Framework for indicator selection to assess effects of land management on ecosystem services

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ABSTRACT

Land management is an important factor that affects ecosystem services provision. However, interactions between land management, ecological processes and ecosystem service provision are still not fully understood. Indicators can help to better understand these interactions and provide information for policy-makers to prioritize land management interventions. In this paper, we develop a framework for the systematic selection of indicators, to assess the link between land management and ecosystem services provision in a spatially explicit manner. Our framework distinguishes between ecosystem properties, ecosystem functions, and ecosystem services. We tested the framework in a case study in The Netherlands. For the case study, we identified 12 properties indicators, 9 function indicators and 9 service indicators. The indicators were used to examine the effect of land management on food provision, air quality regulation and recreation opportunities. Land management was found to not only affect ecosystem properties, but also ecosystem functions and services directly. Several criteria were used to evaluate the usefulness of the selected indicators, including scalability, sensitivity to land management change, spatial explicitness, and portability. The results show that the proposed framework can be used to determine quantitative links between indicators, so that land management effects on ecosystem services provision can be modelled in a spatially explicit manner.

Keywords:

Ecosystem services, indicators, land management, milk production, air quality regulation, recreation

Introduction

Ecosystems provide humans with numerous benefits, such as clean water, medicines, food, and opportunities for recreation. The Millennium Ecosystem Assessment (2005) highlighted the importance of these ecosystem services for sustaining human well-being. The Economics of Ecosystems and Biodiversity study (TEEB 2010) provided insight in the economic significance of ecosystems. As a result, the ecosystem services concept has now gained importance at the policy level, illustrated by the establishment of the International science-policy Platform on Biodiversity and Ecosystem Services (IPBES), and the incorporation of ecosystem services in the 2020 targets set by the 10th Conference of Parties to the Convention on Biological Diversity (Larigauderie and Mooney 2010, Mace et al. 2010).

Policy and environmental planning decisions largely influence how land is being managed (Fisher et al. 2008, Carpenter et al. 2009, Von Haaren and Albert 2011). On a regional scale, land management is one of the most important factors that influence the provision of ecosystem services (Ceschia et al. 2010, Fürst et al. 2010b, Otieno et al. 2011). Land management is defined by the presence of human activities, which affects land cover directly or indirectly (Kremen et al. 2007, Olson and Wäckers 2007, Verburg et al. 2009). It comprises ecosystem exploitation, land use management, and also includes ecosystem management (Brussard et al. 1998, Bennett et al. 2009). Land management refers to human activities; land cover to the biotic and abiotic components of the landscape, e.g. natural vegetation, forest, cropland, water, and human structures (Verburg et al. 2009). Land use refers to the purpose of human activities to make use of natural resources, thereby impacting ecological processes and functioning (Veldkamp and Fresco 1996). Land management includes but does not equal ecosystem management, because ecosystem management only refers to managing an area so that ecological services and biological resources are conserved, while sustaining human use (Brussard et al. 1998, MA 2005). Examples of land management include irrigation schemes, tillage, pesticide use, nature protection and restoration (Follett 2001, Bennett et al. 2009, Blignaut et al. 2010, Carvalho-Ribeiro et al. 2010, Ngugi et al. 2011).

The analysis of ecosystem services to support land management decisions faces a number of challenges. They include: (1) identifying comprehensive indicators to measure the capacity of ecosystems to provide services; (2) dealing with the complex dynamics of the link between land management and ecosystem services provision; (3) quantifying and modelling the provision of ecosystem services by linking ecological processes with ecosystem services; and (4) accounting for the multiple spatial and temporal scales of ecological processes and ecosystem services provision (Turner and Daily 2008, Carpenter et al. 2009, Van Strien et al. 2009, Villa et al. 2009, De Groot et al. 2010b, Bastian et al. 2012).

Given these challenges, it is necessary to have a consistent and comprehensive framework for analysing ecosystem services (Ostrom 2009, Posthumus et al. 2010). A framework provides structure to the research and enables better validation of its outcomes (Bockstaller and Girardin 2003, Niemi and McDonald 2004). Furthermore, it is important to formulate a comprehensive set of indicators (Niemeijer and de Groot 2008, Layke et al. 2012) that enables the assessment of land management effects on ecosystem services provision, on different spatial scales (Carpenter et al. 2009, Van Strien et al. 2009, De Groot et al. 2010b). With indicators, policy-makers and land managers can be provided with information, based upon which interventions can be identified, prioritized and executed (OECD 2001, Layke 2009). Finally, there is a need to test how ecosystem services frameworks can be used for the selection of indicators (Nelson et al. 2009).

The objective of our study was, therefore, to systematically select indicators which can be used to analyse the link between land management and the provision of ecosystem services at multiple scales. To achieve this objective we developed a consistent framework for indicator selection, which builds on existing frameworks, in particular the ones by TEEB (De Groot et al. 2010a) and Haines-Young and Potschin (2010).

We first describe our framework and how it can be used for indicator selection. We then apply it to a case study to assess the effect of land management on ecosystem services provision. Characteristics of and interactions between indicators were studied, and all indicators were evaluated based on a selected set of criteria. The case study was done in a multifunctional rural landscape in the southern part of the Netherlands, where multiple ecosystem services are provided across different spatial scales.

