The landscape at your service

Spatial analysis of landscape services for sustainable development

Monique Gulickx

THE LANDSCAPE AT YOUR SERVICE

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THE LANDSCAPE AT YOUR SERVICE

Spatial analysis of landscape services for sustainable development

Monique Gulickx

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CHAPTER 1

General introduction

1.1 The landscape at your service

The landscape is all around us. Every day we experience the landscape, where we live, on our way to work, to visits friends, or during a leisure activity outdoors. We even travel to other parts of the country or to foreign countries to experience and enjoy characteristic landscapes (Fig. 1.1). The properties of the landscape that compose its character, such as the tree lines besides each side of the road, the elevation differences, or the slow-flowing stream, form the foundation for the provision of benefits to us and our society. The landscape is at our service.

1.2 Relevance of dissertation

The way in which landscapes are formed, structured, and designed have many values for plants, animals and humans. My dissertation focuses on the values of landscapes for humans. Human welfare and livelihoods depend on the landscape for fundamental necessities, such as the availability of clean air and clean water, the potential for food production, and the suitability for housing (UN Millennium Project, 2005). People modify landscapes considerably in order to obtain and strengthen the desired services. With the increase of human populations, our demands on the landscape are also increasing. This has resulted in multifunctional landscapes, in which several services should be provided at the same time (MA, 2003). The provision of multiple services leads to both synergies and conflicts. Examples of synergies are areas that are designed for flood water storage and are also suitable for water purification, or a forest producing wood that has also recreational values. Examples of conflicts are intensive farming with concomitant emission of nutrients and pesticides that are detrimental for the water quality, or the high water level of a wetland habitat that has a negative influence on food production.

A variety of tools and methods are available to analyse and assess landscape services (Haines-Young and Potschin, 2009), but the inclusion of the spatial dimension of landscape services herein, is still in its early stages. Evidently, the understanding of the spatial interactions between landscape services is necessary in order to make sound decisions regarding arising trade-offs between these services (Antle and Stoorvogel, 2006; Bennett et al., 2009). Adequate methods to map landscape services are fundamental for the assessments of synergies and conflicts between landscape services. In order to provide credible maps for all landscape services, further development of current mapping approaches are required (Maes et al., 2012).

In most democracies, decision making on landscape development is decentralising, resulting in an increase of the responsibility of local planning practice and of the involvement of various stakeholders groups (Azerrad and Nilon, 2006; Brody et al., 2004). This process has only recently arisen, and while the process includes a shift to an increase of responsibility of local authorities, it does not include an increase of knowledge necessary for this responsibility. This provides an opportunity for science to collaborate with local planning practice. While local planning practice is focused on how and where the provision of landscape services can be sustained and improved, and how to prevent potential negative consequences of landscape modifications, research can support the spatial planning process by providing valuable knowledge on potential opportunities, consequences, and trade-offs of landscape services. For example, research can provide knowledge on possible impacts of landscape development using impact assessments (*e.g.* Pope et al., 2013) and can provide methods and tools to integrate knowledge of science and practice, such as participatory approaches (*e.g.* Fagerholm et al., 2012).

In recent decades, spatial planning practice is increasingly influenced by the need for sustainable development of the landscape in order to meet current and future requirements for human wellbeing. The aim for sustainable development creates an extra dimension in the integration of scientific research into the practice of spatial planning (de Groot et al., 2010; Termorshuizen and Opdam, 2009). However, actual collaboration between science and planning practice is still exceptional (McNie, 2007), especially when

Fig. 1.1 Four characteristic landscapes. Top left: Dutch polder, The Netherlands (by A.G. van Stek); Top right: Tsavo National Park, Kenya (by S. Foerster); Bottom left: Grand Canyon National Park, US (by L.K. Chao); Bottom right: Java rice fields, Indonesia (by LisArt).

it comes to how to handle spatial synergies and conflicts of landscape services in the context of sustainable development. My dissertation will focus on two main topics: i) the development of spatially explicit methods to analyse the distribution of landscape services; and ii) the integration of scientific knowledge and tools with local planning practice.

1.3 Landscape services concept

The landscape can be considered as a social-ecological system (Cumming et al., 2012). The services humans obtain from the landscape are the products of this combination of social and ecological factors. For example the provision of wood is influenced by both human demand and the biophysical properties of the landscape. The term ecosystem service refers to the service provided by an ecosystem. The concept of ecosystem services is seen as a promising approach, as it considers the links between ecological and social systems in relation to the provision of benefits for society (MA, 2003). Ecosystem services are predominantly associated with natural processes, nature management, and conservation (O'Neill, 2001). However, the provision of landscape services does not only depend on ecosystem properties (in ecosystem patches), but to a similar extent on the spatial organisation of these ecosystem patches, their interactions, and the interactions between these patches and human factors (Termorshuizen and Opdam, 2009). The ecosystem service concept is therefore part of the landscape services concept, where the latter is seen as more relevant and acceptable for local stakeholders involved in spatial planning, including policy makers and planning practitioners, and scientists from various disciplines, such as environmental, social and economic sciences (Termorshuizen and Opdam, 2009).

Many different definitions and classifications of ecosystem and landscape services have been established (see Table 1.1 for an overview, not all-inclusive). The Millennium

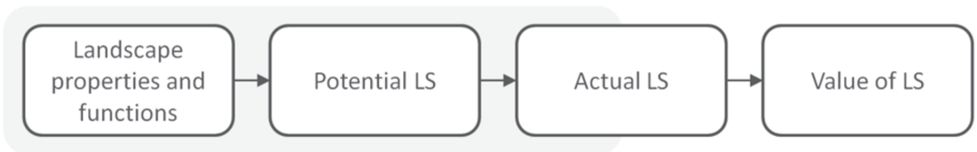

Fig. 1.2 Landscape services (LS) framework. The landscape properties and functions provide a potential for the provision of LS. The potential LS becomes an actual LS when there are beneficiaries. These beneficiaries value the LS, which can be either social, environmental, or economic values. My dissertation focuses on the relation between the landscape properties and function, with the potential and partly the actual LS, which is indicated by the grey rectangular at the background.

Table 1.1 Definitions, classifications and framework properties of ecosystem services (ES) or landscape services (LS) used in different studies.

Literature	Definition of ES/LS	Classification	Framework properties
MA (2005)	The benefits people obtain from ecosystems	Supporting Provisioning Regulating Cultural	Supporting services ↳ Provisioning, regulating, cultural services ↳ Components of wellbeing
Wallace (2007)	The benefits people obtain from ecosystems	Supporting Provisioning Regulating Cultural	Processes and assets of ecosystem ↳ Ecosystem services *(experienced at the individual human level)* ↳ Values
Fisher et al. (2009)	The aspects of ecosystems utilized (actively or passively) to produce human wellbeing	Not specified	Intermediate service *(structures and functions)* ↳ Final services ↳ Benefits
Termorshuizen and Opdam (2009)	The landscape functions that are valued by humans	Not specified	Spatially explicit landscape properties ↳ Level of landscape functions ↳ Values ↳ Benefits
Haines-Young and Potschin (2010)	The contributions (flows) derived from landscape structure, process and functions	Provisioning Regulating Cultural	Landscape structure and process ↳ Functions *(capacity)* ↳ Services ↳ Benefits
de Groot et al. (2010)	Services derived from ecosystem and landscape functions and valued by humans	Provisioning Regulating Habitat Cultural	Biophysical structure and process ↳ Functions ↳ Services ↳ Benefits ↳ Values

Assessment (MA) established a framework consisting of four main categories: i) supporting services (*e.g.* nutrient cycling and soil formation); ii) provisioning (*e.g.* food and timber); iii) regulating (*e.g.* water regulation and water purification); and iv) cultural services (*e.g.* cultural aesthetics and recreation MA, 2003). This framework is widely accepted and applied (Haines-Young and Potschin, 2009). In the MA classification the supporting services are supporting the provision of the other service categories and are therefore indirectly beneficial to humans. Habitat services are sometimes part of regulating services, seen as the primary production (MA, 2003), but also as a category on its own (de Groot et al., 2010). The provision of habitat can have intrinsic values for people, and therefore, can be considered as a direct benefit. In other studies these supporting and habitat services are regarded as 'intermediate services' or 'functions', allowing for differentiation between the intermediate processes and functions and the actual services (e.g. Boyd and Banzhaf, 2007; Fisher et al., 2009). It is argued that this division avoids confusion of intermediate and final products, and hence, the problem of double counting considering only the final benefits would be valued. However, Fisher et al. (2009) do state that a service, such as habitat services, can be considered as both an intermediate or as a final service, depending on its degree of connection to human wellbeing (*i.e.* indirectly or directly, respectively). Such debates about differences between functions and services, and services and benefits are ongoing. Essentially, these classifications are all valuable for different types of studies and for communicating different aspects (Costanza, 2008). Also, frameworks like 'properties – processes – functions – services – benefits – values' can best be seen as instruments to help sort out the complex factors and processes in a given issue under study, rather than as a set of rigid definitions and concepts, into which everybody has to squeeze their objectives (Haines-Young and Potschin, 2010).

In my view, the properties-to-values framework includes the division between potential and actual provision of landscape services (Fig. 1.2). This division provides valuable information, as it explicitly addresses the possibilities of an area to provide landscape services and information and whether this potential is actually utilised. For example, physical properties of a landscape, *e.g.* elevation differences, a meandering stream, and paved paths, provide a potential for the provision of a landscape services, such as the provision of recreation. These potential landscape services, however, do not necessarily have beneficiaries. Only when people actually benefit from the service, it can be recognised as an actual landscape service. In the previous example, when people actually use the landscape for recreational activities. The actual landscape services are the benefits obtained by people, who appreciate the benefit for their social, environmental, or economic. The division between potential and actual landscape services plays an important role in mapping: a map showing the potential services conveys a different message than a map showing the actual service provision.

1.4 Spatial distribution of landscape services

As landscape services are defined in terms of benefits to humans, it is desirable to maintain and strengthen the provision of these services. In order to be able to adequately decide upon the services allocation, we need to know and understand where landscape services are, or can be, provided. Thus, knowledge of the spatial distribution of landscape

Table 1.2 Overview of several studies that have mapped landscape or ecosystem services.

Literature	Landscape or ecosystem services	Potential or actual provision	Type of indicators	Spatial scale
Gimona and van der Horst (2007)	· Biodiversity	Potential	Biophysical	Local
	· Visual amenity	Potential	Social	
	· Forest recreation	Potential		
Egoh (2008)	· Surface water supply	Potential	Biophysical	National
	· Water flow regulation	Potential		
	· Soil accumulation	Potential		
	· Soil retention	Potential		
	· Carbon storage	Potential		
Naidoo et al. (2008)	· Carbon sequestration	Potential	Biophysical	Global
	· Carbon storage	Potential		
	· Grassland livestock production	Potential		
	· Water provision	Potential		
Willemen et al. (2008)	· Residential	Actual	Biophysical	Local
	· Intensive livestock husbandry	Actual	Social	
	· Cultural heritage	Both		
	· Drinking water supply	Actual		
	· Overnight tourism	Potential		
	· Habitat provision	Potential		
	· Arable food production	Potential		
	· Leisure cycling	Potential		
Kienast et al. (2009)	· Cultivated production	Potential	Biophysical	Europe
	· Commercial forest production	Potential		
	· Climate regulation	Potential		
	· Recreation and tourism	Potential		
Reyers et al. (2009)	· Fodder production	Potential	Biophysical	Local
	· Carbon storage	Potential		
	· Erosion control	Potential		
	· Water flow regulation	Potential		
	· Tourism	Potential		
van Berkel and Verburg (2012)	· Aesthetic beauty	Potential	Biophysical	Local
	· Cultural heritage	Potential		
	· Recreation	Potential		
	· Spirituality and inspiration	Potential		

services is required. Most landscapes are spatially heterogeneous with landscape services unequally distributed over an area (Willemen, 2010). The potential of a landscape to provide landscape services depends in first place on landscape properties (Fig. 1.2). Hence, the spatial distribution of these properties, and the relation between these properties and services, are crucial to identify the spatial distribution of landscape services. For the spatial distribution of landscape properties, the large amount and variety in land cover and land use maps that have become available over the last two decades is invaluable. However, often there is no one-to-one relation between landscape services and land cover/land use maps (Verburg et al., 2009). The cultural landscape service leisure hiking, for example, cannot be directly related to one particular land cover or land use type. As a consequence, various approaches have been developed to identify spatial indicators or proxies to map landscape services (see Table 1.2 for an overview, not all-inclusive). These indicators mainly consist of biophysical aspects, sometimes accompanied with social aspects and then predominantly demographical data. Moreover, the type of indicators used for one landscape service can differ between studies. For example, indicators for recreation in one study include the areas that tourists can see from the major tourist driving routes (Reyers et al., 2009) and in another study the indicators refer to landscape structure and composition (van Berkel and Verburg, 2012).

A review of 122 studies identified that the most commonly mapped landscape services are climate regulation, recreation and tourism, food provision, provision of water, and regulation of water flows (Crossman et al., In Press). Especially, cultural, supporting and habitat services have been mapped in a few studies only (Egoh et al., 2012; Martínez-Harms and Balvanera, 2012).

The landscape or ecosystem service maps predominantly show the potential of an ecosystem or landscape to provide the service (Table 1.2). For most landscape services it is very difficult to obtain empirical data on the actual provision, especially for larger areas. But also at the local scale detailed data is often not available (Willemen et al., 2008), because collecting such data is time consuming and expensive. Although the maps showing the potential services are very valuable (*e.g.* Gimona and van der Horst, 2007), the actual provision can, for instance, provide new insights for the recognition of adequate proxies. Also for the valuation of services, maps of the actual provision are needed. For identification of the actual service, the category cultural services requires different approaches than the supporting, regulating, and provisioning services (Hernández-Morcillo et al., 2013; Plieninger et al., 2013). Cultural services require more social approaches for the analysis of the actual provision. To my knowledge, the actual provision of cultural services has not been studied yet.

The rationale for mapping landscape services varies among studies, examples are analysing synergies and trade-offs between different landscape services (Grêt-Regamey et al., 2013; Nelson et al., 2009; Raudsepp-Hearne et al., 2010), comparing landscape services supply with demand (Burkhard et al., 2011; Willemen et al., 2012), valuating landscape services, both monetary (La Notte et al., 2012; van Berkel and Verburg, 2012) and non-monetary (Conte, 2013; Sherrouse et al., 2011), or prioritising areas for spatial planning and landscape management (Chan et al., 2006; Egoh et al., 2008; Petz and van Oudenhoven, 2012). Hence, landscape service maps are relevant for many different purposes, which can supplement each other, such as the valuation of landscape service can be used as input for the trade-off analysis. Maps in general are useful tools for depicting complex relations, such as the connections between landscape properties and the provision of landscape services. They are therefore a powerful communication tool that can be used for transferring spatially explicit information of landscape services to environmental policy makers and planning practitioners (Maes et al., 2012).

1.5 Science - practice interface

In order to make sure that the landscape can provide the desired benefits for present and future generations, the concept of sustainable landscape development has arisen in the early 1980s (WCED, 1987). Because of the multifunctionality of landscapes and the complex interactions between the ecological and social systems, achieving sustainable landscape development is not an easy mission. Scientific knowledge is required to improve our understanding of these interactions, which subsequently needs to be translated into practical applications for planning practice. Integration of science and planning practice to exchange knowledge and experiences is therefore necessary to achieve sustainable development (Termorshuizen and Opdam, 2009).

Sustainability science must ensure the integration of different approaches for knowledge creation to bridge the gap between science and practice (Martens, 2006). Hence, integrated approaches to study landscape development are required, such as transdisciplinary (Fry, 2001; Lang et al., 2012; Tress et al., 2005), community-based (*e.g.* Bodorkós and Pataki, 2009; Conrad and Hilchey, 2011; Fagerholm et al., 2012), and participatory approaches (*e.g.* Grêt-Regamey et al., 2008; Luz, 2000; Patel et al., 2007). All of these approaches aim to improve knowledge exchange between different disciplines and institutes. For the improvement of knowledge exchange between science and planning practice specifically, integrated approaches have been developed and applied (Baker et al., 2010; Steingröver et al., 2010; Wiek and Walter, 2009). Such approaches have shown to be effective in processes like social learning that improves the skills of practitioners to become acquainted with scientific knowledge and tools, and in improving the skills of scientists to provide requisite knowledge for practitioners (Opdam, 2010). In order to make the knowledge transfer between science and practice effective, the scientific information needs to be credible, relevant and legitimate (Cash et al., 2003). This can be partly achieved by involving multiple stakeholders, such as stakeholders from business, government, and civil society (Lang et al., 2012). While scientists invest much of their time in improving the credibility of their work, it seems that both relevancy and legitimacy are getting less attention (Opdam, 2010). To date, there is regularly a mismatch between the developed scientific methodologies and tools and the requirements of practitioners (McNie, 2007; Weitkamp et al., 2012). This mismatch can be eliminated by applying a collective process where the methodology, tool, or knowledge is co-produced by multiple stakeholders (Pohl, 2008). A powerful tool for co-production is participatory scenario development (Hage et al., 2010), which deals with complex, uncontrollable, and uncertain problems (Biggs et al., 2007; Kok and Vliet, 2011; Peterson et al., 2003). Scenario analysis can be employed to achieve surprising, yet plausible plans and unexpected results, which can lead to creative solutions (Ahern, 1999). Commonly, qualitative storylines are developed with a participatory approach, which are then combined with quantitative models that provide detailed information on specific environmental processes (Kok et al., 2011). An important characteristic of scenarios is the degree of quantification (van Notten et al., 2003). Scenarios can be either qualitative, such as storylines, or quantitative, obtained through modelling approaches. Qualitative scenarios are often participatory, while quantitative models, including spatial quantification, are mostly developed without participation of stakeholders (Kok and Vliet, 2011). An exception is shown by van den Brink et al. (2008), they involved stakeholders in scenario development generating spatial information for the assessment of conflicts between land use management and groundwater quality using a negotiation support system. This shows that can be a powerful tool to involve stakeholders, nonetheless, mostly this is not being done (Kok, 2009).

In summary, linking science to practice involves a variety of possible pathways and players, depends on a constructive partnership and convergence of interests, and requires mutual responsibility from both the scientific and practice communities (Vogel et al., 2007). This is not a simple task, but nonetheless essential.

1.6 This dissertation

1.6.1 Challenges and objectives

Understanding the complex interactions between social and ecological systems has become a vast challenge in sustainability science. The provision of landscape services are a result of such interactions. Landscape services maps depict in a comprehensive way a part of this complexity. However, to date, methods to map landscape services and understand the spatial synergies and trade-offs of landscape services are still in progress (de Groot et al., 2010; Maes et al., 2012). The spatial relation between landscape services and landscape properties need to be further studied to recognise appropriate spatial indicators to map these services.

The spatial distribution of landscape services can be highly valuable for planning practitioners. The combination of the landscape service concept with integrated participatory approaches has the potential of co-producing knowledge regarding the spatial distribution of landscape services that is relevant for both science and planning practice.

The overall objective of this dissertation is to analyse the spatial distribution of landscape services and to integrate science and planning practice through participatory approaches and co-production. To achieve this objective two key research questions are defined:

i. How can we analyse current and future spatial distribution of landscape services?
ii. How can we enhance the applicability of scientific knowledge and methods for spatial planning practice?

1.6.2 Structure of dissertation

The following four chapters in this dissertation address this overall objective, these two research questions, and illustrate the approaches. Figure 1.3 depicts a schematic overview of the four chapters of this dissertation. In Chapter 2 a methodological framework is presented to assess spatial indicators for mapping landscape services. An application of the approach is illustrated for two municipalities in the Peel region in The Netherlands. The spatial distribution for the landscape services wetland habitat, forest recreation, recreation for hikers, and land-based animal husbandry are presented. In Chapter 3, a spatial assessment of groundwater quality in relation to landscape properties, land use, and landscape services has been conducted at the landscape level for a rural landscape in the southern sandy region of The Netherlands. The nitrate concentration in the upper groundwater is related to both commercial food production services, including crop production, land-based animal husbandry, non-land-based animal husbandry, and hobby farming, and other services, including field sports and campsite tourism. Nitrate concentrations are attained using a combination of field sampling, existing monitoring schemes, and literature. In Chapter 4, the academic approach to map landscape services, established in Chapter 2, is compared to a planning practice approach to map landscape services using a participatory method. For two case study areas, the landscape services forest habitat, ecological corridor, stream valley habitat, cultural aesthetics, flood water storage, intensive and extensive recreation were mapped by local planning practitioners, and independently by scientists. Together with planning practitioners the possibilities for combining both approaches is evaluated and an integrated method is proposed. In

Chapter 5, two participatory scenarios are developed for 2025 by combining both qualitative and quantitative methods. The scenarios are co-developed using an iterative participatory approach. For both scenarios, the landscape services intensive and extensive food production, intensive and extensive recreation, water quality, and water storage are mapped. The scenarios are applied to evaluate the robustness of current policy strategies. Finally, Chapter 6 provides a synthesis of the different research chapters, focussing on the spatial distribution of landscape services, science-practice interface, and usefulness of this dissertation for sustainable landscape development.

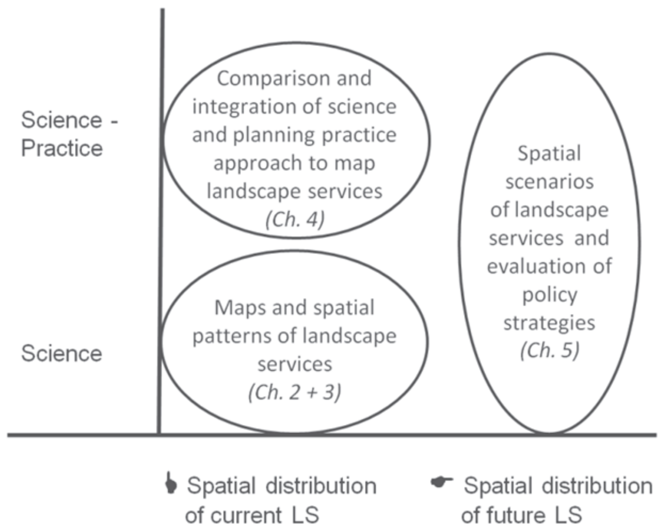

Fig. 1.3 Schematic overview of the chapters in this dissertation *(LS = landscape services)*.

Chapter 2

Mapping landscape services: a case study in a multifunctional rural landscape in the Netherlands

Gulickx M.M.C., Verburg P.H., Stoorvogel J.J.,
Kok K., and Veldkamp, A., (2013)

Ecological Indicators 24, 273-283

Abstract
The wide variety of landscape services, *e.g.* food production, water quality, and recreation, necessitates the use of a wide range of data sources for their identification. Subsequently, an array of approaches is required to analyse and map different landscape services, such as we have explored here in this study. Approaches to identify and map four landscape services are illustrated for the municipalities Deurne and Asten in province Noord-Brabant, The Netherlands: wetland habitat, forest recreation, land-based animal husbandry, and recreation for hikers. The landscape services were identified through ground observations at 389 locations. Spatial indicators were used to identify and map the landscape services. Based on the ground observations, correlations between the landscape services and spatial characteristics (*e.g.* elevation, soil, and road-type) were calculated within a neighbourhood with a radius of 0 m, 50 m, and 100 m. These correlations identified several site-specific indicators to map the landscape services. The accuracy of the landscape service maps was assessed using cross-validation. The indicators proved to be adequately reliable for forest recreation, but less reliable for land-based animal husbandry and recreation for hikers. The landscape service map wetland habitat and forest recreation were shown to be highly accurate. The four landscape services rarely coincide, but within a 1 km radius it is apparent that some occur closer together. The approach that we have used is applicable to a wide range of different services and establishes a fundamental basis for determining their spatial variation. Hence, it should provide vital information for policy makers and spatial planners.

2.1 Introduction

The importance of landscape services, provided by both natural and cultural landscapes, is increasingly recognised (*e.g.* Costanza et al. 1997, MA 2005, de Groot 2006, Termorshuizen and Opdam 2009, Verburg et al. 2009). Landscapes are spatial social-ecological systems that deliver a wide range of functions, which are valued by humans in terms of economic, sociocultural, and ecological benefits (DeFries et al. 2004, Termorshuizen and Opdam 2009). A landscape service is defined here as ‘the goods and services provided by a landscape to satisfy human needs, directly or indirectly’ (Termorshuizen and Opdam 2009). We prefer the term landscape services over ecosystem services, as it infers pattern-process relationships, unites scientific disciplines, and is better understood by local practitioners (Termorshuizen and Opdam 2009). Examples of landscape services include food production, pollination, water regulation, and provision of recreation.

Increasing attention is paid, both by policy makers and scientists, to the multifunctionality (Fry 2001, Holmes 2006, Wilson 2008), and the potential synergies and conflicts that may arise. Policy makers and spatial planners are gradually directing their policies and plans to provide and strengthen desired landscape services. To support the establishment of these policies and plans, geographical maps of existing and desired services are required to identify where services border each other or overlap and, thus, lead to possible synergies or conflicts. In this way, they may be used to determine optimal solutions. Hence, it is necessary to develop methods and tools to quantify and map the different services across the landscape.

The spatial distribution of intended landscape services that are related to the intended land use (*e.g.* food and fibre production) are often documented. However, the spatial distribution of landscape services that is often an unintended consequence of land management (*e.g.* provision of aesthetic beauty), are commonly unknown. Additionally, they may be unrelated to a single land-cover or land-use type, which makes them more difficult to quantify and map. It is postulated that landscape analyses based on land-cover and land-use are inadequate for landscape characterisation of such unintended services, since these approaches are specifically related to the intended use of the land (Verburg et al. 2009). Hence, common observation techniques, available land cover maps and spatial datasets, are insufficient for quantifying and mapping these landscape services (Verburg et al. 2009). Consequently, various spatial attributes, mainly biophysical, but also economic and social ones, are used as indicators to quantify and map the spatial extent of landscape services (*e.g.* Gimona and van der Horst 2007, Egoh et al. 2008, Willemen et al. 2008, Kienast et al. 2009). Yet, indicators related to landscape services are often unknown or based on general assumptions. Identifying suitable indicators is essential for the improvement of landscape service maps. Therefore, a quantification of relations between site-specific attributes and landscape services is required in order to develop reliable indicators. Yet, site-specific indicators for landscape services are hardly investigated.

The vast array of landscape services is delivered across a great range of temporal and spatial scales. Examples of services that apply to different temporal scales are carbon sequestration (long-term carbon storage) and seasonal recreation (short-term visits). Examples of services that apply to different spatial scales are water supply (up to many km^2) and cultural heritage, such as monuments of architecture (as small as m^2). Therefore, the development of a standard procedure to quantify and map landscape services is hampered by the fact that the appropriate spatial scales differ greatly amongst landscape services (de Groot and Hein 2007, Pérez-Soba et al. 2008).

The objective of this study is to develop an approach to identify and map various landscape services, by using indicators and considering spatial scales. Correlations between observed landscape services and spatial characteristics of the surrounding landscape were analysed to ascertain site-specific indicators for landscape services. These indicators were extrapolated into landscape service maps. The methodology and results are illustrated for four landscape services (*i.e.* wetland habitat, forest recreation, land-based animal husbandry, and recreation for hikers) in the municipalities of Deurne and Asten, province of Noord-Brabant, The Netherlands. This case study aimed to obtain insights into the relations between landscape services and the surrounding landscape. The indicators derived are specific to this area, but highlight linkages between landscape services and their surroundings.

2.2 Materials and methods

2.2.1 Study area

The study area comprised the municipalities of Deurne (120 km^2; 5 villages; 31.496 inhabitants; May 2009) and Asten (72 km^2; 3 villages; 16.398 inhabitants; May 2009) in the province of Noord-Brabant, The Netherlands (Fig. 2.1). Both municipalities are part of *De Peel* region (approximately 600 km^2), which is known for its intensive livestock production and nature reserve 'De Groote Peel' (peat-bog that has remained partly untouched by peat cutting). This area has to deal with various conflicting services in the landscape. For example, intensive animal husbandry has an impact on the environment, such as odour emission, which has a negative impact on recreation, such as farm camping. As a result, the national and regional authority has assigned this region as a 'reconstruction area' with high priority, in order to improve the environmental quality of the rural area (Provincie Noord-Brabant 2005).

2.2.2 General design of methodology

At first, point observations of landscape services were made. Based on relations between the occurrence of landscape services and the spatial characteristics of these locations, an extrapolation of these services to the whole study area was conducted. The methodology consists of four components: 1) point observations of landscape services; 2) point observations of spatial characteristics; 3) correlation analysis and selection of indicators; and 4) extrapolation of indicators for mapping landscape services (Fig. 2.2). The four components are described in the paragraphs below. First, we described the sampling method that was used to obtain point data for the observation of landscape services and the spatial characteristics. The study area was divided into grid cells of 1 km^2. Within each grid cell, two points were selected approximately 500 metres apart. This structured sample design provided an equal distribution of data points, resulting in a total of 389 points. Per data point, existing landscape services were identified using ground observations, sometimes complemented with information from governmental databases or management strategies (Table 2.1). In addition, the spatial characteristics (Table 2.2) were assembled at a radius of 0, 50, and 100 metres to ascertain the neighbourhoods of the landscape service. Field observations were carried out from June to August 2009.

