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Land Function: origin and evolution of the concept

Abstract: In this paper we argue that the concept of land function (LF) is the result of a theoretical and conceptual evolution of other recent concepts such as ecosystem services, landscape functions and land use functions. A digest of this conceptual evolution is done through bibliographic review mainly of peer reviewed literature. The preliminary LF mapping and assessment methods are also addressed. This article attempts to justify the pertinence of the LF concept as a further level of analysis of land cover (LC) and land use (LU). Future developments of the theoretical framework of this concept are also proposed.

Keywords: Land Cover, Land Use, Ecosystem Services, Land Function.

Resumo: Neste artigo argumenta-se que o conceito "função do solo" (land function) é o resultado de uma evolução teórica e conceptual de outros conceitos recentes tais como "serviços dos ecosistemas" (ecosystem services) e "funções das paisagens" (landscape functions). Através da análise de literatura científica, é feita uma resenha desta evolução conceptual assim como uma análise dos primeiros esforços para quantificar e mapear as funções do solo. Justifica-se a pertinência deste conceito na medida em que se trata de um nível de análise adicional aos já existentes "cobertura e uso do solo". Finalmente, são propostos futuros desenvolvimentos do enquadramento teórico e conceptual desta temática.

Palavras-chave: Cobertura do Solo, Uso do Solo, Serviços dos Ecosistemas, Função do solo.

1. Land, Land Cover and Land Use

Up to now there have been references to the "functions of land" (for example by FAO/UNEP 1999), but only in more in recent years the concept of land functions (LF) has become more autonomous. Although linkages and dependencies with the cover and the use of land do exist, the term land function intends to refer to a further level of analysis of land. We will start by reviewing the fundamentals of land, land cover (LC) and land use (LU).

At least since the Convention to Combat Desertification (United Nations 1994) that FAO has been using the following broad and holistic definition of land:

> *Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface, climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.).* (FAO 1995)

FAO has also put forward a simple definition of land cover that is still nowadays widely accepted and used nowadays: "Land cover is the observed biophysical cover on the earth's surface" (Di Gregorio and Jansen 1998). It includes all types of vegetation and human structures that cover the land surface. If the concept is strictly considered, "areas where the surface consists of bare rock or bare soil are describing land itself rather than land cover. Also, it is disputable whether water surfaces are real land cover. However, in practice, the scientific community usually describes those aspects under the term land cover" (Di Gregorio and Jansen 1998). Land cover is thus directly observable "from various sources of observation at different distances between the source and the earth's surface": the human eye in the field, aerial photographs, and satellite sensors (Duhamel 1998).

As for land use, it has been recognized that an international agreement on the definition is still lacking, in spite of the attempts made since the 1960's (Jansen 2006). Jansen (2006: 129) states that "the term land use has different meanings across disciplines" and that those different perspectives may all be valid. According to Duhamel (1998), different definitions derive from two possible approaches: the *functional* and the *sequential*. According to the functional approach, land use corresponds to "the description of land in terms of its socio-economic purpose" (Duhamel 1998: 5). On the other hand, the sequential approach, adopted by FAO, defines land use as "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (Di Gregorio and Jansen 1998).

In any case, land use is not always directly observable. Due to the definitions above, land use includes aspects beyond the characterization of the biophysical cover of land. Identifying land use "requires socio-economic interpretations of the activities that take place" on earth's surface (Fisher *et al.* 2005: 86). Land use can often be inferred from simple observation of land cover but to identify some land uses, additional information regarding the human activities on land or the presence of specific elements in the landscape have to be taken into account. Obtaining this information may often require field visits and interviews.

Many factors determine land use. First of all, biophysical factors enhance or constrain land uses (climate, topography, soil, water). Cultural context, local traditions, institutional and political aspects also interfere (Cihlar and Jansen 2001; Jansen 2006) and, finally, demographic and economic dynamics may drive demand for particular services and commodities which in turn influence land use change.