Methods

Framework

Consistent and comprehensive frameworks that link human society and economy to biophysical entities, and include impacts of policy decisions, have been developed during the last decades. For the analysis of ecosystem services such a framework was developed in the context the Millennium Ecosystem Assessment (MA 2003), which was itself based on a Driver, Pressure, State, Impact, Response (DPSIR) framework. We adapted the frameworks by TEEB (De Groot et al. 2010a) and Haines-Young and Potschin (2010) for indicator selection. These are among the most recent and comprehensive ecosystem services assessment frameworks. The TEEB framework explains the link between biodiversity, ecosystem services and human well-being (De Groot et al. 2010a) and builds on several recent studies (MA 2003, Braat et al. 2008, Fisher et al. 2008, Fisher et al. 2009). The TEEB-study calls for the development of indicators for the economic consequences of biodiversity and land use change (De Groot et al. 2010a, Reyers et al. 2010). The stepwise so-called “cascade-model” by Haines-Young and Potschin (2010) is useful for assessing the provision of ecosystem services in a structured way, linking ecosystem properties to functions and services. Although the importance of land management is acknowledged in (descriptions of) both frameworks, land management is not explicitly included. We therefore adapted the framework by including land management, which enables the selection of indicators for assessing the effects of land management and ecosystem services.

Figure 2.1 shows the main elements of our framework: the driving forces, ecosystem, service provision, human well-being, and societal response. The emphasis of our study is indicated by the white boxes in Figure 2.1: land management, ecosystem properties, function and service. Unless stated otherwise, definitions and relations provided are based on or adapted from the TEEB-study (De Groot et al. 2010a). In the framework we use the term “ecosystem”. We note, however, that the interactions which we describe below can refer to ecosystems at multiple spatial scales, e.g. at plot, landscape, regional or even national scale (Hein et al. 2006).

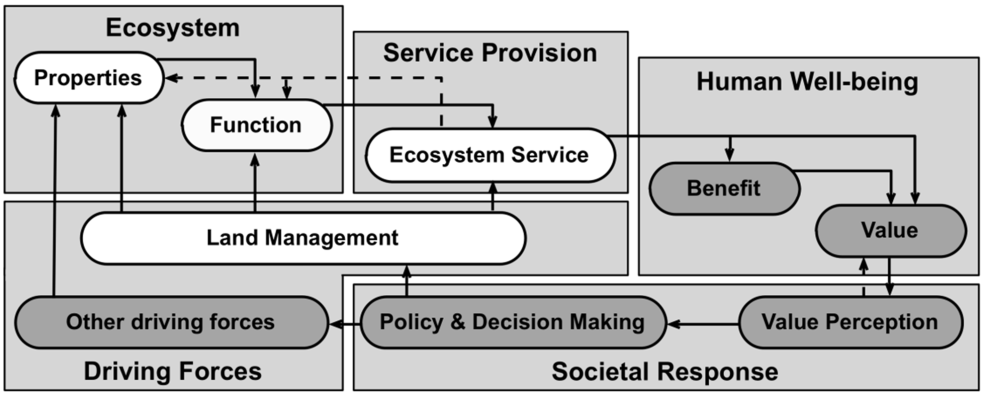

Figure 2.1: Framework for assessing links between land management, ecosystem services provision, and human well-being. Based on Haines-Young and Potschin (2010), Kienast et al. (2009), De Groot et al. (2010a), and Hein (2010). The white boxes indicate the scope of our study. Solid arrows indicate effects; dashed arrows indicate feedbacks.

Drivers or driving forces are natural or human-induced factors which can influence the ecosystem, either directly (e.g. through climate change or environmental pollution) or indirectly (e.g. through changes in demography or economy) (MA 2005). Although drivers such as climate change or environmental pollution have an impact on the ecosystem, we focus in our assessment on the driving force “land management”. As described earlier, land management are the human activities that can affect ecosystem properties and function (Kremen et al. 2007, Chen et al. 2011, Bastian et al. 2012), as well as the ecosystem service that can be provided (O'Farrell et al. 2007, Edwards et al. 2011). Ecosystem properties are the set of ecological conditions, processes and structures that determine whether an ecosystem service can be provided. Examples include net primary productivity (NPP), vegetation cover, and soil moisture content (Johnson et al. 2002, Kienast et al. 2009). Ecosystem properties underpin ecosystem functions, which are the ecosystem’s capacity to provide the ecosystem service (De Groot et al. 2010a). An ecosystem function, or “potential” (Bastian et al. 2012), is the subset of ecosystem properties which indicates to what extent an ecosystem service can be provided. Examples of ecosystem functions include capturing of aerosols by vegetation (Nowak et al. 2006) and carbon sequestration (Díaz et al. 2009). The ecosystem service contributes to human well-being, for example cleaner air and reduced climate change. The benefit is the socio-cultural or economical welfare gain provided through the ecosystem service, such as health, employment and income. Finally, actors in society can attach a value to these benefits. Value refers to importance, and is most commonly defined as the contribution of ecosystem services goals, objectives or conditions that are specified by a user (Costanza 2000, Farber et al. 2002).

The value perception can trigger changes in policy- and decision-making, for instance when certain services or resources are not available or too expensive. Alternatively, value perception can influence the ecosystem service value, for instance through increasing demand for a certain product. Policy- and decision-making form preconditions, constraints and incentives for land management and other drivers (Daily et al. 2009, Fisher et al. 2009).

Indicator selection and evaluation

To operationalize the framework for indicator selection, it is important to select indicators that provide accurate information on all main aspects of ecosystem services provision: land management, ecosystem properties, function, and service (Figure 2.1). To be able to evaluate the usefulness of indicators for our purpose, we compiled a set of criteria. First, we assembled general criteria for indicators, based on information from ecological assessments. We found that the selection process of indicators should be flexible and consistent, and that indicators should be comprehensive and understandable to multiple types of end users. A flexible, yet consistent selection process implies that multiple frameworks can be used, depending on the scope and aim of the assessment (Niemeijer and de Groot 2008). A test for comprehensiveness evaluates whether the whole set of indicators would provide complete and consistent information, which relates to the specific research question (Niemi and McDonald 2004). Considering that information should be communicated among scientists and other stakeholders, indicators need to be clear and understandable in order to be useful to these multiple end-users (Niemeijer and de Groot 2008, UNEP-WCMC 2011).

