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Social mapping of perceived ecosystem services supply – The role of social landscape metrics and social hotspots for integrated ecosystem services assessment, landscape planning and management

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Abstract

This paper contributes to the discussion on integrating societal considerations, stakeholders' perceptions and laymen knowledge into ecosystem services (ES) assessments. The paper illustrates how social mapping of perceived ES supply (or alternatively demand) can contribute to integrated ES assessment. Based on sketched locations of the, according to 38 respondents, most important ES at the local scale, we describe the perceived ES distribution with social landscape metrics (abundance, diversity, richness, risk, rarity) based on traditional landscape ecology indicators. We illustrate how social landscape metrics can inform ES management and planning and describe how synergies between ES as stated by the respondents differ from calculated synergies (the latter based on correlation coefficients between perceived ES abundance). We present indicators pointing to locations where (multiple) ES synergies are perceived by stakeholders (stated synergy index), and to conflicting ES and ES perceived to be at risk (risk index). Overlapping social ES hotspots based on the social landscape metrics with ES hotspots based on more traditional biophysical modelling (biophysical hotspots) and ecological inventories (ecological hotspots) results in social-ecological or social-biophysical hotspots, coldspots and warmspots relevant for nature and landscape planning, management and governance. Based on an analysis of the overlaps between social, biophysical and ecological hotspots on the one hand, and the contribution of ecological quality, land zoning categories and

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conservation statuses on the other hand, we discuss the added value of integrating social ES mapping in integrated ES assessment, above ES assessments based on biophysical or ecological attributes. Given the limited overlap between social hotspots and ecological or biophysical hotspots, we conclude that integrating stakeholders' mapping of perceived ES supply (or demand) into ES assessments is necessary to reflect the societal aspects of ES in ES assessments. However, with a limited sample of respondents, there is a risk of collectivisation of respondents' viewpoints as a common, societal stance. Moreover, the social landscape metrics are not suitable for describing the distribution of ES with low perceived abundance. Finally, we explain how social ES assessment can result in mainstreaming ES in planning, policy and practice.

Keywords: participatory mapping, social valuation, social assessment, integrated valuation, ecosystem services, stakeholders' perception

1. Introduction

Mapping Ecosystem Services (ES) supply is traditionally based on land use and land cover data, or on the spatial distribution of biophysical or abiotic assets and flows (Chan et al., 2012; Fagerholm et al., 2012; Martínez-Harms and Balvanera, 2012; Menzel and Teng, 2009; Plieninger et al., 2013; van Riper et al., 2012). Reviews by Crossman et al. (2013) and Egoh et al. (2012) indicate such approaches focus on ES more easily quantifiable, thereby missing out intangible ES (such as learning opportunities or aesthetics) provided by ecosystems. Menzie et al. (2012) warn against "ecosystem service myopia" occurring when one chooses to focus on one or a few ES over others, probably resulting in missing important trade-offs among services.

A participatory mapping approach can overcome methodological difficulties in mapping intangible ES, and widen the range of ES included in the assessment. Moreover, participatory mapping exercises answer the call to involve stakeholders early and explicitly in ES assessment (Cowling et al., 2008; Menzel and Teng, 2009). We argue participatory mapping can complement more traditional ES mapping approaches, thereby broadening as well the scope of ES included, as the knowledge base (expert, local and lay knowledge). Whereas participatory mapping can include objective (e.g. citizen science-based species distribution or mapping footways used for recreation) and/or subjective data (e.g. perceived landscape quality or the location of intangible ES), we define social mapping as mapping subjective perceptions, the personal use of nature and landscape and intangible ES (see also description of key terms in Table 1). In this manuscript we will focus on social mapping of subjectively perceived ES supply. ES mapping by both experts and laymen in integrated ES assessments can assist landscape planning and ES governance in better complying with users' and beneficiaries' perceptions and expectations (Fagerholm et al., 2012; Menzel and Teng, 2009), and thus conflicts on land use and land management can be prevented (Gunderson et al., 2004; Zhu et al., 2010).

With the growing attention towards cultural ES, a need for alternative approaches for mapping intangible ES and/or perceived ES delivery emerged. Participatory mapping is considered mainly suitable for mapping cultural ES and provisioning ES, that are not unidirectionally linked to land use, land cover, or biophysical characteristics of the landscape (e.g. Bryan et al., 2010; Palomo et al., 2013; Martínez-Harms and Balvanera, 2012; Plieninger et al., 2013). We refer to a review by Brown and Fagerholm (2015) on the use of PGIS (participatory GIS) and PPGIS (public participation GIS) for an overview of technical aspects of participatory mapping of ES (such as selection of ES to be mapped, sampling strategies, methods for mapping and analysing, scale, geographic scope, accuracy, data quality, etc.). Next to a ES-oriented approach in the literature, other terms have been used for describing values perceived by stakeholders, such as social values (Bryan et al., 2011; Sherrouse et al., 2011), community values (Martínez-Harms and Balvanera, 2012), and landscape values (Raymond and Brown, 2006; Zhu et al., 2010).

Table 1. Description of key terms

Term	**Definition**
Biophysical ES assessment	Assessment of ecosystem services supply based on biophysical data sources (mapping, modelling, remote sensing, surveying). This includes ES delivery modelled on land use, land cover or vegetation type (Cowling et al., 2008; Fontaine et al., 2013)
Biophysical hotspot	Site or area where ES delivery (provisioning or regulating) is significantly higher than average in the study area (in our study based on the local Getis-Ord Gi* statistic) (Alessa et al., 2008;

	Donovan et al., 2009)
Coldspot	Site or area where a variable (in our case ES delivery, or a social landscape metric) is significantly lower than average in the study area (based on for example the local Getis-Ord Gi* statistic) (Alessa et al., 2008; van Riper et al., 2012)
Ecological (or biological) hotspot	Site or area where ecological or biodiversity value is significantly higher than average in the study area. The ecological or biodiversity value can be based on species mapping or habitat surveying, summarised e.g. using landscape ecology indicators (diversity, abundance, etc.) (Brown et al., 2004). We applied local Getis-Ord Gi* for defining ecological hotspots
Economic ES assessment	Assessment of the economic value of ES in the study area. This is most frequently in the form of monetary valuation, but also non-monetary quantitative valuation is possible (Cowling et al., 2008; Fontaine et al., 2013)
Hotspot	Site or area where the value is significantly higher than average in the study area. The delineation of the hotspot can be based on the local Getis-Ord Gi* statistic (Fagerholm and Käyhkö, 2009),, on kernel densities (Brown and Pullar, 2012), on expert (Brown et al., 2004) or layman evaluation or on landscape ecology indicators (diversity, abundance, etc.) (Brown and Reed, 2012; Plieninger et al., 2013)
Integrated ES assessment	Assessment of ES supply and/or demand based, integrating social, biophysical and economic ES assessment through e.g. multi-criteria analysis (MCA) or deliberative approaches (Boeraeve et al., 2015; Fontaine et al., 2013)
Local Getis-Ord Gi* statistic	Identifies where high or low values tend to cluster, compared to random distributions. The output of the Gi* statistic is a *z*-score for each grid cell (Fagerholm and Käyhkö, 2009; Zhu et al., 2010). The Gi* characteristic is calculated as (Getis and Ord, 1992):

	$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}(d) x_j}{\sum_{j=1}^{n} x_j}$$ with $\{w_{i,j}\}$ a symmetric spatial weight matrix ($w_{i,j}$ being 1 for cells within distance *d* of cell *i*, and 0 for all other grid cells), x_j is the value associated with cell *j*
Participatory mapping	A mapping exercise by non-experts and/or stakeholders. This can be done through interviews, focus groups, online, deliberative meetings, etc. As well one-to-one interactions as group work is possible. Participatory mapping can include objective data (e.g. species distribution or actual land use, i.c. local and/or layman knowledge) as well as subjective data (e.g. perceptions, intangible ES or desired land use)
Perceived ES distribution	The distribution of ES in the study area, as described by social landscape metrics, based on respondents' sketched locations of perceived ES supply
Perceived ES supply	The locations of ES delivery (or alternatively demand) in the study area as perceived by the involved stakeholders
Social hotspot	Site or area where the perceived ES distribution (ES supply or ES demand) is significantly higher than average in the study area (based on the local Getis-Ord Gi* statistic). The perceived ES distribution can be described with social landscape metrics (Alessa et al., 2008; Whitehead et al., 2014)
Social landscape metrics (SLM)	Generic term for indicators traditionally applied in landscape ecology, but increasingly used as aggregation indices in participatory mapping (including participatory mapping of ES). These include e.g. diversity, abundance, and richness. See Table 3 for on overview of selected social landscape metrics (Brown and Reed, 2012; Bryan et al., 2010; Fagerholm et al., 2012; Plieninger et al., 2013)
Social mapping	A specific type of participatory mapping by non-experts and/or stakeholders, whereby instead of objective or expert data, more subjective data such as respondents' perceptions or perceived intangible ES supply are mapped.

