the heart of the EU biodiversity strategy (EC, 2012). Target 2 of this strategy states the following:"by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems". The concept of ecosystem services may thus help to explain the benefits that the NATURA 2000 network delivers to society; and this information may further increase public support for nature restoration.

In recent years a large variety of methods and models have been developed that may help with performing ES-assessments. These methods range from simple proxy-based indicator methods (Burkhard et al., 2009) and tools (e.g. Peh et al., 2013) to complex models that can incorporate geophysical processes and integrate economical, ecological and social values (e.g. Boumans et al., 2015; Villa et al., 2014; Nelson et al., 2009; Tallis and Polasky, 2009;). Also, to evaluate the impact of Natura 2000 Sites on ecosystem services, some generic guidelines (McCarthy and Morling, 2014; Arcadis et al., 2011) and benefit estimations (Kettunen et al., 2009) were produced. These NATURA 2000 methods build largely on simplified proxy-based indicator methods and benefit transfer methods, but do not take into account the influence of local circumstances (demand, biophysical characteristics) in assessing the delivery of ecosystem services, which limits the suitability on a more local scale.

According to Boerema et al. (2016), ES often remain oversimplified and poorly quantified in many studies. Furthermore, there are still few studies that quantify a broad scope of ES; although, there is an increasing trend towards integrated assessments (Boerema et al., 2016). But integrated studies and tools, which address many services, tend to use expert judgment approaches over biophysical methods (Boerema et al., 2016). Many ES assessments today still make use of the land-cover based proxy method (Burkhard et al., 2009, 2012). It provides a low-effort and straightforward approach to assess current conditions and analyze land-use change scenarios by use of expert scoring (Jacobs et al., 2015; Kroll et al., 2012; Koschke et al., 2012; Lautenbach et al., 2011). The need for spatially explicit multi-ecosystem service models (not a set of independent ES models) was already expressed by Nelson and Daily in 2010. The complex processes and mechanisms by which ES support the societal wellbeing are diverse and their importance are still often overlooked (Fu et al., 2013). Previous studies already demonstrated that there are limitations to the use of so-called land-use based proxies (Eigenbrod et al., 2010; Geijzendorffer and Roche, 2013; Lautenbach et al., 2011). This is not surprising since ES delivery is not only determined by land-use, but also by soil characteristics, groundwater levels (incl. drainage and abstraction infrastructure), infiltration-seepage patterns, fertilizer application, atmospheric nitrogen deposition, population density, etc.

There has been an increase in the availability of tools that incorporate more complex biophysical processes in their quantification methods. The most commonly used tools that do use a biophysical approach rely on SWAT "Soil Water Assessment Tool", e.g. (Vigerstol and Aukema, 2011; Logsdon and Chaubey, 2013; Francesconi et al., 2016) or INVEST "Integrated Valuation of Ecosystem Services and Trade-offs" (Sharp et al., 2015). Since SWAT is basically a hydrological model, it works at catchment level, has high data requirements, and is mainly restricted to hydrological services such as water quantity, sediment regulation, water quality and flood regulation (Francesconi et al., 2016). The InVest model allows for assessment of a broader scope of services, but when the marine and coastal ES are excluded, only 7 ES remain (carbon sequestration, pollination, recreation, scenic quality, sediment retention, water purification and water yield). The review by Bagstad et al. (2013) provides an overview that includes other tools, but does not address the biophysical and socio-economic complexity as an evaluative criterion. Vorstius and Spray (2015) compared InVest to other tools, such as SENCE "Spatial Evidence for Natural Capital Evaluation" and EcoServ-GIS. However, they, too remain unclear in their conclusion, since their conclusion is that performance of any model depends on the match between modelling assumptions and data quality (spatial, thematic and temporal resolution). Assessing and mapping methods are characterised by compromises between what is needed, desirable, practicable, and possible (Schröter et al., 2015; Vorstius and Spray, 2015). In data-rich regions – which often coincides with high landscape complexity – the 'possible' and 'needed' is higher than what is offered by generic methods. A higher spatial resolution becomes especially necessary when including ES that are supplied at a very local scale (Grêt-Regamey et al., 2015). Recent tools, such as LUCI "Land Utilisation and Capability Indicator" (Jackson et al., 2013; Emmett et al., 2016) can capture and deal with these spatially complex interactions, although LUCI currently only models 7 ES (production, carbon, erosion, sediment delivery, water quality and habitat) in an integrated manner. There is also a growing effort to incorporate the spatial interactions between supply and demand in ES assessments. The ES cascade, originally developed by Haines-Young and Potschin (2010), provides a useful conceptual framework for structuring the various aspects that determine ecosystem services. Boerema et al. (2016) concluded that most studies capture only one side of the ES cascade (either the ecological or socio-economic side). Quantitative studies that assess and map the relationship between the supply and social demand of ecosystem services are scarce (Castro et al., 2014), whilst the interaction between supply and demand is crux to the notion of ecosystem services. Recent publications demonstrate an increased awareness to incorporate spatial interactions of supply and demand (Qiu and Turner, 2013; Baro et al., 2016; Rabe et al., 2016; Verhagen et al., 2016).

So far, there have been only a few studies that encompass a broad range of services in a comprehensive, quantitative and spatially explicit manner. According to the review of Seppelt et al. (2011), there are four facets that characterise the holistic ideal of ecosystem services research: (i) biophysical realism of ecosystem data and models; (ii) consideration of local trade-offs; (iii) recognition of off-site effects; and (iv) comprehensive, but critical, involvement of stakeholders within assessment studies.

The main research objective of this study was to develop assessment methods that address these four facets and would have sufficient scientific credibility to stakeholders in a region with high land-pressure and critical appraisal towards nature restoration. The application objective was to assess how benefits from NATURA 2000 sites would evolve after implementation of the NCOs. Such information could be used to develop alternative financing mechanisms that enable a (partial) reflow of the value that the NATURA 2000 network delivers to society. It also raises awareness on the socio-economic return of the NATURA 2000 network and strengthens public support for nature conservation measures.

This study provides a comprehensive, large scale, spatially explicit quantification and valuation of ES delivered by the NATURA 2000 network in the Flemish Region. First, we provide background information on the NATURA 2000 network in the Flemish Region, including more details on the NCO's and associated land-use changes. Next, we present the cascade ES modelling approach, which was developed in close collaboration with institutional stakeholders and governmental research institutes. We used this modelling approach to assess which services the existing network delivers and how these services are influenced after realization of site-specific conservation objectives. We elaborate on the interpretation of the quantitative and monetary results in the discussion. To argue the added value of advanced ES quantification methods, we analyze how the cascade modelling affects correlations between land-use change and change in ES supply. These correlations provide a measure for the complexity of the modelling approach. Standard expert based ES scoring methods by default result in strong relationships to land-use. We demonstrate that advanced modelling will weaken these correlations in general and allow for atypical responses to land-use change, driven by off-site effects and feedback mechanisms.

2. Methodology

2.1. The NATURA 2000 network in Flanders

The Flemish Region (Flanders) is one of the three regions of Belgium; it occupies the northern part of Belgium (13,522 km^2, 44% of the Belgian territory), has a high population density (445 inhabitants/km^2) and one of the densest traffic networks in the world (Lammar and Hens, 2005). Urban sprawl consumes about 25% of the Flemish territory and irrevocably continues to threaten the remaining open space (Poelmans and Van Rompaey, 2009; De Decker, 2011). The rural matrix is spatially heterogeneous, but dominated by agriculture (46%), forests (11%) and protected nature (7%). Consequently, this rural matrix is under pressure and faces increasing competition for land (Kerselaers et al., 2013).

Flanders has a NATURA 2000 network of 166,187 ha, or about 12.3% of its territory, protecting 109 species and 47 habitats in 62 NATURA 2000 sites (Fig. 1). It encompasses both sites designated under the Bird Directive (Special Protection Areas, or SPAs) and sites designated under the Habitat Directive (Special Areas of Conservation, or SACs). Both types can be spatially overlapping. Size of the sites range between 86 ha and 13,125 ha, with a mean size of 2760 ha. At present, the NATURA 2000 sites are only partly managed as nature reserves (Louette et al., 2015). They also encompass urbanized zones (4%) and agricultural land (21%). We look at each NATURA 2000 site as a service providing unit, including other land-uses (beside nature) that occur within their perimeter (see Supplementary materials part C for site-specific land-use).