We also looked for criteria that were more specific for indicators for ecosystem services. We found that indicators need to be sensitive to (changes in) land management, temporally and spatially explicit, scalable, and quantifiable. These criteria apply both to individual indicators as well as sets of indicators and ensure that the indicators can be used for quantification and modelling purposes. Furthermore, indicators should provide information about causal relationships between land management and changes in ecosystem properties and function (Riley 2000, De Groot et al. 2010b). Temporal and spatial explicitness refers to whether trends can be measured and mapped over time, and whether relations between indicators can be linked to specific locations, for instance through mapping and GIS analyses (NRC 2000). An indicator is considered scalable if it could be aggregated or disaggregated to different scale levels, without losing the sense of the indicator (Hein et al. 2006). Quantifiable indicators ensure that information can be compared easily and objectively (Schomaker 1997, Layke et al. 2012).

Finally, we considered data availability, credibility, and portability as other criteria. Data availability is especially essential if information are compared among different studies (Layke et al. 2012). Indicators should also provide credible information. This criterion tests whether indicators actually convey reliable information (Layke et al. 2012). Portability refers to the question whether indicators are repeatable and reproducible in other studies, and across different regions (Riley 2000).

Case study: Indicator selection and evaluation for "Het Groene Woud", The Netherlands

We applied the framework for the selection of indicators for nine ecosystem services in a rural area in the south of The Netherlands (Box 1). First, we focused on interactions between indicators for ecosystem properties, function and service. Secondly, we assessed the effect of land management on the provision of three ecosystem services. For both steps of the case study, we evaluated the indicators using the criteria as introduced in the previous section.

Box 1: Study area description

"Het Groene Woud" (~330 km^2) is located in the southern part of The Netherlands (Figure 2.2), amidst three densely populated cities: Eindhoven (216000 inhabitants), ʼs-Hertogenbosch (140000), and Tilburg (200000) (CBS 2011). The area comprises extensively managed maize & grassland, rural settlements and patches of forest and heath lands (Figure 2.2). Due to its tranquillity, abundant forest patches and cultural historic elements, Het Groene Woud offers many recreation opportunities to inhabitants of surrounding cities (Het Groene Woud 2011). Moreover, agriculture has been an important economic activity in the area. A large part of the area is occupied by cropland (20%, mainly corn and wheat) and grassland (43%, dairy production) (De Wit et al. 1999, Kuiper and de Regt 2007). Finally, an increasing area is part of the Dutch Ecological Main Structure (EHS) and Natura 2000 network (Blom-Zandstra et al. 2010). Therefore, local biodiversity and the connectivity of the natural elements in those segments need to be protected and enhanced (Het Groene Woud 2011).

Het Groene Woud was declared a Dutch National Landscape in 2005, which resulted in the implementation of new policies to protect the area's unique cultural-historical and natural features (Het Groene Woud 2011). The main challenge for local policy-makers and managers lies in maintaining agricultural production while protecting biodiversity and increasing recreation opportunities (Petz and Van Oudenhoven 2012).

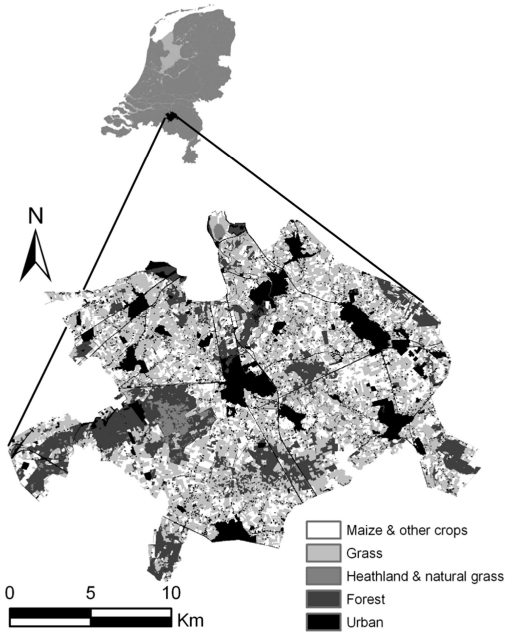

Figure 2.2: Map of case study area. "Het Groene Woud" is located in the southern part of The Netherlands (inset), between three large cities, situated north, west and south of the area. Land cover data by de Wit et al. (1999)

Indicator selection for ecosystem properties, function and service

We made an inventory of ecosystem services provided in het Groene Woud, and of the indicators that describe these services or describe relevant properties. For this, we conducted expert interviews and consulted scientific literature, policy documents, reports from local projects and organisations, brochures, and websites. The typology of the TEEB study (De Groot et al. 2010a) was used to categorise the ecosystem services. The selected ecosystem service types are, with the specific service for the study area between parentheses: food provision (dairy production), air quality regulation (fine dust capture), climate regulation (carbon sequestration), regulation of water flows (water retention), biological control (protection from pest insects), opportunities for recreation & tourism (walking), lifecycle maintenance (refuge for migratory birds), aesthetic information (green residential areas), and information for cognitive development (research and education).

We selected individual indicators for ecosystem properties, function and service for each selected ecosystem service, and determined qualitative relations between them. Examples of these qualitative relations include if and how vegetation characteristics affect water storage and fine dust capture, or relations between carbon stored in vegetation and change in atmospheric CO2 concentration. If insufficient information was available on the provision of ecosystem services in the area, we consulted literature on similar services in other case studies. Examples include air quality studies in other areas in The Netherlands (Wesseling et al. 2008) and in the UK, such as Glasgow (Bealey et al. 2007) and East England (Beckett et al. 2000).