z-score	A statistical measurement that indicates if, and how strong, the value is diverging from the mean. The *z*-score represents the statistical significance of clustering identified by the Gi* statistic. A high positive *z*-score ($z > 1.96$) indicates a hotspot (at significance level 0.05), a low negative *z*-score (< -1.96) indicates a coldspot (Fagerholm and Käyhkö, 2009; Zhu et al., 2010)

There is a need for indicators that summarise and describe the distribution of participatory mapped ES, as a first step to spatially integrate perceived ES supply and demand with biophysical and economic ES valuation assessments. Bryan et al. (2010), Brown and Reed (2012), Fagerholm et al. (2012) and Plieninger et al. (2013) introduced indicators from landscape ecology (such as abundance, diversity, richness and risk) in ES mapping approaches, with the aim to describe the distribution of (perceived) ecosystem service providing units better. Plieninger et al. (2013) term these indicators “aggregation indices” and refer to their capacity for identifying priority areas for ES functioning. Within our study, and in line with Brown and Reed (2012), we will frame these indicators as “social landscape metrics” (SLMs). Social hotspots for perceived ES supply (or demand) can be defined based on SLMs. Comparing the social hotspots with ecological or biophysical hotspots (or coldspots) can indicate potential conflict areas, zones with potential to deliver socially desired ES and win-win solutions, or zones with lower social importance (social coldspots) where societally disputed conservation measures with high impact on the landscape can be located without creating tensions or conflicts (Alessa et al., 2008; Whitehead et al., 2014). Mapping perceived ES supply deals with the challenge to spatially locate and integrate perceptions and values in land-use planning, natural resources management and integrated ES assessment (Brown, 2012; McIntyre et al., 2008; Ryan, 2011). The social landscape metrics contribute to integrated ES assessments by offering spatially located indicators that can be integrated with biophysical indicators and/or monetary valuation results (Bryan et al., 2010; Fagerholm et al., 2012).

However, as social ES mapping is time-intensive and challenging for natural scientists who are usually applying ES assessments, our research question discusses the additional value of social mapping, through comparing its results with results based on more traditional data, such as zoning plans, land use, ecological quality, and/or nature conservation statuses (e.g. nature reserves or other conservation schemes). If we would be able to predict the perceived ES supply (as a social value) through benefit- or value-transfer approaches (Troy and Wilson, 2006) based on conservation status, ecological quality or zoning, there would be no need for social mapping of ES. Previous studies modelled social values on landscape features such as elevation, slope, distance to roads and water, land cover and landforms (Sherrouse et al., 2011) or on biophysical and ecological properties (de Chazal et al., 2008; Lavorel et al., 2011), but it is rather unclear if the status of an area (zoning, conservation status, ecological quality) has an influence on the social value of the site (Palomo et al., 2014; Whitehead et al., 2014). Therefore, we will evaluate the influence of zoning, nature conservation statuses and ecological quality on the perceived ES supply.

In order to discuss the added value of social mapping, we define the following specific aims for this paper:

1. to illustrate the potential of social landscape metrics and social hotspots to describe perceived ES distribution and related trade-offs (conflicts) between ES;
2. to introduce the stated synergy index to describe synergies stated by individual stakeholders (stated synergies) in relation to synergies calculated across stakeholders (calculated synergies);
3. to discern the influence of zoning categories, nature conservation status and ecological quality on perceived ES supply;
4. to compare perceived ES distribution as described by social ES hotspots with biophysical-based hotspots and ecological quality-based hotspots;
5. to discuss potential application of social landscape metrics and social hotspots in integrated ES assessment, landscape planning, nature management and governance.

2. Methodology

2.1. Study area

The study took place in four contiguous municipalities in central-Belgium (Bierbeek and Oud-Heverlee in the Flemish Region, Beauvechain and Grez-Doiceau in the Walloon Region; see Figure 1) under influence of urban sprawl of Brussels, Louvain, and Wavre - Louvain-la-Neuve agglomerations. The area shows a high agricultural, ecological, and landscape quality. In 2010, about 39.000 – rather highly educated – inhabitants lived on 164 km^2 (16.400 ha) (Statistics Belgium, 2015a); the average fiscal income in the area in 2010 was 29% above the Belgian average income (Statistics Belgium, 2015b). The built-up area accounts for 21 % of the total area, (Statistics Belgium, 2012) and is still reflecting the rural past of the area with mainly low-rise building and semi- and detached housing, but ribbon development has been filling the open space between the linear villages at a fast pace.

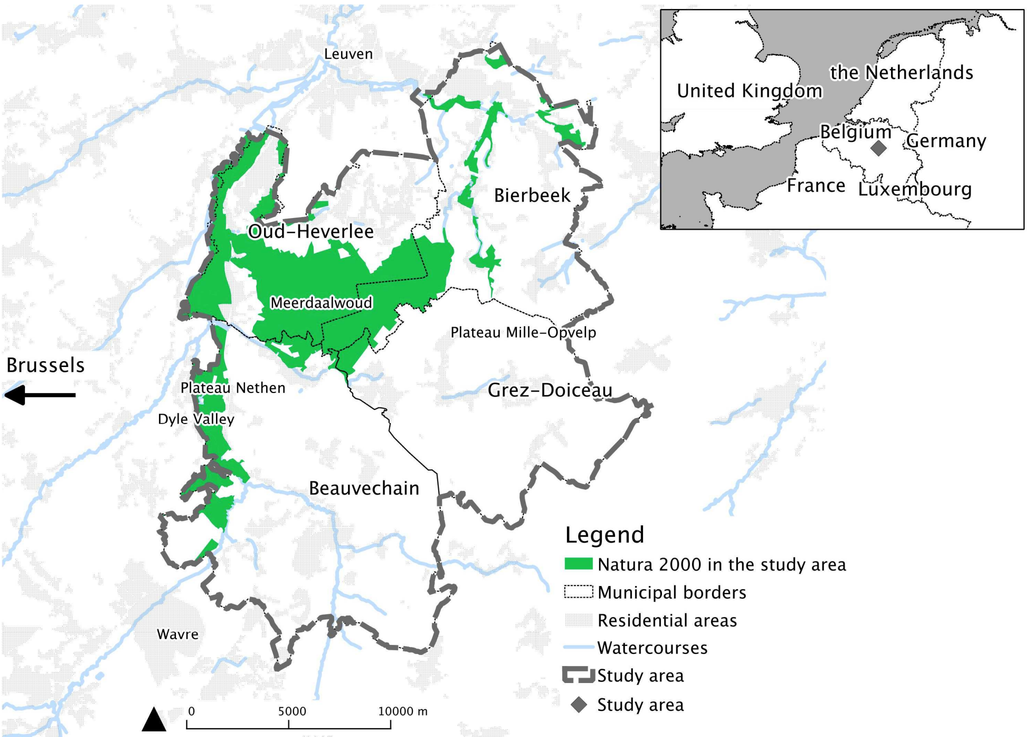

Figure 1. Study area and situation of the Natura 2000 areas in the study area

Main ecosystems in the area are fertile loamy agricultural plateaus in the east and south of the study area, criss-crossed by brook valleys, hollow paths, small woods, and landscape elements, the Meerdaalwoud forest complex (about 2.500 ha) in the north-west and the Dyle valley (situated at the west side of the study area). Both the Meerdaalwoud and parts of the Dyle valley (and its tributaries) are part of the European-wide Natura 2000 network, other areas are protected as nature reserve.

2.2. Data

Given the strong call for including social aspects and participatory methods in ES assessments, Fontaine et al. (2013) developed an integrated ES assessment framework, including a social assessment preceding and guiding the succeeding biophysical and economic mapping and assessment of ES. The social assessment was based on 38 semi-structured interviews (designed after Bryan et al. (2010) and Raymond et al. (2009)) including (1) a discussion of notions of nature of the respondents (De Vreese et al., submitted), (2) a table in which stakeholders scored 32 ES for their importance at the local scale (10 provisioning, 11 regulating and 11 cultural ES; see Table 5), and (3) the social ES mapping exercise (discussed in this article). In the latter, respondents located the, according to them, most important ES in their municipality on a simplified land cover and street map of the municipality, on which they could freely draw (cfr. Black and Liljeblad, 2006; Gunderson et al., 2004; Opdam, 2013). In the further analyses, we also included places stakeholders clearly referred to during the parts 1 and 2 of the interviews.

We applied a modified version of the Millennium Ecosystem Assessment classification (Millennium Ecosystem Assessment, 2005), focussing on 32 ES relevant for the study area (based on authors' knowledge of the socio-ecological systems in the area). Respondents could add ES they considered missing in the list (but none were added).