The designation of the nature conservation objectives (NCO's) has been established stepwise (Louette et al., 2015). Together with societal interest groups, conservation objectives were first set at the regional level by formulating targets for each habitat type without spatial allocation. In a second phase, these objectives were translated to specific targets for individual sites. The spatial allocation of the site-specific NCO's was facilitated by a land-use allocation model (Engelen, 2006) that enabled the incorporation of hard (e.g. current presence of N2000 habitats, reserve perimeters, etc.) and soft conditions (abiotic suitability, agricultural production value). ES were not explicitly considered during the scenario negotiations, which were coordinated by civil servants of the Flemish Agency for Nature and Forest.

The land-use implications of the NCOs were provided by the Flemish Agency for Nature and Forest. To provide a general picture of land-use distribution before and after realization of the NCOs, land-uses were grouped in 9 classes. In the final land-use balance only 6846 ha switched from one land-use class to another, after application of the NCOs (Table).

The increase in Annex 1 habitat types (+23,986 ha) in Table 1 is almost four times higher than the net changes in land-use classes of Table (+6846 ha). This indicates that, to a large extent, the NCOs are realized by conversions to Annex 1 Habitat types within the general land-use classes. Net changes for the entire NATURA 2000 network (Table 2) may be deceptive, since changes for individual sites may cancel each other out (e.g. forest creation in site A and forest removal in site B). Site-specific changes can be consulted in the Supplementary materials part C. On the level of the entire NATURA 2000 network, only 6846 ha (classes 1, 2, 7 and 9 from Table 2) can be considered as net creation of new nature on, for instance, former agricultural land. There is thus a discrepancy between observed changes of general land-use classes and the changes in specific habitat types. For instance, although "species rich grassland" declines slightly in Table 2, there is a large increase when we only consider the Annex 1 habitats (Table 1).

2.2. Ecosystem service models

For the classification of ES, version 4.3 of the CICES list was used (Haines-Young and Potschin, 2013). Given that CICES focusses on the "final services", which provide direct benefits to society and are the final stage of the ES cascade, this classification system is especially useful for ES valuations, so as to avoid double counting (Morse-Jones et al., 2011). An overview of the ecosystem services and functions that have been addressed in this study is given in Table 3.

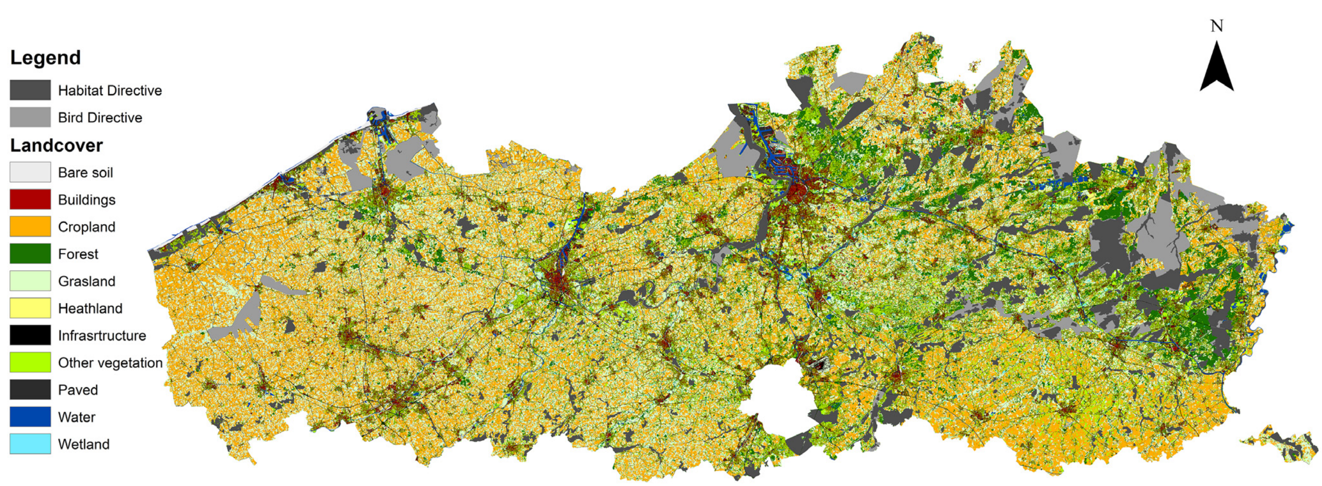

Fig. 1. Map of the Flemish Region with location of the Special Areas of Conservation (Habitat Directive) and Special Protection Areas (Bird Directive).

Table 1
Changes in Annex 1 habitats within NATURA 2000 network before and after realization of the nature conservation objectives.

Habitat type category[a]	Present situation		Future situation		Difference	
	ha	%	ha	%	ha	%
Heath and inland dunes	8930	19.0	12,236	17.3	3306	37.0
Forests and shrubs	23,588	50.3	40,245	56.8	16,657	70.6
Species rich grasslands & tall herbs	4564	9.7	6541	9.2	1977	43.3
Rivers and stagnant waters	1003	2.1	1409	2.0	406	40.5
Wetlands	1347	2.9	1666	2.3	319	23.7
Coastal and estuarine habitats	7485	16.0	8806	12.4	1321	17.6
Total	46,917	100.0	70,903	100.0	23,986	51.1

[a] Classification: Heath and inland dunes (2310, 2330, 4010, 5130, 7150, 4030), Forests and shrubs (9110, 9150, 9120, 9190, 9130, 9160, 91E0, 91F0), Species rich grassland and tall herbs (6120, 6210, 6220, 6410, 6430, 6510), Rivers and stagnant waters (3110, 3130, 3140, 3150, 3160, 3260, 3270), Wetlands (7110, 7210, 7220, 7230, 7140), Coastal and estuarine habitats (1130, 1140, 1310, 1320, 1330, 2110, 2120, 2130, 2150, 2160, 2170, 2180, 2190). Habitat codes according to Habitats Directive (for more information on habitat types and their occurrence http://eunis.eea.europa.eu/).

Table 2
Net changes in general land-use classes within the entire NATURA 2000 network before and after realization of the nature conservation objectives.

Land-use category	Present situation		Future situation		Difference	
	ha	%	ha	%	ha	%
1. Urban and military buildings	12,525	7.6	12,372	7.5	−153	−1.2
2. Agricultural land	55,306	33.4	50,044	30.2	−5262	−9.5
3. Heath and inland dunes	9464	5.7	12,494	7.5	3030	32.0
4. Forests and shrubs	54,356	32.8	56,984	34.4	2628	4.8
5. Species rich grasslands & tall herbs	14,589	8.8	14,300	8.6	−289	−2.0
6. Rivers and stagnant waters	5327	3.2	5388	3.3	61	1.1
7. Wetlands	2448	1.5	2298	1.4	−150	−6.1
8. Coastal and estuarine habitats	7916	4.8	9044	5.5	1128	14.2
9. Other	3640	2.2	2648	1.6	−992	−27.3
Total	165,571	100.0	165,572	100.0		

Table 3
Ecosystem services and functions: [1] Included in the final aggregation of benefits for both the current and future state (realization of the nature conservation objectives) of the NATURA 2000 network in the Flemish Region; [2] Quantified, but not valued; [3] Quantified (and valued) for individual NATURA 2000 sites, but not for all NATURA 2000 sites; [4] Included in the final aggregation of benefits for the current state, but not included in the assessment of the future state.

Seq.	Ecosystem service/function	Final benefit	CICES (class)
1	[3] Erosion prevention	Avoided dredging costs	Buffering and attenuation of mass flows
2	[2] Infiltration	Supporting function	Hydrological cycle and water flow maintenance
3	[1] Avoided nitrate leaching	Avoided treatment costs surface water quality	Filtration/sequestration/storage/accumulation by ecosystems
4	[2] Water retention	Supporting function	Hydrological cycle and water flow maintenance
5	[1] Nutrient removal by denitrification	Avoided treatment costs surface water quality	Filtration/sequestration/storage/accumulation by ecosystems
6	[1] Water provisioning	Avoided treatment costs drinking water, Avoided drinking water import	Ground water for drinking
7	[2] Nutrient storage in soils	Supporting function	Decomposition and fixing processes
8	[1] Carbon sequestration in soils	Climate mitigation	Global climate regulation by reduction of greenhouse gas concentrations
9	[1] Carbon sequestration in biomass	Climate mitigation	Global climate regulation by reduction of greenhouse gas concentrations
10	[2,3] Flood storage	Flood risk reduction	Flood protection
11	[3] Pollination	Supporting function	Pollination and seed dispersal
12	[1] Agricultural production	Agricultural production	Cultivated crops
13	[1] Wood production	Wood production	Fibers and other materials from plants, algae and animals for direct use or processing
14	[1] Air Quality improvement – capture of fine dust particles	Avoided health risk	Filtration/sequestration/storage/accumulation by ecosystems
15	[1] Noise reduction	Impact on real estate value	Mediation of smell/noise/visual impacts
16	[4] Health effects of green spaces (physical exercise, mental health)	Avoided health risk	Physical use of land-/seascapes in different environmental settings
17	[4] Quality of the environment and estate value	Real estate values	Aesthetic
18	[1] Recreation and tourism	Number of visitors, willingness to pay	Enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes

We used a step-by step approach to identify, quantify and monetize the ES, using the best available methods and data for the Flemish Region. The cascade modelling puts regulating and supporting functions at the top of the cascade. The output of these models is then used as input variables to model various providing services. The ES models are interdependent through their input-output relationships and shared variables (Figs. 2 and 3).