Linking indicators for land management and ecosystem services

To analyse the relation between land management and ecosystem services, we studied three services in detail: dairy production, fine dust capture, and opportunities for recreation. For each service, we focused on the role of land management factors as well as relations (including feedbacks) between ecosystem properties, function and service. These relations were also determined qualitatively. There were several reasons for analysing three instead of all nine services. We considered it important to study an example each of provisioning, regulating and cultural services, to test whether the framework would enable the selection of a proper set of indicators for different ecosystem service categories. Moreover, the three services were identified as key services in the area (Blom-Zandstra et al. 2010, Het Groene Woud 2011). In addition, fine dust capture by vegetation is an understudied ecosystem service (Nowak et al. 2006), yet considered highly relevant in The Netherlands (Velders et al. 2007, Wesseling et al. 2008, Hein 2011).

After selecting indicators with management relevance, we studied how these could be linked to indicators for ecosystem properties, function and service. In addition, we looked at their spatial scales and also mapped the function indicators in order to spatially visualize the potential of the area for providing the service. We distinguished between landscape element, plot and landscape scale. We considered landscape elements such as individual trees, bushes, treelines or other physical structures of less than 1 km^2 that could be studied in isolation from the landscape (Grashof-Bokdam et al. 2009, Krewenka et al. 2011); we assumed plot scale to correspond with patches of land cover (e.g. forest or grassland) with a size of 1-10 km^2; and the entire study area (350 km^2) was assumed to be representative of landscape scale.

Results

Indicators for provision of multiple ecosystem services

Relevant indicators for the provision of nine ecosystem services in Het Groene Woud were selected. These ecosystem services were: dairy production, fine dust capture, carbon sequestration, water retention, protection from pest insects, refuge for migratory species, green residential areas, opportunities for walking, and research and education. We identified 12 key indicators for ecosystem properties, nine for functions, and also nine for service provision. An overview of these indicators is presented in Figure 2.3.

Indicators for ecosystem properties could be grouped into five categories, of which three are described as “natural properties” (soil, water, flora and fauna) and two as indicating “human presence” (land cover and landscape structure, and infrastructure). Examples of these human presence indicators include the degree of naturalness (also a measure of urbanisation), noise level (mainly caused by traffic), and number and extent of dairy farms. Function indicators were divided into four categories, in line with the ecosystem functions typology by De Groot et al. (2002) and as also used by Kienast et al. (2009). Function indicators refer to ecosystem’s capacity to provide a service, e.g. amount of water stored in vegetation, fine dust captured by vegetation, and the walking suitability of an area. Service performance indicators were grouped in accordance with the typology of the TEEB-study (De Groot et al. 2010a). These indicators refer to the actual service provision or use from which people benefit. Examples include milk production, change in ground water level, change in atmospheric fine dust concentration, and the number of walkers in an area.

The number of ecosystem properties indicators was highest. All functions depend on land cover and landscape structure, whereas vegetation characteristics influence all but the information and cultural functions. Indicators for ecosystem functions were found to depend on a large number of ecosystem properties and corresponding indicators. Indicators for regulating and habitat functions could be linked to many ecosystem properties indicators: water stored in vegetation to most (eight), followed by carbon stored in vegetation (six), fine dust captured by vegetation (four), and natural predators abundance (four). To each ecosystem function indicator one service indicator was assigned. Therefore, the number of service indicators corresponds with the number of function indicators.

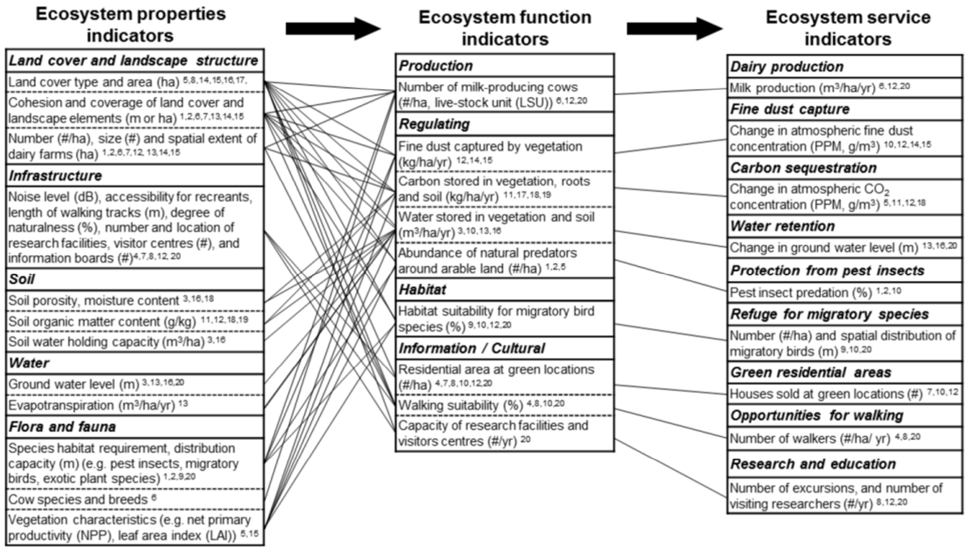

Figure 2.3: Overview of key properties, function and service indicators for nine ecosystem services in the Groene Woud. Units are given between parentheses. Lines indicate linkages between individual indicators. Typology of indicators is based on De Groot (1992), Kienast et al. (2009) and De Groot et al. (2010a).

Sources: [1] Baveco and Bianchi (2007); [2] Bianchi et al. (2008, 2009); [3] De Vries and Camarasa (2009); [4] De Vries et al. (2007); [5] Foley et al. (2005); [6] Naeff and Smidt (2009); [7] Goossen and Langers (2000); [8] Goossen et al. (1997); [9] Grashof-Bokdam and Langevelde (2005); [10] Kienast et al. (2009); [11] Kuikman et al. (2003); [12] Layke (2009); [13] Mulder and Querner (2008); [14] Oosterbaan et al. (2006); [15] Oosterbaan et al. (2009); [16] Querner et al. (2008); [17] Schulp et al. (2008); [18] Schulp and Verburg (2009); [19] Pulleman et al. (2000); [20] Website "Groene Woud" (Accessed on January 20th, 2011, URL: www.groenewoud.com).