Applying a purposive sample technique (Barbour, 2001; Kuzel, 1999), we selected interviewees representing a broad spectrum of viewpoints, without aiming at a statistically sound sample. This included respondents actively using or governing the local landscape (decision-makers, farmers, environmental NGOs, politicians, civil servants, recreationists). Potential interviewees have been identified through document analysis, contacts with informants (including snowball sampling), and authors' knowledge of the area. Respondent identification and interviewing continued until we noticed theoretical saturation, meaning no new information emerged from the interviews (Donovan et al., 2009; Starks and Brown Trinidad, 2007). All 38 interviewees have been living and/or working in the area, most of them a long time. The first author (assisted by the third author for the interviews in French) interviewed the respondents at their homes or offices in summer of 2010; the interviews took 1.5 up to 2 h in general. The qualitative nature of the research, the aim for information-rich cases representing a broad spectrum of ES users and ES beneficiaries, and the labour-intensive data collection (interview-based) and data analysis explain the limited number of respondents. Similar interview-based participatory mapping or PPGIS studies included similar numbers of respondents (cfr. Klain and Chan, 2012; Lechner et al., 2014; Palomo et al., 2014; Raymond et al., 2009).

ES can be mapped through point mapping or through polygon mapping (Alessa et al., 2008). Points indicate the concrete locations (centroids) of ES providing units, without giving any information on the spatial extent and the shape of the unit. As we are interested in the location and perceived extent of the selected ES providing units, we applied polygon mapping (Brown, 2004; Brown and Pullar, 2012).

To compare social mapping with expert-based ecological mapping, we used the expert-based Biological Valuation Map (INBO, 2013) for the Flemish Region and an equivalent interpretation of the land cover data (Région wallone, 2008) and the Sites with High Biological Importance (Région wallone, 2012) for the Walloon Region (see Figure 5). The biological valuation is an overall indicator for the ecological quality, based on the land cover and vegetation, not directly coupled to species abundance or other ecological indicators. The zoning categories were generalised as residential zones, green zones (including parks, woods and nature reserves), agriculture zones, industry zones and other zones, based on the official zoning plans for the area (OC-GIS Vlaanderen, 2004; Région wallone, 2006). The delineation of nature reserves and Natura 2000 areas were retrieved from the administrations (Agentschap voor Natuur en Bos, 2013, 2005; OC-GIS Vlaanderen, 2004; Région wallone, 2012, 2009), complemented with respondent information (for nature reserves). Biophysical data on yield, runoff, soil loss, and carbon storage in the soil were retrieved from Fontaine et al. (2013).

2.3. Data processing

Polygons sketched by the interviewees were digitised in GIS. When relevant and applicable, clear boundaries in the landscape (e.g. forest edges, roads, nature reserve boundaries) were used to delimit the polygons, as most respondents sketched the polygons along those lines. Additional attributes (Table 2) were registered in a geodatabase, based on the transcripts of the interviews: the first author analysed the interview transcripts for implicit or explicit mentions of conflicts or synergies between the ES sketched by the interviewees. Spatially localised information stated during parts 1 and 2 of the interviews (e.g. clear references to the Meerdaalwoud or the Dyle valley) were additionally added.

Table 2. Attributes to the digitised polygons

Name attribute	Description
ID	Polygon number
Interviewee	Name of the interviewee sketching the polygon
Primary ES	ES for which the interviewee sketched the polygon
Secondary ES	ES in conflict (trade-off) or synergy with the primary ES (as mentioned by the interviewee)
Conflict/Synergy	Is the relation between the primary and secondary ES, as mentioned by the interviewee, a conflicting or a synergetic relation?

Overlapping polygons were intersected and frequencies for all individual ES were calculated for each of these intersected polygons. The frequency of individual ecosystem services, ecological quality, land zoning, nature reserves, Natura 2000 status and the four biophysical features yield, runoff, soil loss and carbon storage were rasterised. The raster resolution was 60 m by 60 m, equalling the smallest single feature identified by the respondents, leading to 46.739 pixels in total.

2.4. Data analysis

Previous social mapping exercises applied abundance of ES as the one indicator describing the perceived ES distribution. Scholars as Brown and Reed (2012), Bryan et al. (2010), Fagerholm et al. (2012), and Plieninger et al. (2013) introduced landscape ecological indicators such as diversity, richness, rarity and risk to participatory mapping with the aim to describe the perceived ES distribution better (see Brown and Reed, 2012; Palomo et al., 2014 for an overview). Table 3 presents an overview of selected indicators applied in this study. In our paper, we term these indicators Social Landscape Metrics (SLMs). We calculated the SLMs, and we rasterised them (similar to the rasterisation described above).

Table 3. Overview of social landscape metrics applied (including relevance for policy, planning and management)

Social landscape metric	Description & calculation	References	Relevance for policy, planning and management
Abundance (intensity, density, frequency)	Overall frequency of all ES at the site (summed over all individual ES)	Fagerholm and Käyhkö (2009), Klain and Chan (2012), Raymond et al. (2009), Tyrväinen et al. (2007)	Indicates areas where few or many ES are perceived to be delivered (independent of ES type).
Richness	Number of ES types at a site	Fagerholm et al. (2012), Plieninger et al. (2013)	Indicates areas where suites of different ES types are perceived to occur. Points to interesting places to conserve multiple ES at one site.
Shannon Diversity H'	Number of ES at the site, relative to the area of the site (derived from richness)	Bryan et al. (2010), Fagerholm and Käyhkö (2009), Shannon and Weaver (1949)	Indicates areas where few or many ES are perceived to be delivered (independent of ES type) (area-weighted)
Rarity	Number of times the concentration of ES is higher than the spatial average over the study area. Areas with higher abundance of spatially concentrated ES will have a higher rarity indicator score	Magurran (2004) in Bryan et al. (2010)	Indicates sites where rare ES (but with a potential high societal value) are perceived to be delivered. Helps to focus on conserving rare ES.
Risk	Spatial coincidence of stakeholder-defined conflict areas with stakeholder-defined ES (normalised ES abundance * normalised conflict abundance)	Bryan et al. 2010(2010)	Points to areas where respondents perceive socially important ES (= frequently mentioned ES) to be threatened.
Stated Synergy Index (SSI)	Synergies (count) stated by the respondents, divided by ES abundance at the site and normalised. The SSI describes the distribution of ES bundles.		Selects sites where respondents identify multiple ES types occurring in synergy with each other (ES bundles). Impacting one ES will lead to perceived impacts on other ES.

We introduce the stated synergy index as an additional SLM to describe the distribution of perceived ES bundles. Indeed, interviewees indicated that some ES occur in spatial congruence with each other ("stated synergies"), hinting to Plieninger et al. (2013)'s definition of ES bundles as sets of ES that repeatedly appear together across space or time. We interpreted the concept of ES bundles spatially (cfr. Maes et al., 2012; Raudsepp-Hearne et al., 2010), in contrast with previous research deducting ES bundles based on perceptional surveys (e.g. Martín-López et al., 2012). The stated synergy index is a normalised index calculated as the number of stated synergies between ES at a site, divided by ES abundance at the site. The stated synergy index describes the ES bundles perceived and stated by individual stakeholders.

To get insight in the perceived ES bundles across stakeholders, we calculated non-parametric Spearman correlation coefficients between pairs of individual ES (frequency, further termed calculated synergies) (Fagerholm et al., 2012; Klain and Chan, 2012; Plieninger et al., 2013; Raudsepp-Hearne et al., 2010), using the modified t-test for correlation (correcting the degrees of freedom for spatial autocorrelation), and based on the average correlation of 9 samples of 1.000 pixels each (Dutilleul et al., 1993; Schneiders et al., 2012). The calculated synergies illustrate ES bundles that are not necessarily stated as such by individual stakeholders, but that are present within the perceived ES supply spatial data. To illustrate the potential of SLMs as aggregation indices for perceived ES supply and to inspire the redundancy analysis (RDA, see next paragraph), we also calculated correlation coefficients between individual ES and SLMs, ecological quality, conservation status, zoning categories, and four biophysical features. The correlations for ES not mapped or only mapped in small areas (biofuel production, employment in recreation, motorised recreation, pest and disease regulation, real estate, opportunities for social relations, and spirituality) have not been included in the correlation analysis, as the calculations for these ES generated unreliable results due to the low frequencies.

As we are interested in the additional value of social mapping versus traditional mapping approaches (e.g. benefit transfer based on land use or ecological quality), we analysed the contribution of ecological quality, zoning categories, nature reserves, and Natura 2000 to perceived ES supply through a redundancy analysis (RDA). RDA is a constrained ordination that analyses how the variation in a set of explanatory variables (ecological quality, zoning category, Natura 2000, nature reserves) explains the variation in the response variables (individual ES abundance and social landscape metrics).