The dependencies between the various processes are visually represented in Fig. 3. We distinguished variables (states), ecosystem functions (processes), off-site effects and (final) ecosystem services. Off-site effects refer to calculations where the status of the service at the pixel level is determined by spatial relationships at larger scales. These spatial dependencies have been incorporated in various stages of the modelling by defining topographical relationships (e.g. flow direction of water and sediments), distance and density factors (e.g. drainage ditch density, distance to green infrastructure) or by moving window statistics (e.g. available green infrastructure per inhabitant at different spatial scales). In this way, we were able to incorporate key mechanisms that determine trade-offs and synergies between ES.

The methods for quantification and valuation have been developed in collaboration with public institutions and have been presented to stakeholder groups. We have incorporated the most important parameters in the models, while finding the right balance between complexity and transparency. Special attention was given to the rationale of the modelling approach, which should be intuitive and comprehendible to moderately educated people.

Not all known variables and processes were included in a quantitative manner. For some ES and EF, there is an incomplete understanding of the underlying biophysical and/or socio-economic mechanisms. Therefore, results were not used for the final quantitative assessment (pollination, flood regulation and erosion prevention), as complex spatial-temporal processes, technical challenges and lacking data would have impeded a credible quantification of these ES at the site level. A spatially explicit quantification was done for 18 services, of which 14 were monetized and of which only 11 final services were accounted for in the final benefit assessment of the NCO's.

Valuation methods were based on the most suitable methods and data available. The valuation is partly based on market values (agriculture, wood production, replacement costs, avoided health costs), revealed preference methods (travel cost method for recreation and tourism), and – to a lesser extent – on stated preference methods (valuation of health effects). For most services, different quantification and valuation methods have been reported, applied and compared. This open approach was needed to avoid disputes over the methods, which could foreclose the credibility of the study. Overestimations, biased assumptions and double counting were avoided throughout the study. When considering that many services have not been included in the final valuation (e.g. erosion and flood control), we can state that these final results express a range of minimum benefits that can be attributed to the NATURA 2000 network. More information on the methods and principles behind the identification, quantification and valuation of the ES can be found in Supplementary materials part A.

The ES models were used to evaluate both the current situation as well as the scenario after the NCO's implementation. The conventional spatial resolution for modelling was 25 by 25 m. Spatially distributed quantitative and monetary results were aggregated to the level of individual NATURA 2000 sites.

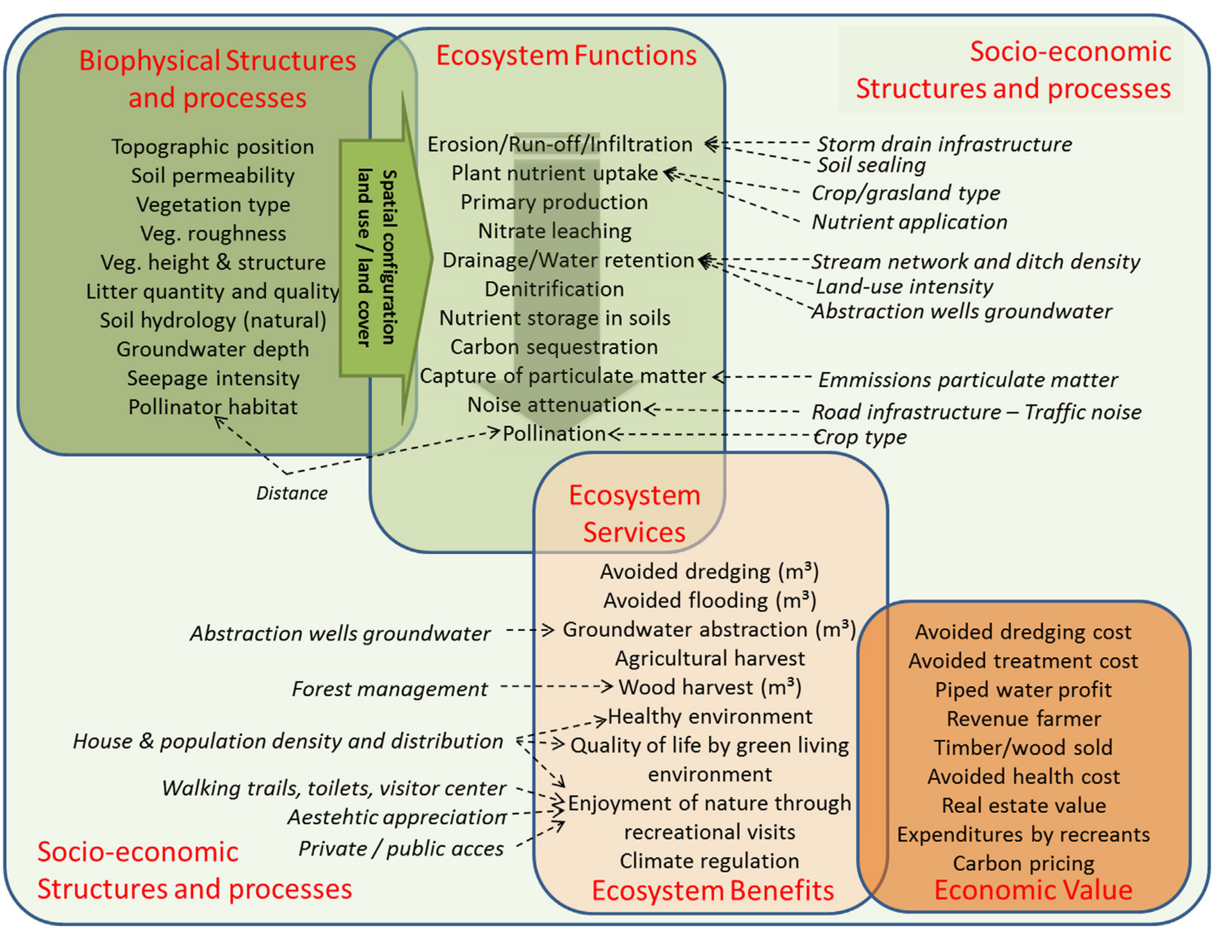

Fig. 2. Allocation of model parameters (variables), modelled ecosystem functions, service delivery (quantification) and monetarization to the ES cascade (Haines-Young and Potschin, 2010).