It has been recognized that the relationship between land cover and land use is complex and usually many-to-many (Fisher *et al.* 2005; Bakker and Veldkamp 2008). "Grass, for example, is a land cover type which can occur in any number of land uses: sports grounds, urban parks, residential land, pasture, etc. At the same time, very few areas of homogenous land use have a single land cover; residential land, for example, may contain trees, grass, buildings and asphalt" (Fisher *et al.* 2005: 89). Although conceptual difference between LC and LU is clear, the relationship between both is strong: land use change is one of the proximate causes for land cover change (De Sherbinin 2002; Brown and Duh 2004). Bakker and Veldkamp (2008) underlined that a *primary land use* (or dominant land use) within a given area is closely related to land cover, affecting and controlling it. *Secondary land uses* may also coexist, but in most cases do not drive land cover change. This view of dominant and secondary land uses is in line with the issue of land multi-functionality. For example, a single patch of forest "may also be used for several forms of recreation, including hunting and hiking, and even for grazing" (Fisher *et al.* 2005: 89).

Contrary to the previous terms, the expression *land function* is more recent and not yet so established among scientists. Before the land function was intentionally used as an autonomous and stand-alone term, "functions of land" were mentioned, for example, by FAO/UNEP (1999). The cited functions of land were all, later on, referred to as ecosystem services (ES), ecosystem functions (EF), land use functions (LUF) or land functions[10]. In the next section, we start by tracing back the origins and evolutions of these concepts. Furthermore, we will try to argue that the concept of LF is a further level of analysis of LC and LU, and that it can unify the other similar and recent concepts of ecosystem services, landscape functions and land use functions. We will try to deepen the conceptual and theoretical framework of this concept and justify its pertinence.

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[10] E.g. Regulation of the storage and flow of surface water and groundwater; provision of biological habitats for plants, animals and micro-organisms; a store of wealth for individuals and communities; production of food, fibre, fuel or other biotic materials for human use; provision of physical space for settlements, industry and recreation, etc (FAO/UNEP 1999: 8).

2. Towards the Land Function concept

Much before the term land function was introduced, other previous and related terms and concepts were developed within the scientific community. Some of those concepts were originated as a mean to assess the human-ecosystem interactions over the last ten to fifteen years. Schößer *et al.* (2010) review most of these concepts, framing them in three main families, all of them with specific origins and identities:

- Ecosystem services;
- Landscape functions;
- Land use functions.

Although these branches can be regarded as referring to different concepts and the result of parallel and somehow independent research processes, as is partially suggested in the analysis by Schößer *et al.* (2010), there was some evolution and interconnection on the use of these concepts.

In very broad terms, it can be said that all terminologies refer in general to the capacity of the different natural or semi-natural components and processes that occur on Earth to provide goods and services which directly or indirectly benefit the human well-being and society as a whole. The goods and services are of ecological, economic, social or cultural value. Different nuances however, exist: most of them regarding the basic unit of analysis (ecosystems, landscapes or land use) and, consequently, the spatial scale of analysis. Underneath these approaches lie also different focuses. Some consider mostly the goods and services provided by the natural or semi-natural systems and processes, but others include also the goods and services provided by the humanized landscapes. Some distinguish also between services (or goods and services) and functions. Functions were defined as the fluxes and processes that occur in ecosystems or landscapes, while goods and services are the material and non-material products actually provided (De Groot 2006).

Ecosystem services

"Ecosystem services, as adopted by the Millennium Ecosystem Assessment (MA 2003), are rooted in the field of ecology and were originally designed for the assessment of (semi-)natural ecosystems (Costanza *et al.* 1997)." With roots in the field of landscape ecology and planning, the approach to landscape functions was developed and used in a wide span of applications, one of which was the characterization of cultural landscapes. Finally, the land use functions approach was developed more specifically within the European project SENSOR, in which tools for Sustainability Impact Assessment (SIA) of policies with impacts on land use change were developed. Addressing similar issues, but developed in parallel within different scientific communities, the concepts use different terminologies for similar aspects, and vice versa (Schößer *et al.* 2010).

Concepts like environmental services (SCEP 1970), public services of the global ecosystem (Ehrlich *et al.* 1977) or nature's services (Westman 1977) appeared during the 1970's. But the similar concept of ecosystem services, firstly coined by Ehrlich and Ehrlich (1981), became the most popular.