Finally, to compare social mapping with expert-based and biophysical mapping, we delineated social (perceived) ES hotspots, based on the SLMs abundance, diversity, risk and richness indicators, and overlapped these with ecological hotspots (based on the ecological quality map) and biophysical hot- or coldspots (runoff, erosion, yield and soil carbon storage). The yield was compared with the summed perceived ES frequency for wood, food and regional products production; carbon storage was compared with the perceived supply of carbon storage. We compared perceived hotspots for erosion control and flood mitigation with biophysical "coldspots" (zones where lower values spatially cluster) for soil loss and runoff: the biophysical variables soil loss and runoff are high in vulnerable zones (e.g. hillsides), but respondents located mitigating areas for flood control (e.g. natural flood plains) and areas with low erosion due to low slopes. The local Getis-Ord Gi* statistic was calculated for defining hot- or coldspot areas (z-score > 1.96 for hotspots and $z < -1.96$ for coldspots, Fagerholm and Käyhkö, 2009; Zhu et al., 2010) and Jaccard-coefficients J were calculated for generating measures of similarity between variables A (social hotspot) and B (biophysical or ecological hotspot), with $J = (area(A \cap B))/(area\ (A \cup B))$ (Raymond and Brown, 2011). Social hotspots overlapping with ecological and biophysical hotspots points towards sites with multiple interests, potentially leading to synergies and/or conflicts between landscape users, and opportunities or threats for ES supply and landscape management.

3. Results

The result section assesses the additional value of social mapping compared with more traditional ES mapping approaches, and of the contribution of social landscape metrics to social mapping. First we discuss the capacity of social landscape metrics to describe the perceived distribution of ES (Section 3.1), associated conflicts (Section 3.2) and the perceived synergies between ES (Section 3.3). Next, we analyse the explanatory power of land use, ecological quality and conservation on perceived ES distribution (Section 3.4) and the overlaps between social, ecological and biophysical hot- and/or coldspots (Section 3.5). If the explanatory power is strong and/or the overlaps elevated, then the added value of social mapping above traditional mapping approaches would be rather limited, and the need for social landscape metrics equally low.

3.1. Social landscape metrics describing perceived ecosystem service distribution

Thirty-eight respondents (see Table 4 for respondent characteristics) indicated a total of 535 polygons with a cumulated surface of 159,486 ha (of which many overlapping polygons), covering 25 of the 32 ES discussed during the interview (see Table 5, 23 ES mentioned as primary ES, 20 ES mentioned as a secondary ES). From the 535 polygons sketched (referring to a primary ES), 264 contained information on a secondary ES, suggesting synergies (see Section 3.3) and trade-offs (conflicts, Section 3.2) between ES. The number of polygons sketched per respondent is ranging between 1 and 49, the polygons extent between a small roadside park with a big single tree and a 2,000 ha large woodland. A single site can provide multiple ES (and thus multiple polygons) for a given respondent (cfr. the ES bundle concept and the stated synergies in Section 3.3). When looking at the abundance of services mapped by the interviewees, cultural ES are far more frequent (372 polygons) than regulating (251 polygons), and provisioning (127 polygons) ES. Table 5 gives an overview of individual ES abundance. Note that hunting and social relations have only been mentioned as secondary ES, appearing in conflict or synergy with other ES. Some ES have been discussed in the interviews but were not mapped by the respondents (see Table 5 for overview and reasons). For 6 % of the polygons respondents refer to urbanisation as a major threat to ES functioning (see Section 3.2).

Table 4. Overview of respondents according to background

	Age group						**Education**		**Total**
	25-44		45-64		65-84		**Secondary**	**Higher**	
Background of interviewee	**Male**	**Fem.**	**Male**	**Fem.**	**Male**	**Fem.**			
Politician (mayor/alderman)		1	1	3	2		1	6	7
Civil servant	2	3		3			0	8	8
Environmental NGO	1		4	1	1		0	7	7
Farmer			3	1			2	2	4
Citizen	1		6	1	4		1	11	12
	8		23		7		4	34	38

Table 5. Overview of results of participatory ES mapping (type ES: C = cultural, R = regulating, P = provisioning, D = disservice)

Primary ecosystem service	**number of polygons**	**number of respondents**	**cumulated area (ha)**	**minimum area (ha)**	**maximum area (ha)**	**Average area (ha)**
Cultural ecosystem service						
aesthetical experiences	108	27	26,019.34	0.52	1,828.27	240.92
education	14	5	8,412.48	0.10	1,943.92	600.89
historical landscape (safeguarding -)	16	4	4,255.74	7.60	1,828.27	265.98
recreation (non-motorised)	89	22	31,285.25	0.14	1,943.92	351.52
research (opportunities for -)	10	4	5,182.94	21.17	1,828.27	518.29
sense of place (creating a sense of place)	15	7	5,329.34	0.01	1,828.27	355.29
therapeutic recovery	5	3	1,030.88	34.68	432.22	206.18
Provisioning ecosystem service						
berry picking	7	5	3,098.95	0.69	1,943.92	442.71
employment agriculture	2	1	116.81	51.99	64.83	58.41
employment nature & landscape management	1	1	181.10	181.10	181.10	181.10
food production	53	14	2,243.44	0.17	388.34	42.33
growing regional products	6	4	34.40	1.25	21.79	5.73
wood production	10	5	7,386.16	7.15	1,828.27	738.62
Regulating ecosystem service						
air purification	2	2	3,656.71	1,828.27	1,828.45	1,828.36
carbon sequestration	9	1	3,782.82	51.88	1,828.27	420.31
climate regulation	4	2	4,845.24	594.35	1,828.27	1,211.31
erosion control	12	3	4,877.37	1.14	1,828.27	406.45
flood protection	31	14	4,394.33	0.39	912.27	141.75
habitat provision	82	22	24,611.85	0.14	1,943.92	300.14
local species (presence of -)	21	8	9,658.26	0.07	1,828.27	459.92
noise protection	8	5	1,562.39	0.07	594.35	195.30
pollination	15	6	5,042.45	1.49	1,828.27	336.16
water purification	14	7	2,427.30	5.20	912.27	173.38
Disservice						
Conflict only	1	1	50.02	50.02	50.02	50.02
Total (or minimum/maximum/average)	**535**	**38**	**159,485.60**	**0.01**	**1,943.92**	**397.13**
Secondary ecosystem service						

Cultural ecosystem service						
aesthetical experiences	40	17	9,604.01	0.01	1,828.27	240.10
education	6	3	262.55	0.69	232.59	43.76
historical landscape (safeguarding -)	9	5	5,237.03	19.93	1,943.92	581.89
recreation (non-motorised)	29	16	10,031.46	0.70	1,828.27	345.91
research (opportunities for -)	2	2	45.19	22.59	22.59	22.59
sense of place (creating a sense of place)	10	6	1,741.18	21.89	630.81	174.12
social relations (creating a setting for -)	4	2	9.29	0.69	3.94	2.32
therapeutic recovery	16	7	2,589.42	0.90	1,943.92	161.84
Provisioning ecosystem service						
berry picking	1	1	1,943.92	1,943.92	1,943.92	1,943.92
employment agriculture	2	2	1,526.74	763.37	763.37	763.37
employment nature & landscape management	1	1	70.06	70.06	70.06	70.06
food production	8	4	508.85	1.25	202.08	63.61
hunting	2	1	81.99	14.82	67.17	40.99
regional products production	16	7	39.20	0.17	21.79	2.45
wood production	3	3	75.72	0.14	63.20	25.24
Regulating ecosystem service						
air purification	1	1	89.49	89.49	89.49	89.49
erosion control	9	3	1,463.32	1.14	388.34	162.59
habitat provision	35	13	8,571.62	0.77	1,828.27	244.90
local species (presence of -)	19	9	6,359.79	0.39	1,828.27	334.73
noise protection	4	3	2,763.21	34.68	1,828.27	690.80
Disservice						
urbanisation	47	15	7,979.34	0.54	989.39	169.77
Total (or minimum/maximum/average)	**217**	**37**	**53,014.04**	**0.01**	**1,943.92**	**300.23**
Ecosystem services discussed but not mapped						
Cultural ecosystem service						
creating a good place to live	0	0				
motorised recreation	0	0				
spiritual experiences	0	0				
Provisioning ecosystem service						
biofuel production	0	0				
employment in recreation	0	0				
real estate (positive impact of nature on -)	0	0				
Regulating ecosystem service						
regulating pests and diseases	0	0				

Note 1. Secondary ES have been mentioned as being in synergy or conflict to primary ES by the respondents.

Note 2. The total number of respondents reflects the number of respondents mapping primary or secondary ES.

Note 3. ES discussed but not mapped because ES not relevant in the area (biofuel production, employment in recreation and tourism), not relevant to the respondents (motorised recreation, biofuel production, regulating pests and diseases, spirituality), ambiguous to the respondents (regulating pests and diseases, real estate), not clearly distinguishable of other ES (providing good places to live and spirituality were seen by most interviewees as closely related to creating a sense of place and therapeutic relieve respectively).

Note 4. "Conflict only": respondent refers to a specific area where local species (beavers) negatively impact on people's experiences of ecosystems, without referring to a specific ES.