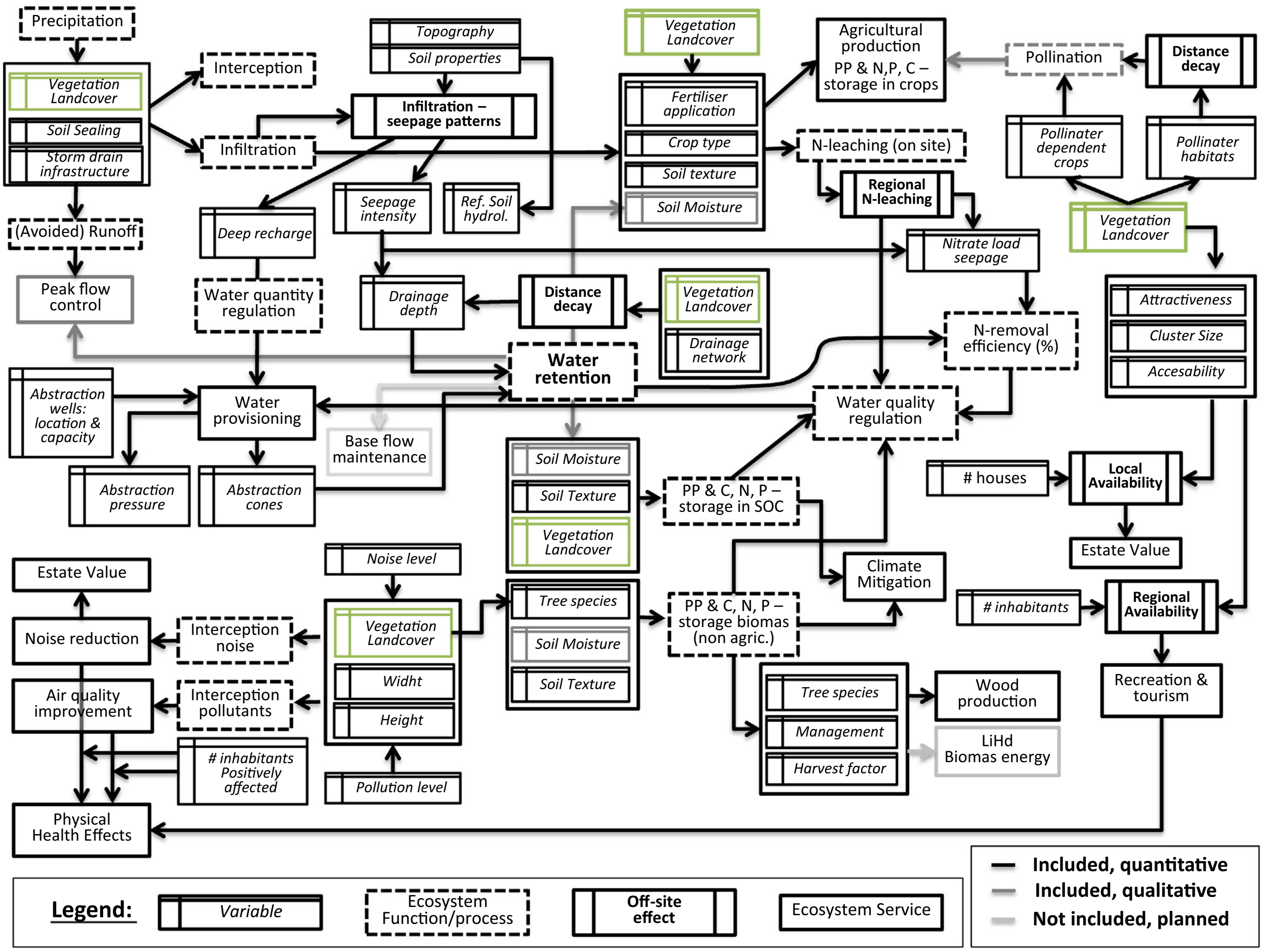

Fig. 3. Relational scheme of variables, ecosystem functions (processes) and final services.

2.3. Data processing and analyses

The applied cascade modelling approach allows one to incorporate shared variables, off-site effects and interdependencies that determine trade-offs and synergies between ES. By analyzing the relationship between changes in land-use and changes in ES supply at the site level, we have a measure for the impact of added complexity. We present an approach for site-selection, land-use reclassification and data-analysis.

2.3.1. Site selection for evaluation

To prepare the data analysis, we needed to make a selection from the 63 NATURA 2000 sites. Firstly, we chose to focus on the special areas of conservation (SACs) for the further interpretation and analysis of the results. The Special protection areas (SPAs), as defined by the Bird Directive (Directive 2009/147/EC), are partly overlapping with the SAC's, as designated under the Habitat Directive (Directive 92/43/EEC). This means only the non-overlapping parts of the SPAs are excluded. These non-overlapping parts of SPAs and SACs are, to a large extent, in agricultural use and also include urban zones. The non-overlapping parts of the 24 SPAs, cover 37% (60,756 ha) of the entire NATURA 2000 network, yet there are only marginal changes in habitat creation (2500 ha). The 38 SACs represent 63% (105,000 ha) of the entire NATURA 2000 network in the Flemish Region. The NCO's are largely focused on the SACs, since 21,500 ha of the 23,986 ha habitat creation (Table) will take place in the SACs. The SACs (BE2300006; BE2500001 and BE2500002) were removed from the dataset. These 3 sites cover mainly estuarine habitats. Each of the SAC's can be identified through the official site-code which is used by the European Environment Agency. Details on the sites (e.g. specific species and conservation status) can be viewed in a web browser: http://natura2000.eea.europa.eu/#.

2.3.2. Land-use reclassification for data analysis

The original input of land-use for the ES modelling included 79 land-use classes (including the Annex 1 habitats). These 79 classes were reclassified to 8 general land-use classes for data analysis: 1. Broadleaf forest, 2. Heathland & Inland Dunes, 3. Intensive agriculture, 4. Mixed forest, 5. Species rich grasslands, 6. Other, 7. Wetland, and 8. Built-up. The reclassification details can be found in Supplementary materials part B. For each of the 35 SACs, the total change in land-use (Diff) and relative changes in land-use (Rel.) were calculated. For further analyses, the class "Built-up" was removed because of the small values and limited relevance to the data analysis. Site-specific details on land-use changes can be found in Supplementary materials part C.

2.3.3. Correlation analyses and multivariate exploration

Prior to analysis, surface effect was removed by dividing land-use and ES data tables by total site surface area. This procedure was applied to T0 and Diff contexts. In Diff context, changes were computed as follows:

$$\frac{T_1 - T_0}{abs(S)_0}$$

T1 = total supply of ES at site level (respective total surface area per land-use category) after implementation of the NCO's; T0 = total supply of ES at site level (respective total surface area per land-use category) before implementation of the NCO's and S = the total site surface area.

Land-use and ES were related and tested by Pearson's correlations. In order to cope with the problem of multiple testing and associated increase in Type I error, a correction of the null hypothesis rejection level α was provided according to the procedure of Benjamini and Yekutieli (2001), based on the control of the false discovery rate, which is the expected proportion of erroneous rejections (errors committed by falsely rejecting the null hypothesis) among all rejections (i.e. significant relationships). This is a sequential Bonferroni procedure preferred in exploratory analysis (Benjamini and Hochberg, 1995). This operation was done in R with the "*p.adjust*" command from the "*stats*" package.

Multivariate ordinations were used to derive the main gradients driving the complexity common to land-use and ES. Co-inertia analyses (Dolédec and Chessel, 1994) were applied to land-use and ES delivery data. It constructs a system of axes maximizing the common information between two multidimensional structures (land-use and ES here); axes express covariances between land-use and ES, and permits highlighting trade-offs. Log-transformed data were arranged in site $\times$ variable tables; land-use table was centred, and ES delivery table was standardized. The relationship between both multidimensional structures was assessed by Rv coefficient (Escoufier, 1973) and tested by a randomization test base on 9999 random permutations of the table lines (Heo and Gabriel, 1999). Computations and graphical representations were performed using R software (R Development Core Team, 2009); co-inertia analyses were performed with the "ade4" package (Chessel et al., 2004).

3. Results

3.1. Introduction to the result section

We will first present the aggregated results for the entire NATURA 2000 network. This is followed by an overview table of the changes that the implementation of the NCO's would bring about. In the second section, we analyze the extent of which (changes in) land-use can explain the observed (changes in) ES delivery.

3.2. Results for the entire NATURA 2000 network

3.2.1. Ecosystem services delivered by the NATURA 2000 network

Quantification and valuation results for the current and future situation of the Flemish NATURA 2000 network are presented in Table 4. Services specifically related to health cover a large part of the total value (air quality, recreation, physical and mental health effects of direct contact with nature). Carbon sequestration in soils, agricultural production and nutrient removal are also substantial, with respect to the total value. Wood production, carbon sequestration in biomass, noise reduction and water provisioning are important in the valuation. The total annual value is minimal in the range of €0.8–1.4 billion per year, which is equivalent to €130–230 per capita per year. Expressed as value per spatial unit, this minimum value is between €4725 and €8454 per hectare per year.