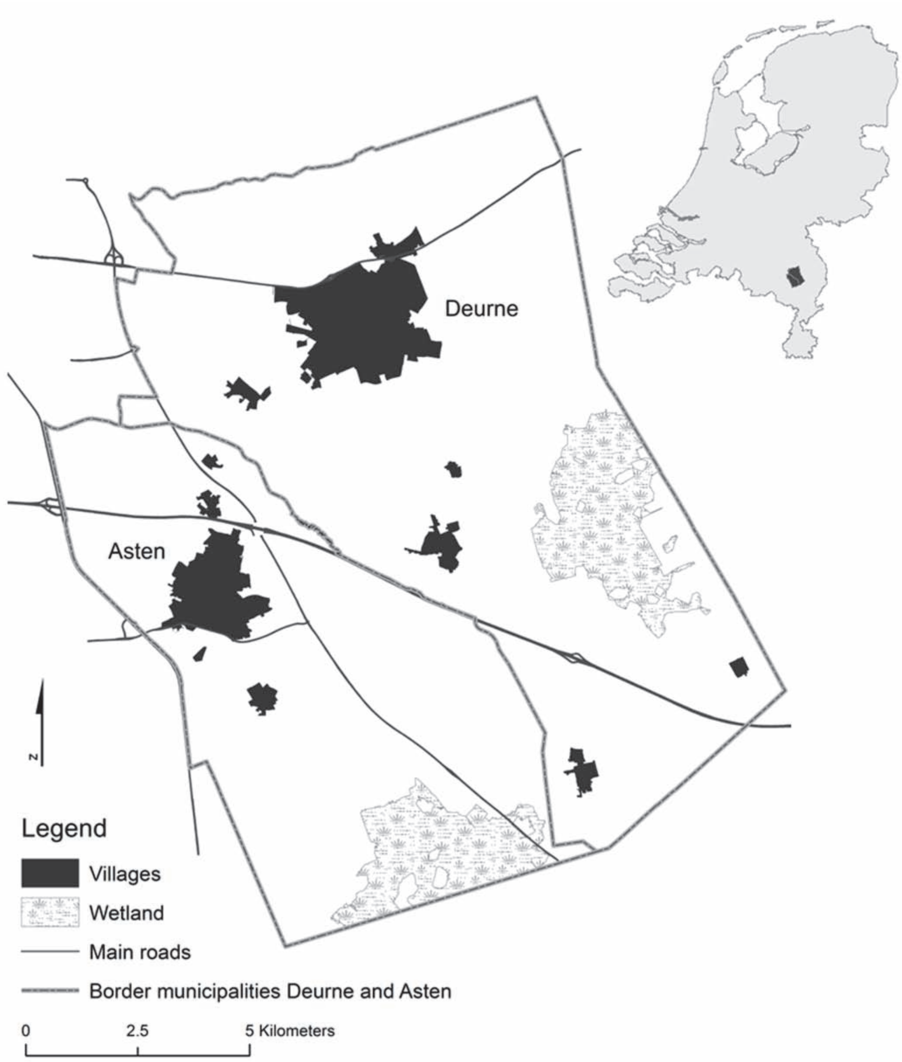

Fig. 2.1 Study area comprising municipalities Asten and Deurne. At the top on the right, the location of the study area (black mark) in the Netherlands is shown.

2.2.3 Point observations of landscape services

Landscape services vary greatly as they, for instance, differ in their properties (de Groot and Hein 2007). Consequently, different methods and data sources are required to identify landscape services (Willemen et al. 2008). In general, we can differentiate between landscape services with a one-to-one relation to land-cover; those, which require one data source and are therefore easy to identify; and other landscape services which require multiple data sources and are more laborious to identify. A list of 25 landscape services present in the study area and the potential data sources to identify the service was composed (Table 2.1). To account for diversity of landscape services, four categories (MA, 2003) are included: regulating services (*e.g.* flood control), supporting services (*e.g.* provision of natural habitat), provision services (*e.g*. food production), and cultural services (*e.g.* recreation).

Broad categories of landscape services bring about a wider set of required data sources to identify the service. For example, food production is a very broad category that contains different types of landscape services, and as such, a diverse set of data sources. Conversely, the subcategory land-based animal husbandry (containing mainly milk production) is more specified, and as a result, includes less diversity in the required data sources. The 25 selected landscape services are therefore specified explicitly.

We opted to present the methodology by describing four different landscape services with different requirements (*i.e.* data sources): wetland habitat, forest recreation, recreation for hikers, and land-based animal husbandry.

Wetland habitat

Wetland habitat in the study area is of great importance to the region for both nature conservation and historical value. Wetlands harbour a great variety of flora (*e.g.* peat moss *Sphagnum magellanicum*, Bog Rosemary *Andromeda polifolia*, and Sundews *Drosera intermedia*), and fauna, including rare birds (*e.g.* Black-necked Grebe *Podiceps nigricollis*

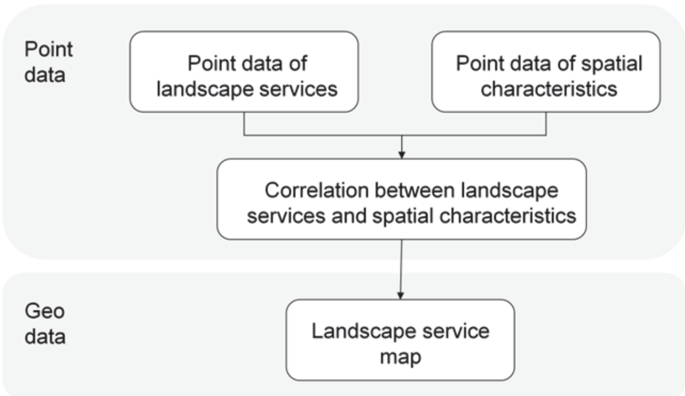

Fig. 2.2 Overview of the overall methodology.

Table 2.1 Landscape services and the expected data sources that are required to identify the landscape service. Services in bolt are further described in this paper.

Landscape service	**Service category**	**Map**		**Governmental database**		**Management strategy**	**Fieldwork**	
		Land cover	*Routes*	*ERD* [1]	*GIAB* [2]		*Observations*	*Counts*
Residential	Provision	X						
Industrial production	Provision	X						
Outdoor sport	Cultural	X						
Fruit and nut production	Provision	X						
Greenhouse food production	Provision	X						
Forest habitat	Supporting	X						
Wetland habitat	**Supporting**	**X**						
Water storage	Regulating	X						
Water supply	Provision	X				X		
Energy supply	Provision	X					X	
Hobby gardening	Cultural	X		X	X			
Crop production	Provision	X		X	X		X	
Overnight tourism	Cultural	X					X	X
Forest recreation	**Cultural**	**X**	**X**			**X**	**X**	**X**
Wetland recreation	Cultural	X	X			X	X	X
Recreation for hikers	**Cultural**		**X**				**X**	**X**
Recreation for cyclists	Cultural		X				X	X
Recreation for horse riders	Cultural		X				X	X
Non-land-based animal husbandry	Provision			X			X	
Land-based animal husbandry	**Provision**			**X**			**X**	
Horse boarding	Provision			X		X	X	
Hobby farming	Cultural			X	X		X	
Ditch bank protection	Supporting				X	X	X	X
Bird protection in agricultural land	Supporting					X	X	X
Bird habitat in agricultural land	Supporting						X	X

[1] *ERD = Environmental Registration Database (StraMis, 2008)*
[2] *GIAB = Agricultural Assessment Database*

Table 2.2 List of included spatial characteristics and used data sources, divided into point observations, distance to, and neighbourhood (occurrence within a radius of 50 and 100 metres).

	Spatial characteristics	Field observation	Database
At data point	Soil type		Soil map (PAWN 2006)
	Ground water table		Soil map (PAWN 2006)
Distance to	Unpaved road	X	TOP10-SE[1] (2006)
	Rural road	X	TOP10-SE (2006)
	Provincial road	X	TOP10-SE (2006)
	Highway	X	TOP10-SE (2006)
	Natural area	X	TOP10-SE (2006)
	City/village	X	TOP10-SE (2006)
	Cultural heritage (monuments)	X	CHW Brabant[2] (2006)
	Industrial area	X	TOP10-SE (2006)
	Greenhouse	X	TOP10-SE (2006)
	Recreational area/element	X	TOP10-SE (2006)
Neighbourhood	Relief	X	AHN[3] (2000)
	Ditch	X	
	Pond	X	
	Solitaire tree	X	TOP10-SE (2006)
	Tree line	X	Google Earth (2009)
	Hedgerow	X	TOP10-SE (2006)
	Bush	X	
	Cultural heritage	X	CHW Brabant (2006)
	Openness		Calculated[4]
	Hilliness	X	AHN (2000)

[1] TOP10-SE = Topographical Map Spatial Edition (vector), including land use classification of TDN (Topographical Service Netherlands), scale 1:10000
[2] CHW Brabant = Cultural Historical Valuable (monumental buildings), Atlas Province Noord-Brabant
[3] AHN = Dutch digital elevation map, spatial resolution 5x5 metres
[4] Openness is calculated using the methodology of Weitkamp at al. (2011)

and Nightjar *Caprimulgus europaeus*), and rare butterflies and dragon flies (*e.g.* Large Chequered Skipper *Heteropterus morpheus* and White-faced Darter *Leucorrhinia dubia*). In addition, historical traces of peat extraction, such as big lakes and small peat pits, are still visible. Wetland habitat was identified using a land-cover map (TOP10 Spatial Edition, 2006).

Forest recreation

The area contains several fragments of forested areas. Forests were predominantly planted between 1840 and 1900 to prevent sand drifting and to provide wood (Bont de

1993). Some natural forests started to grow on the drier and more nutrient-rich soils of the wetland areas. These are dominated by birch *Betula* trees. Over the last few decades, recreational use of the forested areas has increased. Forest recreation is defined as recreational activities in a forest larger than 2 hectares. A land-cover map (TOP10 Spatial Edition, 2006) was used to determine the location of the forested areas. Within these forested areas, recreational activity was ascertained using simple indicators, namely, the presence of walking trails, cycling paths, horse riding trails, picnic tables, and car parks. These indicators were derived from management plans, walking, cycling and horse riding routes, and from field observations. In order to identify the actual service, it is preferred to quantify the amount of visitors to the forested areas, which is unfortunately very time consuming. Instead, we enquired with the land owners of the forested areas to deduce whether these areas are used by people for recreational purposes.

Recreation for hikers

Recreation for hikers is defined as (perceived) attractive landscapes suitable for leisure walking activity. We used a hiking route map ('knooppuntenroute' network of hiking routes, 2008) to identify recreation for hikers. The route is designed to pass important points of interest, along attractive landscapes, and where possible on good quality roads. This hiking route map is the most sold type of hiking map by the tourist information centre, and it is therefore, expected to be mostly used by recreational hikers.

Land-based animal husbandry

Livestock production has intensified rapidly in the study area, similar to other parts of the Netherlands. This has resulted in outbreaks of various infectious diseases amongst livestock, and it has triggered a renovation plan to improve the environmental situation of livestock production. Land-based husbandry is defined as the production of food and goods (*e.g.* milk and wool) by farms that depend on the land quality (*i.e.* they use their own land for fodder production). Land-based husbandry is an important source of income in the region. The environmental Registration Database (StraMis), which details farm types (*e.g.* land-based, non-land-based, horticulture) and their location, was used to identify land-based animal husbandry.

2.2.4 Point observations of spatial characteristics

Several spatial characteristics were identified to analyse the spatial indicators of each landscape service (Table 2.2). For the collection of spatial characteristics, both field observations and spatial databases were used (Table 2.2). This predominantly comprises maps and data sources from 2006, with the exception of the elevation map and Statistics

Netherlands database (AHN 2000 and CBS 2008, respectively). The openness was calculated using the procedure proposed by Weitkamp et al. (2011).

2.2.5 Correlation analysis and indicator selection

In total, five data points were excluded from our data analyses, because the ground observation was not in agreement with the spatial databases. For instance, the land was leased out and the user (the type of farm) of an arable field was not retraceable. Therefore, a total of 384 data points were included in the analyses. Statistical analyses were calculated in SPSS Statistics 17.

Several spatial characteristics (*i.e.* ditch, pond, solitaire tree, tree line, hedgerow, bush, cultural heritage) have binary variables (present=1; absent=0). The relation between the landscape services and the binomial spatial characteristics within a 0, 50, and 100-metre radius, and correlations between landscape services was calculated using Spearman's Rho. Cultural heritage was also calculated within a 500 metre radius, considering cultural heritage does not have to be visible to have an influence. Correlations between landscape services and spatial characteristics with a continuous numeral system (*i.e.* openness, elevation, relief, and distance to spatial characteristics) were calculated for a 0, 50, and 100-metre radius using Pearson's *r*. In The Netherlands, wetland is a well-mapped land-cover type, and therefore, land-cover is considered as the spatial determinant for wetland habitat. Due to this one-to-one relation with land-cover, further calculations for assessing correlations between wetland habitat and spatial characteristics were not applied, considering these correlations are not necessary for mapping wetland habitat.

The identified correlations between landscape services were used as indicators to map the service. For each service, the correlation between the set of indicators and the services was calculated using logistic regression. The goodness of fit of the logistic regression was measured by means of the Receiver Operating Characteristic (ROC) curve (Pontius and Schneider 2001, Verburg et al. 2004), which involves plotting each pair of true positive and false positive proportions for every possible decision threshold between 0 and 1. A ROC curve value of 0.5 indicates that the model is completely random and a value of 1 indicates perfect discrimination.

Logistic regression assumes that the variables are independent. Therefore, we tested the variables for their independency, *i.e.* for multicollinearity (Variance Inflation Factors (VIF) and tolerance test) and spatial autocorrelation (Moran's I).

To evaluate spatial synergies between landscape services, correlations between the various locations of services were calculated (Spearman's Rho). In addition, within a radius of 1 km, the occurrence of other landscape services, and the distance between the different services were assessed. A Kruskal-Wallis test was used to calculate differences between the distances to the different landscape services.

2.2.6 Mapping landscape services

Wetland habitat was mapped by extracting land-cover wetland from the land-cover map (TOP10 Spatial Edition) using ArcGIS 9.3. Land-based animal husbandry, forest recreation, and recreation for hikers were mapped using the fitted logistic regression model (ArcGIS 9.3). The goodness of fit of the maps was tested by a two-by-two contingency table (cross-validation) using the observed data of the landscape services. This resulted in an overall, a producer's, and a user's accuracy.

2.3 Results

The landscape service wetland habitat was present at 8% (N=32) of the analysed data points, forest recreation at 8% (which is 70% of the data points with forest habitat; N=29), recreation for hikers at 41% (N=157), and land-based animal husbandry at 52% (N=200). At 7% of the analysed data points more than one landscape service was provided.

2.3.1 Correlations with spatial characteristics and landscape service maps

Wetland habitat

Wetland habitat was mapped using land-cover type wetland (Fig. 2.3). Validation of the wetland habitat map shows an overall accuracy of 0.96 (Table 2.4), with a producer's accuracy of 0.74 and a user's accuracy of 0.82. Considering that the accuracy is not 1.0 demonstrates that the land-cover map is not 100% accurate.

Forest recreation

The occurrence of forest recreation depends on the presence of the land-cover forest. We found forested areas without recreational activities and forested areas with recreational activities (*i.e.* landscape service forest recreation). Several spatial characteristics explained the presence of forest recreation, specifically a negative correlation with elevation, and positive correlations with soil type, ground water table, and relief (Table 2.3). However, comparing forested areas with the landscape service forest recreation and without this service (*i.e.* forested areas where no recreation was observed), no correlation was found with soil type (Sand cover on peat *on sand, r= -0.24, P<0.09; Earthy topsoil on deep peat, r=0.22, P<0.13; 'Enk' earth soil,* r=-0.13, P<0.38; Drift sand, r=0.15, P<0.30) and ground water table (GWT-I, r=0.22, P<0.13; GWT-VI, r=-0.26, P<0.07; GWT VII, r=0.17, P<0.24). This shows that soil type and ground water table explain the occurrence of forested areas, but not the occurrence of landscape service forest recreation. However, for elevation (r=-0.391, P<0.01) and relief (within 50 m. radius: r=0.29, P<0.04; within 100 m. radius: r=0.32, *P*<0.02) a correlation was found between forested areas with the landscape service forest recreation. This is in agreement with less recreation in the forested areas of the wetlands, considering that the wetland forests are found in higher, flatter areas. In addition, the ground water level in the wetlands was higher (for which no significance was found, nonetheless, GWT-VI does show a negative trend: r=-0.26, P<0.07), resulting in less accessible forests in the wetland. The most significant spatial characteristic was unpaved paths, which was positively correlated with forest recreation (Table 2.3). This makes a forest accessible for recreation. When considering forests with no recreation in combination with unpaved paths, a strong negative correlation was found (r=-0.48, P<0.00). This shows that the presence of unpaved paths is indeed important for forest recreation.

Relief is not included as an indicator, because of its high correlation to forest (VIF of 9). It is evident that the spatial characteristics unpaved paths and land-cover forest are important factors, and therefore, used as indicators of the service (Table 2.4). The ROC value indicates that forest recreation is adequately explained by the designated indicators (Table 2.4). Initially, elevation was also included as an indicator, however, the ROC value showed that including elevation explained forest recreation less well (ROC value of 0.81). Therefore, elevation was not included as an indicator for forest recreation. The resulting map is shown in Figure 2.3. Validation of the forest recreation map shows an overall accuracy of 0.93 (Table 2.4), with a producer's accuracy of 0.83 and a user's accuracy of 0.67.

Recreation for hikers

Understandably, paths to walk on are crucial for recreation for hikers, however, not all paths are equally attractive. Therefore, different types of paths in combination with tree lines have been assessed. Both rural roads and unpaved paths are positively correlated with recreation for hikers (Table 2.3). However, unpaved paths without tree lines are not correlated with recreation for hikers (Table 2.3), hence, assumedly tree lines are essential. Conversely, there was a positive correlation found for rural roads without tree lines within 100 metres. Then again, a positive trend was found between recreation for hikers and rural roads with tree lines (r=0.09, P<0.06). In general, there was a positive correlation between paths and tree lines. Landscape elements (*i.e.* ditches, ponds, solitaire tree lines, hedgerows, and bushes) are positively correlated with recreation for hikers within a radius of 50 and 100 metres (Table 2.3). Separately, only the landscape elements solitaire trees, tree lines, and ditches are positively correlated within 100 metres (Table 2.3). It is not a surprise that ditches are positively correlated, considering the high density of ditches throughout the study area. In addition, no sufficient map of ditches was available for this study area, therefore, ditches were not included as a determinant of recreation for hikers.

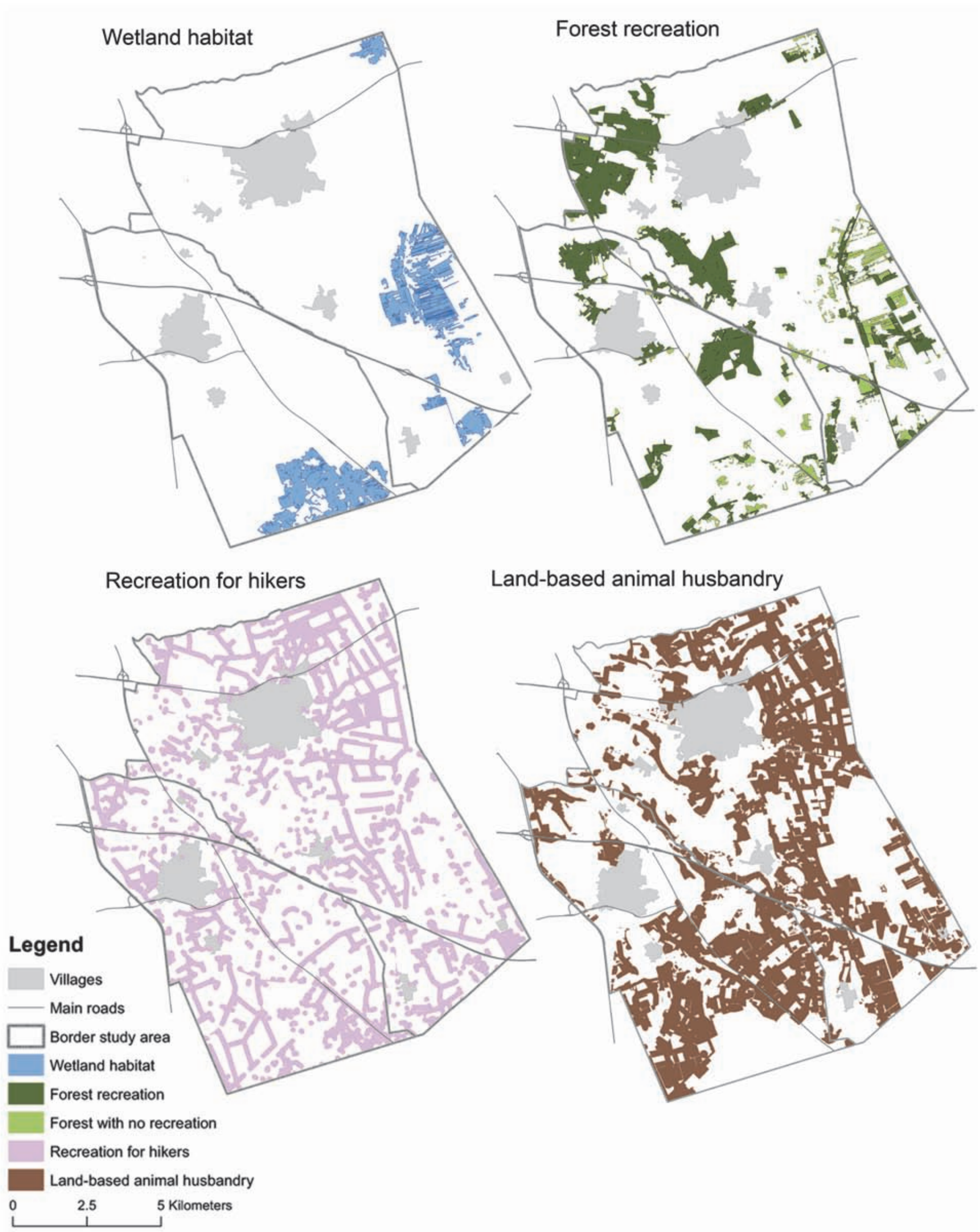

Fig. 2.3 Landscape service maps: wetland habitat; forest recreation; recreation for hikers; and land-based animal husbandry.

Table 2.3 Correlations between landscape services and spatial characteristics. Correlations between landscape services and spatial characteristics are calculated using Pearson's r (normal distributed data) and Spearman's rho (non-normal distributed data) in SPSS Statistics 17. The significance level is indicated with * for p<0.05, ** for p<0.01, *** for p<0.001, and are shown in bolt.

Spatial characteristics	Forest recreation	Recreation for hikers	Land-based animal husbandry
At data point			
Elevation	**-0.12 ***	**-0.13 ****	-0.06
Ground water Table			
I (<20 - <50 cm-gl)	**0.23 *****	**-0.11 ***	-0.09
II (<40 - <50-80 cm-gl)	-0.00	**-0.12 ***	-0.05
III (<40 - <80-120 cm-gl)	-0.08	-0.06	-0.07
IV (<40 - <80-120 cm-gl)	-0.06	0.07	**0.10 ***
V (<40 - <120 cm-gl)	-0.07	0.02	0.01
VI (<40-80 - <120 cm-gl)	**-0.15 ****	0.03	**0.11 ***
VII (>80 - >516 cm-gl)	**0.13 ***	0.03	-0.06
Soil type			
Sand cover on peat on sand	**-0.13 ***	0.04	**0.18 *****
Slightly loamy fine sand	-0.01	0.09	**0.12 ***
Earthy topsoil on deep peat	**0.10 ***	**-0.16 *****	**-0.15 ****
Earthy topsoil on peat on sand	-0.01	**-0.15 *****	**-0.18 *****
'Enk' earth soil	**-0.10 ***	0.04	-0.02
Very loamy fine sand	-0.05	0.09	**0.10 ***
Drift sand	**0.26 *****	0.03	**-0.15 ****
Decreasing distance to			
Roads			
Unpaved path	**0.31 *****	0.09	**-0.11 ***
Rural road	**-0.18 *****	0.10	0.00
Highway and Provincial road	**0.14 ****	0.06	-0.04
Industrial area	-0.01	**0.11 ***	**-0.12 ***
City/village	-0.01	0.07	**-0.11 ***
Greenhouse	**-0.13 ****	0.04	0.01
Cultural heritage	-0.05	**0.13 ****	-0.06
Natural area	-	-0.04	**-0.24 *****

Table 2.3 *(Continued)*

Spatial characteristics	Forest recreation 50m	Forest recreation 100m	Recreation for hikers 50m	Recreation for hikers 100m	Land-based animal husbandry 50m	Land-based animal husbandry 100m
Neighbourhood						
Relief	**0.19** ***	**0.19** ***	0.02	0.06	**-0.31** ***	**-0.28** ***
Openness	-	**0.33** ***	-	0.04	-	**0.37** ***
Land elements [2]	-	-	**0.12** *	**0.18** ***	**0.33** ***	**0.40** ***
Ditch	-	-	0.08	**0.11** *	**0.35** ***	**0.43** ***
Pond	-	-	0.02	0.04	0.06	-0.03
Solitaire tree	-	-	0.06	**0.11** *	0.03	**0.12** *
Tree line	-	-	0.10	**0.15** **	0.08	**0.20** ***
Hedgerow	-	-	0.08	0.037	-0.08	-0.07
Bush	-	-	0.05	0.087	-0.03	0.08
Roads						
Unpaved path	**0.32** ***	**0.29** ***	**0.14****	**0.19** ***	-0.09	-0.07
Without tree line	-	-	0.07	0.04	**-0.18** ***	**-0.12** *
With tree line	-	-	**0.12** *	**0.19** ***	0.07	0.04
Rural road	**-0.18** ***	**-0.24** ***	**0.11** *	**0.19** ***	-0.05	**0.15** **
Without tree line	-	-	0.09	**0.11** *	0.00	0.07
With tree line	-	-	0.05	0.09	-0.06	0.10
Provincial road	0.00	-0.05	-0.03	-0.01	-0.07	-0.09
Highway	-0.04	0.06	0.02	0.00	-0.03	0.04

[1] *Groundwater Table is derived from the Policy Analysis for Water-management of the Netherlands (PAWN, 2006). Groundwater level is expressed in cm below ground level (gl).*

[2] *Land elements is aggregation of ditch, pond, solitaire tree, hedgerow, and bush.*

Table 2.4 Indicators (spatial characteristics) used to map the landscape services, logistic regression of the indicators with Cox&Snell R^2 (significance in brackets), goodness of fit of the logistic regression (ROC curve), and the overall accuracy of the landscape service map (contingency table).

Landscape service	**Indicators**	**Log. Regression**	**ROC**	**Map accuracy**
Wetland habitat	Land-cover wetland	-	-	0.96
Forest recreation	Land-cover forest, and Unpaved path within 200m	0.30 (0.00)	0.98	0.93
Recreation for hikers	Land elements* within 100m, and Rural road within 100m, or Unpaved path within 100m	0.12 (0.00)	0.68	0.56
Land-based animal husbandry	Industry not within 100m, or Villages not within 100m, and Solitaire trees within 100m on sand-cover-on-peat-on-sand or slightly-loamy-fine-sand, or very-loamy-fine-sand, or Rural roads within 100m on sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, or very-loamy-fine-sand, and Grassland on sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, or very-loamy-fine-sand	0.21 (0.00)	0.78	0.64

** Tree lines and solitaire trees*

An unexpected result is the positive correlation between recreation for hikers and short distances to industry (Table 2.3). However, there was no correlation between recreation for hikers and industry within a radius of 50 metres (r=0.00, P<0.99), or within 100 metres (r=0.00, P<0.99). Therefore, industry was not taken into account for mapping recreation for hikers.

Cultural heritage was positively correlated with short distances to recreation for hikers (Table 2.3). Likewise, there was a positive correlation between a high density of hiking routes and cultural heritage (r=0.50, P<0.00). However, cultural heritage was not correlated with recreation for hikers within 50 metres (r=0.01, P<0.89), nor within 100 metres (r=0.07, P<0.16). Cultural heritage seems to have a positive influence on recreation for hikers. Presumably, due to few cultural heritage locations within 50 metres (N=3) and 100 metres (N=12) from walking recreation, no direct correlation with a defined distance to cultural heritage could be recognised, and therefore, is not considered as a determinant for recreation for hikers.

The selected indicators for mapping the occurrence of recreation for hikers are: unpaved paths with solitary trees or tree lines within 100 metres and rural roads with solitary trees within 100 metres (Table 2.4). The ROC value indicates that recreation for hikers is partially explained by the designated indicators (Table 2.4). The resulting map is shown in Figure 2.3. Validation of the recreation for hikers map shows an overall accuracy of 0.56 (Table 2.4), a producer's accuracy of 0.55 and a user's accuracy of 0.56.

Land-based animal husbandry

Land-based animal husbandry has a negative correlation with relief and a positive correlation with openness (Table 2.3), which can be explained by the fact that level and open terrain has benefits for land cultivation. These spatial characteristics do not explain land-based animal husbandry explicitly, but rather agricultural activities in general. Soil type is another spatial characteristic that also has positive correlations with other agricultural landscape services. Land-based animal husbandry was positively correlated with sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, and very-loamy-fine-sand (Table 2.3). Non-land-based animal husbandry was positively correlated with slightly-loamy-fine-sand (r=0.12, P<0.02), provision of tillage crops was positively correlated with slightly-loamy-fine-sand (r=0.145, P<0.00) and sand-cover-on-peat-on-sand (r=0.10, P<0.04), and greenhouse was positively correlated with very-loamy-fine-sand (r=0.16, P<0.00). As there are differences in the relations between soil type and the different agricultural landscape services, soil type can be used as an indicator in combination with other spatial characteristics that are only applicable with land-based animal husbandry. Short distances to nature area, city, and industry are negatively correlated with land-based animal husbandry (Table 2.3). Also for other agricultural landscape services, a negative correlation with short distances to nature areas was found, specifically, non-land-based animal husbandry (r=0.20, P<0.00), provision of tillage crops (r=0.17, P<0.00), and greenhouse (r=0.10, P<0.05). However, no correlation was found with short distances to either village (non-land-based animal husbandry: r=0.01, P<0.90; and provision of tillage crops: r=0.03, P<0.54), or industry (non-land-based animal husbandry: r=0.04, P<0.40; provision of tillage crops: r=0.04, P<0.44; and greenhouse: r=-0.05, P<0.32). In contrast to land-based animal husbandry, greenhouses have a positive relation with villages (r=-0.10, P<0.05).

A positive correlation with all landscape elements assembled was found within both a 50 and 100 metres radius (Table 2.3). For other agricultural landscape services no correlation was found within a 50 metres radius (non-land-based animal husbandry: r=0.07, P<0.17; provision of tillage crops: r=0.04, P<0.45; and greenhouse: r=-0.06, P<0.20). In addition, the positive correlation between solitaire trees and land-based animal husbandry within a 100 metres radius was not found for non-land-based animal husbandry (*r*=-0.01, *P*<0.89), provision of tillage crops (*r*= 0.09, *P*<0.07), and greenhouse (*r*=-0.63, *P*<0.21). These results show that there are differences between spatial characteristics and various agricultural landscape services.

Notably, a negative correlation was found with unpaved paths without tree lines within both 50 and 100-metre radius, even though no correlation was found for unpaved paths in total (Table 2.3). This can be explained by the fact that unpaved paths without tree lines often occur in forested areas where no land-based animal husbandry occurs. When excluding unpaved paths without tree lines in forested areas, no correlation with unpaved paths without tree lines was found (*r*=-0.00, *P*<0.96).