> *Costanza* et al. *(1997) were the first to try to operationalise ecosystem services by calculating the value of the world's ecosystems using this approach. To date, the MA is probably the most extensive, international, scientific study dealing with ecosystem services. (…) The analytical framework of the MA was built upon the concept of ecosystem functionality as the foundation for all other processes and activities on earth. Therein, ecosystems generate ecosystem services and also have and intrinsic value to society.* (Schößer *et al.* 2010: 161)

Ecosystem services were considered a key and central concept of the Millennium Ecosystem Assessment's conceptual framework. MA "was established to help provide the knowledge base" for policy and management interventions that can "reverse ecosystem degradations and enhance the contributions of ecosystem to human well-being". It was designed to provide a comprehensive global assessment of the World's major ecosystems. The MA conceptual framework considers the existence of dynamic interactions between the humans and ecosystems, therefore focusing on the linkages between ecosystem services and human well-being. The entities under assessment in the MA were ten categories of (eco)systems, from those relatively undisturbed to those intensively managed and modified by humans: marine, coastal, inland water, forest, dryland, island, mountain, polar, cultivated and urban. These systems, which may comprise different ecosystems, are then related to its main services.

Services are defined as “the benefits people obtain from ecosystems” and these are considered to include four main categories of services: provisioning, regulating, supporting and cultural. These categories are then exemplified as follows: provisioning services, such as food, water, fiber and fuel; regulating services such as regulation of climate, floods, drought, land degradation, and disease; supporting services such as soil formation, nutrient cycling and primary production; and cultural services such as aesthetic, recreational, spiritual, religious and other nonmaterial benefits. Therefore, it can be said that an anthropocentric perspective lies beneath the all concept of ecosystem services. Indeed, “it is the presence of human beings as valuing agents that enables the translation of basic ecological structures and processes into value-laden entities” (De Groot *et al.* 2002).

Landscape functions

Bastian (1997, 1999) defined landscape functions as the capacity of landscapes to meet societal demands, and thus providing services that present benefits to society. In his 1992 work, De Groot defined ecosystem functions as “the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly”. Because ecosystem includes all the natural processes, biotic and abiotic elements of a given region, as well as all energy flows and nutrient cycles involved between them (De Groot *et al.* 2002), the functions of ecosystem can be of great diversity. De Groot *et al.* (2002) presented a “conceptual framework and typology for describing, classifying and valuing ecosystem functions, goods and services”. A set of 23 ecosystem functions were described and grouped in four primary categories, similar to those later introduced in MA

(2005): regulation, habitat, production and information functions. This classification framework, along with the one from MA (2005), is often being used as basis for mapping efforts of ecosystem functions (Egoh *et al.* 2008; Raymund *et al.* 2009).

Later, De Groot and Hein (2007) considered that ecosystem functions and landscape functions were synonyms, meaning “actual processes and components in ecosystems and landscapes that provide goods and services that have direct or indirect benefic to human welfare”. “Within their concept, the difference between landscape and ecosystem functions lay in the spatial scale at which they were applied. Thereby, ecosystems were relatively small and homogenous whereas landscapes were heterogeneous, comprising various ecosystems” (Schößer *et al.* 2010: 165). “In general, the spatial entities investigated referred to landscape characteristics rather than to administrative districts and were characterized by spatial explicitness” (Schößer *et al.* 2010: 164). Figure 1 compares different land functions / ecosystem services classification systems according to different authors.