3.2.2. Effects of the realization of the conservation objectives on the delivery of ecosystem services by the NATURA 2000 network

Economic valuation works best when so-called "marginal" environmental changes are being assessed (Morse-Jones et al., 2011). If we compare the quantity and value of the ES after implementation of the NCOs with the current situation (Table 4), we clearly observe a negative effect on agricultural production. This is the consequence of the loss of surface for agricultural activities. Wood production remains equal, although significant changes occur, both in terms of location of forests as well as in species composition. Pine forests are cut and transformed to heathland in many places, whilst agricultural land is transformed to broadleaved forest. Removal of fine dust particles (air quality improvement) declines, since pine forests are able to capture fine dust the entire year round and with greater efficiency than other vegetation types. Rewetting of formerly drained land improves carbon sequestration in soils, as well as nutrient retention in soils and nutrient removal by denitrification. These services are all strongly affected by water retention. Recreational benefits will rise through the increased attractiveness of publicly accessible nature. Due to the creation

Table 4
Quantification and valuation of the current and future state (realization of the nature conservation objectives) of the NATURA 2000 network in the Flemish Region. The quantitative and monetary valuation of changes in ecosystem services delivery generated by the realization of the nature conservation objectives are indicated between brackets. NA = Not Assessed for the future state.

Ecosystem services	Quantification per year			Valuation (k€/year)	
	Low	High	Units	Low	High
Agricultural production	89,087 (−7238)		k€ added value production	89,087 (−7238)	
Wood production	161,722 (+167)		m^3 harvested wood	5422 (+213)	
Air quality improvement	3981 (−78)	7975 (−150)	ton captured particulate matter	214,953 (−4250)	430,658 (−8096)
Carbon sequestration in biomass	154,349 (+5024)		ton C sequestration/year	33,957 (+1105)	
Carbon sequestration in soils	28,474,560 (+1,758,763)		ton C stock in soils	156,610 (+9673)	
Noise reduction	321 (NA)		Houses positively affected	7 (NA)	51 (NA)
Infiltration	302,745 (+4692)		1000 m^3 infiltration	Supporting function	
Water retention	227,468 (+9240)		1000 m^3 water retention	Supporting function	
Water provisioning	15,869 (+2163)		1000 m^3 water provisioning from NATURA 2000 sites	1190 (+162)	3174 (+433)
Nutrient removal	1,094,088 (+420,915)		kg N removal	5470 (+2105)	80,963 (+31,148)
Nitrogen storage in SOM	1,735,758 (+101,830)		ton N stock in soils	Supporting function	
Phosphorus storage in SOM	115,717 (+6789)		ton P stock in soils	Supporting function	
Pollination	216 (−4)		ha pollinator dependent crops serviced by NATURA 2000 sites	Supporting function	
Recreation and tourism	25,757 (+4491)	42,928 (+7485)	1000 visits per year	77,270 (+13,473)	386,350 (+67,365)
Effect on estate value	8137 (NA)		1000 houses within 100 m	14,849 (NA)	29,922 (NA)
Health effects (physical – mental)	1801 (NA)		1000 inhabitants within 1 km	183,479 (NA)	
Total				782,296 (+15,288)	1,399,673 (+94,602)
Total in € per ha				4725 (+92)	8454 (+571)

of larger areas, especially, more people are attracted to NATURA 2000 areas. The quantity and quality of groundwater recharge will be positively affected in the surroundings of major water production areas. Recharge quantity will be improved through conversion of pine plantations to broadleaf forest, grassland and heathland. The quality of the infiltrated water will improve through abandonment of intensive agriculture on soils that are highly sensitive to nitrate leaching. The net benefits of the realization of the NCOs are estimated at €15–94 million per year. This estimation is conservative, since not all ES have been included in the valuation (e.g. health effects and impact on real estate values). For these services there was no objective proof that the realization of the NCOs would increase the benefits, although there are reasons to believe that some of these effects do occur.

We can express the net change in benefits resulting from the NCO's as an average added value per hectare. If we project this change onto the entire NATURA 2000 network (165,000 ha), this would result in an added value of 92–571 €/ha (Table 4). The relative change in benefits for the entire network ranges between 2% and 7%. But, this relatively modest change in benefit needs to be put into perspective, considering the efforts undertaken to realise the NCO's. For at least 85% of the NATURA 2000 area, no change in land-use occurs. Adding up land-use changes for the nature categories (Table 2, classes 3–8) increases newly developed nature by 6400 ha, but this number does not take into account the fact that site-specific changes may cancel each other out. From Table 1, we can see that there is a net increase of 23,986 ha of high quality habitats. This is the result of both the creation of new nature and the conversion of low quality nature to high quality nature (e.g. conversion of forest plantations to mixed or broadleaved forest). If we project the change in benefits to the net change in habitat quality, the added value per area unit of change would rise to a range of 637–3944 €/ha. When using this projection, the relative change in benefits per area unit is much higher (12–32%).

3.3. Land-use and ES delivery relationships

It is clear that ES delivery per area unit cannot be interpreted independently from the average land-use per area unit (%). Therefore, data analyses are necessary to identify relative contributions of land-use to ES delivery. As specified in the material and methods section, the quantitative results per site were rendered surface independent by dividing them by site area before data analysis. The same was done for the (change in) ES delivery, following the implementation of the NCOs. The site-specific net land-use changes can be found in Supplementary materials part C and the actual delivery of ES and ES delivery changes are displayed in Supplementary materials part D. We correlate changes in land-use to the changes in the ES delivery (Table 5), followed by a co-inertia analysis between land-use and ES delivery (Fig. 4).

3.3.1. Interrelations between changes in ES delivery and changes in land-use

From the 84 correlations, 2 were highly significant, 7 correlations with moderate significance and 4 with a low significance. As expected, change in agricultural production (AgrPr.) was strongly correlated with change in agricultural land-use. Although not significant, there is a positive correlation with heathland creation. This may have been a (very weak) consequence of a reduction in agriculture on the most infertile soils, which would have increased the average yield per surface area for agriculture. The same mechanisms could be deduced for agricultural land-use, which is negatively correlated with forest creation. Forest (eg. types 9110, 9130 and 9160) creation on relatively fertile agricultural land does take place on several sites (e.g. 2,200,038, 2,300,007, 23,000,444, 2,500,003 and 2,500,004). Many forests will be converted from pine to broadleaved forest, grassland and heathland. Change in timber production (Timber) was positively correlated with broadleaf forests creation by increasing yield and harvest. Negative correlations were expected with all non-forest land-uses. Heathland creation occurs on the most infertile soils, often at the expense of mixed forests, which could explain the negative correlation with heathland creation. Change in air quality improvement (AirQ.) was correlated with broadleaf forest creation. It was negatively correlated with air quality as heathland creation occurs, to a large extent, at the expense of mixed forests. Similarly, sites with a low decrease in agricultural land will have a low creation of broadleaf forests and a low increase in air quality improvement. Change in carbon sequestration in biomass (BOC) shows very similar correlations with timber production and was strongly correlated with broadleaf forest. Again, heathland creation was strongly correlated, because of the very particular land-use transformation. Change in carbon sequestration in soil organic carbon (SOC) was strongly correlated with wetlands and its negative correlation with forest-to-heathland conversion was clearly observed. There are no significant correlations between changes in infiltration (Infil.) and changes in land-use. The effect of mixed forest to heathland conversion is weakly present. These mixed forests have a relatively high interception, due, especially, to a high prevalence of pine forest on mostly dry and infertile soils. Forest creation – at the expense of agriculture – has negative effects on infiltration. However, this effect is certainly preferable from a groundwater quality viewpoint. Although this effect is strong for some sites with dry sandy soils, the correlation appears non-significant. Change in groundwater retention (GWRet.) was not significantly correlated with land-use changes, although a significant correlation with wetland creation was expected. Change in water production quantity (WpQuant) was weakly increased under a lesser agricultural land-use. Patterns were comparable to those for the change in infiltration, although water production was only relevant for a subset

Table 5
Pearson's correlations between change in land-uses and change in ES for NCO's. Rejection levels: *, <0.05; "**", 0.01; "***", 0.001. See Supplementary materials for land-use reclassification details. Land-use categories: Leaf F. = leaf forest; Heath = heathland; Agric. = Agriculture; Mixed F. = mixed forests; Nat. Gras. = high biodiversity grassland; Other = other; Wetl. = wetlands. Ecosystem services categories: AgrPr = agricultural production (revenue); Timber = high quality timber; AirQ = Air quality regulation; BOC = organic carbon stored in biomass; SOC = organic carbon stored in soils; Infil = infiltration; GWRet = water retention in soils; WPQuant = total recharge (m^3) of groundwater abstraction sites; WPQual = recharge (m^3) of groundwater abstraction sites under nature management (clean water); N rem = Nitrate removal (avoided nitrate leaching & denitrification); Poll = pollination; Recr = recreation.