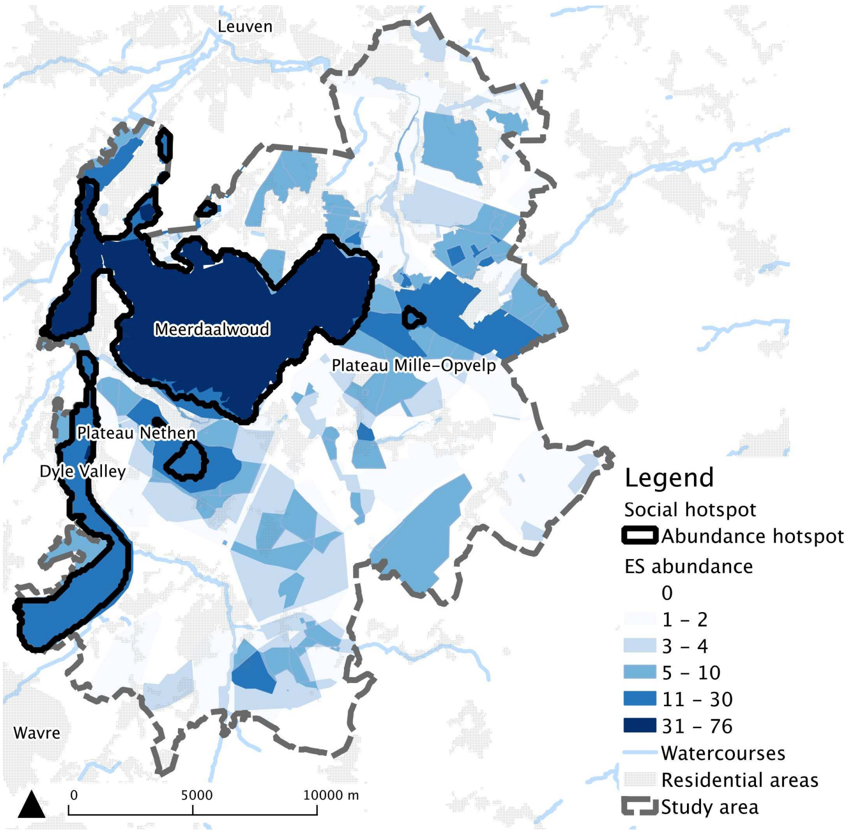

Figure 2. Abundance of ecosystem services in the study area (as indicated by the respondents)

The social landscape metrics give a good insight in the complexity of perceived ES distribution in the study area. Figure 2 shows the abundance of ES in the study area. The richness indicator (see Figure 5) provides a similar image as the abundance indicator, meaning sites with high ES abundance in general also host a broad range of different ES. The diversity indicator (Figure A1) is relatively similar to the abundance indicator. The rarity indicator (Figure A2) confirms the distribution of ES as visualised by ES diversity, richness and abundance indicators, but points to few parcels with a high concentration of a limited range of rare ES (e.g. the few sites where hunting, providing opportunities for social relations, regional products or water purification are situated).

To have an indication on the suitability of the social landscape metrics as indicators for perceived ES distribution, we calculated correlation coefficients between the mapped individual ES abundance on the one hand and the social landscape metrics on the other hand (Table A1). The social landscape metrics show moderate to high correlation coefficients with most individual ES. However, some ES show weak to very weak correlations with the social landscape metrics ($R^2 < 40$ %), due to low abundance of these indicators, and due to the water-related nature of some specific ES (that are less frequently mapped). This means that the SLMs are not very well suited for ES that occur infrequent.

3.2. Social landscape metrics describing conflicting ecosystem services

Respondents mentioned 71 conflicts between ES or between ES and urbanisation (see Table 6, cumulated area 12,722 ha, 1 - 8 conflicts stated per respondent). Twenty-one respondents referred mainly to the negative impact of urbanisation on ecosystem services, other conflicts described refer to providing habitats versus recreation. The risk indicator (Figure 3) indicates which conflicted areas are socially more important than others by taking the abundance of the sites into account.

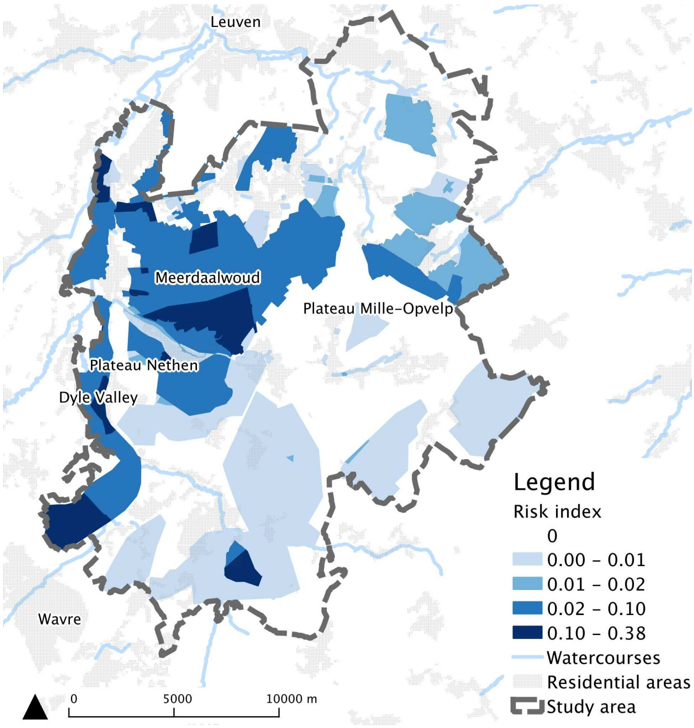

Figure 3. Risk index (based on perceived threats to ES)

Table 6. Conflicting ES as indicated by respondents (# is the number of polygons; area is the cumulated area of the polygons)

Secondary ESS	air purification		employment agriculture		erosion		food/ fodder		habitat		local species		recreation (non-motorised)		regional products		urbanisation		wood production	
Primary ESS	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)	#	area (ha)
aesthetics													1	58.8			16	2,768.8		
berry picking	1	89.5																		
conflict only											1	50.0								
flood protection									1	0.8							8	110.4	1	63.2
food/fodder																	9	244.4		
habitat			2	1,526.7			1	8.8					2	1,841.8	1	1.8	6	1,104.7		
historical landscape									1	7.6										
noise protection																	2	853.5		
recreation (non-motorised)					1	102.0	1	85.7	3	315.0							6	3,294.1		
regional products									3	8.4										
research													1	133.4						
sense of place																	1	9.0		
water purification									2	43.5										
Total	**1**	**89.5**	**2**	**1,526.7**	**1**	**102.0**	**2**	**94.5**	**10**	**375.2**	**1**	**50.0**	**4**	**2,033.9**	**1**	**1.8**	**48**	**8,384.8**	**1**	**63.2**
Grand Total	**71**	**12,721.6**																		

Note. Areas are cumulated and include overlapping polygons indicated by single or multiple respondents.

"Conflict only": respondent refers to a specific area where local species (beavers) negatively impact on people's experiences of ecosystems, without referring to a specific ES

Table 7. One-sided synergy matrix as stated by the respondents (colours refer to correlation classes, see legend below)

	aesthetical experience	air purification	berry picking	carbon seques-tration	climate regulation	education	employm. agriculture	employm. nature & landscape	erosion control	flood protection	food production	habitat provision	historical landscape	hunting	local species	noise protection	pollination	regional products	research opport.	sense of place	social relations	recreation	therapeutic recovery	water purification	wood production	Total
Individual ES	#		#	#		#		#	#	#	#	#	#			#	#			#	#	#				#
aesthetical experience																										0
air purification																										0
berry picking																										0
carbon sequestration																										0
climate regulation																										0
education	1																									1
employment agriculture	*	*			*																					0
employment nature & landscape management	*	*	*		*		*																			0
erosion control				7			*																			7
flood protection	9	*	*		*				1																	10
food production		*	*		*	3	*																			3
habitat provision	6		2			2		1	2	1																14
historical landscape	4					3	*																			7
hunting	1	*			*		*						1													2
local species	4					2						15		*												21
noise protection							*					1		*												1
pollination						1	*				1	3		*												5
regional products	*	*			*		*				16			*			1									17
research opportunities												7		*				*								7
sense of place	9						*				1		1	*				*								11
social relations											3															3
recreation	43		2				*				3	4	1	*		3		*		3	1					60
therapeutic recovery	3						*					9		*		2		*				5				19
water purification		*			*		*							*				*	*				*			0
wood production							*	1				3	1	*				*						*		5
Total	80	0	4	7	0	11	0	2	3	1	24	42	4	0	0	5	1	0	0	3	1	5	0	0	0	193

group 1 very strong correlation (r > 0.8)
group 2 strong correlation (0.6 < r ≤ 0.8)
group 3 moderate correlation (0.4 < r ≤ 0.6)
group 4 low correlation (0.2 < r ≤ 0.4)
group 5 very low correlation (r ≤ 0.2)
correlation not calculated (too few pixels for calculating correlation)

Note 1. The table does not differentiate between primary and secondary ES and should be read as a one-sided cross-table. The colours show calculated synergies based on Spearman correlation coefficients calculated between pixels after intersecting and rasterising respondent's polygons).