Land-based animal husbandry occurred mainly within the land cover grassland, indicating the importance of grassland for this service. Grassland was indeed positively correlated (*r*=0.49, *P*<0.00), even though it can provide many services. As such, we have calculated the correlation with grassland located on the soil types sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, or very-loamy-fine-sand (soil types that are positively correlated with land-based animal husbandry; Table 2.3), which still showed a positive correlation (*r*=0.41, *P*<0.00). Non-land-based animal husbandry was also positively correlated with slightly-loamy-fine-sand, however, not with grassland on slightly-loamy-fine-sand (*r*=0.06, *P*<0.09). Considering the importance of grassland for land-based animal husbandry, this land cover type, in combination with the three soil types, was included as an indicator for the service.

The objective of this study was to map the occurrence of land-based animal husbandry, and not agriculture in general. Hence, we have only included correlations with spatial characteristics that are not correlated with other agricultural landscape services (*i.e.* tree lines and solitary trees within 100m on sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, or very-loamy-fine-sand, grassland on the same 3 soil types, and by excluding distances to nature areas). These correlations are assumed to be more related to land-based animal husbandry and less to agriculture in general.

The selected indicators to map land-based animal husbandry are: no villages within 100m; no industry within 100m; solitaire trees within 100m; rural road within 100m; and grassland on either sand-cover-on-peat-on-sand, slightly-loamy-fine-sand, or very-loamy-fine-sand (Table 2.4). The ROC value indicates that land-based animal husbandry is reasonably explained by the designated indicators (Table 2.4). The resulting map is shown in Figure 2.3. Validation of the land-based animal husbandry map shows an overall accuracy of 0.64 (Table 2.4), with a producer's accuracy of 0.57 and a user's accuracy of 0.54.

2.3.2 Correlations between landscape services

Land-based animal husbandry, forest recreation, and wetland habitat have opposing requirements. Therefore, no overlap of these services was found. Land-based animal husbandry has a negative correlation with forest recreation (r=-0.20, P<0.00) and wetland habitat (r=-0.15, P<0.00). In addition, forest recreation and wetland habitat do not occur within a radius of 550 metres around land-based animal husbandry (Fig. 2.4d). This indicates that they do not occur close to each other either. Similarly, a negative correlation was found between recreation for hikers and wetland habitat (r=-0.10, P<0.04). This was partly due to the fact that the selected hiking routes only intersect a fraction of the wetlands, but also because large parts of the wetland habitat are inaccessible. However, within 1 km radius, recreation for hikers occurs regularly, and even at the same location (N=3; Fig. 2.4c), showing that these two services can occur closely together. Recreation for hikers does occur at the same location as land-based animal husbandry and forest recreation, yet, no positive correlations are found. Within a distance of 1 km radius it is apparent that recreation for hikers occurs regularly at a short distance with both forest recreation (Fig. 2.4b) and land-based animal husbandry (Fig. 2.4d).

The assessment of the occurrence of different landscape services within a 1 km radius shows that some landscape functions do occur together within this range (Fig. 2.4), whereas they did not occur together within a range of 100 metres. In addition, wetland habitat did not occur with forest recreation and land-based animal husbandry within a 100-metre radius. The assessment of a 1 km radius shows that forest recreation and land-based animal husbandry do not occur within a range of 680 and 570 metres, respectively.

2.3.3 Multicollinearity and spatial autocorrelation

The Variance Inflation Factors (VIF) and the tolerance test showed no evidence for multicollinearity between the variables used as indicators for the landscape services (VIF ranged between 1.01 and 1.73, tolerance ranged between 0.58 and 1.00; VIF more than 5 and tolerance less than 0.2 are considered to be a cause for concern for multicollinearity (Menard 2001). However, the variables relief and forest did show multicollinearity (VIF of 9), therefore, relief was not included as an indicator for forest recreation.

The spatial autocorrelation analysis of the spatial indicators of forest recreation has indicated a weak positive dependence on the geographical space (Moran's I=0.13, P<0.00), which can be explained by the fact that forests are concentrated in patches across the study area. A random spatial pattern was found for the indicators of both recreation for hikers (Moran's I=0.06, P<0.10) and land-based animal husbandry (Moran's I=0.01, P<0.10).

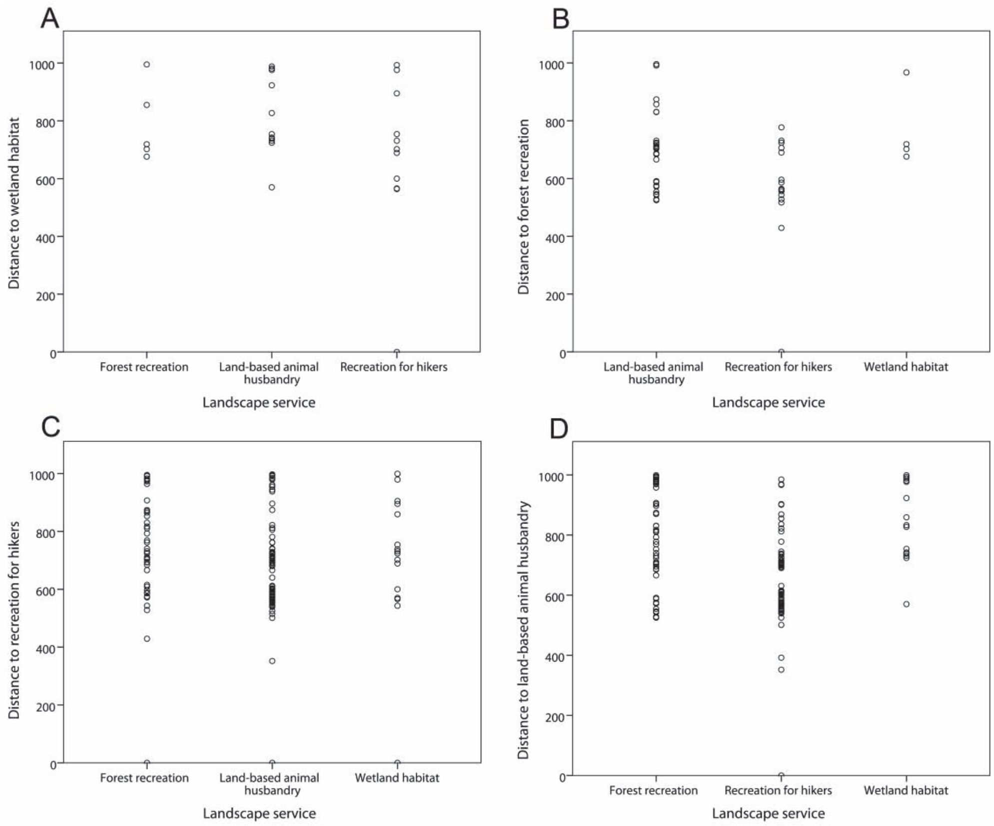

Fig. 2.4 Error bars of the mean distances of landscape services to: A) Wetland habitat; B) Forest recreation; C) Recreation for hikers; D) Land-based animal husbandry.

2.4 Discussion

In this paper we set out to develop an approach to identify and map landscape services. We have created four landscape service maps. The obtained indicators are site-specific, however, they indicate that linkages between landscape services and physical properties of the environment exist. Hence, our approach can be applied in other regions. However, relations between landscape services and spatial indicators are likely to differ by region depending on the environmental and socio-economic context. In the following sections we discuss the strength and weaknesses of the methods and results of this study.

2.4.1 Overall methodology

This study shows that a wide variety of data sources are needed to identify and map landscape services, as indicated by Willemen et al. (2008). The necessity for these various data sources can be ascribed to the vast variety of landscape services. As a consequence, a standardised approach to identify and map landscape services is not feasible, and perhaps even wrong. The methodology presented here takes this variety into account, and thus provides a robust framework and a flexible way of assessing landscape services.

In general, the potential of the landscape to provide landscape services was mapped (*e.g.* Gimona and van der Horst 2007, Egoh et al. 2008, Willemen et al. 2008, Kienast et al. 2009, van Berkel and Verburg 2011). The potential landscape services are often based on proxies (*e.g.* Egoh et al. 2008, Willemen et al. 2008), on generalised relations with land cover and use (Burkhard et al. 2011), or on expert knowledge (Kienast et al. 2009, Haines-Young et al. 2012). Some of these studies are based on general assumptions and not on site-specific quantified relations, which is a drawback of these approaches (de Groot et al. 2010). A valuable feature of our methodology is that the indicators of the landscape services are based on site-specific relations. These are necessary to map the actual landscape service. The actual service requires specific information of the area that is often not available. In this study we used ground observations to obtain information on the actual distribution of landscape services and based our maps on site-specific correlations accordingly. However, for forest recreation and recreation for hikers, it would have been ideal to include the number of visitors, which gives the most accurate depiction of the actual service. Unfortunately, it is very time consuming to acquire such specific information. As an alternative, proxies such as the location of frequently used hiking trails were used as indicators and checked with experts of the area (*e.g.* land owners), which provided a valuable substitute for counting visitors.

2.4.2 Analysing spatial scales

Our study has shown that the spatial scale of indicators of landscape services differ, which is also recognised by other researchers (de Groot and Hein 2007, Pérez-Soba et al. 2008). We have found that 19% of the correlations between landscape services and spatial characteristics are different for the 50 and 100-metre radius. This indicates that differences are found even at a relatively small spatial scale. The largest scale of 100 metre radius in this study is presumably not adequate for the recreation for hikers, considering the landscape -as far as the eye can see- has an influence on this service, which can easily range beyond 100 metres. Therefore, in case of recreation for hikers, a larger scale would be advisable. In addition, distances between landscape services are different at various scales. Correlations between landscape services at the same location can differ from the assessment within a 1 km radius. However, various studies of landscape services do not consider different spatial scales. Bearing in mind that the spatial scale is important for landscape services and the fact that the effective spatial scales of most landscape services are still uncertain, it is essential that future studies include spatial scale differences.

2.4.3 Strength of correlations and validation

The efficiency of mapping landscape services can be improved by recognising indicators for landscape services. Several spatial indicators for landscape services have been found, although most have weak correlations (Table 2.3), as corroborated by in other studies (*e.g.* Chan et al. 2006, Egoh et al. 2008). The results of the logistic regression show that combining spatial characteristics improves the strength of correlations (Table 2.4). Presumably, the surroundings of the studied landscape services have so much variability that they cannot be explained by individual spatial characteristics. For instance, hiking routes pass through as many attractive landscapes as possible, but, it is impossible to avoid all less attractive sites. The indicators found for forest recreation proved to be adequately reliable (Table 2.4). The indicators for land-based animal husbandry and recreation for hikers explain the landscape services reasonably well. However, the validation of the created landscape service maps, which are based on the indicators, show that only forest recreation is highly accurate. The landscape service map recreation for hikers and land-based animal husbandry have an accuracy of only 60%, which can be partly explained by the high variability of their location, as stated above. In addition, recreation for hikers is established using hiking routes that are assumed to be used by hikers, however we did not consider the use of these routes to make the demand more explicit. By including the demand of the hiking routes, indicators for recreation for hikers are likely to become more accurate, and are therefore recommended. We have carefully selected the hiking routes that are currently promoted by the tourist information centre and most frequently sold, therewith assuming a frequent use of these routes. For land-based animal husbandry it is difficult to determine correlated spatial characteristics, considering agricultural landscape services have numerous similar spatial characteristics. Distinction between agricultural landscape services is therefore difficult. Yet, several distinct indicators for land-based animal husbandry are found, but these alone are not enough to make a highly accurate map. Additional data (*e.g.* the environmental permit database that includes the type and size of agricultural activities) could be used to increase the accuracy. Unfortunately, we were not allowed to duplicate spatial data from this database due to privacy issues. Inaccessibility and the lack of data is a critical constraint in landscape service research (Verburg et al. 2009). Collaboration with governing bodies and other institutions with landscape service interest will improve the availability of data, either by gaining access to existing databases or by involving them in the collection of the necessary data. Additionally, data sources are harboured at different organisations and within different databases, which makes the collection of data extremely arduous. Collaboration with all organisations that might have useful information for the analysis of the landscape services of interest is essential and needs to be further developed in order to improve the accuracy of landscape service maps.

2.4.4 Applicability of landscape service maps

Opposing to the definition as we presented it, a landscape service is more often defined as ‘the capacity of the landscape to provide goods and services that satisfy human needs, directly or indirectly’ (MA 2005, de Groot 2006, Hein et al. 2006, Syrbe et al. 2007, Willemen et al. 2008, Kienast et al. 2009, Verburg et al. 2009, Posthumus et al. 2010). In this paper, we did not consider landscape capacity, but instead looked at the actual presence of a service. By regarding the capacity to provide landscape services, a more in-depth representation of the potential benefits can be obtained, as the actual supply of landscape services can rapidly change due to, for instance, change in human demand or depletion of supply (de Groot and Hein 2007). However, measuring or even defining the capacity for a landscape services has proven to be difficult, which is also recognised by de Groot and Hein (2007). The assessment of the capacity is complicated further through human technology that can increase our capability to adjust the landscape to our desires. The assessment of the actual presence of a landscape service, *i.e.* the landscape provides the related goods and services, has proven to be difficult due to insufficient data, which is also discussed above. However, the proposed methodology can be used to show different gradations of suitability (Willemen et al. 2010). For instance, when all indicators are present, the location is highly suitable, but when only half of the indicators are present the location is moderately suitable. These suitability maps can be of great value for policy makers and spatial planners.

2.5 Conclusions

To analyse and map various landscape services different data sources and approaches are required, therefore, standardisation is not possible. Instead, this study provided and tested a robust framework and a flexible approach to analyse and map landscape services. The results show that the effective spatial scales and patterns of landscape services differ, which is important for assessing indicators to map these services and for analysing the multifunctionality of a landscape. The landscape service maps provide policy makers and spatial planners insight on actual landscape services, which they can support them in their decision making.

CHAPTER 3

Groundwater nitrate variability in a Dutch rural multifunctional landscape

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In preparation for publication

Abstract

Nitrate is one of the most important contaminants of groundwater and may be regarded as a prime indicator of groundwater quality in agricultural land. At the landscape level, nitrate emissions occur along with the provision of various of landscape services including: I) food production, II) habitat provision, III) residence provision, and IV) other services (*i.e.* hobby farming, field sports, and campsite tourism). While most monitoring of groundwater is done along with food production, less attention is paid to emissions along with other landscape services. In this study, nitrate concentration in the upper groundwater was estimated in a multifunctional landscape on the southern cover sands in the Netherlands. We analysed nitrate concentrations in the upper groundwater for landscape services in all four categories using a combination of field sampling, existing monitoring schemes, and literature. The results showed that the region exceeded the target of the EU Nitrate Directive, which aims to reduce concentrations below 50 mg NO_3^- l^{-1} in the groundwater. Food production was the main source of nitrate leaching, although high nitrate concentrations were also found for the other landscape services, particularly for campsite tourism. Nonetheless, on average the other services did not exceed the EU target. The variation between landscape services, but also within landscape services, and even within fields was large. The spatial variability can have important implications for policy implementation of the target values. In the case of drinking water supply aggregated values are most relevant, while for habitat provision in surface water the local values may be most important.

3.1 Introduction

Rural landscapes wide deliver a range of landscape services. In these multifunctional landscapes, most attention goes to those services that are highly correlated to land cover (*e.g.* food production). Less visible, but of similar importance, is the provision of other landscape services like groundwater quality. The analysis of multifunctional landscapes is complex as a result of interactions between landscape services. Groundwater quality, for example, is influenced by the intensity of fertilisation for food production, while the groundwater quality influences the provision of aquatic habitat. In addition, different services have different spatial dimensions. The provision of drinking water is a service provided at the landscape level, whereas the presence of cultural heritage provides mostly a cultural service at a particular point. This study analyses the interaction between groundwater quality and various landscape services, with a special attention to the spatial dimensions of these interactions.

One of the most important contaminants of groundwater is nitrate (Nitrates Directive, EC 1991). Therefore, the nitrate concentration may be regarded as a prime indicator of groundwater quality (*e.g.* Addiscott 2005; Sonneveld et al. 2012). The implementation of various environmental policies at European and national level has resulted in substantial improvement in groundwater quality all over Europe since the implementation of the Nitrates Directive in 1991. The Nitrate Directive aims to reduce concentrations below 50 mg NO_3^- l^{-1} in the groundwater. The implementation of the European Nitrate Directive is left to the member states. Despite the implementation of the Nitrates directive many regions appear to lack improvement, especially in the last few years (*e.g.* Lindinger and Scheidleder 2004; EC 2010).

In the Netherlands, the European Nitrate Directive is translated into the 'Dutch agricultural mineral policy', which has led to a strong improvement of the groundwater quality (from 140 to 75 mg NO_3^- l^{-1}) between 1992 and 2007 (Zwart et al. 2008). Despite the improvement, the EU limit value of 50 mg NO_3^- l^{-1} is still exceeded at 50% of the monitoring sites in the Netherlands, especially in the sandy regions in the southern part of the country (Willems et al. 2012). In recent years, it has become evident that the concern about nitrate concentrations in groundwater remains and further improvement is imperative.

Nitrate concentrations in groundwater are well studied in agriculturally dominated areas. Agricultural practices, such as the use of nitrogenous fertilisers and manures, are a major source of nitrate to groundwater (Howden et al. 2011; Menció et al. 2011), even though fertiliser usage is not always directly correlated with groundwater nitrate concentrations (McLay et al. 2001). Monitoring approaches of agricultural land are often used to study changes in nitrate concentrations (*e.g.* Chang 2008; de Goffau et al. 2012; Scheidleder et al. 1999), which are often long-term processes (*e.g.* Broers and van der Grift 2004; Honisch et al. 2002; Tomer and Burkart 2003). Various studies have assessed the status of individual contaminants at the landscape scale. However, few studies have attempted an integrated assessment of groundwater quality with respect to nitrate at the landscape scale (Sonneveld et al. 2012). It is increasingly recognised that the landscape scale is highly relevant for addressing environmental concerns in agricultural areas (Viaud et al. 2010). While locally high nitrate levels can be found, this might be balanced out at the landscape scale, considering the inclusion of also non-agricultural landscape services where low levels of nitrate are expected.

The impact of non-agricultural land use and landscape services on groundwater quality is less studied. Some studies found low groundwater nitrate concentrations in nature areas (Masselink and de Goffau 2010; Rothe and Mellert 2004; van den Brink et al. 2008; van Elzakker et al. 2009), although in 5-30% of these areas the limit of the EU Nitrate Directive was exceeded (Boumans et al. 2008; Masselink and de Goffau 2010; van Elzakker et al. 2009). Possible explanations for the high nitrate concentration levels are soil type, *e.g.* high nitrate concentrations for sandy soils, low for peat and clay, vegetation type, *e.g.* higher nitrate concentrations are found under pine trees, and edge effect, *e.g.* nitrate concentrations decrease with size of nature areas (Boumans 1994). High nitrate concentrations are also found in urban areas, mainly caused by landfill leachate and sewage leakage (van den Brink et al. 2008; Wakida and Lerner 2005). Relations between groundwater nitrate concentrations and other land uses, such as field sport and hobby farming (farms where the primary income is obtained from non-agricultural practices) are unknown, though they might apply fertilisers to improve the field conditions. Legislation for these non-agricultural activities is often unclear, not known, and sometimes lacking. This strongly implies that for the analysis of groundwater quality not only agricultural land should be taken into account, but the whole landscape including non-agricultural services.

We have recognised four categories of landscape services: I) commercial food production; II) habitat provision; III) residence provision; and IV) other landscape services (*i.e.* hobby farming, field sports, and campsite tourism). The aim of this study was to analyse the spatial variability of nitrate in the upper groundwater at the landscape level including multiple landscape services. We applied this study in rural area that is part of the southern sandy region of The Netherlands, where nitrate concentration is a great concern. Therefore, we analysed nitrate concentrations in the upper groundwater in relation to the various categories of landscape services using field observations, existing Dutch monitoring programmes and literature. We specifically analysed the interactions between the four categories of landscape services and groundwater quality and discussed the spatial dimension of services like the provision of groundwater and surface water quality.

3.2 Materials and methods

3.2.1 Study area

The study area is part of the Peel region in the province of Noord-Brabant in The Netherlands, comprising the municipalities of Deurne and Asten (51.4◦ N, 5.8◦ E; Fig. 3.1). The landscape is strongly influenced by the Peel boundary fault (Houtgast and van Balen, 2000), which is oriented northwest to southeast. The area is a relatively flat with altitudes ranging from 18 to 33 m above mean sea level. Groundwater tables are shallow, usually within 1-5 m below the surface. The area comprises a natural network of brooks, which provided drained areas where humans settled and applied agricultural activities since the 19th century. The wet peaty areas were artificially drained during the 20th century to allow for agricultural use, resulting in a dense network of ditches, drains and small watercourses (Visser et al. 2007). The Peel region belongs to the southern sandy region. Within the study area two main soil types developed in the weak structured loamy fine cover sand. Following the IUSS Working Group WRB (2006) the soils are classified as Cumulic Anthrosol (Dutch map unit zEz21) and Cambic Podzol (Dutch map unit Hn21). The Netherlands has a moderate maritime climate, with an average annual temperature of 14.4 degrees and an average precipitation of 774 mm per year (KNMI, 2011).

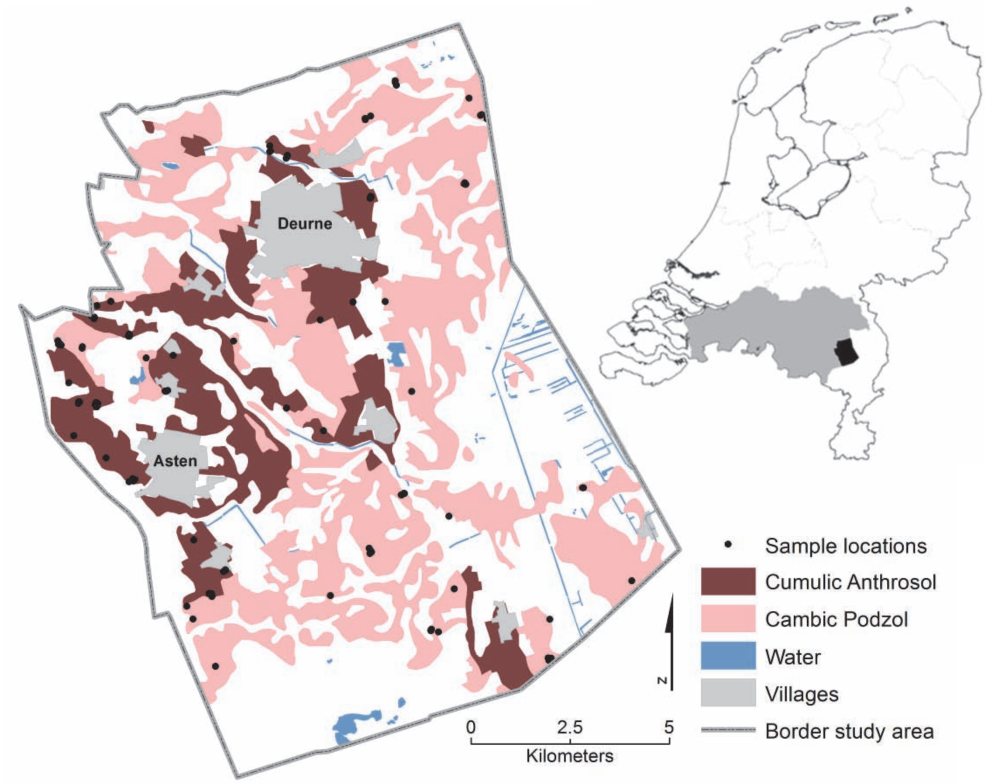

Fig. 3.1 Overview of study area comprising municipalities Deurne and Asten. At the top on the right, the location of Province Noord-Brabant (grey) and the study area (black) in the Netherlands is shown.

Land cover is highly variable in the area (Fig. 3.2). Land cover is dominated by grassland (38%), maize (16%), and other crops (11 %). Grassland can have a range of different uses, including agricultural, nature, recreation, and sport. Approximately 15 to 30% of all agricultural land belongs to non-commercial farms, *i.e.* hobby farms that are maintained without being the primary source of income (CBS et al., 2012). Nature covers about 22% of the area and urban areas about 12%. The area accommodates around 28 campsites and 22 field sport locations.

The Netherlands adopted the Dutch manure policy, which was refined in 2006 (LNV 2006). For different soils and crops, it consists of application standards for N in organic manure and total N application standards (including fertiliser). The application standard

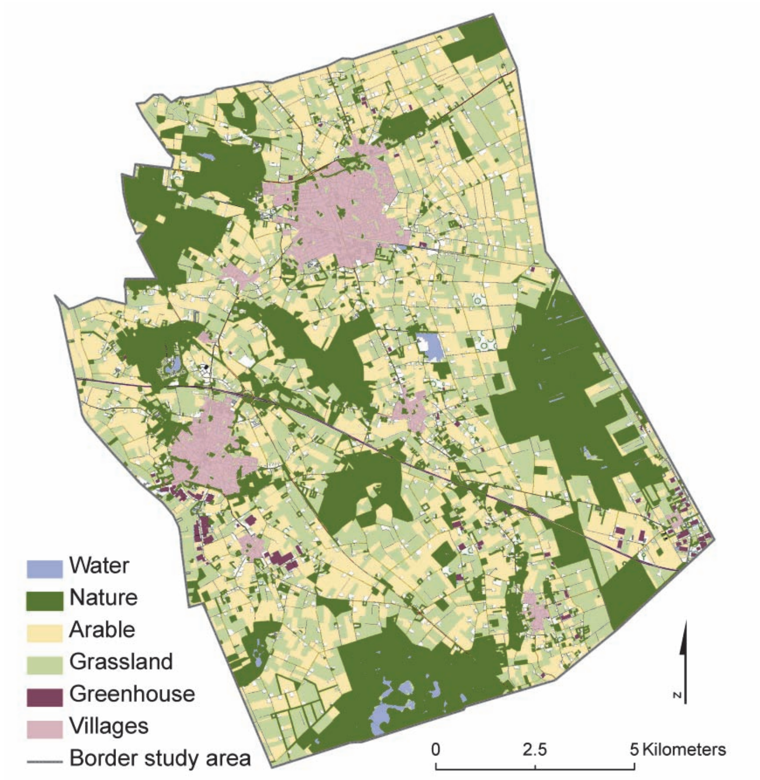

Fig. 3.2 Main land covers of the study area.

for grassland is 170 kg N/ha from organic manure, but farms that fulfil the criteria for derogation may apply up to 250 kg N/ha from organic manure (Schröder and Neeteson 2008). The Dutch agricultural mineral policy does not apply to sport fields, hobby farming, allotment and leisure gardening. There are policies for all four, but these are largely unknown to land users (Smit et al. 2008) and government enforcement is almost absent. For sport fields, an organisation for sports accommodation management (BSNC) provides recommendations for fertilisation usage, taking the EU limit value of 50 mg NO_3^- l^{-1} into account. The recommended rates vary between 95 and 225 kg N ha^{-1}, depending on usage intensity and mowing frequency (Bussink and van de Draai 2008). Only golf courses need to register their manure applications.

3.2.2 Identification of landscape services

Recently, a study has identified the distribution of landscape services in the study area (details are described in Gulickx et al., 2013). This study evaluated landscape services at

Table 3.1 Landscape services, their description, how they are identified and which data sources are used (based on Gulickx et al., 2013).

Landscape service	Description	Identified by	Data source
Commercial food production			
Crop production	The production of beetroot, fodder beet, sugar beet, or cichorium.	Land cover beetroot, fodder beet, sugar beet, or cichorium, and arable farm	Field observations and environmental permit database
Land-based animal husbandry	The production of food and goods (*e.g.* milk) by farms that depend on the land quality (*i.e.* they use their land for fodder production).	Permit for land-based animal husbandry	Field observations and environmental permit database
Non-land-based animal husbandry	The production of food and goods (*e.g.* meat) by farms that do not depend on the land quality (*i.e.* they buy their fodder from another region).	Permit for non-land-based animal husbandry	Field observations and environmental permit database
Other services			
Hobby farming	Recreational farming at a farm that is maintained without being a primary source of income.	3-20 dsu*, non-agricultural prime income	Field observations, interview
Field sports	Grasslands that are used for sports, such as football and field hockey.	Land use field sports	Land use map, field observations
Campsite tourism	Privately owned campgrounds, usually divided into a number of pitches, where people can camp overnight using tents, camper vans, or caravans.	Land use campsite	Topography map, field observations

** A farm with 3-20 Dutch size units (dsu) is considered a hobby farm (Statistics Netherlands (CBS); Valbuena et al. 2008). Dsu represent the economic size of a farm including the amount and use of the land; in 2010, a dsu was equal to 1420 euro.*

The study area can be subdivided into food production (60%), habitat provision (22%), residence provision (12%), and other services (6%). Food production can be further subdivided into land-based animal husbandry (32%), non-land-based animal husbandry (20%) and crop production (8%). Agricultural grassland is mainly used for fodder production in land-based animal husbandry. Maize was mainly provided by non-land-based animal husbandry. Crop production included the crops beetroot, fodder beet, sugar beet, and cichorium. The landscape services campsite tourism (5% of the area), hobby farming (1% of the area), and sport fields (1% of the area) occurred with land cover grassland.

3.2.3 The assessment of groundwater nitrate concentrations

Nitrate concentrations in the upper groundwater were estimated by sampling, data from the Dutch monitoring network, and literature.

Field sampling focused on commercial food production (Category I) and other landscape services (Category IV). Although Category I is also included in the Dutch National Monitoring Programme for Effectiveness of the Minerals Policy (LMM), no site-specific data for the study area were available for this study, due to privacy policy of the RIVM. We therefore decided to specifically sample the area and use the LMM database for comparison. For category IV there were simply no data available. Yet, these other services provide an interesting comparison to the food production services, whereas both include grassland with different management. Sport fields may apply fertiliser nitrogen to their fields, but are ignored in many studies of groundwater quality. Campsites are expected to receive little to no fertiliser nitrogen. For hobby farming it is expected that fertiliser is applied, but rates are highly variable.

Groundwater nitrate concentrations for nature areas (Category II) were derived from the Dutch Acidification Monitoring Network (TMV). Given the limited variation in the cover sands under natural conditions, it was assumed that the results for a larger region were comparable to the study area. TMV was initiated by the RIVM in 1989 to monitor and analyse changes of the groundwater quality in nature areas of sandy soils (forest and heathland). Data from October 2006, January and December 2007, and March 2008 were used for the analysis. We selected 33 locations from the cover sand area, similar to the area of this study. Per location a transect of 10 samples was taken at least 20 metre from the border of the area and 5 metre from each other. Samples were taken from the top 1 meter of the groundwater using a hand auger. The nitrate concentration was tested both in the field and by the laboratory of RIVM. In total, 323 samples were included in the comparison. A full description of the TMV methodology can be found in the report of (Masselink and de Goffau, 2010).