	AgrPr	Timber	AirQ	BOC	SOC	Infil	GWRet	WPQuant	WPQual	N rem	Poll	Recr
Leaf F.	−0.4	0.52*	0.63**	0.58**	−0.02	−0.25	0.11	−0.29	−0.35	−0.05	−0.04	0.50*
Heath	0.44	−0.51*	−0.58**	−0.54**	−0.64***	0.33	−0.32	0.19	0.06	−0.27	0.16	−0.22
Agric	0.75***	−0.39	−0.43	−0.38	−0.07	0.39	0.13	0.39	0.50*	−0.11	−0.54**	−0.54**
Mixed F.	−0.37	0.36	0.23	0.32	0.21	−0.40	−0.10	−0.33	0.10	0.13	0.03	−0.20
Nat. Gras	−0.21	−0.15	−0.16	−0.18	−0.07	−0.04	−0.31	−0.05	−0.30	0.06	0.32	0.17
Other	−0.15	0.06	0.02	0.05	0.20	−0.07	0.13	0.17	0.25	0.10	−0.11	−0.09
Wetl.	−0.12	−0.03	0.01	−0.05	0.60**	−0.02	0.31	0.11	0.13	0.30	0.15	−0.02

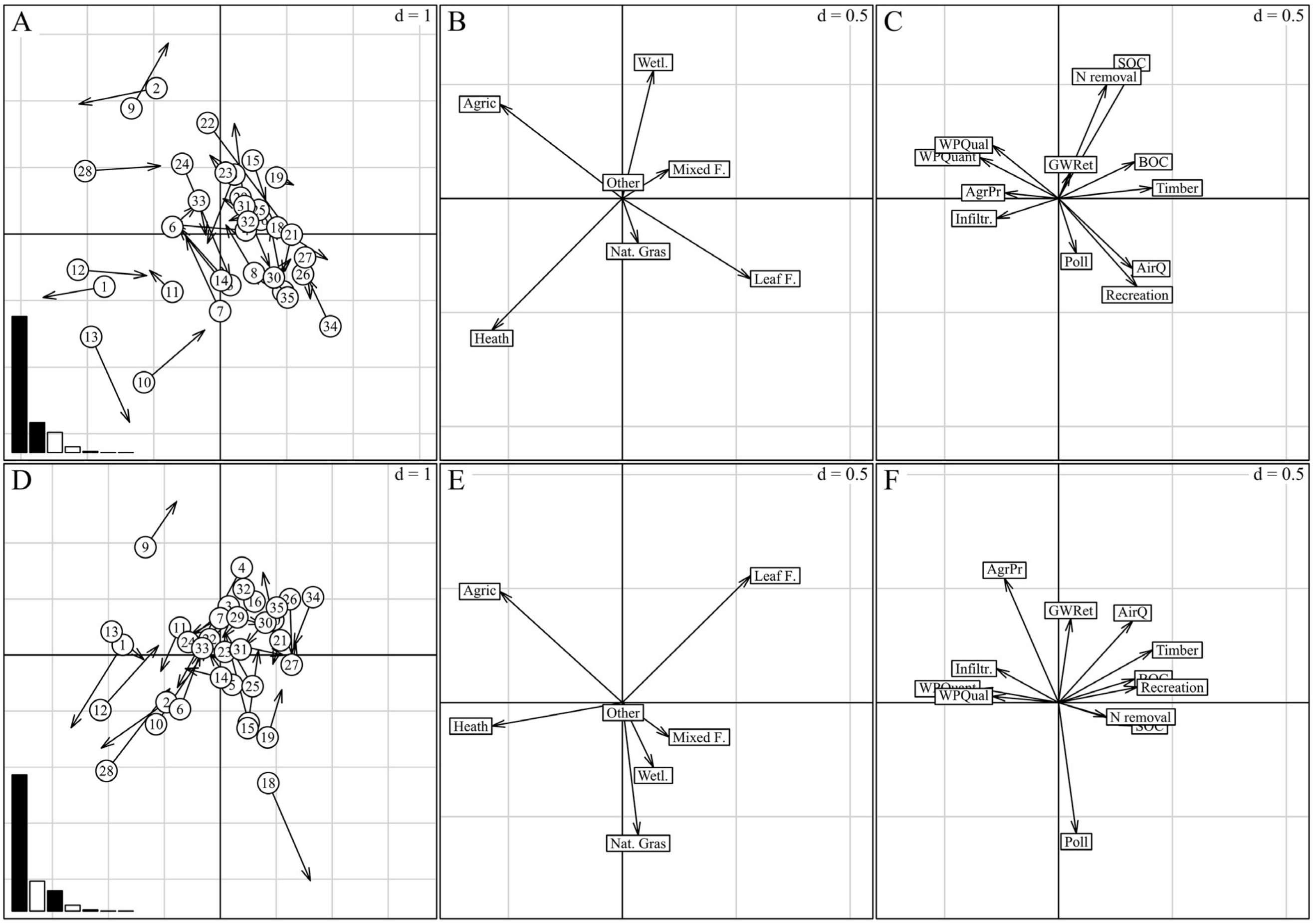

Fig. 4. Co-inertia analysis between land-use changes and changes in ES delivery. (A–C) Axis 1 (horizontal; 70%) and axis 2 (vertical; 15%); (D–F) axis 1 and axis 3 (vertical; 10%); eigenvalue diagrams are inserted in A and D. (A and D) Co-structure between land-use (circles) and ES delivery (arrow tip) patterns (both resulting from the projections of the lines of land-use and ES delivery data tables); each arrow represents a site; arrow length indicates the lack of fitting. Numbers within circles correspond to site codes in Supplementary materials part C. Supplementary materials part C and D provide details on land-use change and change in ES delivery. Pearson's correlation coefficients between the coordinates (circles versus arrow tips) on the first axis: r = 0.78, p < 0.001. On the second axis: r = 0.71, p < 0.001. On the third axis: r = 0.57, p < 0.001. "d" indicates the grid scale.

of the sites. A significant relationship with mixed forest-to-heathland conversion was expected, but the correlation was non-significant when considering all sites. The correlation of water production quality (WPQual.) to changes in agricultural land is evident. A decrease in agricultural land increases quality of infiltrated water. This ES is expressed in 100 m^3 of water abstracted from infiltration processes under extensive land-use. The response is nonetheless dependent on the presence of water abstraction in, or near, the sites and can explain the weak significance. The ES nitrate removal (N rem.) is very complex and depends on both (local) supply of nitrate (from agricultural land) and presence of wetlands for denitrification. Although correlation signs were coherent, relationships were not significant. Changes in pollination (Poll.) were observed only for 2 sites (BE2200038 and BE2400012) and these sites were responsible for a decrease in agricultural land; orchards will disappear for the creation of nature so that the relationship is consequential to a decreasing demand for pollinators, rather than a decrease in supply of pollinators. Recreation (Recr.) was positively correlated with broadleaf forests creation on agricultural land. Recreants prefer large connected areas over smaller areas and forests over other land-use types for recreational purposes. The sensitivity of recreational visits to changes in land-use can differ as this also depends on population density and availability of concurrent green space.

3.3.2. Cointertia analysis results

The relationship with change data was significant ($Rv = 0.43$; $p < 0.001$) and data were organized along three main axes, encompassing 97 and 89% of the variances of land-use and ES delivery respectively (Fig. 4).

Fig. 4B displays the land-use trade-offs. First, there is a land-use trade-off between agricultural land (Agric.) and broadleaf forest (Leaf F.). Also, heathland creation (Heath.) and wetland creation (Wetl.) are strongly represented. For all sites, agricultural land (Agric.) and mixed forest (Mixed F.) are converted to other land uses. Natural grasslands (Nat. Gras) also decrease in most sites (30 out of 35 sites). Transformations to broadleaf forests (Leaf F.) were associated with higher recreation and air quality. Creation of wetlands (Wetl.) covaried with an increase in N-removal and carbon sequestration in soils (SOC) (Fig. 4B and C). Remarkably, there is not a very strong relation between the reduction in agricultural land (Agric) and agricultural production (AgrPr). New nature was, to a large extent, created on marginal, low productive land (very dry or wet conditions). Furthermore this change in agricultural land (Agric.) and heathland creation (Heath) are both slightly associated with improvement of water quantity and quality improvement (WPQual & WPQuant). A reduction of mixed forest covaries with the increase in timber production (Timber) and carbon in biomass (BOC), since these mixed forests are mostly compensated (at site level) with the creation of broadleaf forest (Leaf

F.) that have longer stand rotations, produce high quality timber and are attractive for recreational activities.