Note 2. Areas are cumulated and include overlapping polygons indicated by single or multiple respondents.

Note 3. All correlations are significant at $p < 0.05$, except the underlined asterisks (*) or underlined figures.

3.3. Synergies between perceived ecosystem services

3.3.1. Stated synergies and the stated synergy index

Interviewees stated 193 synergies between ES (Table 7, Table A1, Figure 4). The aesthetical experiences – recreation synergy is most frequently mentioned, followed by regional products – food production (referring to local kitchen gardens) and the synergy between presence of local species and providing habitats. Also synergies between aesthetical experiences and sense of place, between providing habitats and therapeutic recovery opportunities, and between food production and aesthetical experiences are regularly mentioned.

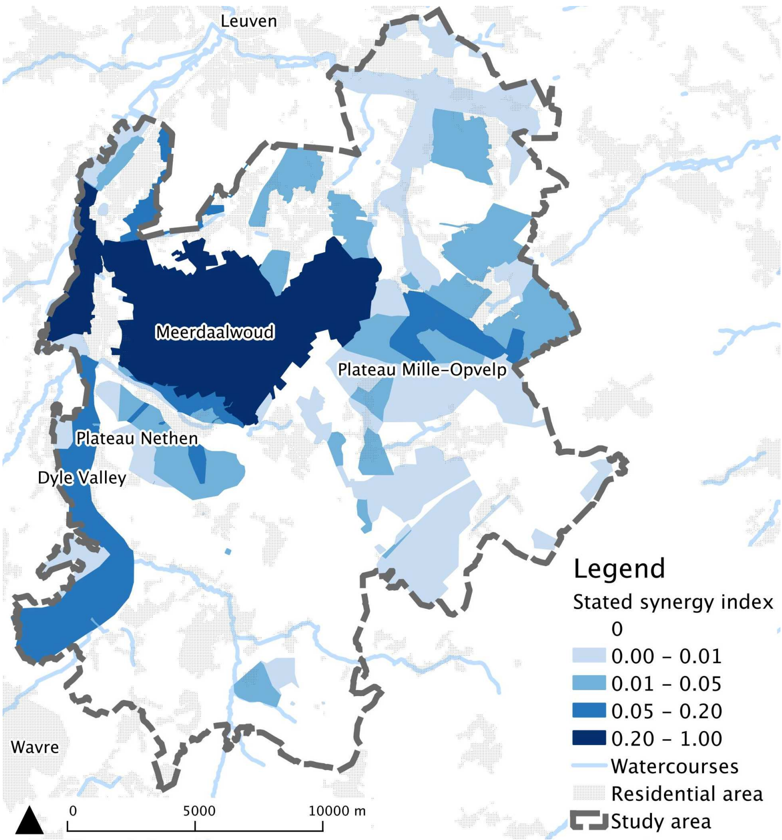

Figure 4. Stated synergy index

The stated synergy index (Figure 4) indicates sites where individual respondents mentioned multiple synergies between ES. These sites are socially interesting, as respondents perceive a multitude of ES supplied synergistically at the same spot. Intervening in these sites can be socially undesirable, due to the high interest respondents adhere to these places.

3.3.2. Calculated synergies

We calculated non-parametric Spearman correlations between pairs of ES mapped across stakeholders (Table 7, Table A1, colours indicate correlation classes). About 45 % of the correlations are very weak (39 %, $R^2 < 0.20$, e.g. between food production and protection against floods) or weak (6 %, $0.20 \leq R^2 < 0.40$, e.g. between opportunities for soft recreation and food production). Among the remaining pairs, 18 %, 21 % and 9 % show respectively moderate ($0.40 \leq R^2 < 0.60$, e.g. between berry picking and perceiving a sense of place), high ($0.60 \leq R^2 < 0.80$, e.g. between historical landscapes and protection against noise pollution) or very high correlations ($R^2 \geq 0.80$, e.g. between erosion control and historical landscape). The correlation coefficients between ES with low abundance and the SLM stated synergy index are (very) low (see Table A1). The remaining ES show moderate to high correlation coefficients to the stated synergy index.

3.4. Influence of ecological quality, zoning and nature conservation on perceived ecosystem service supply

The correlations between ecological quality on the one hand, and landscape metrics and individual ES on the other are very low to moderate (Table A2). Correlations between the conservation statuses Natura 2000, nature reserves, and individual ES are higher (moderate to high). The social landscape metrics are only moderately correlated to the Natura 2000-areas and nature reserves. The stated synergy index shows a higher than overall correlation with Natura 2000 areas, meaning that respondents referred more frequently to synergies between ES in Natura 2000. Agriculture and residential zones are only limited (very low to low), and negatively, correlated to individual ES. Green areas are moderately correlated to individual ES.

Table 8. Results from redundancy analysis with ecological quality, Natura 2000-status, nature reserve-status and aggregated zoning categories as explanatory variables

	RDA1	RDA2
Eigenvalue	8.9	0.1
Proportion explained of total variance (%)	35.6	0.6
Cumulative proportion explained of the total variance (%)	35.6	36.1
Proportion explained of variance explained by explanatory values (%)	96.8	1.49

<table>
<tr><th>Biplot scores</th><th>RDA 1</th><th>RDA 2</th><th>Single explanatory variables</th><th colspan="3">Combined explanatory variables</th><th colspan="2">Marginal contribution to variance</th></tr>
<tr><td>Ecological quality</td><td>0.55</td><td>-0.23</td><td>10.8%</td><td></td><td rowspan="3">35.9%</td><td rowspan="9">36.8%</td><td>0.04</td><td>**</td></tr>
<tr><td>Natura 2000</td><td>0.94</td><td>-0.31</td><td>31.4%</td><td rowspan="2">35.7 %</td><td>1.77</td><td>**</td></tr>
<tr><td>Nature reserves</td><td>0.91</td><td>0.39</td><td>29.6%</td><td>1.66</td><td>**</td></tr>
<tr><td>Agriculture zone</td><td>-0.45</td><td>0.23</td><td>7.6%</td><td rowspan="6"></td><td rowspan="6">20.0%</td><td>0.00</td><td>**</td></tr>
<tr><td>Green zone</td><td>0.74</td><td>-0.18</td><td>19.6%</td><td>0.00</td><td>**</td></tr>
<tr><td>Residential zone</td><td>-0.25</td><td>0.08</td><td>2.4%</td><td>0.01</td><td>**</td></tr>
<tr><td>Industrial zone</td><td>0.02</td><td>-0.20</td><td>0.0%</td><td>0.01</td><td>**</td></tr>
<tr><td>Other zones</td><td>0.03</td><td>0.00</td><td>0.2%</td><td>0.00</td><td>**</td></tr>
</table>

** = significant at $p < 0.01$

A redundancy analysis (see Table 8) gave more details on the influence of ecological quality, Natura 2000, nature reserve and zoning category on the perceived ES supply. The former variables were considered as explanatory variables and contribute significantly ($p < 0.01$) to explaining the variance within the perceived ES supply. Overall, the explanatory variables explain 37 % of the variance in the dataset. The main contributors to the first RDA axis are Natura 2000 (score = 0.94), nature reserves (0.91), and green zones in the zoning plan (0.74) (see also the marginal contribution of the variables to the variance in Table 8). Ecological quality (0.54), agriculture zones (-0.45) and residential zones (-0.25) are also significant, but contribute less. Natura 2000 is the most influential explanatory variable, contributing to 31 % of the variance in perceived ES frequency; Natura 2000 and nature reserves combined explain 36 % of the total variance and their marginal contribution to the variance is much higher (1.77 and 1.66 respectively) than the marginal contribution from other variables (0.04 for ecological quality and lower for the zoning categories). Ecological quality as a single explanatory variable explains 11 %, the combined contribution of zoning categories as explanatory variables is 20 % of the variance in perceived ES frequency.

3.5. Analysing overlap between social hotspots, ecological hotspots and biophysical hot- or coldspots

Table 9 shows Jaccard coefficients of similarity for several combinations of hot- and coldspots. The similarity between ecological hotspots (ecological quality) and societally important areas (social hotspots) is highest for diversity (56%), followed by richness and risk (both 46%) and abundance (43%). Rarity shows the smallest similarity (34 %) with the ecological hotspots. Overlapping social hotspots with Natura 2000 areas shows a different pattern (see Figure 5): Natura 2000 areas are more frequently home to “social” rare (65 %) and rich (58 %) hotspots than to zones with diverse (46 %), abundant (38 %) or conflicted (risk, 38 %) perceived ES.