The urban areas (Category III) are very difficult to sample and relatively low concentrations are expected. Therefore literature data was used.

Table 3.2 The sample scheme per landscape service, including the total number of samples, total number of locations where samples are taken, average number of samples per location, and additional information about the sample scheme.

Landscape service	**Total samples**	**Total locations**	**Avg. samples per location**	**Additional information**
Crop production	14	5	2.8	39 locations crop production was identified, from which five were selected to sample groundwater.
Land-based animal husbandry	16	11	1.5	157 locations that provide land-based animal husbandry were identified, of which ten were randomly selected to sample groundwater.
Non-land-based animal husbandry	32	18	1.8	99 locations that provide non-land-based animal husbandry were identified, of which 18 were randomly selected to sample groundwater.
Total food production	*34*	*13*		
Hobby farming	4	1	4	Four hobby farms were identified. However, only one of the four land owners gave permission to take groundwater samples.
Field sports	10	3	3.3	Field sports were identified at three locations, at all three locations groundwater quality was sampled.
Campsite tourism	20	9	2.2	18 campsites were identified, from which nine are randomly selected to sample groundwater.
Total other services	*62*	*34*		
OVERALL TOTAL	96	47		

3.2.4 Sampling

A random sample of 47 locations (Fig. 3.1) with landscape services from categories I and IV on the two main soil types were selected. Within field variability is expected to be high (See *e.g.* Addiscott 2004, Bouma et al. 2002, Ersahin 2001), therefore, multiple samples were taken from almost 50% of the fields yielding a total of 96 samples (Table 3.2). At least one sample is taken in the centre of the field, in order to diminish influence of surrounding fields that might have another landscape service. At sports fields, it was not allowed to drill a hole in the centre of the field, therefore, the samples were taken in between the sports fields. The locations of multiple samples within one field were taken unevenly, ensuring unequal distances between the sample locations and at least 15 meters from field boundaries.

The upper groundwater was sampled by means of temporary hand-drilled holes up to groundwater at a maximum of three metres depth using a hand auger. After the hole was drilled several minutes were given to let groundwater from the surrounding soil flow towards the bore hole to refill it. With a small cup the groundwater was elevated and subsequently preserved in a clean sampling container. Fertiliser applications after September are not permitted in the Netherlands. The samples were taken from October 6 - November 8 in 2010. Because weather conditions can have a major influence on nitrate leaching and nitrate concentrations (Fraters et al., 1998; Kolpin et al., 1999), the period for collecting samples was kept as short as possible. During the sampling period the average temperature was 12.7°C and the average precipitation was 1.6 mm per day. We do not expect that the weather conditions had a significant influence on the nitrate concentration of the samples, considering the precipitation was relatively evenly spread out over 20 days of the 34 in total. Additionally, considering that samples for one landscape service are made throughout the sampling period, it is assumed that this cannot have led to extra differences between landscape services.

3.2.5 Nitrate analysis

Two methods were used for the analysis of the nitrate concentration. Most samples were analysed spectrophotometrically at the Chemical Biological Soil Laboratory of Wageningen University (68 samples). The samples were persevered at 4°C in the refrigerator and analysed within 36 hours. The nitrate concentration of 49 samples was analysed in the field using the Nitrachek-Reflectometer type 404® (referred to as Nitrachek). Per sample the average was taken from at least three measurements that did not differ more than 10% from each other. The accuracy of the Nitrachek was validated by comparing 21 samples that were analysed by both the Nitrachek and spectrophotometrically.

The accuracy of the Nitrachek was verified by comparing the nitrate concentrations of 21 samples obtained by the laboratory with those obtained by the Nitrachek (Fig. 3.3). The comparison showed a very strong correlation between the two dataset (*P*=0.00, R^2=0.97) indicating that the two methods are interchangeable.

3.2.6 Comparison with LMM data

The Dutch National Monitoring Programme for Effectiveness of the Minerals Policy (LMM) was initiated to allow detection of a statutory reduction in nitrate leaching caused by a decreasing N-load (Boumans et al., 2005). The LMM is developed and maintained by The National Institute for Public Health and the Environment (RIVM) and the Agricultural Economics Institute (LEI, Wageningen University & Research Centre). Farms were the basic units for monitoring, which were selected via stratified random sampling. The principal parameters for stratification were farming type, size of farm and geographical position, expressed as the region of a farm. We selected farms occurring in the cover sand area, similar to the area of this study. The LMM included four farming types: dairy, industrial livestock, arable, and other farm types. We included arable farms which produced the same crop types that were present in the dataset of this study and excluded other farm types from the comparison. Dairy and industrial livestock farms are similar to land-based (*P*>0.17; *Z*=-1.38), both periods were included for the analysis. Groundwater was sampled

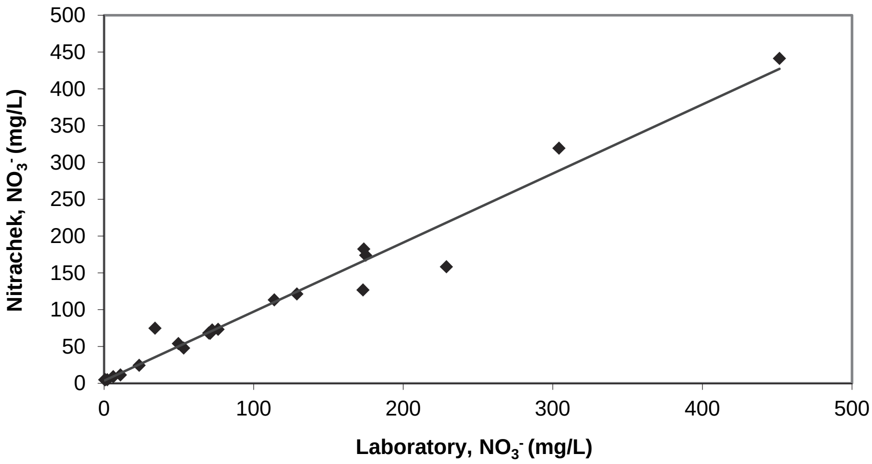

Fig. 3.3 Correlation between nitrate concentrations of samples (N=21) measured with the nitrachek Reflectometer 404® and by the Chemical Biological Laboratory (*P*=0.00, R^2=0.97).

at 16 locations per farm. Samples were taken from the top 1 meter of the groundwater. The groundwater samples were tested both in the field and by the laboratory of RIVM. A full description of the LMM methodology can be found in the report of de Goffau et al. (2012). In total, we used 2161 samples from the LMM dataset.

3.2.7 Statistical analysis

To assess the aggregated results, nitrate concentrations were first averaged over the various fields and locations. Subsequently an area-weighted average and a pooled standard deviation were derived for the various categories of landscape services. Finally an area weighted average was calculated for the entire multifunctional rural landscape. Several factors might have an impact on the nitrate concentration, such as soil type, groundwater level, land cover, and land use (Kolpin et al., 1999; McLay et al., 2001; Menció et al., 2011; Wesström et al., 2001). Therefore, the statistical relationship between these factors and the mean nitrate concentration was calculated (Spearman's *r*). Differences between groundwater nitrate concentrations of the commercial agricultural services, provision of habitat, and other landscape services were calculated (Mann-Whitney *U* test). The nitrate concentration of the commercial agricultural services sampled in this study were compared with the data from the LMM (Mann-Whitney *U* test) in order to test if the samples of this study were comparable to the more extended monitoring programme.

3.3 Results and discussion

3.3.1 Nitrate concentration in groundwater under different landscape services

Table 3.3 summarizes the differences in groundwater nitrate concentrations between the various categories of landscape services. The average nitrate concentrations in food production were more than double the EU threshold of 50 mg l^{-1}. The high concentrations under commercial agriculture were related to all landscape services in that category, but particularly by non-land-based animal husbandry and crop production. The average nitrate concentration of all other landscape services was below the threshold value but still rather high given the low fertiliser rates. Few data were available for urban areas. Van Drecht et al. (1996) present values of nitrate concentrations in the upper groundwater for the urban areas in the Dutch cover sand area based on extensive monitoring in 1992. The 95% confidence interval ranged between 1 and 5 mg l^{-1} nitrate in the upper groundwater indicating that nitrate concentrations are relatively low under the urban areas in the sand areas.

For a proper interpretation of the results, it is good to keep in mind that there is a large nitrogen deposition in the areas with intensive animal husbandry in the Netherlands. In a recent study Buisman (2010) measured close to the study area a total yearly N input of 14.7 kg N ha^{-1} in rainfall. This nitrogen input may explain some of higher nitrate contents in the unfertilised areas. In addition, there may be some residual nitrogen available. This can be illustrated with the data from the campsites. All campsites were established on former agricultural land. The campsites were between 5 and 42 years old and the age was negatively correlated to the nitrate concentration in the groundwater (P<0.05, R^2=0.20). Considering they all did not apply N-fertiliser to their fields, it might be that the former agricultural activities still have an impact on the groundwater quality. Changes in agricultural practices may take several decades to fully result in improvements of the groundwater quality (Tomer and Burkart, 2003).

For the study area, the nitrate concentrations in the upper groundwater were on average around 77 mg l^{-1}. As a result the region as a whole also seems to surpass the EU threshold for nitrate concentrations in the upper groundwater.

3.3.2 Spatial variability

Monitoring schemes for groundwater nitrate concentrations are hampered by large spatial and temporal variation. The current study focused on the spatial variation. High

Table 3.3 Nitrate concentrations in the upper groundwater for various landscape services.

Landscape service category	**Landscape service**	**Nitrate concentration (mg l^{-1})**		**Number of locations**
		Avg.	*s.d.*	
I: Commercial food production[1]		**112**	**98**	**34**
	Land-based animal husbandry	86	93	11
	Non land-based animal husbandry	140	110	18
	Crop production	137	90	5
II: Habitat provision[2]		**25**	**38**	**323**
	Forest	30	51	268
	Heath/grassland	11	7	55
III: Residence[3]		**3**	-	-
IV: Other services[1]		**37**	**35**	**13**
	Hobby farming	48	-	1
	Field sports	32	33	3
	Camping tourism	50	50	9

[1] *Average per field based on field sampling*
[2] *Average per site based on the Dutch Acidification Monitoring Network*
[3] *Average per location based on Van Drecht et al. (1996)*

spatial variation of nitrate concentration in groundwater has also been recognised by other studies (Baily et al., 2011; Rouxel et al., 2011). Many factors can account for the variation, including land use, nitrate application, weather conditions, soil type, and geohydrological characteristics of the aquifer (Zwart et al., 2008). Table 3.3 shows that under all landscape services the landscape variability was very high with coefficient of variation of around 100%. An analysis of variation shows that 55% of the variation in food production, 48% of the variation in habitat provision, and 13% of the variation in other landscape services occurred within the fields or sites. The large variation within fields has major repercussions for monitoring groundwater nitrate concentrations.

3.3.3 Comparison with LMM

The nitrate concentrations of the LMM dataset are shown in Table 3.4. The nitrate concentrations in this study and the LMM database were comparable (land-based animal husbandry: $P>0.97$, $Z=-0.03$; non-land-based animal husbandry: $P>0.25$, Z=-1.15; crop production: $P>0.34$, $Z=-0.95$; Fig. 3.4). In both datasets nitrate concentration did not differ for each land cover type (maize: $P>0.08$; $Z=-0.10$; grassland: $P>0.48$; $Z=-0.71$; agricultural grassland: $P>0.83$; $Z=-0.22$; other crops: $P>0.97$; Z=-0.03). Considering that the dataset of this study is similar with the more extensive LMM dataset, we can conclude that the data of our study is representative subset.

Table 3.4 Nitrate concentration for the dataset of this study (*2010*), the National Monitoring Programme for Effectiveness of the Minerals Policy (*LMM, 2009-2011*), and the Acidification Monitoring Network (*TMV, 2006-2008*), showing the average mg NO_3^- l^{-1} (*avg.*), total number of samples (*N*), and standard deviation (*s.d.*). Nitrate concentrations exceeding the EC Nitrate Directive limit are shown in bold.

Landscape service	***Land cover***	***This study***			***LMM***		
		avg.	*s.d.*	*N*	*avg.*	*s.d.*	*N*
Land-based animal husbandry	All	**74.5**	93.9	16	**71.9**	88.1	1265
	Grassland	**79.1**	95.3	15	**57.0**	78.5	860
	Maize	4.4	0	1	**105.8**	97.5	311
	Other crops	-	-	-	**96.0**	102.3	93
Non-land-based animal husbandry	All	**179.6**	162.1	32	**155.5**	160.5	536
	Grassland	**88.5**	0	1	**110.1**	165.3	84
	Maize	**182.6**	163.9	31	**146.0**	154.7	258
	Other crops	-	-	-	**187.9**	160.5	194
Crop production	All	**147.2**	162.9	14	**100.7**	99.7	360
	Grassland	-	-	-	**70.1**	49.3	6
	Maize	-	-	-	**52.5**	61.1	94
	Other crops	**147.2**	162.9	14	**119.0**	106.0	260

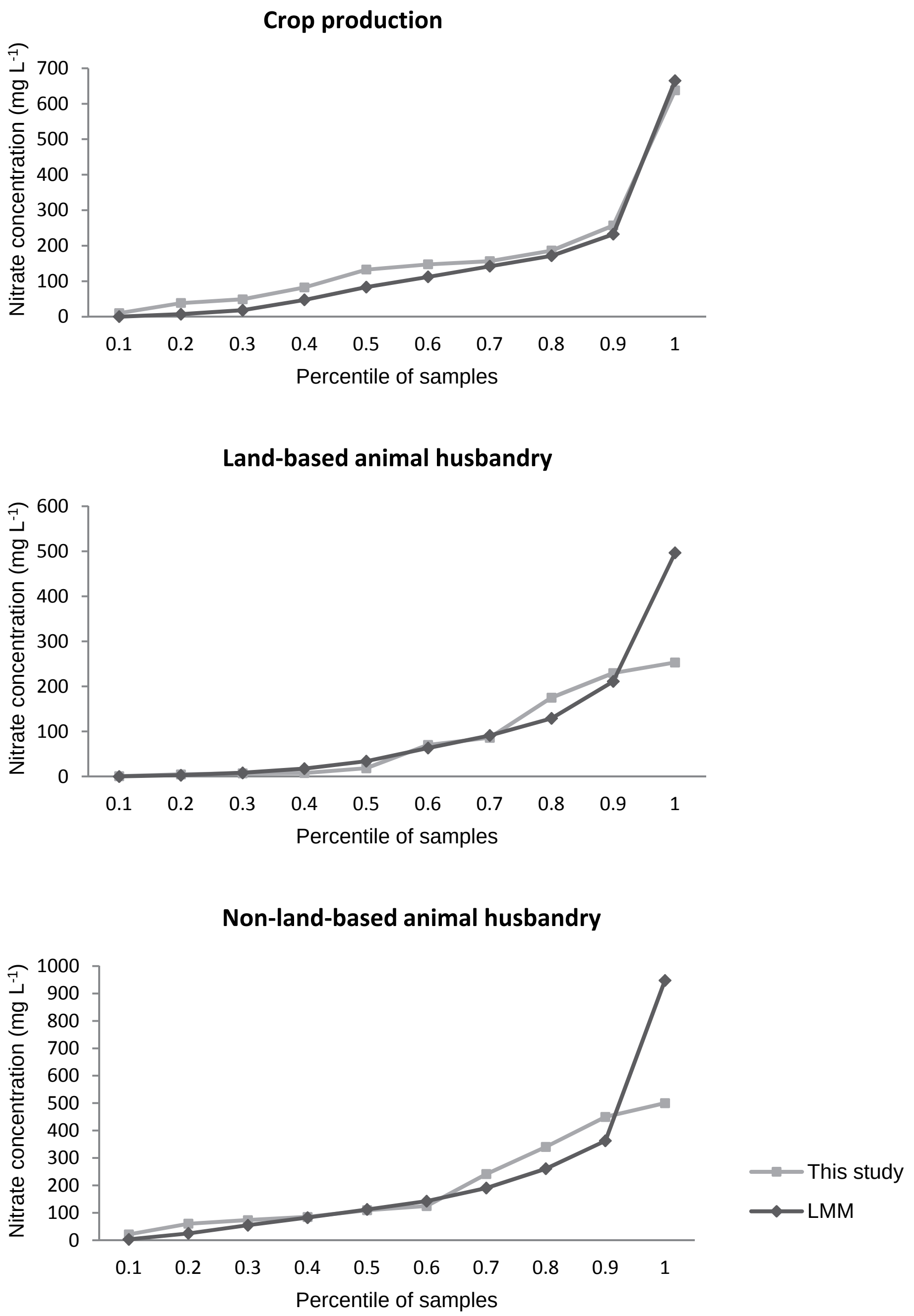

Fig. 3.4 Comparison of nitrate concentration sampled in this study and sampled for the Minerals Policy Monitoring Programme (LMM) of the southern sandy region of The Netherlands.

3.3.4 Correlations with landscape characteristics and comparison between landscape services

Several correlations between nitrate concentration in groundwater and landscape characteristics were found (Table 3.5). The average nitrate concentration in groundwater for Cumulic Anthrosols was lower than for Cambic Podzol. No significant correlations in nitrate concentration were found between soil type and either land cover or landscape service. Nitrate correlation is correlated with groundwater level, however, no significant linear correlation was found (P>0.21; R^2=-0.02). Land cover grassland, for both food production and other services, had a lower nitrate concentration than maize and cropland. Nitrate concentration did not differ between maize and cropland. We also found that with an increase of ditch length within a radius of 500 metre, nitrate concentration in groundwater also increased. No significant correlation was found with plot size in a radius of 500 metre. With the data of this study we cannot explain the correlation between ditch

Table 3.5 Correlations (Spearman's *r*) between landscape characteristics and nitrate concentration of all landscape services (N=96), agricultural services (N=62), and non-agricultural services (N=34).

Landscape characteristic	NO_3^-	Agricultural services	Non-agricultural services
Point data			
Soil type	**-0.20***	-0.17	-0.10
Height	0.13	-0.04	-0.05
Groundwater level	**0.23***	**0.28***	0.16
Land cover maize	**0.36****	0.23	-
Land cover crops	0.14	0.03	-
Land cover grass (all)	**-0.43****	**-0.28***	-
Land cover agricultural grass	-0.04	**-0.61***	-
Land cover non-agricultural grass	**-0.38****	-	-
Area			
Length of ditches in 100 m radius	0.12	0.04	0.25
Length of ditches in 500 m radius	**0.30****	**0.30***	0.04
Mean plot size in 500 m radius	0.17	0.06	0.35
Mean plot size in 1000 m radius	0.90	0.08	0.22
Nature area size in 1000 m radius	0.11	0.07	0.25
Decreasing distance to			
Nature	0.02	-0.04	0.20
Land cover maize	**-0.39***	-0.22	-0.18
crops	-0.10	0.10	-0.14
agricultural grass	**0.32***	0.18	-0.12
agricultural land (all)	-0.14	0.02	-0.16

*The significance level is indicated in bold with * for p < 0.05, ** for p < 0.01, *** for p < 0.001* length and nitrate concentration and we are not aware of other studies that investigated relations between ditch density and nitrate concentrations in groundwater. All of the correlations that were found are very weak, which indicate that the landscape characteristics cannot be used as reliable indicators for groundwater quality.

The nitrate concentration differed between the landscape services, even within the category commercial food production. Land-based animal husbandry had lower nitrate concentrations than non-land-based animal husbandry (P<0.01, Z=-2.76). Non-land-based animal husbandry and crop production did not differ, nor did land-based animal husbandry with crop production. There was no difference in nitrate concentration between the other landscape services. The commercial food production had higher nitrate concentration than the other services (P=0.00, Z=-3.72), however, land-based animal husbandry did not differ from the other services, nor from habitat provision.

3.4 General discussion

In this study, we have found high concentrations of nitrate in groundwater, not only along with commercial food production, but also along with other services. This indicates that other landscape services than commercial food production need to be considered to better assess and understand the distribution of nitrate concentrations in the upper groundwater. In addition, the differences within different types of commercial food production also indicate that agriculture cannot simply be regarded as the same.

The quality of groundwater has an influence on other landscape services, such as provision of aquatic habitat. Especially in rural areas with increasing tourism, such as our study area, aquatic habitat that provides landscape aesthetics is very important. High nitrate concentrations in upper and shallow groundwater lead to exceedance of the quality standards in receiving surface waters, especially during quick flow periods (Rozemeijer and Broers, 2007). Several studies found that the high levels of nitrates heavily impact the overall health of the water and its inhabitants (*e.g.* Hayashi and Rosenberry, 2002; Khan and Ansari, 2005). Recovery time, on the other hand, is much longer for groundwater (van den Brink, 2008). The response of groundwater quality to new agricultural practices may take decades in some landscapes (Tomer and Burkart, 2003).

The interpretation of the results for the landscape services drinking water provision and aquatic habitat provision, however, is very different. Groundwater is typically extracted at a greater depth where the nitrate concentration is the aggregated result over a larger area and a larger time span. Local fluctuations or short peaks of high concentrations do not matter. In this context the aggregated result of 77 mg NO_3^- l^{-1} is important. There might be a serious threat that nitrate concentration in important aquifers for drinking water will also be contaminated. In this context there is an ongoing discussion whether monitoring and reporting should be below the current upper five meters of groundwater (Fraters et al., 2006). Although they conclude that this does not matter, particularly on the sandy soils. On the other hand, the upper groundwater as measured in this study is often directly linked to surface water through shallow subsurface flow and tile-drains. Local and temporary increases in nitrate concentrations may be a serious threat to the local quality of surface water, and hence, have a negative impact on the aquatic habitat provision.

The nitrate concentration for urban areas is based on data of almost two decades ago. In general, nitrate concentrations are improved since the 1990s. However, considering the nitrate concentration of urban areas was low, it is expected that these concentrations have not changed much and do still correspond to current conditions.

Given the large variation in groundwater nitrate concentrations in space (as shown in this study) and time (*e.g.* Smit et al., 2004) policies aiming at good groundwater quality need to define the proper spatial and temporal scale levels to set the threshold concentrations. General target values at the European level, which do not include the spatial and temporal scales and have general indications on monitoring depth, allow for large differences in interpretation. However, the general targets do allow for specific adaptations relevant to local agro-ecological conditions.

3.5 Conclusions

Nitrate concentrations in the upper groundwater aggregated over a Dutch rural multifunctional landscape were found to exceed the EU threshold level of 50 mg NO_3^- l^{-1}. However, the levels were lower than the values measured for the commercial food production alone, which is often the main landscape service in monitoring schemes. The results showed that the spatial variation in nitrate concentrations was very large (with coefficients of variance around 100%) for all categories of landscape services. This can have important implications for policy implementation that aim to meet the target values set by the EU Nitrate Directive. For drinking water supply, aggregated values are most relevant, while for habitat provision in surface water the local values may be most important.

CHAPTER 4

Mapping landscape services: towards an integration of approaches for spatial planning

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Abstract

Both environmental scientists and planning practitioners identify and quantify landscape services. However, both use their own approaches and have different objectives. We have analysed the differences between two approaches to map landscape services and evaluated the possibility to come to an integrated approach. For two case study areas, seven landscape services (*i.e.* forest habitat, ecological corridor, stream valley habitat, cultural aesthetics, flood water storage, intensive and extensive recreation) were mapped by local planning practitioners, and independently by scientists. Approaches were explained and discussed during three interactive meetings with the goal to map and compare landscape services, and to explore possibilities for integration of the approaches. The main aspects of the differences appeared to be the focus, spatial indicators and process. Overall, the maps showed an average balanced concurrency of 71%, with the highest concurrency for forest habitat (94%), and the lowest concurrency for cultural aesthetics and extensive recreation (45%). Both approaches started with evaluating biophysical aspects of the landscape. However, the academic approach based the location of the landscape services on quantified relations with biophysical aspects, whilst the planning practice approach used the biophysical aspects as base layers and did not directly link them to landscape services. The planning practitioners based their decisions also on social aspects, which influenced the location of the landscape services. Possibilities for an integrated approach are discussed. This study shows that maps of the provision of landscape services are potentially a valuable addition to spatial development plans.

4.1 Introduction

The landscape provides goods and services that are of economic, social or ecological value (de Groot 2006; DeFries et al. 2004). The term 'landscape services' is derived from the ecosystem services concept (Termorshuizen and Opdam 2009). Examples of landscape services are food production, water regulation, and the provision of recreation. Humans change the landscape to optimise the provision of these values and benefits. The landscape services concept incorporates both natural and socioeconomic aspects and by this it enables a consideration of the landscape in terms of the physical basis for sustainable development (Termorshuizen and Opdam 2009). The concept has potential to benefit both scientists in understanding landscape processes and patterns, and planning practitioners to decide upon the spatial arrangement of the landscape. It also creates a common ground for collaboration between the two groups to ultimately achieve sustainable development (Termorshuizen and Opdam 2009).

Within the field of environmental science several methodologies and frameworks to quantify and map the spatial distribution of landscape services are developed (*e.g.* Gulickx et al. 2013; Petz and van Oudenhoven 2012; van Berkel and Verburg 2011; Willemen et al. 2008). These studies show that mapping landscape services is not an unambiguous process and exemplify that many different indicators and proxies can be used. These frameworks and mapping tools have great value for scientific application, but have less direct value for practitioners (Termorshuizen et al. 2007; Weitkamp et al. 2012). Several studies highlight the need of involving stakeholders to improve application opportunities (de Groot et al. 2010; Termorshuizen and Opdam 2009). They can be engaged in exploration and negotiation about the type of benefits to include, and the methods and spatial scale for mapping these benefits (Gimona and van der Horst 2007). However, collaboration between scientists and planning practitioners when defining and assessing services appears to be exceptional (McNie 2007; Termorshuizen and Opdam 2009).

More broadly, multiple participatory approaches have been developed and applied to improve knowledge exchange between science and practice (*e.g.* Baker et al. 2010; Hage et al. 2010). Such approaches have shown to be effective in processes like social learning that improves the skill of practitioners to become acquainted with scientific knowledge and tools, and in improving the skills of scientists to provide requisite knowledge for the practitioners (Opdam 2010). To make this knowledge transfer effective it needs to be credible, salient and legitimate (Cash et al. 2003), but also transparent, area specific, understandable, practical, and incorporate local knowledge (Steingröver et al. 2010). Hence, collaboration between science and practice is not a simple undertaking (Vogel et al. 2007). Yet, collaboration is essential for making scientific methods and tools more comprehensive and more applicable.

In this study, we used a participatory method to analyse the differences between a planning practice and an academic approach to map landscape services, and to evaluate the possibilities for integration of both approaches. The approaches and maps are illustrated for seven landscape services (*i.e.* forest habitat, ecological corridor, stream valley habitat, cultural aesthetics, flood water storage, intensive and extensive recreation) in two case study areas in the province Noord-Brabant, The Netherlands. This study aims to providing novel knowledge about differences and synergies of a planning practice and academic approach to identify the distribution of landscape services.

4.2 Case study area

4.2.1 General

This study focussed on two case study areas, *i.e.* Green Valley and White Hills (Fig. 4.1), both part of the Peel region (approximately 600 km2) in province Noord-Brabant, the Netherlands. The local planning authority developed a spatial plan for each area. These plans were recently finalised at the moment this study started, so their approach was fully established. The spatial plans contain both the current situation and destined change of the landscape. Considering the plans were fully approved, we presumed that the destined

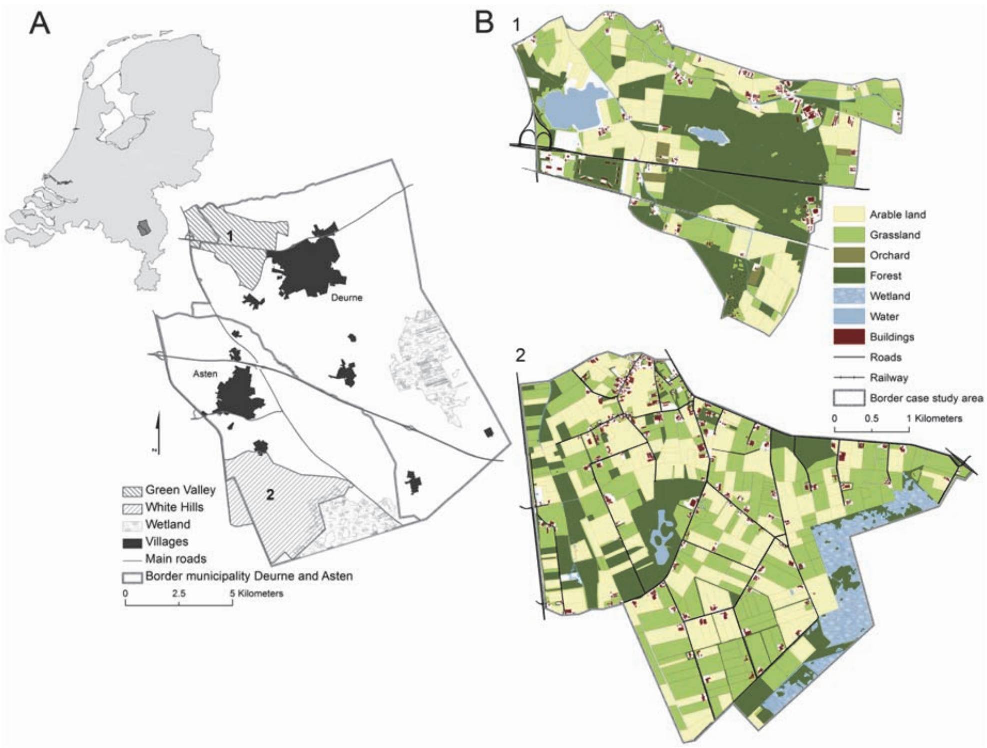


Fig. 4.1 A) Case study areas Green Valley (1) in municipality Deurne and White Hills (2) in municipality Asten. The location of the study area (grey mark) in the Netherlands is shown at the top on the left. **B)** Land cover of case study areas Green Valley (1) and White Hills (2).

change will be accomplished. The landscape is heterogeneous providing a variety of landscape services, which potentially generate synergies and conflicts. The national and regional authority has assigned this region as a 'reconstruction area' with high priority in order to improve the environmental quality of the rural area (Provincie Noord-Brabant 2005).

4.2.2 Green Valley

Case study area Green Valley (10 km2; Fig. 4.1b) is located in the municipality of Deurne and a small part in the municipality of Helmond. The case study area predominantly consists of agricultural land and forest (Table 4.1), and functions as a leisure area for the

Table 4.1 Percentages of land cover types of case study area *Green Valley* and *White Hills*.