The second axis (Fig. 4E and F) gives comparable information regarding land-use changes. Creation of broadleaf forests was associated with a bundle of ES, related to forest creation (Air quality, Timber production, recreation, carbon storage in biomass). Creation of heathland (and agricultural land) was accompanied by increase in infiltration and improvement of water provisioning, both for the quantitative as well as qualitative aspect. The increase of the pollination service (Poll.) was related to natural grasslands creation (Nat. Gras).

In general, the first axis (Fig. 4B and C) highlighted a forest coverage trend from left (agriculture and heath land uses) to right (mixed and broadleafed forests). Independently, the second axis represented a gradient of moisture from bottom (dry, heath and broadleaf forest) to top (wet, mainly wetland associated to N removal and SOC). The third axis (Fig. 4E and F) evidenced a complementary gradient of pollination from top to bottom (high delivery by natural grasslands and wetland to a lesser extent).

4. Discussion

We first discuss the quantification and valuation results for the entire NATURA 2000 network and the potential policy implications. In the second part, we discuss the added value of investing in an advanced cascade modelling approach.

4.1. Interpretation of the valuation results: a mirror for policy programs?

The total annual value of services currently delivered by the NATURA 2000 network is in the range of €0.8–1.4 billion per year. These numbers clearly point out that these sites are important to society. But quantification and valuation of the total value of the NATURA 2000 network for a static situation poses several methodological problems (Fisher et al., 2008; Toman, 1998). Such a value merely represents the hypothetical value of replacing the current state of the NATURA 2000 network with "nothing", which is, realistically, an implausible scenario. In addition, such a drastic scenario would certainly affect the valuation methods, which are only valid for marginal changes in ES supply. However, it may be useful to demonstrate which services and values the NATURA 2000 network represents. Quantification and valuation units are expressed per year and not by total value, by which we already compromise on some of the issues.

The study only explores the impact of the NCO's on the current situation. We ignore the fact that land-use outside NATURA 2000 network may change over time. Evidently one can expect a further increase in population and associated urbanization (Poelmans and Van Rompaey, 2009; De Decker, 2011). On the other hand, certain environmental pressures may decrease due to technological innovations and stricter standards.

The scenario results give us a better understanding of the implications of the NCO's. It is important to notice that not all services are included in the scenario assessment. Flood prevention, through peak flow control, could not be modelled accurately enough to be included, although this is recognized as an important ES. Also for health effects and property values, we were unable to differentiate the impacts of specific land-use types. Although we intuitively understand that quality and typology of open space matters, this information could not be drawn from the available data at the time of this study.

Besides being incomplete, the numbers in Table 4 are also aggregated values for the entire network and cannot be used as standard values in cost-benefit studies. Site-specific data tables for each NATURA 2000 site have been made publicly available (the Supplementary material dataset has been uploaded – a screenshot illustration can be found in annex part F). Table 6 summarizes some aspects associated with the total (change in) ES value, expressed per unit of land-use change and habitat creation. Both in terms of land-use change (Table 6c and d) and changes in ES value (Table 6e and f), there are considerable discrepancies.

It is clear that the NCO's have a differentiated impact at the site level. Changes in land-use vary between 2% and 33%, with a central value of 9% (Table 6d). The change in habitat area is equally variable and has a central value of 19% increase (Table 6d). The creation of habitat area is often higher than land-use change and can occur through changes that remain within the main land-use class, e.g. by converting poplar plantations to wetland forest. The change in ES value that changes in land-use and/or habitat creation exert shows us that not all changes have positive effects. For 30 of the 38 sites, these effects are positive, but 8 sites have negative values associated with habitat creation (mean of high and low estimate). The negative mean values range from €−792 to €−3280, but are not as distinct as the positive mean values that range from €1183 to €17,960 per ha. The extremes in the valuation are mainly associated with changes in Air Quality Regulation, Water Quality Regulation and Recreation Benefits. Therefore, we have often provided a high and low estimate for the valuation. Since there is no scientific basis, weighted or mean numbers have not been provided.

The valuation of ecosystem services is undoubtedly controversial for many ecologists and there is a comprehensive range of literature on the matter (Jax et al., 2013; Schröter et al., 2014; Spangenberg and Settele, 2010). For policy makers, too, these valuation exercises can be challenging. The valuation of ES points to societal demands (e.g. limited publicly accessible green space) and legal standards that are currently not met (e.g. air quality, water quality). Delivery of ES like air quality and water quality improvement can be valued as marginal benefits (saved expenses of marginal costs of existing measures and investment programs). But, this relatively high valuation, points rather to the inadequacy of the current policy measures to meet the (local) demand. This can indicate a high sense of urgency in the short term, but may not be a driver for ES based planning, since more efficient measure programs can substantially decrease these marginal benefits. The issue of poor air quality in the Flemish Region (Amann et al., 2011; Buekers et al., 2011) can, for instance, not be solved by planting trees.

It is clear that there are large benefits associated with restoration and/or conservation of ecosystems. Whether their (potential) ES supply and associated monetary value should be a leitmotiv in land-use planning remains disputable. Investments in conservation, restoration and sustainable ecosystems can often result in " win-win situations", which generate substantial ecological, social and economic benefits (de Groot et al., 2010). In the case of the Flemish NATURA 2000 network, the scenario was primarily inspired by ecological objectives. Nevertheless, the added value of the restoration measures ranges between €15 and 95 million per year and if this value is projected on the net increase of high quality habitat area (+23,986 ha), the added value per area unit of change is substantial (+637–3944 €/ha).

Aristotle's quote "The whole is greater than the sum of its parts" has particular relevance to the NCO's. The predicted changes in ES supply depend on the full execution of the actions and measures to achieve them. Imagine a scenario where two existing private forest complexes will become publicly accessible and will be connected by a newly developed forest corridor. The corridor by itself would not attract extra visitors if the site is not publicly accessible. Making the two separate forest sites publicly accessible (without corridor) would also not result in the same

Table 6
Distributions of the magnitude in land-use change and ES value per hectare at site level.

a: ES value per hectare for current situation			b: ES value per hectare for future situation		
n = 38	Low estimate (€/ha)	High estimate (€/ha)	n = 38	Low estimate (€/ha)	High estimate (€/ha)
Min	3277	7253	Min	3151	7393
P25	4766	10,443	P25	4900	11,085
P50	5455	13,076	P50	5646	14,347
P75	6197	16,153	P75	6357	17,401
Max	11,614	34,082	Max	11,624	34,030
c: Land-use and habitat change (absolute)			d: Land-use and habitat change (relative)		
n = 38	Change in LU	Change in habitat area	n = 38	Rel change in LU	Rel. change in habitat area
Min	6	10	Min	2%	1%
P25	102	184	P25	6%	12%
P50	193	360	P50	9%	19%
P75	439	660	P75	16%	29%
Max	1327	2408	Max	33%	40%
e: Change in ES value per hectare of land-use change			f: Change in ES value per hectare of habitat change		
n = 38	Low estimate (€/ha)	High estimate (€/ha)	n = 38	Low estimate (€/ha)	High estimate (€/ha)
Min	−1233	−2329	Min	−2635	−3925
P25	−380	878	P25	−661	2055
P50	627	2913	P50	1345	6090
P75	1851	8695	P75	2908	15,270
Max	3598	29,515	Max	6236	32,042

impact, since we know that larger sites attract more visitors. It's the sum of actions to achieve the NCO's that makes up the result, not the individual elements.

4.2. Added value of complexity: the cascade modelling

One of the biggest challenges of the ES concept is to have impact on real-life decision making (Ruckelshaus et al., 2015). In addition to the 6 lessons stated in the paper by Ruckelshaus et al. (2015), we would like to emphasize that credibility of the methods is also an important factor in achieving impact. Ecosystem service research should be geared towards implementation; and scientists should assist this process by responding to institutional needs from the outset, and by becoming involved in collaborating with and empowering institutional stakeholders in strategy development and implementation (Cowling et al., 2008). Therefore, it is important to design and parameterize models that are able to incorporate the complexity of the natural environment and its variation across space and time (Bateman et al., 2013). The quantification and valuation methods that have been used in this paper are the result of many interactions between the developers and a broad range of organisations that are involved in the management of the open space in Flanders (recreation, agriculture, nature, and water). These consultations and interactions were already initiated with the development of the Nature Value Explorer (Broekx et al., 2013) and were continued for this study. The methods presented in this paper reflect an actual – and policy-relevant – approach to ecosystem services for the Flemish Region, rooted within principles and classifications of international ES literature, but based on local environmental, social and economic datasets. While the principles behind the quantification and valuation methods can be transferred to other regions with comparable data availability, it is highly unlikely that parameter values can be transferred. As is the case with other modelling platforms (e.g. InVest, ARIES), it is a demanding but indispensable task to derive correct parameter values from local studies and datasets.