Effect of land management on ecosystem properties, function and service: example for three ecosystem services

Food provision: dairy production

Management for dairy production affects ecosystem properties, function and service provision (Figure 2.4). Application of pesticides and nutrients, the first land management indicator in Figure 2.4, influences several ecosystem properties. For instance, the net primary productivity (NPP) of grass can be enhanced by applying fertilizers (Jangid et al. 2008, Batáry et al. 2010). Veterinarian measures can influence the cows' milk producing capacity through disease prevention and additional feeding. Mechanisation can affect the area of grassland and farm size that is required for milk production. Moreover, mechanisation can alter the grass properties through mowing; the milk producing capacity of the cows through more efficient feeding; and the milk production through mechanised milking.

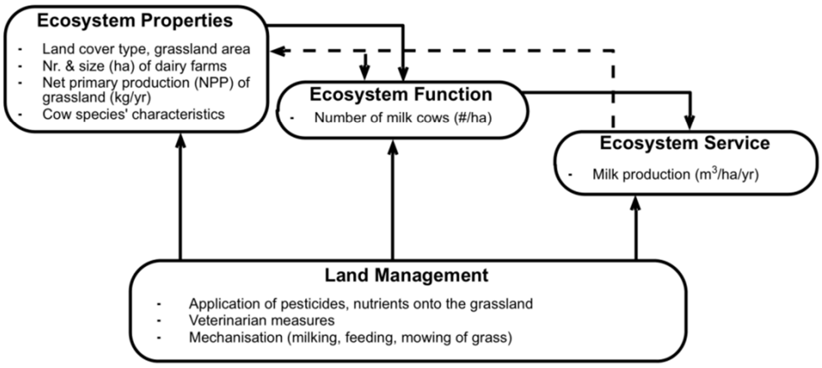

Figure 2.4: Framework with indicators for land management, ecosystem properties, function, and services, for the provisioning service milk production. Arrows indicate direct linkages between the boxes; the dashed line indicates feedback.

The number of milk cows (function indicator) is not only influenced by management, but also by ecosystem properties. The land cover type as well as the size and number of dairy farms influence how many cows can graze on how much land. Milk production is influences by the cows' characteristics and NPP of grass influence, which in turn also determines the required grassland area. The milk production (service indicator) is directly related to the number of cows. However, milk production can also influence the ecosystem function and properties. For instance, if the (targeted) milk production is too high, the number of cows and the area of grassland would have to be altered. This would require either more nutrient application and mechanisation, increasing the number of cows or area of grassland, or lowering the milk production.

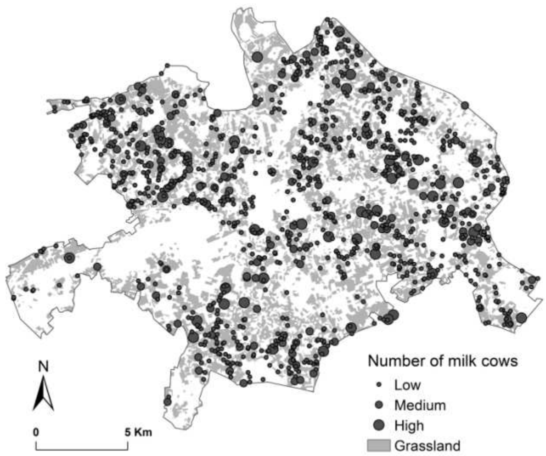

Figure 2.5: Map of the Groene Woud, indicating where the service milk production can be provided. The service indicator number of milk cows (dots) and function indicator area of grassland (light grey) were mapped. Land cover data by de Wit et al. (1999), milk cow data by Naeff and Schmidt (2009).

The service dairy production is provided on grassland, which at the moment covers about 60% of the study area (Figure 2.5). The highest numbers of cows (function indicator) are kept in the northwest, south and east, but generally these numbers are evenly distributed over the area. The actual service performance can be measured on plot (grassland) and landscape (entire area) scale, as its spatial pattern follows the allocation of the grassland across the landscape. Only a few parts of the area are at the moment not used for dairy production. They include forest patches and urbanized areas.

Air quality regulation: fine dust capture

The key management action that influences the fine dust concentration (Figure 2.6) involves selecting the location and planting (species choice) as well as maintaining forest plots and woody elements (Beckett et al. 2000, Oosterbaan et al. 2006, McDonald et al. 2007). Woody elements are forest patches and tree rows. For example, on a yearly basis coniferous tree species can capture twice as much fine dust as deciduous tree species (Oosterbaan et al. 2009). Vegetation characteristics such as leaf area and hairiness determine the deposition speed onto and therefore the capture of fine dust by vegetation (Beckett et al. 2000, Oosterbaan et al. 2009). Spatial planning is important because the distance between woody elements and fine dust emission sources (such as roads, intensive agriculture, and cities) determines the woody elements' capacity to capture fine dust (function indicator) (Tonneijck and Swaagstra 2006).

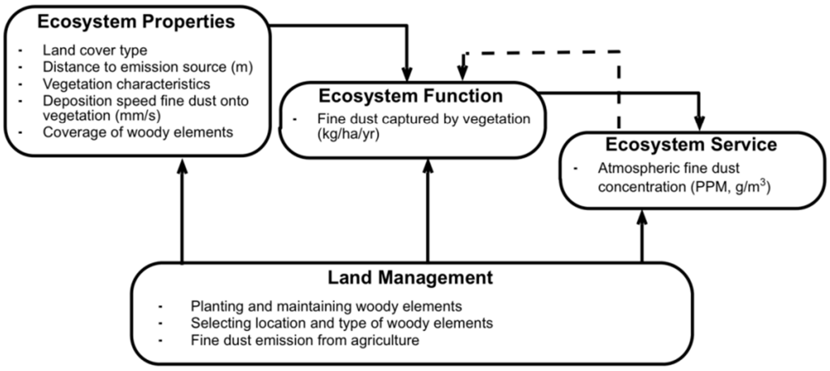

Figure 2.6: Framework with indicators for land management, ecosystem properties, function, and service, for the regulating service fine dust capture. Solid arrows indicate direct linkages between the boxes; the dashed line indicates feedback.