Land cover types	Green Valley *(Proportion of area in %)*	White Hills *(Proportion of area in %)*
Residential area	1.2	1.4
Arable land	27.7	35.0
Grassland	23.8	36.7
Orchard	0.9	0
Forests	38.5	15.2
Wetland	0	5.9
Water	4.4	1.2
Other land cover	3.5	4.6
Total:	100	100

citizens of both Deurne and Helmond. The local planning authority aims to develop a sustainable attractive landscape that provides excellent tourism and recreational facilities (Provincie Noord-Brabant 2005). In order to achieve this, the local planning practitioners developed a spatial development plan (Marcellis et al. 2011).

4.2.3 White Hills

Case study area White Hills (18 km2; Fig. 4.1b) is located in the municipality of Asten and a small part in the municipality of Someren. The case study area predominantly consists of agricultural land, with some forested areas (Table 4.1). There is a decrease in supply of agricultural employment, and hence, an increase in demand for alternative employment. One form of alternative employment is through recreational development. The province designated White Hills as an intensive recreational area (Provincie Noord-Brabant 2005). In order to improve the landscape quality, the local planning practitioners developed a spatial development plan (Snellen and Doomen 2008).

4.3 Materials and methods

4.3.1 Selection of landscape services

In an interactive meeting we identified together with the planning practitioners the landscape services that were represented in the spatial development plans and selected the services that were present in the plans of both case study areas. Although the spatial development plans did not directly mention landscape services, they did contain landscape elements which are directly linked to landscape services. The selected landscape services were: the provision of intensive and extensive recreation, ecological corridor, flood water storage, forest habitat, stream valley habitat, and cultural aesthetics.

4.3.2 Academic approach to map landscape services

The academic approach was based on spatial indicators, which is a commonly used methodology in science (Egoh et al. 2012). The methodology comprised of two steps: (1) selection of spatial indicators; and (2) interpolation of indicators for mapping landscape services (Fig. 4.2a; based on Gulickx et al. 2013).

Selection of spatial indicators

In many cases, landscape services do not have a one-to-one relation with land use or land cover (*e.g.* cultural services). Therefore, indicators are used for assessing and mapping landscape services. We selected a set of suitable spatial indicators for each landscape service based on literature to determine the location and area of the service (see Table 4.2 for an overview).

Stream valley habitat

Stream valley habitat includes habitat of the riparian zone of a stream that runs through a low-lying area with soil type sand and peat (Bal et al. 2001). The geomorphological map of The Netherlands was used to locate the stream valleys (Alterra 2008a). Spatial data of typical habitat of stream valleys was not available, hence, all nature areas within the stream valley were considered as stream valley habitat. The indicators included geomorphic aspects of a stream valley and nature areas within the stream valley.

Flood water storage

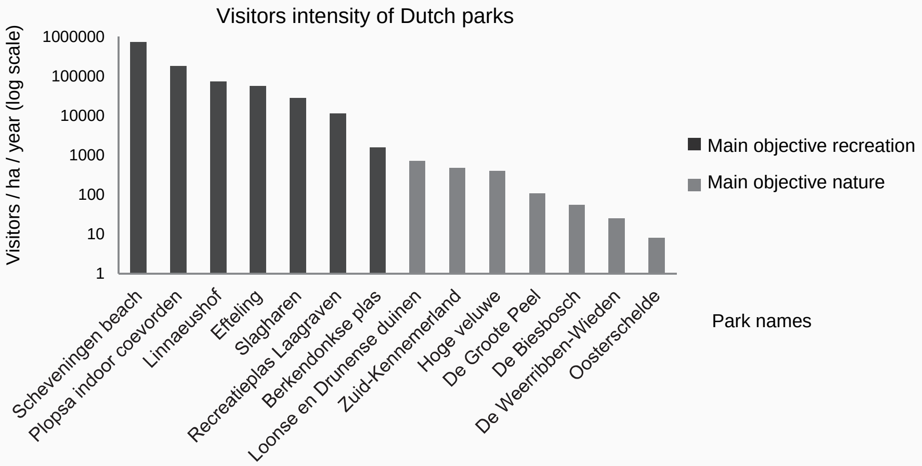
Flood water storage includes locations that are constructed to store surplus water in case of impending flooding. The indicators used to map flood water storage was high inundation risk ($\geq$ 1/100 year; Royal-Haskoning 2007) that occur at locations with medium or high water storage capacity (Alterra 2008b).

Intensive recreation

Intensive recreation includes areas with recreational activities where large quantities of visitors are expected (more than 1150 visitors/ha/year; Box 4.1). The indicators used to map intensive recreation are overnight accommodations, play grounds, golf courses, and leisure parks.

Box 4.1 Quantification of intensity of recreation

It is difficult to define the intensity of recreation, considering no clear definitions could be found in the literature. Therefore, we have considered fourteen parks with recreational activities within The Netherlands and calculated for each park the number of visitors per hectare per year, shown in the chart below. We have categorised parks with the main objective recreation as intensive recreation (N=7; average = 152,899 visitors/ha/year; minimum = 1,571 visitors/ha/year; Standard Deviation = 271266) and parks with the main objective nature conservation as extensive recreation (N=7; average = 256 visitors/ha/year; maximum = 726 visitors/ha/year; Standard Deviation = 281). We have set the minimum number of visitors for intensive recreation and the maximum number of visitors for extensive recreation at 1150 per hectare per year, which is the median of the overall number of visitors of the parks.



Extensive recreation

Extensive recreation includes recreational activities for which minor or no modifications of the landscape have been made and have low quantities of visitors (less than 1150 visitors/ha/year; Box 4.1). Several indicators for extensive recreation were recognised for this area (Gulickx et al. 2013), including hiking routes, unpaved paths, rural roads with solitaire trees or tree lines, which are also used as indicators in this study. In addition, the

Table 4.2 Landscape services, their description, indicators used for identification and which data sources are used in the planning practice and academic approach.

	Description	Academic approach		Planning practice approach	
Landscape service		*Indicators*	*Data source*	*Indicators*	*Data source*
Stream valley habitat	Habitat of the riparian zone of a stream that runs through a low-lying area. The benefits for humans comprise a decreased flood risk and maintenance of ecological diversity.	Geomorphic aspects of stream valley landscape; nature areas	Geomorphological map[1], TOP10[2]	Stream in the valley	Digital Atlas RLG[3]
Flood water storage	Locations that are constructed to store surplus water in case of impending flooding. The benefit for humans comprises a decreased flood risk.	Inundation risk of ≥ $^{1}/_{100}$ year; not in areas with low water storage capacity	Inundation risk map[4] Water storage capacity map[5]	Frequently flooded areas; low-lying areas; located directly upstream of urban areas; in agreement with stakeholders	Water board Aa and Maas, Unpublished
Intensive recreation	Recreation for which changes in the landscape are required, or where large quantities of visitors are expected. The benefit for humans comprises leisure activities.	Overnight accommodation; Play grounds; Golf course; Leisure park	BORIS-50[6] BORIS-50[6] BORIS-50[6] BORIS-50[6]	Overnight accommodation; Golf course; (Nature) leisure park	Reconstruction plan[7]
Extensive recreation	Recreation for which no or minor changes is required and with low quantities of visitors. The benefit for humans comprises leisure activities.	Leisure routes; Near stream; Unpaved paths with tree lines or solitaire trees within 50 metre	Leisure route map[8] TOP10[2] TOP10[2], Google earth satellite image (2011)	Stream valley; Cultural landscape (large-scale reclamation)	Spatial plan[9]
Forest habitat	Forested areas ≥ 2 hectares. The benefit for humans comprises maintenance of ecological diversity.	Land cover map forest	TOP10[2]	Forested areas	Digital Atlas RLG[3]

Table 4.2 *(Continued)*

Landscape service	**Description**	**Academic approach** *Indicators*	*Data source*	**Planning practice approach** *Indicators*	*Data source*
Cultural aesthetics	Cultural landscape includes historical landscape patterns, historical landscape elements (*e.g.* tree lines), and cultural heritage. The benefits for humans comprise education, regional identity, and heritage value.	Cultural heritage monuments; Archaeological value; Historical green	Cultural map database[10]	Agricultural land; Large-scale reclamation landscape	TOP10[2]; SRE[11]
Ecological corridor	Areas of habitat connecting core habitat areas that are separated by anthropogenic obstacles (*e.g.* roads, rails) to enable migration of flora and fauna. The benefits for humans comprise maintenance of biological and genetic diversity.	Tree lines; Stream banks;	TOP10[2]; EHS[12]	Ecological Network (EHS); Ecological connection zones (EVZ)	Digital Atlas RLG[3]; EHS and EVZ[13]

[1] Geomorphological map: scale 1:50000, Alterra, 2008; [2] TOP10: Topographical Map Spatial Edition (vector), including land use classification of TDN (Topographical Service Netherlands); scale 1:10000, Alterra, 2008; [3] Digital Atlas RLG: Atlas of revival of the rural landscape, Provincie Noord-Brabant, 2005; [4] Inundation risk map: Inundatiegebieden Boven Aa (inundation areas of Boven Aa region): scale 1:50000, Royal Haskoning, 2007; [5] Water storage capacity map: scale 1:250000, Alterra, Wageningen UR, 2008; [6] BORIS-50: Policy Support Spatial Information System (In Dutch: Beleids Ondersteunend Ruimtelijk Informatie Systeem), scale 1:50000, 2002-2009; [7] Reconstruction plan: Policy plan to improve the environmental quality of the rural area (Provincie Noord-Brabant 2005); [8] Leisure route map: 'knooppuntenroute' network of hiking and cycling routes; scale 1:10000, SRE (Corporation Region Eindhoven for Environmental services), 2008; [9] Spatial plan: spatial distribution of extensive recreation is described in text of the spatial plan (White Hills on page 25 (Snellen and Doomen 2008); Green Valley on page (Marcellis et al. 2011); [10] Cultural map database: Database with maps of cultural history (scale 1:10000, 2010), archaeological values (scale 1:25000, 2009), historical green (scale 1:25000, 2006) of the Province Noord-Brabant, 2009: (http://www.brabant.nl/kaarten/culturele-kaarten.aspx); [11] SRE (Corporation Region Eindhoven for Environmental services): Cultural historical value map, scale 1:30000, 2009; [12] EHS: Ecological Network, scale 1:10000, 2009: (http://www.brabant.nl/kaarten/natuur-en-landschap-kaarten/informatiekaart-ecologische-hoofdstructuur-ehs.aspx); [13] EHS & EVZ: SRE (Corporation Region Eindhoven for Environmental services), scale 1:30000, 2009.

general public has a strong preference for landscapes with water related features (*e.g.* Dorwart et al. 2009; Howley 2011), therefore we included streams as an additional indicator.

Cultural aesthetics

Cultural aesthetics are cultural elements in the landscape that are appreciated by humans, both local inhabitants and tourists. The indicators used to map cultural aesthetics were historical landscape patterns (Schaich et al. 2010), historical landscape elements (Reinbolz et al. 2008; Schaich et al. 2010), and cultural heritage (Schaich et al. 2010).

Forest habitat

Forest habitat is defined as forested areas larger than 0.5 hectares (Eurostat 2011). Forest habitat is well documented as land cover forest in the Topographical Map Spatial Edition (TOP10 Spatial Edition 2008), which was used to determine the location of the service forest habitat.

Ecological corridors

Ecological corridors (equivalent to habitat corridors) are linear strips of vegetation that provides a near continuous pathway between two habitats (Bennett 1999; Kindlmann and Burel 2008). Linear strips that do not continue fully from one to another habitat were included, considering they can function as stepping stones (Vogt et al. 2007). In The Netherlands the nature policy 'National Ecological Network' (EHS) has been developed to preserve nature through an increased connectivity between nature areas (MANFS 1990). The indicators for ecological corridors were the EHS, stream banks, and vegetation lines.

Mapping landscape services

For mapping landscape services spatially referenced data of the indicators were used (Table 4.2). The landscape service maps were created using the indicators as a function of the landscape service (ArcGIS 10).

4.3.3 Planning practice approach to map landscape services

The local planning authority of both study areas appointed planning practitioners from the environmental consultancy Grontmij to develop the spatial plans. We organised two interactive meetings with the planning practitioners to: 1) identify the planning practice approach; 2) confirm the planning practice approach framework.

For the identification of the planning practice approach, essential reports and official memos were provided and deliberated to unravel the steps of their procedures and the decision-making processes. We processed this information into a simplified framework, which was confirmed by the planning practitioners.

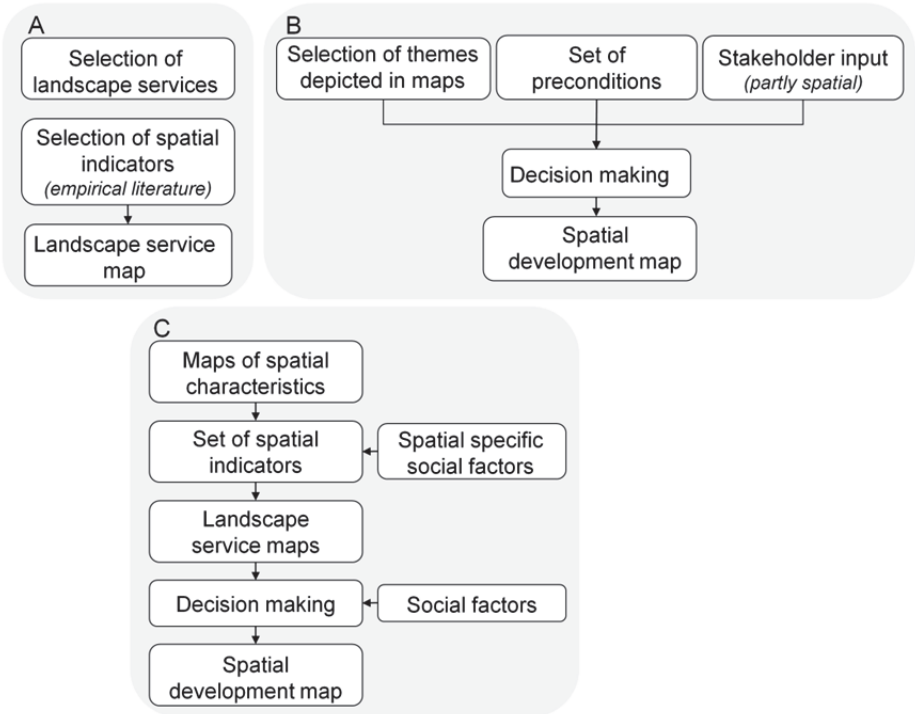


Fig. 4.2 Framework of academic approach (A; based on Gulickx et al., 2013); planning practice approach (B); and proposed integrated approach (C).

4.3.4 Comparison of planning practice and academic approach

The processes and maps of both approaches were compared in the second interactive meeting with the planning practitioners. Dissimilarities were discussed and plausible causes and implications were evaluated. Maps were compared using a confusion matrix (Kohavi and Provost 1998), showing the true-positives, true-negatives, false- positives, and false-negatives. We calculated the total and the balanced concurrency for each landscape service and the average balanced concurrency between the two study areas.

4.3.5 Exploring potential to integrate planning practice and academic approach

During a third interactive meeting with the planning practitioners, the valuable elements of both approaches were conferred and an outline for an integrated approach was made. The possibilities to operationalise the proposed integration were discussed.

4.4 Results and discussion

4.4.1 Planning practice approach

The planning practice approach comprises of five components (Fig. 4.2b). The first component 'selection of themes depicted in maps' is part of a general assessment of the study area. Several themes were assessed using maps showing the spatial characteristics per theme. The themes differed by study area and depended on the objectives of the planning authority. Within the Green Valley study area seven themes were identified, including soil, water ways and surface water, groundwater protection areas, green structures, cultural historical value, and intensive husbandry. The themes of the White Hills study area included water ways and water storage, green structures, cultural historical value, and agricultural policy zones. The second component 'set of preconditions' was set by the planning authority, using political and social considerations. The third component 'stakeholder input' comprised of the involvement of various stakeholders (*i.e.* water board, nature organisations, congregation of companies, federation of agriculture and horticulture, individual farmers, and citizens), who provided input into the projected plans. The fourth component 'decision making' comprised of the advice of the planning practitioners, who deliberate the spatial characteristics and the set of preconditions to propose the most suitable spatial plan to the planning authority (*i.e.* executive municipalities). Finally, the planning authority prioritised and decided. The Fifth component 'spatial development map' comprised of the process of converting the concluding decisions into a final spatial development plan. This plan included one map illustrating the landscape services: provision of intensive and extensive recreation, ecological corridor, flood water storage, forest habitat, stream valley habitat, and cultural aesthetics.

4.4.2 Comparison of planning practice and academic approach

Both similarities and large differences were found between the two approaches. For instance, both approaches included an assessment of spatial characteristics. A crucial difference is that planning practitioners aimed to map favourable functions and values of an area that can be current or planned in the near future, and scientists aimed to map the current landscape services to obtain insight of their spatial distribution. We will discuss differences in focus and indicators, and process.

Focus and indicators

The planning practice approach focussed on several themes that were found important for the area. These themes are directly or indirectly related to landscape services, but such

Fig. 4.3 Landscape service maps for study area Green Valley and White Hills by planning practice approach (a) and academic approach (b).

connection was not explicitly included in their approach. Because landscape services were selected in close collaboration with the planning practitioners, there was a large degree of overlap between the themes and the selected landscape services. However, interpretation of the themes and the indicators used for mapping differed. For instance, the planning practice approach did not include a theme recreation for Green Valley, and because the other themes were not directly connected with recreation, this might have led to less provision of recreational services (Fig. 4.3). And different indicators were used to map, for instance, cultural aesthetics (Table 4.2), which resulted in great differences between the two maps (Fig. 4.3). Hence, most of the differences in the maps are caused by differences in the selection procedure of the indicators for the different services.

Process

The planning practice approach included a set of preconditions that were based on political and social considerations, as well as stakeholder involvement, which provided additional input for the spatial development plan. Social aspects played a crucial role in the final allocation of several services. The allocation of intensive recreation in White Hills, for instance, was subjected to the precondition of developing intensive recreation in this area. The academic approach did not include social aspects, it lacked local knowledge and used more general relations between landscape characteristics and the provision of landscape services. The added value of local knowledge has been recognised in various studies (*e.g.* Fagerholm et al. 2012; Tengberg et al. 2012), which indicates that by including local knowledge the landscape service map could be improved.

4.4.3 Comparison of landscape service maps

In total, fourteen landscape service maps were developed for each study area (Fig. 4.3). The map concurrencies of Green Valley and White Hills were similar (Mann-Whitney U-Test, $z=-0.32$, $p>0.81$), therefore, we have combined the case study areas for the statistical analysis. Overall, the maps had an average balanced concurrency of 71%, with the highest concurrency for forest habitat (94%), and the lowest concurrency for cultural aesthetics and extensive recreation (45%; Table 4.3).

Stream valley habitat

The maps of stream valley habitat were similar to a large extent (average balanced concurrency of 86%; Table 4.3). Yet, in Green Valley, the planning practice approach let to a much smaller area classified as stream valley habitat. In the past, almost the whole valley was transformed into agricultural land and large areas of natural habitat were lost. The stream and partly its natural banks have remained. At a few locations larger parts of natural habitat do occur, however, this is not always native stream valley vegetation. The planning practice approach did not map these areas as stream valley habitat, whilst the academic approach did. Hence, the planning practice approach is expected to have underestimated and the academic approach is expected to have overestimated the allocation of this service.

Flood water storage

The maps of flood water storage shows great differences, especially in Green Valley (balanced concurrency of 42%; average balanced concurrency of 61%; Table 4.3). The allocation of flood water storage is very complex and simple indicators are not adequate to allocate flood water storage. The academic approach used the outcome of two models: 1) prediction of inundation risk; and 2) water storage capacity, which accounted for a part of the complexity. The planning authority contracted water specialists of the water board, who worked together with experts of an engineering consultancy to assess the most suitable locations for flood water storage. The current policy of the water board is to store water predominantly at the locations which would flood naturally, which is according to the Guidelines on sustainable flood prevention of the United Nations and Economic Commission for Europe (2003). This resulted in allocating flood water storage at locations where the soil has less capacity to hold water, which was compensated by allocating a larger area for this service. In White Hills, an opportunity to incorporate flood water storage with the realisation of a golf course arose, which had economic benefits for the local government. The water storage would then partly be allocated at a location with no inundation risk, however, the total area was found suitable for water storage. Finally, the academic approach mapped locations in White Hills which are assigned for flood water storage in 2050 (total of 128 ha; 62% of the academic flood water storage map). The planning practitioners did not include these prospective locations, since they only included current water storage and developments of the near future.

Intensive recreation

The maps of intensive recreation had an average balanced concurrency of 70% (Table 4.3). The locations of intensive recreation were rather similar in Green Valley, although the borders differed. Particularly the locations in the east and west were larger in the map of the planning practitioners. This is primarily because they also mapped future development. In White Hills, the planning practitioners also assigned a larger area for intensive recreation (146 ha; 65%). Planning policies at the provincial level allocated this area for development of intensive recreation, which was therefore a precondition for this spatial plan. Although, the planning authority adopted this policy, the only activities that are allowed in the south western part of this area (comprising 50% of the total area) are extensive recreational activities, such as hiking. Therefore, the service that is delivered in this area is in fact similar.

Table 4.3 Comparison of landscape service maps created by the planning practice and academic approach for study area Green Valley and White Hills using a confusion matrix (Kohavi and Provost, 1998). The confusion table shows the amount of hectares for the true positive detection ([a]), true negative detection ([d]), false positive detection ([b]), false negative detection ([c]). The total and the balanced concurrency were calculated for each landscape service. The average balanced concurrency is the average between the two study areas.

		Green Valley				**White Hills**				**Both areas**
Landscape service		*LS pp[1] (ha)*	*NLS pp[2] (ha)*	*Total concurrency (%)*	*Balanced concurrency (%)*	*LS pp (ha)*	*NLS pp (ha)*	*Total concurrency (%)*	*Balanced concurrency (%)*	*Average balanced concurrency (%)*
Stream valley habitat	*LS sc[3]*	6.7 [a]	52.0 [b]	94.4	93.1	76.7	22.0	95.9	79.7	86
	NLS sc[4]	0.6 [c]	884.7 [d]			49.4	1607.9			
Flood water storage	*LS sc*	0	146.2	82.1	42.1	53.7	153.5	90.0	80.6	61
	NLS sc	22.4	775.4			22.7	1526.1			
Intensive recreation	*LS sc*	44.9	18	93.0	73.0	77.1	1.3	91.6	67.2	70
	NLS sc	48.4	832.7			146.2	1531.4			
Extensive recreation	*LS sc*	19.9	411.8	53.1	46.6	251.6	283.4	39.1	42.4	45
	NLS sc	30.8	481.5			785.4	435.6			
Cultural aesthetics	*LS sc*	216.9	472.6	34.0	38.6	518.3	612.3	49.4	50.8	45
	NLS sc	150.3	104.2			275.5	349.9			

Table 4.3 *(Continued)*

		Green Valley				White Hills				Both areas
Landscape service		*LS pp[1] (ha)*	*NLS pp[2] (ha)*	*Total concurrency (%)*	*Balanced concurrency (%)*	*LS pp (ha)*	*NLS pp (ha)*	*Total concurrency (%)*	*Balanced concurrency (%)*	*Average balanced concurrency (%)*
Forest habitat	*LS sc*	349.8	16.1	96.0	95.7	230.8	7.4	97.1	91.8	94
	NLS sc	21.8	556.3			43.8	1474.0			
Ecological corridor	*LS sc*	26.5	63.0	93.3	96.2	22.7	281.9	83.9	89.4	93
	NLS sc	0.2	854.3			1.2	1450.2			

[1] *LS pp: Landscape service detected by planning practice approach*
[2] *NLS pp: Landscape service not detected by planning practice approach*
[3] *LS sc: Landscape service detected by academic approach*
[4] *NLS sc: Landscape service not detected by academic approach*
[a] *Amount of hectare where both approaches detected the landscape service*
[b] *Amount of hectare where the planning practice approach detected the landscape service, but the academic approach did not*
[c] *Amount of hectare where the academic approach detected the landscape service, but the planning practice approach did not*
[d] *Amount of hectare where both approaches did not detect the landscape service*

Extensive recreation

The maps of extensive recreation showed great differences (average balanced concurrency of 45%, Table 4.3). In Green Valley, the planning practitioners mapped a small area as extensive recreation, whilst in the text of the spatial plan a larger part was allocated as extensive recreation, namely the stream valley landscape. In contrast, the academic approach allocated extensive recreation in a small part of the stream valley landscape. If extensive recreation in the stream valley landscape is included in the planning practice map, the similarity with the academic map even decreased (balanced concurrency of 14%).

The differences in patterns of extensive recreation can predominantly be ascribed to the fact that the academic approach used line features (*i.e.* routes, roads, and streams) as basis for extensive recreation, whilst the planning practice approach allocated areas. Even though the patterns differed, it is expected that the more specific locations of the academic approach would fall within the more general areas of the planning practice approach. This was not the case. The planning practitioners did not identify all locations that provide extensive recreation, but they accentuated areas where they want to stimulate extensive recreation. More specific maps of extensive recreation can support planning practitioners to enhance the allocation of this service in their plans. However, to date we have not yet recognised an adequate set of indicators to map extensive recreation (Gulickx et al. 2013). It would be valuable to achieve more understanding of the relation between landscape characteristics and extensive recreation in order to obtain suitable indicators for extensive recreation that can be used by planning practitioners.

Cultural aesthetics

The maps of cultural aesthetics differed greatly (average balanced concurrency of 45%, Table 4.3). Many different landscape characteristics can be related to the provision of cultural aesthetics, therefore, the decision of which elements are important in an area is decisive. In White Hills, it was recognised that tourists and recreationists preferred relatively unaffected cultural landscapes (Snellen and Doomen 2008). The large-scale reclamation landscape was acknowledged as an unaffected cultural landscape, and therefore, expected to provide cultural aesthetics. In Green Valley, it was recognised that large parts of cultural elements of the landscape are lost, consequently, the ambition was to strengthen the provision of cultural aesthetics (Marcellis et al. 2011). The agricultural landscape of Green Valley was assigned as ‘to strengthen cultural aesthetics’, which included both high and low valued cultural landscapes (SRE 2009). The academic approach lacked such local knowledge and used more general relations between landscape characteristics and the provision of cultural aesthetics. However, there might have been differences in how the value of these cultural elements was weighted. By including local knowledge, a quality gradient can be displayed in the cultural aesthetic map, which expectedly will increase the relevance of the map for planning practitioners.

Forest habitat
The maps of forest habitat had a high concurrence (average balanced concurrency of 94%, Table 4.3), feasibly because both approaches applied a similar method for classifying forest habitat. Additionally, accurate maps of land cover forest are available for The Netherlands, which are directly related to the provision of the landscape service forest habitat. For both study areas the planning practice approach allocated slightly more forest habitat (1.5% in Green Valley and 15% in White Hills), because both spatial plans included expansion of forest habitat.

Ecological corridor
The maps of ecological corridor had a high concurrence (average balanced concurrency of 93%, Table 4.3). The academic approach identified more areas providing this service, however, these locations encompassed only a small area compared to the total size of the study area. The large area that is similarly allocated as not providing the service had big influence on the balanced concurrency. The differences can be explained by the fact that the planning practice approach included only the main corridors, whilst the academic approach also included small linear vegetation patches. These small patches are not defined as ecological corridors in policies, even though they regularly connected two habitat patches or have this potential (Vogt et al. 2007). Again, the academic approach aimed to be all-inclusive, whilst the planning practice approach selected the important ones.

4.4.4 Proposed integrated approach

The planning practitioners and the scientists recognised one vital aspect of the academic approach and one vital aspect of the planning practice approach, which had potential to enhance the other approach: 1) inclusion of landscape services and 2) inclusion of spatial specific social aspects. These two aspects were the main input for the proposed integrated approach (Fig. 4.2c).

Inclusion of landscape services
The main objective of the planning practitioners was to determine the functions and values of an area, in order to decide upon favourable developments. The landscape service concept can be useful to achieve this objective, considering the functioning of the landscape accommodates the provision of services, which are the benefits for society that can be valued (*e.g.* Haines-Young and Potschin 2010; Müller et al. 2010). The planning practitioners were very interested in landscape services and acknowledged the value and

usefulness of the concept. The main advantage they recognised was that it can strengthen and structure their background analysis and contribute insightful information for the decision making process. Furthermore, they were interested in the potential of the landscape to provide landscape services, which are extremely valuable for the evaluation of spatial development prospects. However, in order to provide appropriate information to planning practitioners, which enables them to create maps of the (potential) provision of landscape services, we must improve our knowledge of the spatial distribution of many landscape services and provide adequate indicators for their spatial assessment (Syrbe and Walz 2012; UNEP-WCMC 2011).

Inclusion of social aspects
The inclusion of social aspects is a major challenge, nonetheless, essential for understanding the allocation of landscape services. Social aspects can be political, economic, influenced by culture, and are highly dynamic over space and time (Hein et al. 2006). Data on social aspects are seldom spatially explicit (Beeco and Brown 2013; Ryan 2011), which further complicates their inclusion. This study gives some insights in the social aspects that influenced the allocation of landscape services, however, it does not provide a procedure how scientists can consider them in the assessment of the spatial distribution of landscape services. To our knowledge, such a procedure does not exist yet. The Variance Inflation Factors (VIF) and the tolerance test showed no evidence for multicollinearity between the variables used as indicators for the landscape services (VIF ranged between 1.01 and 1.73, tolerance ranged between 0.58 and 1.00; VIF more than 5 and tolerance less than 0.2 are considered to be a cause for concern for multicollinearity (Menard 2001). However, the variables relief and forest did show multicollinearity (VIF of 9), therefore, relief was not included as an indicator for forest recreation.

The spatial autocorrelation analysis of the spatial indicators of forest recreation has indicated a weak positive dependence on the geographical space (Moran's I=0.13, P<0.00), which can be explained by the fact that forests are concentrated in patches across the study area. A random spatial pattern was found for the indicators of both recreation for hikers (Moran's I=0.06, P<0.10) and land-based animal husbandry (Moran's I=0.01, P<0.10).

4.5 General discussion

4.5.1 Collaboration of planning practitioners and scientists

Practice and science have clearly different terminology, objectives, and cultures (Held 2006; Tress et al. 2005), which was also found in this study. Our collaboration started with creating mutual understanding of fundamental terminology, obtain a mutual objective, and identify how the collaboration can be valuable to all participants. Especially recognising the value of the collaboration is vital for a successful outcome (Baker et al. 2010). The planning practitioners were not familiar with the scientific methods to map landscape services that have been developed. They do not have access to most scientific journals and they do not get time at work to examine scientific papers, which is found to be true for local planners in general in The Netherlands (Gulickx, unpublished). This study facilitated knowledge transfer between practice and science, resulting in novel and relevant knowledge about both approaches.