The biggest innovation is that we developed one large meta-model that incorporated interactions and trade-offs between the various ecosystem functions and services. We were able to develop and apply a cascade modelling methodology, where shared variables and input-output relations between ES modules have been implemented. Concomitant to the conceptual ES cascade, as initially presented in CICES (Haines-Young and Potschin, 2013), it places supporting ecosystem functions at the top of the cascade. In contrast, most studies neglect the role of these supporting ecosystem functions throughout the modelling approach (Seppelt et al., 2011). Many regulating ES have final benefits but also affect other ecosystem services. The regulating services, especially, affect multiple final services and, therefore, need to be accounted for. For example, erosion prevention has direct benefits to avoiding dredging costs, but equally affects infiltration (groundwater recharge) and flood risk control (reduced peak flows). Therefore, the sequence by which the ES needs to be calculated is of importance (as indicated in the first column of Table 3, and by the data flow chart in Fig. 3).

Demonstrating the added value or accuracy of advanced ES quantification methods is difficult when no independent ES monitoring data is available (Schulp et al., 2014). Studies that evaluate the quality and accuracy of ES mapping and modelling are scarce. Comparison of alternative mapping methods (Schulp et al., 2014), can give insight on the congruence of modelling results, but cannot provide conclusions on the ranking of their quality.

The review by Seppelt et al. (2011) demonstrated that the inclusion of off-site effects and feedbacks are important criteria for integrated ES assessments. When these relationships are not incorporated adequately, an important aspect of the ES concept is neglected. In contrast to studies that compare alternative methods (e.g. Vigerstol and Aukema, 2011; Bagstad et al., 2013; Nemec and Raudsepp-Hearne, 2013; Malinga et al., 2015; Vorstius and Spray, 2015), we chose to analyze the strength of LU-ES correlations as an indicator for the quality of the modelling approach. The LU-ES correlations thus provide ex-post information on how important it is to consider off-site effects, feedbacks and contextual information for quantification.

For example, the number of recreational visits to a site depends on surrounding population density (off-site variable), attractiveness of the site's land-use (on-site), the presence of substitution alternatives at multiple scales (off-site variable) and the aggregated connected area of accessible green space within the site (off-site variable). Feedbacks are considered implicitly, since potential visitors (based on population parameters) are redistributed by the model. By changing the attractiveness or size of a recreation site, other sites will receive fewer visits.

It was a deliberate choice not to perform a pixel-by-pixel LU-ES comparison, as performed by Van der Biest et al. (2015), but to rather look at responses of ES supply at the site level. The results show that NATURA 2000 sites have very different responses to land-use changes and this information would otherwise be obscured. The ES delivery and land-use have been made area independent. Without doing this, the results of the correlations would be dominated by scale effects (large sites). This would not provide any information on the relative performance of the sites or the effects of the NCO's. On the other hand, it may obscure the relevance of the transformations in respect to the total ES delivery by the NATURA 2000 network.

Our method also has some limitations. The land-use variables were reduced from 79 to 8 classes, which is a severe reduction of complexity, but necessary in order to perform a statistical analysis. By reclassifying to 8 classes, we are unable to account for some transformations that remain within the general land-use classes (e.g. conversion from unmanaged wetland to habitat type 91EO). We assume that these subtler transformations have a limited effect on the analysis.

Due to ES being assessed at the site level, the relative proportion of agricultural land-use, for example, negatively affects the prevalence of other land-use types, such as broadleaf forest. This means that we can also expect less obvious correlations between certain land-use types and ES (trade-off effects). These effects are a consequence of the methodology and should not be interpreted as universal mechanisms affecting ES supply. On the other hand, such correlations also show that the NCO measures display some logic of efficiency, where possible. For sites BE2200029, BE2100026 and BE2200030 there will be 633, 402 and 332 ha of heathland restoration, respectively, through direct or indirect conversion of agricultural land. Although the quantity of the service "agricultural production" declines, the quality of the service delivery on the remainder is improved with 20%, 11% and 19%, respectively. This implicit optimization, by abandoning marginal agricultural land for heathland restoration, only occurs in a few sites. However, it may still pervade through by the remarkable, but not significant, positive correlation (0.44) between agricultural production and heathland creation.

5. Conclusion

The cascade modelling approach, which was used to quantify the impact of the nature conservation objectives, (NCO's) successfully incorporated multiple off-site effects, feedbacks and trade-off mechanisms. The methods provide a level of complexity that allows incorporating basic system functioning, whilst remaining intuitive and transparent enough to stakeholders. An ex-post data analysis was used to demonstrate the impact of the cascade modelling. Only a few direct correlations between land-use change and ES supply could be observed. This confirmed our hypothesis that the system is complex and has to be analytically considered in a multivariate context. Especially in the context of regulating and cultural services, actual ES supply is clearly dependent on processes that include spatial dependencies (off-site effects) and biophysical processes (e.g. soil hydrology).

Co-inertia analysis did reveal strongly concordant co-structures between the two patterns. Axes 'relationships' and 'global co-structure' bear witness of common patterns, even if we cannot always provide a precise mechanistic explanation that fits for all of the sites. This can be perfectly expected as many non-significant univariate relationships between land-use and ecosystem services nonetheless show some trends. The fact that some relationships were not significant in the bivariate correlation analysis does not mean that involved variables do not play any significant role in the system. In this respect, the co-inertia did reveal much more. Significant correlations of variables with co-inertia axes are certainly more numerous. In a system, in general, most of variables are co-linear (direct and/or indirect relations), and the significance of their roles mostly take place in the multivariate context.

This proves that advanced assessments, which include additional biophysical and socioeconomic variables, significantly impact quantification and valuation results. We advise against applying land-use based expert scoring methods at regional scales or a collection of sites, given that the needed contextual information cannot be realistically incorporated in a scoring matrix (Van der Biest et al., 2015). Expert based land-use scoring methods may be well suited and applicable at the site level, since local experts and stakeholders would implicitly take the needed contextual knowledge into account.

The results of the study show that the realization of the nature conservation objectives has positive effects on the total value of ES delivery by the Flemish NATURA 2000 network. The net benefits associated with the NCO's are in the range of €15–94 million for the entire NATURA 2000 network. At least 24,000 ha are affected by land-use transformations associated with the NCO's.

For this study, the impact of the NCO's on the monetary valuation is generally positive, but for some sites we observe rather low and even negative values. Our results point out that forest conversion to grassland, especially, and heathland negatively affects the valuation results. Forests are associated with high ES supply: they sequester carbon, regulate air quality and are attractive for outdoor recreation. It can be acknowledged that some high biodiversity habitats, such as heathland, are less effective in delivering specific ES than other habitat types.

Additionally, not all methodologies are suited to truly grasp all the differences between habitat types on aspects such as the impact of landscape diversity on recreation. Policy makers need to be aware of methodological issues and safeguard that biodiversity remains the key-priority for the restoration of NATURA 2000 sites and protected sites in general.

The results of this study were communicated and discussed with a broad range of stakeholders, with little direct effect on the NCO issue. Ongoing debates between stakeholders are still focused mainly on achieving NCOs while minimizing – as much as possible – harmful effects to stakeholders, such as agriculture and business to a maximum extent, which – in some cases – prevents the identification of potential win-wins and multi-functional solutions. Whereas the direct impact at the time was low, an added value of the ecosystem services concept for public policy was recognized. The interest from policy and societal actors on this subject has been steadily growing at different policy levels. Whether or not this interest was triggered by this study (being one of the very first to be conducted in a policy-decision context in Flanders) is up for debate.

However, plenty of work is still needed to mainstream the concept in general policy. Furthermore, whether or not triggered by this study, practical examples demonstrating the difference these types of assessments can make were, and are, being set up by various actors.

Progress on developing alternative financing mechanisms is slow. One of the insights the study provides is the potential of the NATURA 2000 network to mitigate climate change through carbon sequestration. This potential could be used to set up domestic offset schemes, whereby carbon sequestration, as a direct result of nature restoration, is financially compensated by organizations and individuals that want to off-set carbon emissions produced elsewhere. This idea is currently being explored by the Agency for Nature and Forests.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoser.2017.02.020.

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