Intensive agriculture together with traffic are the main fine dust emission sources in the Groene Woud (Oosterbaan et al. 2009). Local emission directly influences the amount of fine dust that can be captured by vegetation (Nowak and Crane 2000, Nowak et al. 2006), and naturally causes a change in atmospheric fine dust concentration (service indicator). On locations where concentrations are higher, e.g. "point sources" such as pork stables, vegetation can capture more fine dust than on other locations. The amount of fine dust captured by vegetation (function indicator) results in a change in atmospheric fine dust concentration (service).

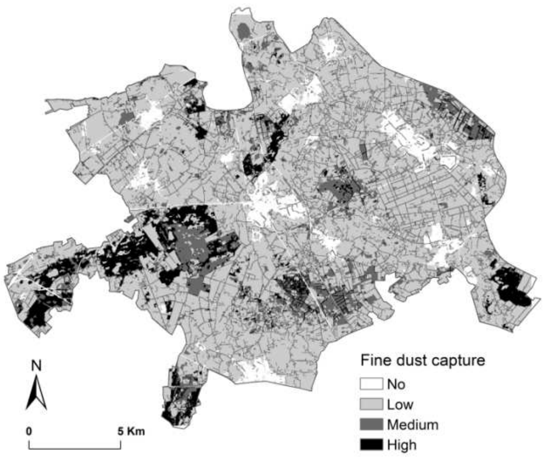

Figure 2.7: Map of the Groene Woud, indicating where the service fine dust capture can be provided. The function indicator "fine dust capture" was mapped, based on the capacity of land cover, land use, and woody elements to capture fine dust. Forest areas (black) have a higher capacity to capture fine dust than other types of land cover. Air quality information by Oosterbaan et al. (2009), land cover data by de Wit et al. (1999).

There are large differences in capacity of land cover types to capture fine dust, and therefore deciding on the location and extent of land cover can have a large influence on fine dust concentration. Forests and woody elements have a higher capacity to capture fine dust than all other types of land cover. Moreover, adding or maintaining woody elements can further increase the area's total capacity, as is shown in Figure 2.7. Fine dust capture can be measured on the landscape element (e.g. tree-rows), plot (forest patch) and landscape scale (entire area). Figure 2.7 shows the spatial pattern of woody elements and forest plots across the landscape in the Groene Woud area. It can be seen that all areas except those with urban infrastructure (white on the map) contribute to the capture of fine dust in the area.

Opportunities for recreation: walking

Managing the Groene Woud area to improve walking opportunities influences the area's ecosystem properties and functions (Figure 2.8). Developing and maintaining nature reserves, parks and green areas influences the area's degree of naturalness. It can also increase the length of walking tracks and the accessibility (Goossen and Langers 2000). Protecting and maintaining historical landscape elements improves the historical distinctiveness of the area (Edwards et al. 2011, Het Groene Woud 2011). Finally, improving the accessibility of rural landscapes and nature areas determines whether walkers can actually visit the areas (De Vries et al. 2007). Many walkers prefer to visit locations where parking space, route indication, walking routes and information boards are available (Goossen and Langers 2000, De Vries et al. 2007).

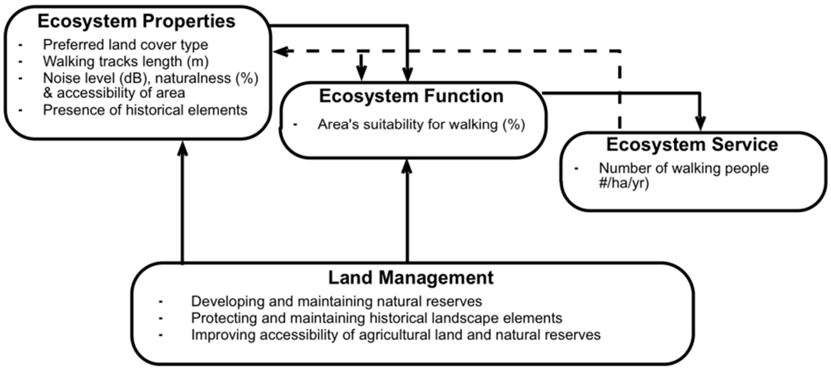

Figure 2.8: Framework with indicators for the land management, ecosystem properties, function, and service boxes, for the cultural service opportunities for walking. Arrows indicate direct linkages between the boxes; dashed lines indicate feedbacks.

The area's suitability for walking (function indicator) can be improved by designating separate areas for walking. However, the suitability mainly depends on the area's properties, such as land cover preference, accessibility, the length of walking tracks, the naturalness, the noise level and the presence of historic elements in the area (Goossen et al. 1997). Land cover types that are preferred by walkers are forest or heath land over arable land, grassland or urban areas (Goossen and Langers 2000). The diversity of land cover is also highly appreciated by walkers (Van den Berg et al. 1998, De Vries et al. 2004).