4.5.2 Integration of planning practice and academic approach

Both the planning practice and academic approach have their strengths and weaknesses, hence, one approach is not better than the other. By comparing both approaches the strengths become apparent and can be used to enhance the other approach. In the present study, two aspects were mentioned as important for integration: the inclusion of landscape services and the inclusion of social aspects. For the inclusion of landscape service maps in the planning practice approach, reliable and useful methods to map landscape services need to be available to planning practitioners. Considering that most landscape services can not directly be mapped using land cover and land use data (Verburg et al. 2009), we require adequate and practical indicators to map landscape services (Söderman et al. 2012). Single indicators are usually insufficient to quantify and map landscape services, hence, many different indicators and thus data sources are needed to quantify them (Egoh et al. 2012; Gulickx et al. 2013). In short, the process of mapping landscape services is complicated, while simple methods that are clear and applicable for practitioners are required. Finding the right balance between simplification and complication (Singh et al. 2009), and hence, between practicality and accuracy, is an ongoing challenge.

For the inclusion of social aspects in a spatial explicit assessment we do not have the necessary knowledge and methodologies just yet (Beeco and Brown 2013; Ryan 2011). In order to improve the spatial assessment of landscape services, novel ways to deal with social data that are not (directly) location specific, and advanced analytical methods to integrate social data within spatial assessment are required (Beeco and Brown 2013; Ryan 2011).

4.5.3 Maps of landscape services

Different indicators are used in different studies to assess the spatial distribution of the same landscape service, resulting in different maps. This variety makes comparison of landscape service maps difficult (Egoh et al. 2012), and moreover, it can be very confusing for practitioners. It is important to realise that often these landscape service maps represent only a small thematic proportion of a service (Haines-Young et al. 2012), or display a different aspect of the landscape service (*e.g.* actual provision or demand of landscape services).

Landscape service maps will be more useful when they are properly validated and uncertainties are recognised. The validity of landscape service maps is difficult to quantify, due to lack of independent data for validation (Egoh et al. 2012), and because of complications with social-cultural service data that are stakeholder, location, and time specific (Hein et al. 2006). Therefore, the different magnitudes of uncertainty needs to be clearly communicated to end-users in order to avoid misinterpretation of the landscape service maps (Egoh et al. 2012; Hou et al. In Press). In our study, the comparison of the different approaches was the most important objective. The comparison of the planning practice and academic landscape service maps can be considered as a validation exercise. In the future, when an integrated approach is further developed, it would be advisable to collect additional independent data to properly validate the landscape service maps.

4.5.4 Usefulness for sustainable development

In sustainable landscape development, humans change the landscape to improve its functioning and create additional value for present and future generations (Cortner 2000; Termorshuizen and Opdam 2009). Local spatial planners are often the driving forces behind changes of the landscape and rely on adequate information for their decisions. This information is partly provided by environmental scientists. The landscape service concept seems an appropriate concept to link scientific knowledge to the field of collaborative spatial planning (Termorshuizen and Opdam 2009), which is confirmed by this study. The planning practitioners considered the concept of landscape services to be very suitable to improve landscape development. Especially the maps showing the potential provision of landscape services are found to be a valuable addition to the planning practice approach. A coherent and integrated approach to come to practical application of the concept of landscape services in spatial planning is still needed (ICSU-UNESCO-UNU 2008; Söderman et al. 2012). This study is a step towards such an integrated approach to operationalise the landscape service concept for sustainable development.

CHAPTER 5

Participatory scenario development to assess the spatial distribution of landscape services in a Dutch rural landscape

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Abstract

Spatial planning is increasingly focused on the provision and the strengthening of desired landscape services. For this reason, planning practice requires adequate knowledge of potential synergies and trade-offs between landscape services in order to make thorough decisions about the spatial distribution of these services. The objective of this study is to co-develop scenarios with local planning practitioners to explore possible future outlooks of the spatial distribution of a set of landscape services. We used participatory approaches, both workshops and consultation, to develop two scenarios up to 2025, using the case study area the Peel region in the Netherlands. In total, twelve local stakeholders and seven experts participated. During the first workshop the stakeholders opted for two opposed scenarios to obtain insight in two extremes possible future outlooks, namely Profitable Nature and Green World Economy. For each scenario story lines were developed, which were enriched by means of consultations with experts of agriculture, recreation, nature and water. Spatial indicators were obtained from the qualitative scenarios to map six landscape services (*i.e.* intensive and extensive food production, intensive and extensive recreation, water quality, and water storage) for each scenario. In a second workshop, the landscape service maps of the scenarios were discussed and amended. Both the stories lines and maps were subsequently used to evaluate current policy strategies. Of the 18 policy strategies, 12 (67%) were found potentially successful for both scenarios, the others being partially successful at best. The spatial scenarios of landscape services provided insights in the synergies and trade-offs between particular services and in the potential consequences of spatial planning decisions. The planning practitioners found the tools relevant and useful and were interested in further developing these approaches for planning practice.

5.1 Introduction

Most landscapes are managed and transformed by humans to obtain and strengthen benefits for society. The rural landscape provides, for instance, food, recreation, and water regulation. In many places, this has led to multifunctional landscapes (EC, 2006). This multifunctionality is inherently related to the provision of multiple services that are beneficial to society, which can lead to both synergies and trade-offs between these landscape services (Antle and Stoorvogel, 2006; Nelson et al., 2009). For example, food production can coexist with recreation, but can have negative consequences for water quality. Local planning practices are concerned with how and where to improve the provision of landscape services and how to prevent potential negative consequences of landscape modifications. Scientific research can support spatial planning decision making by providing knowledge about potential opportunities for, consequences of, and trade-offs between landscape services.

Environmental science has developed ways to analyse the spatial distribution of landscape services (Martínez-Harms and Balvanera, 2012). Various methodologies and frameworks to quantify and map landscape services have been developed (Egoh et al., 2008; Gimona and van der Horst, 2007; Gulickx et al., 2013; Kienast et al., 2009; Petz and van Oudenhoven, 2012; van Berkel and Verburg, 2011; Willemen et al., 2008). Although these frameworks and mapping tools have shown their value for environmental sciences and contain useful information for planning practice, they are not directly applicable for planning practitioners (Termorshuizen and Opdam, 2009; Weitkamp et al., 2012). As yet, there is little systematic research showing in which form scientific knowledge best fits into the procedures of planning practice (Beunen and Opdam, 2011). This integration is difficult as planning practice has developed its own methodology for mapping landscape functions and services, (Gulickx and Kok, Submitted), which are largely undocumented. Consequently, scientists are not familiar with the methodological abilities and knowledge requirements of planning practice. Hence, enhanced communication and knowledge exchange between science and planning practice is necessary in order to improve scientific support to planning practice.

Over the last two decades, participatory approaches have been developed and applied to improve this knowledge exchange between science and practice (Baker et al., 2010; Hage et al., 2010). Such approaches have shown to be effective in processes like social learning that improves the skill of practitioners to become acquainted with scientific knowledge and tools, and in improving the skills of scientists to provide requisite knowledge for the practitioners (Opdam 2010). However, there is still a discrepancy between the supply of scientific knowledge and the knowledge demand of planning practice (McNie, 2007; Weitkamp et al., 2012). The knowledge exchange can be improved by applying a collective process where the methodology, tool, or knowledge is co-produced by multiple stakeholders (Pohl, 2008). Participatory scenario development, which deals with complex, uncontrollable, and uncertain problems (Biggs et al., 2007; Kok and Vliet, 2011; Peterson et al., 2003; Vervoort et al., 2010), is recognised as a powerful tool for knowledge co-production (Hage et al., 2010). Scenario analysis can lead to creative solutions for planning practice as they may generate unexpected, yet plausible outcomes (Ahern, 1999). Scenarios provide different possibilities for future outlooks and are therefore a popular tool for exploring alternative plausible futures of landscape development (Rounsevell and Metzger, 2010; Verburg et al., 2006). In addition, optimal policy strategies can be identified using scenario development (e.g. Lempert et al., 2006). In turn, spatial planners and policy makers can also inform research by bringing local knowledge into the development of scenarios for their region (Rickebusch et al., 2011).

Many types of scenarios can be developed (van Notten et al., 2003), one main distinguishing characteristic being the degree of quantification. Scenarios can be either qualitative, such as storylines, or quantitative, e.g. obtained through modelling approaches. Qualitative scenarios are often acquired using participatory methods, while quantitative spatially explicit models are mostly developed without participation of stakeholders (Kok, 2009). These models are often highly complex, encompassing information on a multitude of spatial and non-spatial drivers and impacts, and therefore close to impossible to comprehend by non-experts. As a result, most spatial models are regarded as a black box, which reduces credibility of the resulting maps. Identification of the spatial distribution of landscape services likewise requires complex methodologies. For many landscape services, there is no one-to-one relation to land cover and thus other proxies are required for mapping (Egoh et al., 2012; Verburg et al., 2009). The cultural landscape service leisure hiking, for example, is related to landscape properties such as hiking trails, relief differences, and openness of the landscape. Complex models, such as logistic regression models, are therefore developed to map landscape services (e.g. Willemen et al., 2008). Spatially explicit scenarios have been developed for landscape service to analyse various trade-offs between the provision of different services (van Berkel and Verburg, 2012). Although they apply a participatory approach, the spatial explicit model was developed and applied by the scientists. Hence, because of the lack of a knowledge co-production process, the model itself is not directly applicable for planning practice. Approaches for collaborative development of comprehensible spatially explicit scenarios of landscape services with planning practitioners need to ensure direct applicability.

We embarked upon a study of spatial scenario development for landscape services through the integration of planning practice, local expertise, and science. We developed qualitative stories based on existing scenarios. Based on these stories together with input of local experts, quantitative spatially explicit maps were developed. These stories and maps were used to evaluate to what extent existing policy strategies would be suitable across the different scenarios. The main objective of this paper is to describe and analyse the applied scenario development method, focusing on the spatial explicit aspects of landscape services and the potential for improvement of the knowledge transfer between science and practice. The approach is applied for the Peel region in The Netherlands.

5.2 Description of case study area

5.2.1 General

The spatial planning process in The Netherlands is increasingly decentralising with the allocation of tasks and responsibilities from the national level to the levels of regions and localities (Tosics et al., 2010). The local authorities have recently acquired extensive autonomy and are principally responsible for landscape planning practices. As a result, local communities are involved in most spatial planning decision making processes. For this study we opted for a region that is dealing with a multifunctional landscape with many potential trade-offs between landscape services, and with a high involvement of the local community. The Peel region in province Noord-Brabant, the Netherlands, (approximately 600 km2) is densely populated with 406 inhabitants per km2, causing high pressure on the limited available land. Agriculture is the main land use, covering 60% of the area (Fig. 5.1a). The landscape is heterogeneous and a wide range of landscape services are provided, such as food production, habitation, water regulation and storage, recreation, and habitat provision. The region is known for its intensive livestock production and the peat-bog nature reserve 'De Groote Peel'. The increasing intensive agriculture and its drainage system have a negative effect on the peat-bog nature areas, and conversely, the high water level of the peat-bog wetland has a negative effect on the production in the intensive agriculture. The drainage system of agriculture and its expansion has also resulted in an increase of water runoff and in less space for waterways. As a result, the peak discharge, volume, and frequency of floods increased in nearby streams, where there is little space for water storage. Additionally, to stimulate the local economy of the rural area, recreational activities (e.g. leisure cycling and camping) are increasingly developed and supported by the local government. However, recreation can be negatively impacted by the growing intensive livestock production due to, for instance, unpleasant odour emissions. Besides these conflicts, in this highly multifunctional landscape many other trade-offs can occur. This development of increasing pressure on land is occurring in many other regions all over the world (UNEP, 2012), making the case study illustrative beyond the local context.

5.2.2 Current policy strategy

The rural area of Povince Noord-Brabant was facing a number of environmental problems. For example, the area had to cope with several animal disease outbreaks, a decreasing water quality, increasing odour emissions from intensive livestock farms, fragmentation of nature areas, and loss of characteristics of the landscape, such as the geomorphological feature of the historical 'plaggen' agriculture. Additionally, the area suffered from two severe animal diseases (classical swine fever and foot-and-mouth disease) in the late 1990s. Therefore, the national government decided that the region required improvement of the landscape quality. In 2002, the national government established the Reconstruction Act, which aims at an integral quality improvement of the landscape. Based on the act, the regional government developed a reconstruction policy to enhance landscape composition regarding agriculture, nature, recreation, water, environment, and infrastructure, in order to improve work and living environment and the economic structure (Provincie Noord-Brabant, 2005). In 2011, a strategic report was published for 2012 to 2015 to adopt the reconstruction policy to the current situation, (Reconstructiecommissie and Streekplatform, 2011). The main focus has shifted more towards economic development, targeting regional employment and increasing the added

A

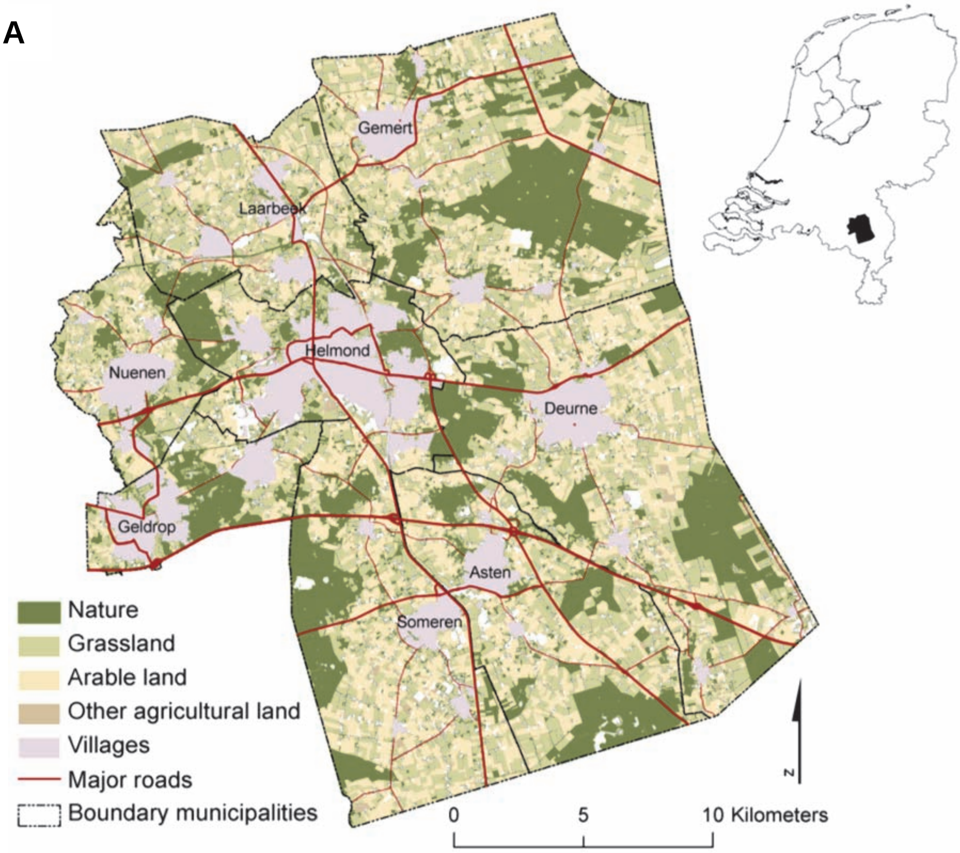

Fig. 5.1 A) Map of study area de Peel. In the top right corner the border of The Netherlands, with in black the location of the Peel region.

B

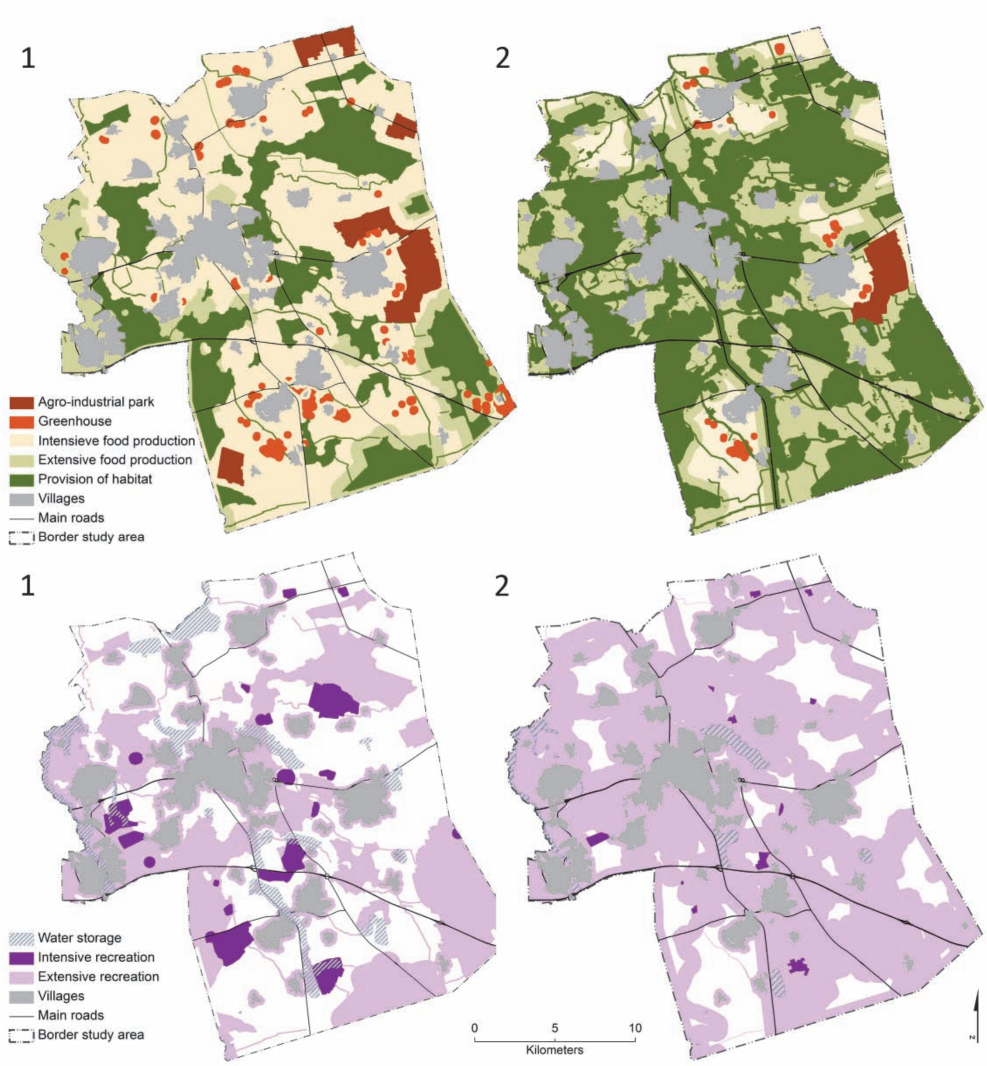

Fig. 5.1 B) Spatial distribution of landscape services extensive and intensive food production (including agro-industrial park and greenhouse), intensive and extensive recreation, provision of habitat, water storage, and groundwater quality for 2025 for scenario 'Profitable Nature' (1) and scenario 'Green World Economy' (2).

value of the landscape, and towards integrative approaches aiming at initiatives which include various stakeholders to achieve these targets.

5.3 Methods

Conceptually, the approach of this study consisted of three main moments of interaction between environmental scientists and local stakeholders, including two workshops with planning practitioners and policy makers, and a consultation process with specialists (Fig. 5.2). Additionally, the approach included several feedback moments with the planning practitioners and policy makers, and the specialists. The process consisted of six main elements that are described below: 1) selection of landscape services; 2) selection of stakeholders; 3) qualitative scenario development; 4) spatial scenario development; 5) evaluation of policy strategies; and 6) evaluation by stakeholders (Table 5.1).

5.3.1 Selection of landscape services

Landscape services were defined as 'the goods and services provided by a landscape to satisfy human needs, directly or indirectly', which is a specification of the ecosystem services concept (Termorshuizen and Opdam 2009). Several key landscape services provided in the case study area were identified using knowledge from earlier work in the same area (Gulickx and Kok, Submitted; Gulickx et al., 2013). Included were: intensive and

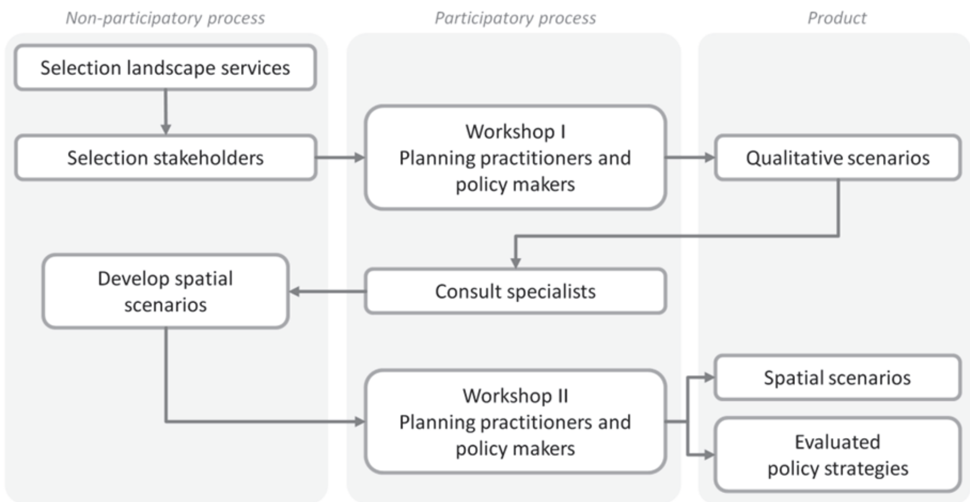

Fig. 5.2 Methodological steps, divided into three pillars: 1) non-participatory processes (*i.e.* carried out by academics), 2) participatory processes, and 3) resulting products.

Table 5.1 The approach of this study included five participatory steps. Per step the process actions are described, plus the used tools and the people involved.

Participatory steps	***Process actions***	***Tool***	***Who***
1. Selection of stakeholders	Set criteria for the selection of stakeholders	Literature	Academics
2. Qualitative scenario development	Develop two qualitative scenarios	Interactive workshop	Province, municipality, water board, consultancy agency
	Validate workshop outcomes	Email	Province, municipality, water board, consultancy agency
	Obtain additional information on both scenarios	Consultation	Nature specialist Agriculture specialist Recreation specialist Water quality specialist Water storage specialist
3. Spatial scenario development	Translate scenarios into maps of landscape services	GIS	Academics
	Discuss spatial scenarios	Interactive workshop	Province, municipality, water board, consultancy agency
	Correct maps of landscape services	GIS	Academics
	Final validation with initial developers	Email	Government (Province + Municipality) Water board, Planning agency
4. Evaluation of policy strategies	Evaluate the suitability of current policy strategies for each scenario	Interactive workshop	Province, municipality, water board, consultancy agency
5. Evaluation of approach by stakeholders	Evaluate the participatory approach and scenario development tools	Interactive workshop, email	Province, municipality, water board, consultancy agency

extensive food production, recreation, provision of habitat, water storage, and groundwater quality. These services were used to select relevant stakeholders for the scenario development. However, the stakeholders were given the opportunity to alter the list and change priorities during the first workshop.

Table 5.2. Stakeholder selection and attendance. In total, 17 stakeholders with different roles (spatial planner, policy maker, policy advisor, alderman) were invited for the workshops and 7 experts for the consultation. Signals for reaction: + = positive reaction; - = negative reaction; 0 = no reaction. Signals for attendance: x = attended; - = not attended.

Institution	#	Reaction	Attendance	Spatial planner	Policy maker	Policy advisor	Alderman	Local scale	Regional scale
Workshops									
Province	1	+	x		x				x
	2	0	-						x
Water board	3	+	x			x			x
	4	+	x		x				x
Municipality	5	+	x				x	x	
	6	+	x	x				x	
	7	+	x				x	x	
	8	+	-				x	x	
	9	+	-				x	x	
	10	+	x	x				x	
	11	+	-		x			x	
	12	0	-				x	x	
	13	0	-		x			x	
	14	0	-				x	x	
	15	0	-				x	x	
Environmental consultancy	16	+	x	x		x		x	x
agency	17	+	x	x		x		x	x

Table 5.2. *(Continued)*

Institution	#	Reaction	Attendance	Spatial planner	Policy maker	Policy advisor	Alderman	Local scale	Regional scale
Consultation *(expertise)*									
Federation of agriculture	1	+	x			x			x
and horticulture (ZLTO)	2	+	x	x				x	
(agriculture)	3	+*	x	x				x	
Partnership region Eindhoven (SRE) *(recreation)*	4	+	x			x			x
Brabant Environment Federation (BMF) *(Nature)*	5	+	x			x		x	x
Water board *(Water storage)*	6	+	x			x			x
Water board *(Water quality)*	7	+	x			x		x	

** Stakeholder was not invited, but requested to attend the consult meeting.*

5.3.2 Selection of stakeholders

We decided to focus on influential stakeholders who are directly involved in planning practice. We divided the stakeholders into two groups: planning professionals and experts For the Peel region, two levels of government are primarily involved in planning practice; regional, *i.e.* province and water board, and local, *i.e.* municipalities. Environmental consultancy agencies are often engaged in the spatial planning processes of the government. We selected, therefore, stakeholders of the province, municipality, and environmental consultancy agency (Table 5.2). The variety was maximised in terms of profession (*i.e.* spatial planner, policy maker, policy advisor, and alderman) and age (junior and senior employees).

Expert knowledge was used to refine the scenarios. The required expertise was based on the chosen landscape services. In consultation with the coordinator of the Peel region, experts working in the case study area with knowledge of agriculture, recreation, nature, water storage, and water quality were selected (Table 5.2). The variety was maximised in terms of profession (*i.e.* spatial planner, policy maker, and policy advisor), the spatial scale of their work, and age (junior and senior employees).

5.3.3 Qualitative scenario development

Worldwide, many sets of scenarios have been developed, including various sets of global scenarios that are well-known in both the scientific and policy arena (IPCC, 2000; MA, 2005). Using a set of existing higher-level scenarios has the advantage to kick-start the process, allowing more time for the development of local scenarios. We therefore started the process of scenario development with the four global storylines of the IPCC Special Report on Emission Scenarios (IPCC, 2000). These can be considered as four contextual scenarios providing the boundary conditions. The scenarios leading objectives are structured along two axes distinguishing globalisation from regionalisation, and focus on economic development from a focus on environmental protection. There are several advantages for the use of the IPCC scenarios, including credibility (developed by the global climate community) and legitimacy (many stakeholders were involved). Moreover, the IPCC storylines were downscaled to the Netherlands (van Egmond et al., 2007), which are used to outline the Dutch perspective, which was a useful starting point for this study.

We used an explorative approach (Kok et al., 2006) to develop two qualitative scenarios for 2025 in a one-day workshop. The workshop consisted of four main stages: 1) scenario selection; 2) identification of key events and processes; 3) indication of temporal dynamics; and 4) determining key landscape services. The stakeholders selected the two scenarios anonymously by means of electronic instant voting using a personal response system (Turning Point Response Card). For both scenarios, a mind map was constructed to identify important events and processes in the case study area. Mind mapping is a tool that stimulates imagination and creativity and helps to logically synthesise all the relevant information in an organised way. Mind maps are widely used in scenario workshops as a tool to structure group understanding of key concepts and issues (*e.g.* van Berkel and Verburg, 2012). This exercise enables the stakeholders to get familiar with the scenario concept and to visualise possible developments for their region. The stakeholders placed the events and processes on a time horizon from 2012 to 2025. At the end the stakeholders were asked which landscape services they found important for the area. This was not done at the beginning, in order to create an open arena for the stakeholders at the start without being confined to pre-set landscape services. Afterwards, the scientists translated both scenarios into a storyline, which was documented and sent to the stakeholders for a final check.

5.3.4 Spatial scenario development

Expert consultation

The experts were grouped by their expertise (*i.e.* agriculture, recreation, nature, and water), and each group was consulted independently. Preceding the meeting, the experts received the report of the qualitative scenario workshop. During a two-hour meeting, the experts were informed about the scenario concept and the developed scenarios. Subsequently, they were asked to refine both scenarios and to provide their considerations on the expected changes in the spatial distribution of the landscape services for both scenarios. The list of events and processes, the time line, and a variety of printed maps, including general topography and specific landscape characteristics concerning the four expertise topics, were used during the consultation. Additionally, the experts were asked to indicate for both scenarios the expected policy consequences. The expert knowledge was used as input for modelling the spatial distributions of landscape services for 2025.

Modelling spatial distribution

The contextual scenarios were assessed to identify spatial conditions of changes in the spatial distribution of the landscape service. These spatial conditions consisted of landscape characteristics and spatial policies, which were used as indicators to map the spatial distribution of each landscape service for 2025 (Fig. 5.2). The indicators were processed with ArcGIS 10.

5.3.5 Evaluation of policy strategies

Nine key policy strategies were selected from the strategy report of the Peel region (Reconstructiecommissie and Streekplatform, 2011) for evaluation during the second workshop with the planning professionals. We divided the strategies into 18 more specific strategies, which we sent to the planning professionals for confirmation prior to the workshop. The information from experts on expected policy consequences was used as additional information for the evaluation of the strategies with the planning professionals. During the second workshop the stakeholders evaluated and discussed the suitability of the policy strategies for each scenario. This exercise was conducted to test the suitability of the combination of qualitative and spatial scenarios for evaluation of policy strategies.

5.3.6 Evaluation of process

At the end of both workshops, the stakeholders were given a feedback form, to assess their findings of the workshops. The process, tools, and products were evaluated against four criteria: relevance, usability, credibility and feasibility (Weitkamp et al., 2012). The stakeholders rated the procedure against each of the criteria on a scale ranging from 1-10, where 1 is not at all relevant, usable, credible, or feasible, and 10 is extremely relevant, usable, credible or feasible. We asked the stakeholders to rate the overall process on a scale of 1-10, and to give additional feedback through several open questions on the form. As a final step of the workshop, the stakeholders were given an opportunity to explain and discuss the overall process.

5.4 Results

5.4.1 Stakeholder participation

In total, 17 stakeholders were invited to participate in the workshops, of which 12 accepted the invitation (Appendix A). Of those accepted, three were not able to attend, hence, nine stakeholders participated in one or both workshops (Table 5.2). All the invited experts accepted the invitation (Table 5.2) and attended the consultations.