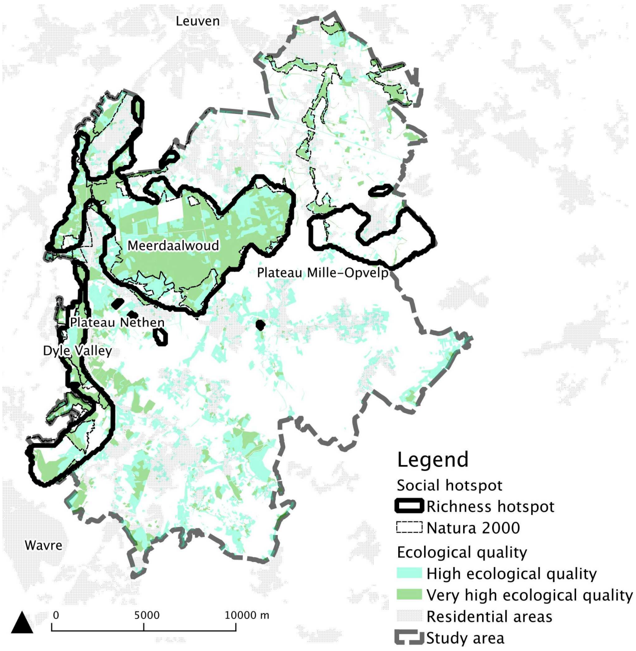

Figure 5. Ecological quality and Natura 2000 mapped against the social richness hotspot

Table 9. Jaccard similarity coefficients for ecological, biophysical and social hot- or coldspots

Social hotspots	**Abundance**	**Diversity**	**Rarity**	**Richness**	**Risk**
Ecological hotspots					
Natura 2000	38%	46%	65%	58%	38%
Ecological quality	43%	56%	34%	46%	46%

Social hotspots	**Carbon storage**	**Erosion control**	**Flood protection**	**Yield (wood, food, regional products)**
Biophysical hot/coldspots				
Carbon storage in soil	35%			
Soil loss (coldspot)		26%		
Runoff (coldspot)			14%	
Yield				9%

The social hotspots show rather low overlap with biophysical hot- or coldspots. The perceived yield hotspot (based on the summed wood, food and regional products) only overlaps with 9 % of the biophysically modelled yield hotspots. Runoff (14 %) and erosion (26 %) coldspots are less similar with the perceived flood protection and erosion mitigation hotspots. The areas perceived important for carbon storage show a moderate (35 %) similarity with the modelled soil carbon storage (see Figure 6).

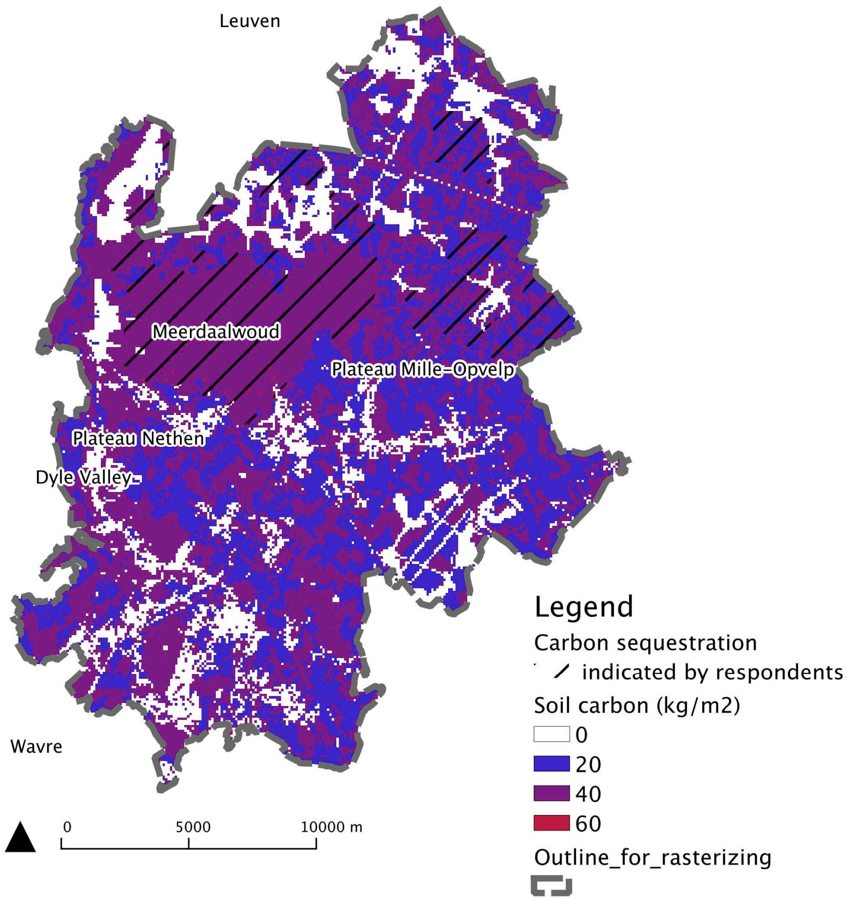

Figure 6. Comparing soil carbon from biophysical modelling with the ES carbon sequestration mapped by respondents

4. Discussion

4.1. On sketching the perceived ES

The results show that participants are able to locate and map ES perceived as important in their environment, even though we challenged respondents map reading and orientation skills. As we are more interested in respondents' perceived ES supply than in "listed" or official information (e.g. a systematic overview of the location of nature reserves or stormwater basins), the interviewers had to probe into respondents' personal experiences to locate the perceived ES providing units. Interviewers however should find a balance between a systematic approach striving towards the full picture, in the same time keeping the respondents engaged in the mapping process and avoiding attention fatigue with the respondents (see also Brown and Fagerholm, 2015).

Locating ES perceived as important and sketching polygons was not easy – "Where to draw the line?" (cfr. Brown, 2004; Brown et al., 2002). Perceived ES often have imprecise boundaries and/or should be regarded as continuous, so a strict delineation of perceived ES providing units is in contrast with stakeholders' interpretation of the landscape, the underlying social processes and ES physical characteristics (Brown and Pullar, 2012;

Fagerholm and Käyhkö, 2009; Gunderson et al., 2004; Opdam, 2013). Sharply lined polygons can give a false impression of accuracy, so the drafted polygons should be regarded as approximate (see Lechner et al., 2014 for a more detailed discussion). However, we chose to use biophysical boundaries to delineate the polygons when digitising them, as this was in line with how most interviewees delineated the polygons themselves. The alternative point mapping method is less successful in giving insight into the extent and size of the perceived area (Brown and Pullar, 2012). Point mapping is then more appropriate for self-administered surveys and larger samples, possibly internet-based, for three reasons: (1) the interviewees are less intensively guided (or not guided at all) through the mapping; point mapping is then less complicated for the respondents to apply; (2) the input from larger samples are more easily processed with point data than with polygon data (by using e.g. kernel density models); (3) in these approaches and with the larger samples, getting insight and background information on the extent and size of the area is generally less the focus of the research. Carver et al. (2009) introduced a hybrid method for digital data collection: respondents can map perceived fuzzy boundaries using a spray can tool. This method can be used in further web-based participatory mapping exercises.

4.2. On perceived synergies, conflicts and the risk of collectivisation

Spearman correlation coefficients indicate synergetic relations between some ES (although these synergies do not necessarily imply causal relations). The synergies mentioned by the respondents (stated synergies) are – in general – synergies with moderate to very strong correlation coefficients (calculated synergies), but we also notice stated synergies with (very) low correlation coefficients (e.g. synergies with food production, hunting, employment in nature en landscape management, regional products, erosion control). In contrast, some synergies with moderate to very strong correlation coefficients (high calculated synergy) have not or rarely been mentioned by the respondents (e.g. the regulating services air purification, climate regulation, protection against noise, pollination, the cultural services historical landscapes and research opportunities, and the provisioning services berry picking and wood production). The discrepancy between the stated and the calculated synergies indicates the sensitivity of the stated synergy index to error and nuance and to the risk of collectivisation of individual respondents' perceptions (but also a risk towards collectivising individually perceived conflicts) (see also Brown and Pullar, 2012; Lechner et al., 2014). This discrepancy is most likely linked to the low sample size, so broadening the sample (e.g. internet-based mapping) and developing other methodologies for eliciting ES synergies from stakeholders can give better insight into the discrepancy and/or will lead to less diverging results.

4.3. On the role of social landscape metrics in landscape planning and management

The social landscape metrics (abundance, rarity, richness, risk, diversity and stated synergy index) clearly show potential to inform planning and management on the perceived distribution and societal relevance of ES in a focus area. Depending on the policy or planning goal, one can choose the most suited social landscape metric for integrating perceived ES supply into ES assessment and landscape planning (see also Table 3): for protecting ES rarely mentioned by respondents (but with a potential high importance to the respondents), the rarity indicator is the most suitable; for protecting a maximum range of different ES types, one has to consult the richness indicator; and the abundance and diversity indicators indicate areas where most ES are perceived, independent of the type of ES present. The risk indicator points to areas where respondents perceive conflicts and trade-offs between socially important ES and where negative impacts of further development on ecosystems and their services are expected by the respondents. The stated synergy index points towards locations where respondents indicate synergies between ES, and thus where win-win solutions can be realised: improving delivery of a specific ES will result in increased perceived supply of multiple other ES. On the contrary, a high stated synergy index can also mean that, when managing a certain ES, there is a risk of unintentionally impacting perceived supply of other ES. However, SLMs are not suited for describing the perceived distribution of individual ES with low abundance.