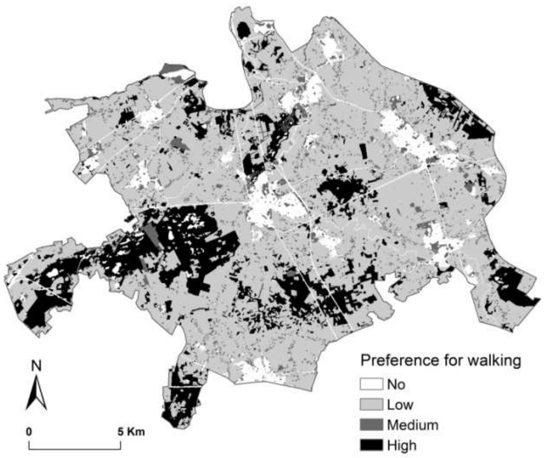

Figure 2.9: Map of the Groene Woud, indicating where the service opportunities for walking can be provided. The properties indicator preferred land cover type for walking was mapped. Forest areas (dark) are preferred most by walkers, compared to agricultural area (grey) and urban area (white). Recreation preference information by Goossen and Langers (2000), land cover data by de Wit et al. (1999).

The actual service performance can be measured by the number of walkers (service indicator), which is directly related to the walking suitability. Naturally, an area with higher suitability is more likely to attract larger numbers of walkers (Goossen and Langers 2000, De Vries et al. 2004). At the same time, too many walkers can influence the function and properties, for instance through increased noise level and loss of naturalness (Van den Berg et al. 1998). Forest and areas with high land cover diversity are preferred the most for walking (Figure 2.9). This land cover preference (properties indicators) can be measured on plot (e.g. forest patch) and landscape (entire region) scale. The map also indicates the distance from cities to potential walking areas. The majority of the area is either highly suitable or not suitable at all for walking.

Discussion

Methods: framework & indicator selection

In this paper we presented a framework to analyse effects of land management on ecosystem services. The framework elements (driving forces, ecosystem, service provision, human well-being and societal response) basically follow the DPSIR approach (Driving forces, Pressure, State, Impact, Response), which was also used by Braat et al. (2008), Niemeijer and De Groot (2008), Layke et al. (2009), and others. However, our framework enables the assessment of how land management can affect ecosystems ("state"), and their services and human well-being ("impact"). These are two subjects of which ecosystem assessments face most scientific challenges (ICSU-UNESCO-UNU 2008, Carpenter et al. 2009).

To clarify the distinction between "state" and "impact", Kienast et al. (2009) adapted the "cascade model" from Haines-Young and Potschin (2010) and defined the meaning of the terms "landscape function" and "ecosystem services". The stepwise "cascade-model" was also referred to by Bastian et al. (2012) and De Groot et al. (2010a, 2010b), but to our knowledge, the framework we present is a first actual application focused on the biophysical aspects and underlying management effects that matter for the provision of ecosystem services. Our framework enables this analysis in a structured and stepwise manner, avoiding the confusion between ecosystem properties, functions and services and thereby also avoiding double-counting (Bateman et al. 2011). This specification is essential to link ecosystem service assessments to valuation studies (Farber et al. 2006). Some remaining challenges are briefly described below.

Flexibility and comprehensiveness

Ecosystem assessment frameworks should be flexible enough to be modified in line with the aim of the assessment (De Bello et al. 2009, Czúcz et al. 2011). Many studies have been carried out on impacts of land use on ecosystem services provision (Schröter et al. 2005, Fürst et al. 2010a, Richert et al. 2011, Barral and Oscar 2012) and on policy and land use planning in relation to ecosystem services (van Meijl et al. (2006), Fisher and Turner (2008), and Fürst et al. (2011). Incorporating their findings into the framework would be an important next step to make it more comprehensive. Specifying more detailed relationships between policy and other drivers would also allow for a more complete ecosystem services assessment.

Quantification of indicators

Establishing causal relationships is an import factor, when seeking to improve more accurate quantitative relationships (Lin et al. 2009). Our framework can help to determine quantitative relationships between the various steps of service provisioning, e.g. how does ecosystem functioning depend on ecosystem properties, how do ecosystem functions provide ecosystem services, and how to measure the benefits derived from ecosystem services? Quantified relationships could also provide input for more reliable and accurate mapping and modelling and for determining the value of ecosystem services.

Practical applicability

Indicators are important to understand how ecosystem services are provided, through both qualitative and quantitative links between the different steps. Initiatives like the Biodiversity Indicators Partnership (BIP[1]) and the World Resources Institute (WRI) ecosystem services indicators database (Layke 2009), as well as studies by Fisher et al. (2009) and others offer examples of frameworks for indicator selection and sets of ecosystem services indicators. However, practical guidelines to select multiple appropriate indicators, that can be used to both quantify and model ecosystem services provision, are still lacking (ICSU-UNESCO-UNU 2008, UNEP-WCMC 2011). A lack of robust procedures and guidelines for selecting indicators could decrease the validity of the information by the indicators (Dale and Beyeler 2001).

The criteria we used to evaluate indicators for land management and ecosystem services provision can be seen as a first step towards a more streamlined indicator selection procedure for ecosystem services. Many criteria stemmed from ecological studies (Dale and Beyeler 2001, Lin et al. 2009), but also recent studies focused more strongly on ecosystem services provided us with useful criteria (UNEP-WCMC 2011, Layke et al. 2012). The twelve criteria could be divided into criteria that help evaluating the indicator selection process, the practical aspects of ecosystem service assessments, the indicators' ability to convey information, and causal links between indicators.

Case study: applying the framework

In the first part of the case study, the complex relationships between ecosystem properties, functions and services were investigated. Each properties indicator could be linked to several ecosystem functions which shows the fundamental role of ecosystem properties in the provision of multiple ecosystem services. The indicators provided a comprehensive overview of the biophysical state and structural characteristics of the study area.