5.4.2 Qualitative scenarios

Scenario selection
The stakeholders first choice was equally divided over scenario ‘regionalisation and economy first’ and ‘globalization and economy first’. After a discussion, a second voting round resulted in a unanimous preference for ‘regionalisation and economy first’. This scenario was found to be business as usual. Their second choice was directly unanimous for scenario ‘globalization and environment first’. The stakeholders thus opted for two opposed scenarios to obtain insight in two extremes possible future outlooks.

Scenario description
The scenarios were given titles that reflected the content: Profitable Nature for the scenario regionalisation and economy first, and Green World Economy for the scenario

globalization and environment first. For both scenarios many events and processes were mentioned during the mind map session (Table 5.3). These were put on a time horizon, showing differences in when an event would start and how long the process would take. For both scenarios all events started before 2025, but not all would be fully established or achieved. Due to different priorities in the scenarios, there were substantial differences in when similar events would start, though the duration of these events was similar. Participants did not identify any new landscape services, with one exception. For recreation it became clear that a division between intensive (e.g. theme park and golf course) and extensive (e.g. leisure hiking and cycling) was needed, allowing for the substantially different processes that were driving both.

The consultation with experts resulted in additional insights for both scenarios, which were mostly in agreement with the storylines of the planning professionals (Table 5.3). Information provided by the agriculture experts deviated the most. They, for instance, envisioned for the scenario 'Profitable Nature' that there will not be any scale enlargement of agriculture, no agro-industrial parks, and no bio-energy production. The main reason was that the region was considered too small for these developments. They did project intensification of agriculture, but in a regional focussed scenario where the production is for the local market, there is no need for agro-industrial parks. During the feedback workshop the additions of the agriculture experts raised questions, such as 'How big is the market region of the Peel area?' and 'What are agro-industrial parks exactly?'. These ambiguities were discussed and clarified, and the storyline was adapted accordingly.

5.4.3 Spatial scenarios

Process

For each landscape service several spatial indicators were identified (Table 5.4). During the feedback workshop the stakeholders recognised that some areas with intensive recreation and several corridors of the ecological network were missing. Additionally, the stakeholders preferred to divide intensive food production into three categories, explicitly agro-industrial park, greenhouse, and other intensive food production. The missing features were added and intensive food production was divided into the three categories. The possibility to map water quality was heavily debated. Many factors and complex processes are involved in the spatial distribution water quality, which cannot be fully taken into account. Considering the high uncertainty and the fact that water quality is a sensitive issue, it was decided not to map water quality.

Scenario description

The Profitable Nature map (Fig 5.1b) is shaped by two main economic focuses, i) food production and ii) provision of recreation. Food production will intensify at most locations,

Table 5.3 Events and processes resulted from the brain storm session in the workshop with planning professionals for scenarios '*Profitable Nature*' and '*Green World Economy*' categorised by theme. Additions from the experts of agriculture, recreation, nature, water quality, and water storage are specified.

	Scenario *Profitable Nature*		Scenario *Green World Economy*	
Theme	*Outcome of workshop*	*Additions from expert consultation*	*Outcome of workshop*	*Additions from expert consultation*
Agriculture	Scale enlargement; Less fragmentation; Development agro-industrial parks; Production of bio-energy; Food more expensive; Local markets; Products better traceable	Intensification; No agro-industrial parks; No bio-energy production; High quality products	Sustainable agriculture; Extensification; Urban agriculture; More production of crops and bio-energy; Introduction other agriculture (GMO); Decrease of productivity; Development new technologies; Many environmental policies	Development agro-industrial parks; Clear zones for agriculture and nature; Extensification, though increase in size; Closed cycles for crop farming
Energy	Production of bio-energy; Alternative energy production, *e.g.* biomass, sun and water; Development new technologies; Local production and market		Production of bio-energy; Alternative energy production, *e.g.* biomass, sun, water, geothermal heat pump, waste water; Development new technologies	
Residential	Migration out of rural areas; More wealthy people living in rural areas; Increase in difference in wealth in rural areas		Less migration out of rural areas; Conversion of farms and company building into residential buildings; Less difference in wealth in rural areas	
Infrastructure	Improvement of infrastructure; Commercial and public waterway transportation; Increase of travels within region; Increase of working from home		Development and improvement of public transport; Technological development, *e.g.* Flexible public transport, use of digitalisation; Commercial and public waterway transportation; Less cars; Employment of elderly people for public transport, considering aging of population	

Table 5.3 *(Continued)*

	Scenario *Profitable Nature*		Scenario *Green World Economy*	
Theme	*Outcome of workshop*	*Additions from expert consultation*	*Outcome of workshop*	*Additions from expert consultation*
Recreation	Increase accessibility of nature; Development intensive recreation activities, *e.g.* theme parks and water sports; Development of hiking and cycling routes; More recreational use of water	Zoning recreation (areas with intensive agriculture are not attractive); Recreation directly around villages; Development of alternative recreational activities at farms	Development of hiking and cycling routes; Recreation in nature, only providing nature is not disturbed; Global publicity for region to attract more tourists	Link recreation and farming: fidelity and sustainability
Nature	Increase accessibility of nature; Increase of recreational use of nature; Lease of nature areas; Production from nature for local market	Ecological network will slowly be developed (fragmented nature requires more management, hence is more expensive); Nature won't be able to adopt to climate change	High quality of nature and landscape; Increase of enjoyment of landscape; Nature less accessible; Increase of enjoyment of nature; Development of ecological network	Expansion of ecological network; Development of nature suitable for location properties; Nature able to adopt to climate change
Water	Commercial and public waterway transportation; Water storage integrated with other services, *e.g.* stilt housing; Energy production using water; Increase recreational use of water	More water storage is required (intensification of agriculture results in higher peak discharges); Less regulation: no limit for nitrate in groundwater; Decrease of groundwater quality; Water treatment is expensive; Expect resistance of citizens	Improvement of water quality; Water quality of high importance; Water storage integrated with other services, e.g. with food production; More space for water and nature; Energy production using water	Closed water systems in agro-industrial parks; Less water storage is required, current water storage is sufficient (less peak discharge, due to more space for nature and storage possibilities in agro-industrial parks); More regulation for water quality
Governance	More alliance and responsibility local governments; Maintain identity; Local identity is important; High involvement of citizens		Low responsibility of local government; Increase of environmental policies; Increase of regulation; Government detached from citizens: little involvement of citizens	

Table 5.4 Indicators used in the model to map the landscape services for the scenario 'Profitable Nature' and 'Green World Economy'. It was found inapplicable to map landscape service groundwater quality based on the input during the workshop and from the experts. More in depth knowledge is required for an adequate map.

Landscape service	Spatial indicators *Profitable Nature*	*Green World Economy*
Intensive food production	· Expand intensive agriculture · Develop 1 agro industrial park in current intensification area	· Develop agro industrial parks in current intensification areas
Extensive food production	· Maintain restricted areas for extensive agriculture	· Expand extensive agri-culture at all locations except agro industrial parks
Intensive recreation	· Expand intensive recreation · Develop (further) recreation hubs at borders of nature areas	· Maintain current intensive recreation · No new development
Extensive recreation	· Develop in all nature areas · Develop around villages · Not in intensive agricultural areas	· Develop in border of nature areas · Develop in extensive agricultural areas · Develop around villages
Water storage	· Establish all water storage areas reserved for 2050	· Maintain current water storage · No develop of water storage
Provision of habitat	· Maintain natural habitat	· Maintain natural habitat · Develop (further) ecological network
Groundwater quality	[Not mapped]	[Not mapped]

exceptions are around wetland habitat and few cultural historical landscape sites. At several locations agro-industrial parks will be developed, supplying food for the Dutch, German, and Belgium market. The current greenhouse locations will expand further. Recreation will develop mainly in and around nature areas. Nature will be fully accessible and at border recreational facilities, such as restaurants, are established. Intensive recreation provision will expand at current locations and new locations are developed. Nature will be important to facilitate the recreational activities. These developments increase the pressure on the water system. The drainage system of agriculture and its expansion will increase peak discharge, so that substantially more water storage is needed. It will also have a negative influence on the water quality, which will overall deteriorate.

The development in the Green World Economy map (Fig. 5.1b) is focused on improvement of both quality of nature and the environment. Food production will extensify at most locations, although several areas will still have intensive food production. At one location an agro-industrial park with a closed-loop system will be developed. Environmental policies and regulation will increase, reducing the use of fertilizers and pesticides. Current provision of intensive recreation is maintained, but will not be expanded. Extensive recreation is mainly developed in agricultural areas and at the border of nature areas, or where some disturbance has little effect on the quality of nature. The ecological network will be optimised, so that core habitats are connected. Nature areas are expanded to increase the habitat quality. These developments provide more natural water storage and less pressure on water quality. Therefore, no expansion of flood water storage is needed and the water quality will improve.

Several differences in spatial organisation between landscape services have been recognised (Table 5.5). A substantial difference can be found in the intensity of agriculture. The Profitable Nature scenario predominantly provides food from intensified agricultural systems, in contrast to the extensive food production in the Green World Economy scenario. The focus of the Profitable Nature scenario will be on the regional market, including The Netherlands and the neighbouring countries, for which several agro-industrial parks will be developed. At several locations, intensive food production is disadvantageous over extensive food production, due to conflicts with natural areas. In these areas the focus will be on extensification and recreational development. In the Green World Economy the general focus will be on a congruous relation between food production and natural habitat provision. Most agricultural areas will therefore extensify. An agro-industrial park with a closed-loop system will be developed, where high production of food is provided in a sustainable way.

The provision of recreation has fundamental economic importance in the Profitable Nature scenario. Especially intensive recreation will be developed further, resulting in expansion of intensive recreation areas. The landscape attractiveness of areas with intensive food production is expected to decrease and therefore not suited for extensive recreation. The nature areas are easily accessible and suitable areas for the provision of recreation, both extensive and intensive. In addition, around the villages extensive recreation, such as leisure hiking, is provided. The Green World Economy has different patterns for the provision of recreation, especially concerning extensive recreation. The rural landscape consists predominantly of extensive food production, providing an attractive landscape for extensive recreation. In order to preserve high quality of nature, sensitive nature areas, as well as habitats with special value, are inaccessible for recreationists. Current areas that provide intensive recreation are maintained, but will not increase.

In both scenarios provision of habitat played an important role, however, in the Profitable Nature scenario habitat provision had an economic consideration, whilst in the Green World Economy scenario habitat provision was considered for its intrinsic value. The different considerations revealed in differences in the quality and amount of habitat. In the Profitable Nature scenario, the quality is less important than the profit that can be made resulting in low quality of habitat, although there is a minimum quality required to attract recreationists. The current amount of core nature areas will be maintained and the connectivity between nature areas will be improved, hence, the connectivity can contribute to a minimum quality of the habitat. Considering the quality is not the main objective, the improvement of connectivity will go slow and will not be much different in 2025. In the Green World Economy the quality of nature is the most important factor and will therefore be high. The core nature areas and the connectivity between them will substantially expand.

Water storage is a concern in the Profitable Nature scenario. Due to the large areas providing intensive food production, peak discharge will increase in both volume and

Table 5.5. Synergies and conflicts between landscape services that occur close to each other. Symbols indicate: + = synergy; - = conflict; +/- = both synergy and conflict recognised; 0 = neither synergy nor conflict recognised.

	Intensive food production	Extensive food production	Intensive recreation	Extensive recreation	Provision of habitat	Water storage
Extensive food production	0					
Intensive recreation	+	0				
Extensive recreation	-	+	-			
Provision of habitat	-	+	-	+		
Water storage	+/-	+	+/-	+	+	
Water quality	+/-	+	0	+	+	+

frequency. Substantially more storage is needed by 2025. However, there are also new opportunities to combine water storage with the agro-industrial parks. Also the water quality is a concern in this scenario. Both the increase of agricultural intensity and the decrease of government regulation have a negative impact on the water quality. The overall water quality will decrease. In the Green World Economy scenario, both water storage and water quality are of no concern. The increase of nature areas, especially around the waterways provides natural water storage. In addition, the peak discharges will decrease due to the extensification of agriculture. In this scenario more stringent international regulations for water quality are imposed. However, it is expected that no extra effort has to be made to meet these regulations as the extensification of agriculture and the expansion of nature will lead to good water quality.

5.4.4 Evaluation of policy strategies

Of the 18 policy strategies, 12 (67%) were found potentially successful for both scenarios. Of these 12 strategies, three (17%) were found highly suitable for both scenarios and nine (50%) partially suitable in one scenario and highly suitable in the other. We will exemplify the suitability for three strategies. The first example concerns the policy strategy *Biobased Economy*, which aims for an economy based on efficient use of crops and biomass for food, feed, materials, chemicals, energy and fuel. This strategy was found to be highly suitable for both scenarios, although the rationale and process differs. In the Profitable Nature scenario the strategy contributes to the identity of the region and a good reputation, which is of great importance in this scenario. The bottom-up structure of the scenario provides good opportunities for close cooperation between government, companies, and research to develop new technologies, such as biotechnology. These technologies can contribute to a biobased economy. The Green World Economy scenario fit well with a biobased economy strategy because it contributes to environmental improvement through sustainable use of resources. The strategy will be more enforced through international regulations and supported by, for instance, subsidies.

The second example concerns the policy strategy *Aesthetic landscape*. This strategy was found to be partially suitable for Profitable Nature, but highly suitable for Green World Economy scenario. In the Profitable Nature scenario the attractiveness of the landscape is important for the economy. The leisure sector forms an essential economic source for which the aesthetic quality of the landscape is an important factor. However, in this scenario a large part of the landscape consists of intensive agriculture which is less attractive. The landscape in the Green World Economy scenario consists mostly of extensive agriculture and high quality nature, which goes well together with high aesthetic quality.

The third example concerns the policy strategy *Brainport Development*, which aims for cooperation between government, companies, and research (including education) to develop solution for the benefit of societal issues. This strategy was found to be only suitable in the Profitable Nature scenario. The bottom-up structure of this scenario provides good opportunities for involvement and collaboration of different stakeholders and institutions. The top-down structure of the Green World Economy scenario gives local governments and other institutions less authority, there is little local involvement, and hence, there will be less opportunities and incentives for such collaborations.

5.4.5 Evaluation of workshops

The average score from the stakeholders for the entire process of scenario development was a 7.5 (SD=0.5). For all four criteria combined the average score was 8.2 (SD=1.4). The qualitative comments provided by the stakeholders are summarized below.

Relevance
Two components were mentioned to be highly relevant. Firstly, the exploration of possible outlooks, which broadened the view of the participants, two stakeholders stated: “the scenario development provided several eye-openers”. The translation of the qualitative scenarios to the spatially explicit scenarios made the scenarios more specific and hence, more relevant for the region. Secondly, the evaluation of policy strategies for both scenarios provided valuable insights and was considered highly relevant (further explained in 4.5.3). Some discussions on principles were considered less relevant, which diverted the attention from the focal issues. The workshop setting was perceived as a relevant tool for obtaining new insights, considering the useful contribution of other participants.

Usability
The scenario development approach contributed to obtaining insight into the different choices and the possible consequences of these choices. The combination of the qualitative and spatial scenario was especially useful for the evaluation of policy strategies. One stakeholder stated: “We should have had this tool earlier”.
The opinions about the usability of the experts’ contribution were divided. Some preferred a workshop together with the experts (40%) to be able to discuss contradicting projections for the scenarios directly. The others (60%) stated that these discussions can deviate from the core issue rather easily, making it less relevant and taking too much time. All but one agreed that the provided input of the experts was valuable.

It was thought that the strength of the scenarios may be enhanced by increasing the distinction between the two scenarios even more. However, this might decrease the credibility of the scenarios. The stakeholders recommended that when a follow-up workshop is organised, ample time should be spend on recollecting the discussions and results of the previous workshop. To use the available time as efficiently as possible, the separate sessions should be planned shortly after one other.

Credibility

Both scenarios were considered credible (average score of 8.4). Accordingly, the scenarios were believed to give a reliable foundation for the evaluation of the policy strategies. Two terms appeared to be not fully clear during the second workshop. This might have resulted in discrepancy between the projections of the planning professionals and the experts. The credibility of the expert contribution was therefore slightly discredited. Although, due to the discrepancy, it was recognised that the terminology was unclear amongst the stakeholders. This led to a valuable discussion and a more thorough outcome. It is debatable if all words that might lead to confusion can be recognised at the beginning.

Feasibility

The stakeholders considered it feasible to apply the scenario development approach in their work. They expected to have access to the necessary data and tools. However, assistance of an independent scenario specialist would be an advantage for guidance of the process and to ensure focussed discussions.

5.5 Discussion and conclusions

5.5.1 Landscape services and scenarios

For the qualitative scenario development we did not focus directly on landscape services in order to start off with a fully open and unbiased session. Commonly, the planning professionals focus on the functionality of the landscape, incorporating primarily multiple land uses. Nonetheless, the stakeholders acknowledged the landscape service concept and had no problem with identifying the key landscape services for their region. During the process of developing the spatial scenarios, the focus on landscape services broadened the view of the planning professionals. For example, by linking land use and landscape properties directly to landscape services, locations with potential for multiple services became apparent. Especially for cultural services, such as extensive recreation, additional areas could be identified for the provision of this service.

5.5.2 Spatial distribution in scenarios

The development of the spatial scenarios was a successful aspect of the method, both in enthusing stakeholders and in producing rather detailed maps of the main landscape services. These maps facilitated a more focused and detailed discussion on landscape services and spatial synergies and trade-offs between services became more apparent. It also highlighted important differences between planners and experts that might have otherwise been hidden.

The discussion of the spatial distribution of the landscape services allowed for strong interaction between the scientists and planners, giving more opportunities to exchange scientific and planners' knowledge. In short, the addition of a specific focus on spatial distributions and participatory map making is highly recommended and needs to be experimented with.

5.5.3 Consistency of terms and concepts

In this paper, we evaluated a participatory approach to develop scenarios with local planning practitioners to explore possible future outlooks of the spatial distribution of several landscape services.

At the beginning of the first workshop important terms and concepts were explained and defined. Throughout the process additional terms were introduced, of which not all seemed to require a tuned definition at the time they were mentioned. During the second workshop two terms became unclear, *i.e.* size of the region and the definition of an agro-industrial park. This was triggered by the feedback of the experts and caused confusion and uncertainty about the meaning of the information given by the experts. However, it also led to a valuable discussion and a more thorough outcome. It is difficult to recognise all elements that require clarification during the scenario development process. This shows the importance of feedback tools in the scenario approach, through which ambiguity can be identified and clarified.

5.5.4 Synergies and trade-offs

The planning professionals deal with the spatial configuration of a multifunctional landscape, providing multiple services. For making thorough decisions about sustainable landscape development, knowledge and awareness of the interactions between landscape services are necessary in order to make well-balanced judgments regarding such trade-offs (Bennett et al., 2009; Grêt-Regamey et al., 2013). The spatial scenario development provided the opportunity to explore synergies and trade-offs between landscape services. Considering the recognition of synergies and conflicts was not the core objective of this research, the identified trade-offs are not explored in-depth. Nevertheless, for several landscape services synergies were recognised, for instance amongst extensive recreation, extensive food production, water storage, and water quality. The main conflicts arose amongst intensive food production and intensive recreation. We recognise that the scenario development approach has great potential for assessing trade-offs between landscape services, both qualitatively and quantitatively.

Recently, trade-offs between landscape services, including soil conservation, water quality, flood regulation, and carbon storage, are analysed using scenario approaches (Goldstein et al., 2012; Nelson et al., 2009; Power, 2010). These studies do not include participatory approaches though, which might make them less applicable for planning practice. Considering the value of trade-off analysis for planning practice, it is recommendable to also produce such assessments with planning practitioners and policy makers. Additionally, a wide range of landscape services are lacking from these studies, such as cultural services, of which we have recognised trade-offs with other services in this study.

5.5.5 Evaluation of policy strategies

The evaluation of policy strategies was perceived as one of the most useful aspect of the scenario development approach. Currently, the planning professionals do not have a tool to test their policy strategies, and they did recognise the added value of using such an approach for the development of policy strategies.

Several studies have demonstrated the usefulness of scenario approaches for the evaluation of policy strategies (Dewar, 2002; EEA, 2009; Lempert et al., 2006), however, little documented information is available on the application with planning practice. Evaluation of existing policy strategies in the context of scenario analysis is a crucial aspect of the methodology that deserves to be included as standard part of any local scenario development method. The development of diverging scenarios needs to be followed by an evaluation and/or development of strategies, in order to make the exercise relevant and usable for planners.

Most strategies were found suitable to some extent for both scenarios, however, the incentive and implementation would differ. It is, therefore, important to incorporate the motivation and application process of the strategies as well. By including more than two scenarios, the robustness of the strategies can be more thoroughly assessed. Additionally, some strategies were rather general, which are likely more flexible and hence robust. More specific strategies are expected to become less vigorous.

5.5.6 Implementation for planning practice

The scenario development approach was considered to be relevant and usable for planning practice. The planning practitioners involved in this study indicated that they require and welcome support from scientist to increase their understanding of landscape development in order to make more thorough decisions. The potential for implementation of the scenario development approach will be further explored in forthcoming cooperation. This study has demonstrated that scenario development can be applied for exploring the spatial distribution of landscape services and possible synergies and trade-offs, and for evaluating the robustness of policy strategies.

CHAPTER 6

Synthesis

6.1 Introduction

The key objective of my dissertation was to map and analyse the spatial distribution of landscape services and to integrate scientific knowledge and approaches for mapping landscape services with planning practice. With the research, I endeavoured to contribute to our understanding of spatial patterns of landscape services and to close the gap between science and practice. This final chapter provides a synthesis of the preceding chapters and an assessment of their contribution to the objective of this dissertation and science in general. For that purpose, I will focus on three issues: i) sustainable landscape development, ii) spatial distribution of landscape services, and iii) science-practice interface. The final section presents the key conclusions of this study.

6.2 Towards sustainable landscape development

Landscapes represent an important scale domain for sustainable development (Wu, 2013a). Local planning practice plays a key role in transformations of the landscape to provide and strengthen desired landscape services. Sustainable landscape development is increasingly part of international policies, however, translation of these policies to practice remains a major challenge (Adger and Jordan, 2009; Franklin and Blyton, 2011).

A key aspect of sustainability science in general, is the integration of different disciplines and institutions (*e.g.* Adams, 2006; Lang et al., 2012), with co-production and co-learning as central elements (Martens, 2006). For landscape sustainability science, in particular, it is essential to analyse landscape services in a spatially explicit way (Wu, 2013a). During this study, integrative approaches are applied for analysing landscape services, in which spatially explicit methodologies of natural sciences (*e.g.* spatial analysis) are combined with social sciences (*e.g.* scenario development), and co-producing knowledge with stakeholders of business, government, and scientific institutions.

Sustainable landscape development can be supported by providing maps of the spatial distribution of landscape services, especially when they are firmly embedded in local planning practice. In this way, the integrated approaches of this study can provide a scientifically valuable and societal useful contribution to the sustainable development of the landscapes we live in.

6.3 Spatial distribution of landscape services

6.3.1 Maps

The landscape is a spatially heterogeneous area (Wu, 2013b). Addressing the spatial component is, therefore, essential for both understanding the heterogeneity including the interactions between landscape properties, functions, and services, and for linking science to planning practice. Considering that maps are a shared medium (Hauck et al., In Press), maps play an important role in the analysis of landscape services and thus in my dissertation. The importance of maps for the spatial analysis of ecosystem services is also recognised by the European Commission (EC, 2011). On behalf of the European Commission, the working group on Mapping and Assessment on Ecosystems and their Services (MAES) has committed itself to assist EU Member States to map the state of ecosystem services by 2014 (Maes et al., 2013).

My research provides insights into linkages between landscape properties and landscape services (Chapter 2 and 3). For several landscape services reliable maps were produced, for instance, for forest recreation and the provision of wetland habitat. For some other landscape services the produced maps were not fully reliable, such as provision of extensive recreation, cultural aesthetics and water quality. In fact, this indicates that for many landscape services it is very difficult, if not impossible to provide fully reliable maps. Nonetheless, maps that include these and other services that are difficult to map are being used as input for further analysis, such as valuation and trade-off analysis. However, if the basic input data are unreliable, the analysis will likewise be unreliable. More attention needs to be paid to avoiding this 'Garbage in, garbage out' problem.

Maps of landscape services can convey different occurrences of a service, such as the potential or actual landscape service (Fig. 1.2). In the literature, mostly the potential landscape services are illustrated (Martínez-Harms and Balvanera, 2012), although the differentiation is not always made clear. This distinction is important in communicating the spatial distribution of landscape services. For example, when a map representing the potential landscape services is used to show the actual services for valuation, the value of the service will mostly be overestimated, as actual use is lower than potential use. Additionally, using a map representing the actual landscape services as the potential provision, might underestimate the potential of the landscape to provide the service. In chapter 2 and 3, the focus was on the provision of the actual landscape service. For some landscape services, it proved difficult to identify the locations of the actual provision, especially for extensive recreation and water quality. The methodological challenges are described in section 6.2.2. During the collaboration with planning practitioners the usefulness of both types of map were discussed. The practitioners indicated that the maps representing the potential are especially useful for the spatial planning process, since they provide explicit information on the potential of the landscape which they can use for their planning practice (Chapter 4).

Landscape service maps are the basis of landscape service analysis. Yet, a proper basis needs to be established in order to be able to analyse the spatial distribution of landscape services.

6.3.2 Mapping

For the establishment of a proper basis to provide reliable landscape service maps, we require adequate mapping methods. The variety and fundamental differences between landscape services, however, inhibit the realisation of a standardised methodology for mapping. Overall, there is an agreement amongst scientists that spatial indicators are essential for mapping landscape services, but methodologies and data sources for identifying indicators differ greatly. Many different aspects have been encountered in this study that are inherently related to this inconsistency. In total, twenty landscape services have been studied and for fourteen services spatial indicators have been recognised (Table 6.1). A first aspect that plays a role in the need for multiple methods is the existence of multiple levels for a landscape service. For example, provision of recreation can be divided into intensive and extensive recreation, which both requires different indicators (Chapter 4). Then again, extensive recreation can be further divided into, amongst others, forest recreation and recreation for hikers, both requiring different indicators as well (Chapter 2). Hence, when mapping the landscape service recreation, the identification of indicators depends on the definition and rationale for the use of the landscape service map. An example of a difference in the rationale of landscape service maps, is the distinction between representing the potential and the actual provision of the service. For the actual provision, data of people actually benefiting from the provision are required, while the potential provision requires information on the potential of a landscape to provide the service. Understandably, this distinction brings about the necessity for different types of methodologies, indicators, and data sources. For the potential provision of extensive recreation, for instance, landscape properties (*e.g.* presence of tree lines or that are related to the service can be used as indicators, while the actual provision requires data on the number of people hiking through the landscape for leisure. Also, when only focusing on the actual provision, approaches differ largely between different landscape services. For example, the actual provision of hiking recreation can be directly obtained by observations or indirectly by questionnaires, but the actual provision of flood water storage requires data on the implementation of constructions to ensure water storage for peak discharges, which can be obtained through spatial zoning plans. Another aspect involves differences in the spatial scale of landscape services. Some landscape services are provided locally, such as food production and natural habitat provision (Chapter 2 and 4). Other landscape services are provided throughout the landscape, such as recreation for hikers (Chapter 2) and water quality (Chapter 3). Especially at the landscape scale, a single service might be related to many landscape properties, which complicates the identification of prime indicators for that service. Therefore, generally a mixture of methodologies and data sources is required for identifying spatial indicators to map landscape services.

Table 6.1 Overview of landscape services (LS) and indicators identified in my dissertation.

Landscape services	Identified spatial indicators	Method	Data sources
Intensive food production[2]	Agro industrial park, policy intensive farming zone	Workshop, consultation	Agricultural policy map
Non-land-based animal husbandry[3]	-	Observations	Governmental database
Extensive food production[2]	Policy extensive farming zone, agro industrial park	Workshop, consultation	Agricultural policy map
Land-based animal husbandry[1]	Industry or villages not within 100m, solitaire trees within 100m, grass- land on specific soil type	Observations, logistic regression	Governmental database, topographical map, soil map
Crop production[3]	-	Observations	Land cover map
Natural habitat[2]	Land cover natural habitat	Workshop, consultation	Ecological network policy
Wetland habitat[1]	Land cover wetland	Observations	Land cover map
Forest habitat[1]	Land cover forest	Literature	Land cover map
Stream valley habitat[1]	Nature areas on geomorphic features of stream valley landscape	Expert knowledge	Geomorphological map, land cover map
Ecological corridor[1]	Tree lines, stream banks	Literature	Topographical map, ecological network policy
Groundwater quality[3]	-	Measurements, workshop, consultation	-
Flood water storage[1,2]	Inundation risk of ≥ 1/100 year, not in areas with low water storage capacity	Literature, expert knowledge	Inundation risk map, water storage capacity map
Hobby farming[3]	-	Observations, interview	Governmental database
Field sports[3]	-	Observations	Google earth satellite image
Intensive recreation[1,2]	Overnight accommodation, play grounds, golf course, leisure/ theme park	Expert knowledge, workshop, consultation	Database with maps of recreational locations
Extensive recreation[1,2]	Cycling and hiking routes, near stream, unpaved paths with tree lines or solitaire trees within 50m	Literature, expert knowledge, workshop, consultation	Leisure route map, topographical map, Google earth satellite image
Recreation for hikers[1]	Landscape elements within 100m, or rural road within 100m, or unpaved path within 100m	Observations, logistic regression	Land cover map, topographical map, hiking routes
Forest recreation[1]	Land cover forest; unpav-ed paths within 200m	Observations, logistic regression	Management strategy, topographical map
Campsite tourism[3]	-	Observations	Paper tourism map
Cultural aesthetics[1]	Cultural heritage monuments, archaeological value, historical green	Literature, expert knowledge	Database with maps of cultural history

[1] *Current LS maps;* [2] *Future LS maps;* [3] *LS not mapped*

These methodological challenges obstruct the identification of corresponding spatial indicators. In fact, for many landscape services adequate indicators have not yet been identified (de Groot et al., 2010; Egoh et al., 2012). To date, mostly expert knowledge and literature are used for identifying spatial indicators to map landscape services, while few studies have based the identification of indicators on empirical relations (Martínez-Harms and Balvanera, 2012). Empirical research, however, is vital to improve scientific capability to map landscape services between landscape properties and landscape services. In this study, an empirical approach showed that the most accurate maps represented landscape services that were directly related to land cover, *i.e.* wetland habitat and forest habitat. The maps of cultural services were the least accurate, *i.e.* recreation for hikers and cultural aesthetics. These services can be related to many different landscape properties (Chapter 2 and 4). The landscape properties that were related to cultural services were mainly local properties (*e.g.* tree lines and unpaved paths). Such services are not included in higher level studies, considering the map resolution is too coarse.