4.4. On the discrepancy between biodiversity and perceived ES supply

The low correlation of ecological quality with individual perceived ES seems surprising, but this is in line with other studies (see e.g. Haines-Young and Potschin, 2010; Maes et al., 2012; Schneiders et al., 2012; Whitehead et al., 2014 for a discussion on the contribution of biodiversity on ES delivery). Correlation coefficients are (very) low to moderate, with cultural and regulating ES – in general – showing higher correlation with ecological quality than provisioning services. Constrained analysis (RDA) shows that ecological quality only explains 11 % of the variance in the data. The overlap of ecological quality hotspots with social hotspots is moderate (between 43 % for abundance and 56 % for diversity; explained by the higher area of high biological value than the combined area Natura 2000 and nature reserve). However, rarity (65 %) and richness (58%) overlap more with Natura 2000 and nature reserves than with ecological quality. Thus, rare ES, and more different ES types, are found more frequently in conservation areas, confirming the importance of nature conservation for increasing the range of perceived ES delivered.

Natura 2000 and nature reserves show higher correlation (than ecological quality) to individual ES and contribute to explaining the variance in perceived ES supply data: combined, the conservation statuses Natura 2000 and nature reserve explain 36% of the variance in the RDA. This confirms Whitehead's et al. (2014) suggestion that the protected status of nature conservation zones increase the social value of an area.. The explanation of the combined zoning categories is 20 %, with green areas (positive correlation) and agriculture (negative correlation) the most important impacting zoning categories on the perceived ES supply. The reasons for the low correlation between biodiversity (ecological quality) and ES delivery are twofold. Firstly, ES delivery is not always connected to high biodiversity: the vistas at agricultural plateaus have been indicated frequently as important for the aesthetical experiences, but biodiversity is rather low at these fields. As a counter-example, the wetlands in the Dyle valley with a higher ecological quality and high importance for flood protection, show similar ES abundance than the agricultural plateaus. Secondly, ES closely connected to biodiversity (e.g. pollination) are less well understood, known and mentioned by respondents.

Similarity coefficients show that the overlap between biophysical hot- or coldspots and social hotspots is rather limited. Reasons therefore include, first, the different scope of the biophysical model (fully covering the study area, especially important for yield) and the social mapping (focused on the most important areas according to the respondents); second, the definition of the biophysical variables applied did not accord fully with respondents' understanding of these biophysical variables; and third, lay people have less interest and insight in biophysical issues, leading to less frequent mapping of the corresponding regulating ES (cfr. Agbenyega et al., 2009; Brown and Fagerholm, 2015). This does not mean, however, that the lay input regarding (regulating) ES is not relevant or invalid. Lay input is dealing with perceptions, societal and local use of the landscape: to build support for nature and landscape, and to avoid conflicts in landscape and nature management, integrating lay input can be very important. A social ES assessment can help to break down the "black box" aura surrounding ES assessment, and so increase the mainstreaming of the results of ES assessment into decision-making, planning and management.

4.5. On the role of social mapping within integrated ES assessment

However the rather limited numbers of respondents involved, the trends described above illustrate that social ES mapping complements the more traditional methods of mapping ES: social mapping gives insight into perceived ES supply, additional to ES supply assessed with biophysical modelling, or ES supply based on land use, zoning, ecological quality, or nature conservation status. This does not mean that social mapping by laymen can replace expert-based (ecological) mapping: laymen have probably less knowledge of ecological processes, but social ES mapping can integrate lay perceptions, lay knowledge and other (intangible) ES into the ES assessment or landscape planning process (Brown and Fagerholm, 2015; Whitehead et al., 2014). The results of social mapping help to identify sites with high perceived, societal value for ES supply (social hotspots) where measures with (potential) negative impact should be avoided (see also the concept of social-ecological hotspots, warmspots and coldspots below). The social landscape metrics applied have the potential to summarise the multitude of data on perceived ES supply into a limited set of features and/or social hotspots for ES supply. In this way, social ES mapping is contributing to integrated ES valuation inspired by the sustainability paradigm, thereby integrating the social, environmental (biophysical) and economic pillars in an integrated valuation approach (Boeraeve et al., 2015; Fontaine et al., 2013). We refer to the concept of social-ecological hotspots, warmspots and coldspots as defined by Alessa et al. (2008) (see Table 10), and the possible strategies for dealing with synergies and conflicts between social and biological values as outlined by Whitehead et al. (2014). A social-ecological hotspot combines a social hotspot (based on the social landscape metrics) with an ecological hotspot; a social-ecological warmspot has a high ecological quality, but a low social landscape value. Alternatively, social-biophysical hotspots, warmspots and coldspots can be defined.

Conservation measures that impact on the social value of nature and landscape should be localised in social-ecological warmspots, rather than in social-ecological hotspots. Alternatively, when planning landscape management in social hotspots, managers should take the high social value into account and discuss the proposed management with stakeholders, or inform them at least about the planned operations (including explaining why these measures are implemented).

Table 10. Defining social-ecological hotspots, warmspots and coldspots (Alessa et al., 2008)

	High ecological quality (ecological hotspot)	Low ecological quality (ecological coldspot)
High social landscape value (social hotspot)	Social-ecological hotspot	Social-ecological warmspot
Low social landscape value (social coldspot)	Social-ecological warmspot	Social-ecological coldspot

Social mapping as illustrated in this paper, is a powerful tool for localising perceived ES supply, as a first step to integrate social, biophysical and economic ES mapping, and as a source for planning, policy and decision-making, based on geographic data. Integrating our participatory approach with expert- or science-based ES mapping (e.g. ecological quality and biophysical variables) can increase the validity and the acceptability of ES mapping to laypeople, planners, managers and policy-makers, and therefore, can contribute to mainstreaming ES governance in policy and planning, and to empower ES beneficiaries and ES providers.

4.6. Drawbacks and future research directions

The main drawbacks of the method are (1) the potential collectivisation of individual perceptions, priorities, and conflicts, due to the limited number of respondents involved, (2) the time and effort needed for our approach, and (3) the undocumented uncertainties related to social data and spatially combining social with biophysical mapping and geographical data (Lechner et al., 2014). The number of respondents involved can be increased through the use of internet-based participatory GIS tools, or through collaborative group mapping (which as a co-benefit results in co-creation of data and mutual learning). However, the limited respondent group gave us the opportunity to discuss into depth – and to understand – the reasons for selecting an area, to learn about perceived ES supply in the study area and its influencing factors, and to stimulate respondents to map all the places they perceive as being important. Accordingly, developing a webtool for social mapping can lower the workload for managers and planners willing to include the results of social mapping in their daily work. Based on stakeholders' input, the webtool can easily calculate the social landscape metrics and social hotspots for ES supply.

Whereas our paper discussed perceived ES supply, the method can also be applied for ES demand. ES demand is probably even more difficult to be assessed with traditional methods based biophysical modelling, land use or ecological inventories, here too social mapping can help to bridge this gap.

5. Conclusions

We demonstrated the capacity of participatory ES mapping and of social landscape metrics to describe the perceived distribution of ES supply, and to operationalise the social ES assessment pillar within an integrated ES valuation approach. We introduced the stated synergy index as a tool to locate sites of high social interest due to multiple perceived synergies, pointing towards locations where win-win solutions can be delivered. Although the mapping exercise is challenging, stakeholders are able to map the subjectively most important ES, resulting in a bottom-up approach to ES mapping and including local and laymen knowledge.

We also discussed the added value of integrating social mapping into ES assessments, additionally to biophysical-based mapping and modelling, economic valuation-, and ecological quality-based ES assessment. The overlap between social hotspots on the one hand, and biophysical and ecological hotspots on the other hand is rather limited. Also the predicting power of green areas in the zoning plan, or conservation sites (Natura 2000 areas and/or nature reserves) to delineate perceived ES supply is rather low. This indicates that social mapping adds considerably to integrated ES assessments, not only by including lay knowledge and social perception regarding ES, but also including non-expert interpretations of ES, and intangible ES regularly missed out in expert-based ES assessment. This can lead to more equitable, fair, valid, sustainable and broadly supported ES assessments, involving empowered ES users and ES beneficiaries, and leading to mainstreaming ES into decision-making and planning. However, social mapping is time-consuming and challenging, as well for the respondents as for the researchers involved.

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Supplementary material

https://www.researchgate.net/publication/295840936_Social_mapping_of_perceived_ecosystem_services_supply_-_The_role_of_social_landscape_metrics_and_social_hotspots_for_integrated_ecosystem_services_assessment_landscape_planning_and_management