Function indicators proved to be a subset or combination of ecosystem properties indicators, as was earlier suggested by Kienast et al. (2009). Function indicators were more specific than properties indicators and corresponded to only one specific service indicator. Although function indicators generally provide information about service potentials, they were rarely similar to service indicators. However, they often had corresponding units. Properties

[1] www.twentyten.net. Accessed last August 6th, 2011

and function indicators, together also called state indicators, provide information on how much of a service an ecosystem can potentially provide in a sustainable manner (Layke 2009, De Groot et al. 2010b). Service indicators, also called performance indicators, provide information on how much of the service is actually provided and/or used (Fisher and Turner 2008, Layke 2009, De Groot et al. 2010b). For ecosystem services assessments, be it quantitative, mapping or modelling studies, it would be commendable to select at least one state and one performance indicator per studied ecosystem service (UNEP-WCMC 2011). It is also important to make the distinction between indicators for ecosystem function and for service.

Applying the framework to three different services (i.e. food provision, air quality regulation and recreation) illustrated that the linkages (including feedbacks) differ per ecosystem service. Indicators for land management related to land cover, nature protection, application of pesticides and mechanisation, among others. Interestingly enough, they also included indicators that go beyond “traditional” ecosystem management (Grumbine 1994). Results showed that land management can affect ecosystem services directly (food provision and air quality regulation) or indirectly through ecosystem properties and functions (air quality regulation and recreation). This underlines the importance of management (input) and the smaller contribution of nature’s capacity in the case of production of food. Moreover, management aimed at a certain function or service could have feedbacks on the properties that are fundamental for the provision of other services. Applying the framework and mapping of functions enabled us to see at which spatial scale services were provided and, additionally, at which spatial scale land management could affect the provision of these services. The consideration of multiple scales is important not only because service provision can occur at several scales, but also because the level of service provisioning and decision making might differ (Hein et al. 2006, Daily et al. 2009, Seppelt et al. 2012). The selected indicators could be linked to landscape element, plot, and landscape scale. Results showed that properties indicators and some function indicators could be linked to all three scales, whereas some function and all service indicators could only be linked to plot and landscape scales.

Our criteria can be used as guidelines to select and evaluate indicators. The evaluation of the indicators can be seen in Table 2.1. Although we did not test the indicators for usefulness to multiple end-users, quantification and modelling, and portability, we conclude that the selection procedure was sufficiently flexible and allowed for the selection of a consistent set of comprehensive indicators. Although some indicators (e.g. refuge for migratory species) were difficult to link to land management, the large majority was sensitive to changes in land management. All function indicators were or could be made temporally and spatially explicit, and many could be linked to one or more of the three spatial scales. The amount of available literature and other information indicates that the indicators are credible, i.e. provide reliable information. In general, indicators for ecosystem properties were found to be most difficult to fully comprehend and utilize, because fewer criteria were met. Especially habitat and cultural functions met only a few criteria. It can be expected that such indicators, which meet only a few criteria, will be difficult to utilize in ecosystem service assessments and mapping and modelling exercises.

Table 2.1: Evaluation of indicators that were identified in the case study. Indicators for ecosystem properties, functions and services (vertical) were evaluated using eight criteria. When it could not be reliably established if indicators met certain criteria, it was indicated by "unclear".

Criteria / Indicator type	Flexible selection process	Consi-stency	Compre-hensive	Sensitive to (..) land management	Temporarily explicit	Spatially explicit	Scalable	Credibility
Ecosystem properties indicators								
Land cover and landscape structure	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Infrastructure	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Soil	Yes	Unclear	Unclear	Unclear	Unclear	Yes	Yes	Unclear
Water	Yes	Unclear	Unclear	Yes	Yes	Unclear	Unclear	Unclear
Flora and fauna	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Yes	Yes
Ecosystem function indicators								
Production	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regulating	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes
Habitat	Yes	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes
Information / Cultural	Yes	Unclear	Yes	Unclear	Yes	Yes	Yes	Unclear
Ecosystem service indicators								
Milk production	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fine dust capture	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Carbon sequestration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water retention	Yes	Unclear	Unclear	Unclear	Unclear	Yes	Yes	Unclear
Protection from pest insects	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Unclear
Refuge from migratory species	Yes	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes
Green residential areas	Unclear	Unclear	Unclear	Unclear	Yes	Yes	Yes	Unclear
Opportunities for walking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Research and education	Yes	Unclear	Unclear	Unclear	Yes	Yes	Yes	Unclear

Perhaps an important criterion to further develop would be one that focuses on evaluating whether an indicator would be suitable as a property, function or service indicator. The set of indicators presented here, as well as the maps, could provide local decision-makers with useful information when developing regional management plans. Although the case study yielded indicators that could be relevant for other ecosystem services assessments, we point out that the indicators we found were specific to the area's policy needs, socio-economic situation and spatial configuration.

Conclusion

This paper describes a framework to select indicators to assess effects of land management on the provision of ecosystem services. The framework was tested in the Groene Woud area, a multi-functional landscape in the Netherlands. Our framework explicitly connects land management to ecosystem properties, functions and services. For the nine studied ecosystem services, we identified twelve key ecosystem properties, nine function and nine service indicators. Indicators for ecosystem properties that could be linked to each function were land use, land cover and landscape structure. Indicators for regulating and habitat functions could be linked to most ecosystem properties indicators. Furthermore, land management was found to affect ecosystem properties and functions, as was the case for three key ecosystem services in the study area: milk production, fine dust capture, and recreation),. In the case of food provision and air quality regulation, ecosystem services were also found to be affected directly by land management.

We conclude that the framework enables the flexible selection of indicators to analyse land management effects on ecosystem services at multiple scales. The criteria we used to evaluate the selected indicators can be seen as a step towards practical guidelines for indicator selection. We recommend that future ecosystem service assessments follow an equally structured methodology, and select at least one state and performance indicator per ecosystem service. The framework we presented in this paper is useful to better understand and quantify the interactions between land management, ecological processes and the provision of ecosystem services. Therefore, the framework can be used to determine quantitative links between indicators, so that land management effects on ecosystem services provision can be modelled in a spatially explicit manner.

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