In this study, the chosen approach to landscapes and landscape services proved to be appropriate for mapping. For example, both extensive recreation (Chapter 2, 4 and 5) and groundwater quality (Chapter 3) were associated with the landscape as a whole and included several ecosystems, such as agricultural and forest ecosystems. Local planning practitioners also focus on the landscape for their spatial plans (Chapter 4 and 5). The MAES working group focuses on ecosystems and their services, although they do include 'artificial surfaces', such as the heterogeneous agricultural ecosystem. Yet, these agricultural ecosystems are considered separately from other ecosystems, for instance, forest habitat. In order to make these ecosystem services maps relevant and usable for local planning practice, transformation to a landscape approach will likely be necessary. Based on the experiences of this study, I can recommend the landscape service concept for the application at the local scale.

Although several methodologies to identify indicators for mapping landscape services are suitable, for many landscape services adequate indicators have not been identified. This study addresses only a subset of all possible landscape services. Therefore, more empirical work is needed to establish relations between landscape properties and the spatial distribution of landscape services to identify spatial indicators for developing reliable maps.

6.3.3 Stakeholder involvement

Maps of landscape services are often based on indicators of biophysical properties. Although it has been recognised that within a landscape the social system plays an important role, social aspects are rarely included in mapping landscape services. Social aspects usually cannot be mapped in the same manner as biophysical aspects (Ryan, 2011), mostly because of a lack of spatial data or inherent spatial characteristics of the service. Participatory mapping is a valuable tool to capture spatial information on social aspects at the landscape level, that does not depend on available data (Fagerholm and Käyhkö, 2009; Soini, 2001). In this study, the importance of social aspects in the spatial distribution of landscape services became clear through an evaluation of a mapping approach of spatial planners (Chapter 4). As a consequence, stakeholder involvement and participatory mapping stimulate the analysis of the full spectrum of landscape services, especially at the local scale (Fagerholm et al., 2012).

For several landscape services participatory mapping is a suitable tool, however, this is not necessarily the case for all landscape services. In this study, I found that the simplified indicators for mapping groundwater quality (Chapter 3 and 5) lacked credibility for stakeholders (Chapter 5). The spatial explicit map was deemed to be too specific and too uncertain. Especially in a region such as the Peel, where groundwater quality is a main concern and hence a sensitive topic, the credibility of the basic data is crucial. Therefore, not only for understanding complex relations and processes, but also for collaboration with planning practice and policy, quantitative models can be a prerequisite. However, the indicators for many other landscape services were considered reliable by the stakeholders. Apparently, there is a point to which stakeholders consider to be within their capacity of comprehension and what they consider beyond their expertise. Co-development of landscape service maps leads to a high degree of ownership of the results. Yet, for services where stakes are high and causing strong debates, the credibility can be lower.

Stakeholder involvement can provide essential knowledge on the spatial distribution of landscape services, particularly related to social services, which can advance the identification of indicators to map landscape services. Yet, attention needs to be paid to the perceived credibility of landscape services that are difficult to map.

6.4 Science-practice interface

The landscape service concept is expected to help communication between science and practice (Termorshuizen and Opdam, 2009; Wu et al., 2013), although the actual usefulness of the concept has not yet been documented. In this study, the majority of the involved planning practitioners were not familiar with the concept and ample time was needed for clarification. Subsequently, however, the practitioners seemed to have no trouble in processing the general idea of landscape services into their 'own' concepts of planning practice. The landscape service concept was considered to be a useful concept by both scientists and planning practitioners (Chapter 4 and 5), yet an inclusive evaluation of the advantages and disadvantages of using the landscape concept when working with practitioners can help to better apply the concept.

In the overall process of collaborating with practitioners, the initial phase of the collaboration is crucial, but also difficult. Getting stakeholders with different backgrounds and objectives involved requires building bridges and finding common grounds. When the added value is not clear for stakeholders right from the onset, collaboration will likely be limited. However, predominantly the procedure for the initial collaboration is not described (*e.g.* Karl et al., 2007). Hence, it is difficult, if not impossible, to learn from each other about which approaches to get stakeholders involved are successful. The stakeholders, with whom I first communicated about collaboration for this study, stated that it is important for scientists to begin with solely focusing on the added value for other stakeholders. In fact, they considered the objectives of the researchers to be irrelevant to them at the initial stage. Additionally, it appeared fruitful to notify the invited stakeholders who already had agreed to participate. During the feedback session, most stakeholders stated that this notification had a positive influence on their decision to participate, as the collaboration gave them an extra advantage, namely networking.

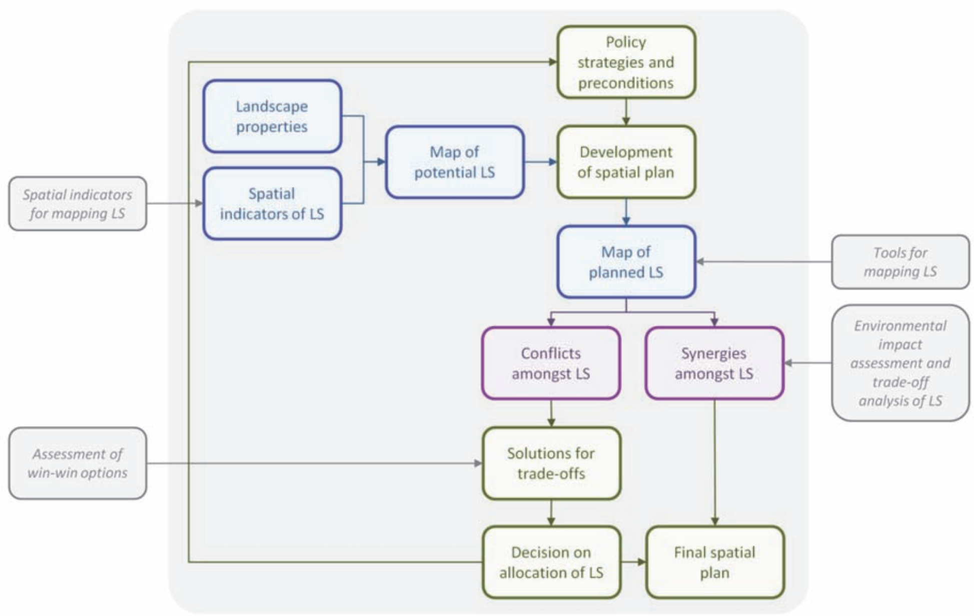

Fig. 6.1 Framework for landscape services application in planning practice. The green boxes indicate the steps of the current spatial planning process. The blue boxes indicate the addition of landscape services to the planning process. The purple boxes indicate a mixture, where the impact assessment is currently part of the planning process in The Netherlands, but the inclusion of landscape services in the impact assessment is new. The grey boxes indicate components of ongoing scientific research for improving knowledge and tools, which can potentially support planning practice at the different phases in the planning process.

I applied several kinds of participatory approaches to jointly create and exchange knowledge on the spatial distribution of landscape services. In Chapter 4, interactive meetings with planning practitioners provided a suitable setting for learning. The meetings were informal, flexible, and knowledge was transferred in both ways. The collaboration was extremely efficient in exchanging a large amount of in-depth knowledge in a short period of time. Yet, the actual integration of science and practice approaches requires more than learning from each other. In Chapter 5, spatially explicit scenarios of landscape services were developed using a participatory scenario development approach by means of stakeholder workshops. The employed method to create landscape service maps was transparent and simple, *i.e.* the procedure and indicators for mapping were fully understood by the participants, and perceived as useful for planning practice by the planning practitioners. The focus on the spatial distribution of landscape services enhanced knowledge exchange and discussion between the stakeholders. These two case studies show the potential to integrate knowledge and methods of science and practice. Nonetheless, before such integration is customary in science and planning practice, further development of these participatory approaches and their implementation is needed.

Most landscape service frameworks give conceptual outlines that are mainly valuable for scientific purposes, rather than for application in planning practices (Haines-Young and Potschin, 2009). Yet, one of the main objectives of the landscape service concept is to improve decision making in policy and practice concerning landscape development (MA, 2003). A framework that integrates the landscape service concept with the planning practice process provides a basis for the implementation of landscape services into planning practice. In Figure 6.1, I propose a way how we can implement the landscape service concept in planning practice. In this figure, the green boxes depict the structure of a planning process that is common in The Netherlands (Chapter 4). The planning process starts with identifying the preconditions for the spatial development plan, such as the emphasis on recreational development. Taking these preconditions into account, together with the policy strategies, such as the focus on bio-based economy, a concept spatial plan is developed. Maps representing the potential landscape services within the focal area (blue boxes) form the basis for the development of the concept spatial plan (Chapter 4). This plan will undergo a so-called environmental impact assessment (EIA) in which spatial planning options are evaluated on their possible effects on the environment, for example in terms of pollution, odour, and noise (purple boxes). An EIA sometimes involves different scenarios (*e.g.* maximise economic development versus maximise environmental quality) to analyse possible trade-offs between these different scenarios. However, an EIA does not consider landscape services, and seldom, if at all, social values. The development of methodologies to integrate landscape services in an EIA is in its early stages (Baker et al., In Press).

Finally, mutual learning and knowledge exchange between science and practice is the way forward. Scientific methods to interact with planning practitioners need to be developed further and improved to be able to develop the landscape in such a way that desired landscape services are provided and their provision is also ensured for the future.

6.5 Key conclusions

- Maps of landscape services enhance communication between scientists and planning practitioners. And communication between scientists and planning practitioners enhance the development of maps of landscape services.

- Maps of landscape services are not always sufficiently accurate, due to the deficiency of adequate spatial indicators to map these services. For scientific advancements in the field of landscape services, a focus is needed on improving of the quality of the base data, rather than on their application and further use.

- The landscape is an appropriate domain for integrated analyses of the ecological and social properties and the corresponding provision of landscape services. Especially cultural landscape services can only be correctly characterised by indicators on the landscape level.

- Understanding spatial distribution of landscape services can be an important stepping stone towards interaction with planning practice and, therefore, towards sustainable landscape development.

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Summary

Landscapes are managed and transformed by humans to obtain and strengthen benefits for society. The provision of such benefits, *i.e.* landscape services, is a result of the interactions between social and ecological systems. Landscape services maps depict in a comprehensive way a part of this complexity. To date, methods to map landscape services and to understand the spatial synergies and trade-offs of these services are still in development. The spatial relation between landscape services and landscape properties need to be further studied to recognise appropriate spatial indicators to map these services. The spatial distribution of landscape services can be highly valuable for planning practitioners. The combination of the landscape service concept with integrated participatory approaches has the potential of co-producing knowledge regarding the spatial distribution of landscape services that is relevant for both science and planning practice. The overall objective of this dissertation is to analyse the spatial distribution of landscape services and to integrate science and planning practice through participatory approaches and co-production.

In Chapter 2, an empirical approach to identify and map four landscape services, *i.e.* wetland habitat, forest recreation, land-based animal husbandry, and recreation for hikers, was developed and illustrated for the municipalities Deurne and Asten in province Noord-Brabant, The Netherlands. The landscape services were identified through ground observations at 389 locations. Spatial indicators were used to identify and map the landscape services. Based on the ground observations, correlations between the landscape services and spatial characteristics (*e.g.* elevation, soil, road-type) were calculated within a neighbourhood with a radius of 0 m, 50 m, and 100 m. These correlations identified several site-specific indicators to map the landscape services. The accuracy of the landscape service maps created was assessed. The indicators proved to be adequately reliable for forest recreation and reasonably reliable for land-based animal husbandry and recreation for hikers. Only landscape service map forest recreation was shown to be highly accurate. The four landscape services rarely coincide, but within a 1 km radius it is apparent that some occur closer together. The approach that we have used is applicable for a wide range of different services and establishes a fundamental basis for determining their spatial variation. As such, it should provide vital information for policy makers and spatial planners.

In Chapter 3, a spatial assessment of groundwater quality in relation to landscape properties, land use, and landscape services has been conducted for a rural landscape in the southern sandy region of The Netherlands. At the landscape level, nitrate emissions occur along with the provision of various landscape services including: I) food production, II) habitat provision, III) residence provision, and IV) other services (i.e. hobby farming, field sports, and campsite tourism). We analysed nitrate concentrations in the upper groundwater for landscape services in all four categories using a combination of field sampling, existing monitoring schemes, and literature. The results showed that the region exceeded the target of the EU Nitrate Directive, which aims to reduce concentrations below 50 mg NO_3^- l^{-1} in the groundwater. Food production was the main source of nitrate leaching, although high nitrate concentrations were also found for the other landscape services, particularly for campsite tourism. On average the other services did not exceed the EU target. The variation between landscape services, but also within landscape services, and even within fields was large. The spatial variability can have important implications for policy implementation of the target values. In the case of drinking water supply aggregated values are most relevant, while for habitat provision in surface water the local values may be most important.

In Chapter 4, we have analysed the differences between an academic and planning practice approach to map landscape services and evaluated the possibility to come to an integrated approach. For two case study areas, seven landscape services (*i.e.* forest habitat, ecological corridor, stream valley habitat, cultural aesthetics, flood water storage, intensive and extensive recreation) were mapped by local planning practitioners, and independently by scientists. Approaches were explained and discussed during three interactive meetings with the goal to map and compare landscape services, and to explore possibilities for integration of the approaches. The main aspects of the differences appeared to be the focus, spatial indicators and process. Overall, the maps showed an average balanced concurrency of 71%, with the highest concurrency for forest habitat (94%), and the lowest concurrency for cultural aesthetics and extensive recreation (45%). Both approaches started with evaluating biophysical aspects of the landscape. However, the academic approach based the location of the landscape services on quantified relations with biophysical aspects, whilst the planning practice approach used the biophysical aspects as base layers and did not directly link them to landscape services. The planning practitioners based their decisions also on social aspects, which influenced the location of the landscape services. Possibilities for an integrated approach were discussed. This study showed that maps of the provision of landscape services are potentially a valuable addition to spatial development plans.

In Chapter 5, two scenarios were developed together with local planning practitioners to explore possible future outlooks of the spatial distribution of a set of landscape services. We used participatory approaches, both workshops and consultation, to develop two scenarios up to 2025, using the case study area the Peel region in the Netherlands. In total, twelve local stakeholders and seven experts participated. During the first workshop the stakeholders opted for two opposed scenarios to obtain insight in two extremes possible future outlooks, namely Profitable Nature and Green World Economy. For each scenario story lines were developed, which were enriched by means of consultations with experts on agriculture, recreation, nature and water. Spatial indicators were obtained from the qualitative scenarios to map six landscape services (*i.e.* intensive and extensive food production, intensive and extensive recreation, water quality, and water storage) for each scenario. In a second workshop, the landscape service maps of the scenarios were discussed and amended. Both the storylines and maps were subsequently used to evaluate current policy strategies. Of the 18 policy strategies, 12 (67%) were found potentially successful for both scenarios, the others being partially successful at best. The spatial scenarios of landscape services provided insights in the synergies and trade-offs between particular services and in the potential consequences of spatial planning decisions. The planning practitioners found the tools relevant and useful and were interested in further developing these approaches for planning practice.

To conclude, Chapter 6 provides a synthesis of the four research chapters and assesses their contribution to the objective of my dissertation. I have drawn four key conclusions from my study. Firstly, maps of landscape services enhance communication between scientists and planning practitioners, and conversely, communication between scientists and planning practitioners enhance the development of maps of landscape services. Secondly, maps of landscape services are not always sufficiently accurate, hence, scientific advancements in the field of landscape services needs to focus on improving of the quality of the base data, rather than on their application and further use. Thirdly, the landscape is an appropriate domain for integrated analyses of the ecological and social properties and the corresponding provision of landscape services. Especially cultural landscape services can only be correctly characterised by indicators on the landscape level. And finally, understanding spatial distribution of landscape services can be an important stepping stone towards interaction with planning practice and, therefore, towards sustainable landscape development.

Samenvatting

De mens beheert en verandert het landschap om diverse producten en diensten te verkrijgen en te versterken. Deze producten en diensten, landschapsdiensten genoemd, leveren een positieve bijdrage aan de maatschappij. Interacties tussen sociale (menselijke) en ecologische (natuurlijke) systemen maken de voorziening van Landschapsdiensten mogelijk. In het landschap zijn er synergiën en conflicten tussen diensten, waardoor keuzes gemaakt moeten worden, oftewel we hebben te maken met trade-offs tussen diensten. De interactie tussen de systemen, samen met de ruimtelijke verwevenheid van de diensten zorgen voor hoge complexiteit. Kaarten van landschapsdiensten kunnen deze complexiteit, of een deel daarvan, helder weergeven en daardoor bijdragen aan een beter begrip van de interacties en bijkomende trade-offs. Dit begrip helpt ons bij het voorkomen van conflicten tussen diensten en geeft ons betere mogelijkheden om gewenste diensten te versterken. Voornamelijk ruimtelijke planners en beleidsmakers hebben veel baat bij deze informatie. Geschikte kaarten van landschapsdiensten zijn daarom van groot belang. Methoden om landschapsdiensten goed in kaart te brengen zijn nog volop in ontwikkeling en zijn momenteel vaak nog niet adequaat genoeg. Om deze kaarten verder te ontwikkelen hebben we kennis nodig over de ruimtelijke relatie tussen landschapsdiensten en landschappelijke elementen. Meer onderzoek is nodig naar deze ruimtelijk relaties om zodoende landschappelijke elementen te identificeren die kunnen fungeren als indicatoren voor het karteren van landschapsdiensten. Om ervoor te zorgen dat de kaarten bruikbaar en waardevol zijn voor ruimtelijk planners is het van belang om samen met hen kennis te genereren en methoden te ontwikkelen. In de praktijk wordt dit nog zelden gedaan. Door gebruik te maken van geïntegreerde participatieve methoden kan kennis gecoproduceerd worden, waardoor deze kennis relevant is voor zowel de wetenschap als voor de praktijk. De doelstelling van dit proefschrift is het analyseren en in kaart brengen van de ruimtelijke distributie van landschapsdiensten en het integreren van methoden en kennis van ruimtelijke planning uit de praktijk en de wetenschap.

In hoofdstuk 2 is een empirische methode ontwikkeld om landschapsdiensten te identificeren en in kaart te brengen. Voor de gemeenten Deurne en Asten in de provincie Noord-Brabant in Nederland zijn de landschapsdiensten moerashabitat, bosrecreatie, grondgebonden veehouderij en wandelrecreatie in kaart gebracht. Met behulp van veldwerk zijn voor 389 locaties de landschapsdiensten geïdentificeerd. Voor deze locaties zijn correlaties tussen de aanwezige landschapsdiensten en landschappelijke elementen (zoals hoogteligging, bodemtype en type weg) binnen een radius van 0, 50 en 100 meter berekend om zo ruimtelijke indicatoren te identificeren die gebruikt kunnen worden voor het karteren van de diensten. De betrouwbaarheid van kaarten is geëvalueerd met behulp van kruisvalidatie. De ruimtelijke indicatoren voor bosrecreatie leverden een betrouwbare kaart op. De indicatoren voor grondgebonden veehouderij en wandelrecreatie waren minder betrouwbaar. De kaarten voor bosrecreatie en moerashabitat waren zeer accuraat. De vier landschapsdiensten overlapten nauwelijks in het landschap. Toch komen bepaalde landschapsdiensten vaker samen voor binnen een km^2. De methode die is ontwikkeld bleek bruikbaar voor diverse landschapsdiensten en vormt een fundamentele basis voor het bepalen van de ruimtelijke verdeling van diensten.

In hoofdstuk 3 is een ruimtelijke analyse gemaakt van de grondwaterkwaliteit in relatie tot landschappelijke elementen, landgebruik en landschapsdiensten. De studie is uitgevoerd voor het zuidelijk zandgebied in de regio de Peel in Nederland. De kwaliteit van het grondwater wordt beïnvloed door menselijk gebruik van het landschap, zowel door commercieel agrarisch gebruik waar veel onderzoek naar wordt gedaan, als door ander landgebruik waar weinig onderzoek naar wordt verricht. Wij hebben de waterkwaliteit bepaald door het nitraatgehalte in het bovenste grondwater te analyseren voor de landschapsdiensten voedselproductie, wonen en andere diensten (zoals hobbyboeren, veldsporten en camping toerisme). We hebben hiervoor gebruik gemaakt van veldbemonstering, bestaande monitoringsprogramma’s en literatuur. De resultaten tonen aan dat op landschapsschaal de limiet van 50 mg $NO_3^- \ l^{-1}$, vastgesteld in de EU Nitraatrichtlijn, wordt overschreden. Voedselproductie bleek de voornaamste bron van nitraatuitspoeling, hoewel ook hoge concentraties werden gevonden voor andere landschapsdiensten, voornamelijk voor camping toerisme. Gemiddeld overschreden de andere landschapsdiensten de limiet van de EU richtlijn niet. De ruimtelijke variatie tussen landschapsdiensten, maar ook binnen een landschapsdienst en zelfs binnen een veld, was groot. Deze ruimtelijke variatie kan belangrijke implicaties inhouden voor beleidsinvoering van limiet waarden. Voor drinkwatervoorziening zijn geaggregeerde waarden het meest relevant, terwijl voor waterorganismen lokale waarden het belangrijkst zijn.

In hoofdstuk 4 hebben we het verschil tussen een academische benadering en een benadering uit de praktijk van de ruimtelijke planning voor het karteren van landschapsdiensten geanalyseerd en de mogelijkheden geëvalueerd om de twee benaderingen te integreren. Voor twee studiegebieden zijn zeven landschapsdiensten (boshabitat, beekdalhabitat, culturele esthetiek, ecologische verbindingszone, waterberging en intensieve en extensieve recreatie) onafhankelijk in kaart gebracht door zowel lokale ruimtelijke planners als door academici. Beide benaderingen zijn uitgelegd en bediscussieerd gedurende twee interactieve bijeenkomsten en in een derde bijeenkomst zijn mogelijkheden voor integratie geëxploreerd. De belangrijkste verschillen bleken de focus, de ruimtelijke indicatoren voor karteren en het proces. Over het algemeen kwamen de kaarten voor 71% overeen. De grootste overeenkomst was tussen de kaarten van boshabitat (94%) en de kleinste overeenkomst was bij culturele esthetiek en extensieve recreatie (45%). Beide benaderingen beginnen met het evalueren van biofysische aspecten van het landschap. De academische benadering baseerde de locatie van de landschapsdiensten op gekwantificeerde relaties met de biofysische aspecten, terwijl de ruimtelijke planners de biofysische aspecten gebruikte als basis, maar ze niet specifiek relateerde aan landschapsdiensten. Daarnaast speelden sociale aspecten een grote rol in de benadering van de ruimtelijke planners. Er bleken mogelijkheden voor integratie van de benaderingen, waarvoor een voorstel wordt gegeven. Deze studie geeft aan dat kaarten van landschapsdiensten potentieel een waardevolle toevoeging zijn voor ruimtelijke planning.

In hoofdstuk 5 zijn samen met lokale ruimtelijke planners twee scenario's ontwikkeld om mogelijke toekomstige ruimtelijke ontwikkelingen van diverse landschapsdiensten te verkennen. Met behulp van participatieve methoden, zowel workshops als consultatie bijeenkomsten, hebben we voor 2025 twee scenario's ontwikkeld voor de regio de Peel in Nederland. In totaal participeerden twaalf lokale ruimtelijke planners en zeven lokale experts. Gedurende de eerste workshop kozen de participanten voor twee tegenovergestelde scenario's om zo inzicht te krijgen in zeer verschillende mogelijke ontwikkelingen. Voor beide scenario's werden verhaallijnen ontwikkeld, die door experts op het gebied van landbouw, recreatie, natuur en water werden verrijkt. Met behulp van deze kwalitatieve scenario's werden ruimtelijke indicatoren bepaald om de landschapsdiensten intensieve en extensieve voedselproductie, intensieve en extensieve recreatie, waterkwaliteit en waterberging in kaart te brengen. Tijdens de tweede workshop werden de kaarten bediscussieerd en aangepast. Huidige beleidsstrategieën werden met behulp van de verhaallijnen en kaarten geëvalueerd. Van de 18 strategieën waren er 12 voor beide scenario's potentieel geschikt bevonden. De ruimtelijke scenario's hebben meer inzicht gegeven in synergiën en trade-offs tussen landschapsdiensten en in de consequenties van keuzes in ruimtelijke plannen. De ruimtelijke planners vonden de scenario benadering relevant en bruikbaar en zijn geïnteresseerd in het verder ontwikkelen van deze methode.

In hoofdstuk 6 worden de onderzoeken uit de vier hoofdstukken samengebracht en hun bijdrage aan de doelstelling van dit proefschrift geëvalueerd. Ik heb vier hoofdconclusies getrokken uit mijn studie. 1) Kaarten van landschapsdiensten versterken de communicatie tussen academici en ruimtelijke planners uit de praktijk, en andersom, communicatie tussen academici en ruimtelijke planners uit de praktijk versterkt de ontwikkeling van kaarten van landschapsdiensten. 2) Kaarten van landschapsdiensten zijn vaak nog niet betrouwbaar, daarom moet de wetenschap zich meer inzetten op het verbeteren van de kwaliteit van de kaarten, in plaats van focussen op de toepassing. 3)

Het landschap is een geschikt domein voor integreerde analyse van ecologische en sociale aspecten en de bijbehorende voorziening van landschapsdiensten. In het bijzonder, culturele esthetiek kan alleen correct worden gekarteerd op landschapsniveau. 4) Tot slot, het begrip van de ruimtelijke distributie van landschapsdiensten kan een belangrijke ontwikkeling zijn om interactie met de planningspraktijk te bevorderen en zodoende een belangrijke stap richting duurzame landschapsontwikkeling.

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Curriculum Vitae

Monique Gulickx was born on May 26, 1981 in Tilburg, The Netherlands. She attended secondary school at Northgo College in Noordwijk, The Netherlands, where she obtained her HAVO degree in 1998. Of her many interests she decided to enrol in the BSc Landscape Management at the Applied Agricultural University (HAS) in Delft. For her BSc thesis, conducted at the Government Service for Land and Water Management (DLG), she designed landscape plans for two farmland areas (7.5 ha and 15.5 ha) that were designated as a cultural and nature park, respectively. Both plans have been realised. In 2002, she obtained her BSc. degree.

After working as a trainee green manager at the municipality of The Hague for two years, she had a strong desire for more in-depth knowledge in natural processes. In 2004, she enrolled in the MSc. course Biology at Leiden University. She firstly focussed on animal behaviour, researching the influence of city noise on the song of the European Blackbird *Turdus merula* and the effects of social deprivation on social interactions in rhesus monkeys *Macaca mulatta*. Because she missed a link between people and the landscape in these studies, she turned her focus onto conservation biology. She extended her Masters with another research thesis at Cambridge University. Under supervision of Professor William S. Sutherland, she studied the effectiveness of conservation practices in both the United Kingdom and The Netherlands. She obtained her MSc. degree in 2007.

During and after her Masters she worked for the B&A Groep. As a Civil Society Development Coordinator, she organised and developed new initiatives concerning civil society issues in Amsterdam, The Netherlands.

In 2008, she started her PhD research at the Soil Geography and Landscape group, Wageningen University, resulting in this thesis.

Monique is interested in the intricate interactions between anthropogenic and natural systems. She is eager to take on the challenge to realise sustainable development of the landscape.

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PE&RC PhD Training Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC), which comprises of a minimum total of 32 ECTS (= 22 weeks of activities).

Writing of project proposal (4.5 ECTS)

- Land function as a prime aspect in assessing and modelling land change (2009)

Post-graduate courses (10.2 ECTS)

- I-GIS course: PE&RC (2009)
- Land dynamics: getting to the bottom of Mt. Kenya; PE&RC (2009)
- Ecosystem services: integrating science and practice; SENSE and ESP (2011)
- Integrating scientific research and policy with spatial data; ialeUK (2012)
- Introduction to R for statistical analysis; PE&RC (2012)

Invited review of (unpublished) journal manuscript (3 ECTS)

- Oryx – The International Journal of Conservation: understanding patterns of decline and extinction of the Eurasian Otter (2010)
- Agriculture, Ecosystems and Environment: landscape changes and accessibility in agricultural landscapes (2011)
- Agriculture, Ecosystems and Environment: impact of land degrading threats on ecosystem services (2012)

Deficiency, refresh, brush-up courses (2.1 ECTS)

- Spatial modelling and statistics (2009)
- Basic statistics (2010)

Competence strengthening / skills courses (1.8 ECTS)

- PhD Competence assessment; WGS (2009)
- Techniques for writing and presenting scientific papers; WGS (2010)
- PhD Career assessment; WGS (2012)

PE&RC Annual meetings, seminars and the PE&RC weekend (2.5 ECTS)

- PE&RC Introduction weekend (2009)
- PE&RC Day: intelligent communication (2009)
- Mini-symposium: how to write a world-class paper (2011)
- PER&RC Day: extreme life (2012)
- PE&RC Last year's weekend (2012)

Discussion groups / local seminars / other scientific meetings (5.1 ECTS)

- Symposium: how to design contributes to effective knowledge for sustainable landscape development; Land Use Planning, WUR (2009)
- Workshop: remote sensing of the environment; ESG, WUR (2009)
- Spatial methods; discussion group (2009-2012)
- Scaling and governance; discussion group (2009-2010)
- SENSE Research cluster XIII: does your research make sense; presented presentation (2011)
- Congres ondernemen met groen; KennisBasis IV, WUR (2011)
- Young ESG-event: op zoek naar de I-factor (2011)
- SENSE PhD Day research cluster XIII: ecosystem services as a contested concept; what is the reply to critics: presented presentation (2012)

International symposia, workshops and conferences (8.8 ECTS)

- Landscape functions in a changing environment; ialeUK, Brighton, UK (2010)
- Landscape ecology for sustainable environment and culture; IALE world, Beijing, China (2011)
- Ecosystem services: integrating science and practice; ESP, Wageningen, the Netherlands (2011)
- Landscape ecology: society and ecosystem services; ialeUK, Edinburgh, UK (2012)

Lecturing / supervision of practical's/ tutorials (3 ECTS)

- Multi-functional Land Use (LAD); 4 days (2009, 2010)
- Integrated Environmental Assessment (ESA); 2 days (2010)
- Tourism Geographies (SGL); 14 days (2012, 2013

Supervision of a MSc student; (3 ECTS)

- Relating landscape functions to groundwater quality; 10 days

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