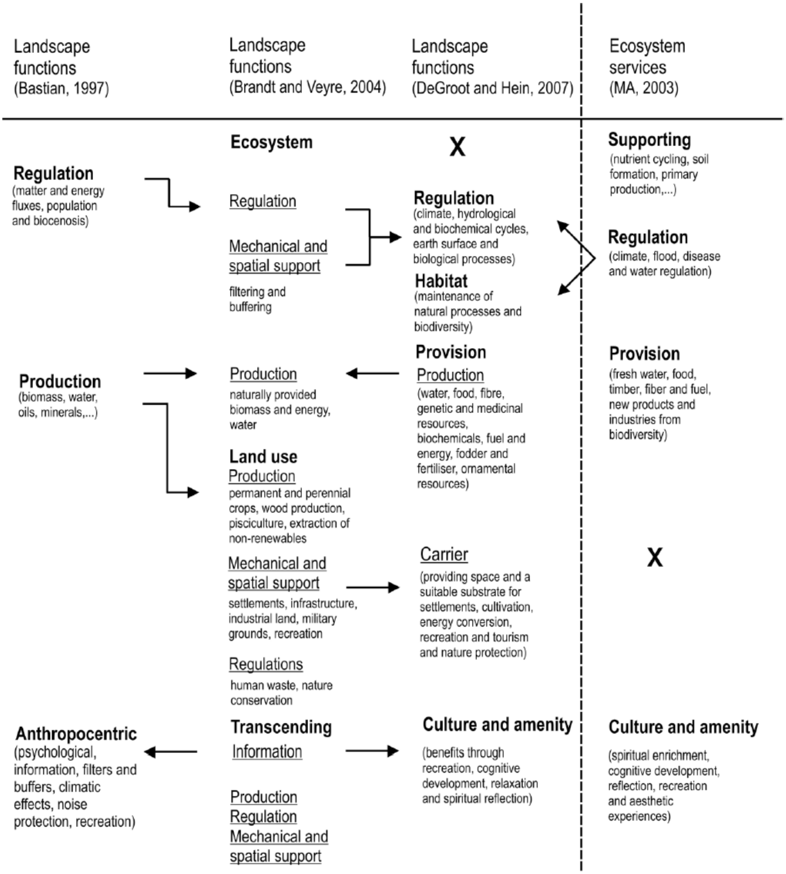

Figure 1. Comparison of different classification systems for landscape functions and their relation to the concept of ecosystem services. Extracted from Schößer *et al.* 2010: 166.

In a recent PhD, Willemen (2010) adopted the term landscape functions and tried to make them spatially explicit for a small region in the Netherlands. Function is interpreted as a characteristic of the landscape that enables it to provide goods and services that satisfy human needs. Landscape is addressed, instead of ecosystem, because “landscapes consist of different systems, arranged in specific spatial patterns”, which was considered more appropriate to the "strongly modified by humans" study area: "Landscapes are considered holistic spatial system in which humans interact with their environment, while ecosystems are often perceived as merely natural and semi-natural systems" (Willemen 2010: 8). "Making landscape functions spatially explicit, adds an important component to research conducted in the field of quantification of goods and services", as well as "could support policy makers and spatial planners by providing insight into the functional capacities of the landscape" (Willemen *et al.* 2008).

Willemen *et al.* (2008) are among the few who actually tried to map different functions of landscape. Their approach was not to systematically identify, classify and map all possible landscape functions. It was rather a methodological essay, in which a discretionary selection of eight landscape functions of a small region was mapped.

The complexity of the task required different mapping approaches to each considered function. Some of the functions were completely delineated using land cover data or policy documents. In other cases, only a partial delineation was possible from existing data. Finally, a group of landscape functions lacked any delineation data. In these two last situations, full delineation was only possible through direct or indirect spatial indicators and decision rules. In simple lexis, each function was mapped separately, resulting individual landscape function maps, at a high spatial resolution.

Further steps of Willemen's work included the analysis of the interaction between multiple landscape functions, their economic valuation and finally, the modeling of their spatio-temporal dynamics. The analysis of the interaction between multiple landscape functions allowed, for instance, to reveal that "some landscape functions are negatively affected by the presence of other functions while some other landscape functions seem to benefit from multifunctionality". In addition, the adopted modeling framework was a first step to assess the impact of land management actions and policy plans on the supply of multiple landscape services, identifying, quantifying and visualizing trade-offs. All of this was possible mainly because of the limited spatial extent of the analysis (a small region in the Netherlands), but also because of detailed spatial and indicator data was often available to be collected. The modeling framework was applied to three landscape functions (plant habitat, arable production and cultural heritage) for a temporal target of 15 years, starting from 2000.

The work of Kienast *et al.* (2009) uses the concept of landscape functions and attempts to map functions at quite a different spatial extent and scale. NUTS-X[11] were used as basic spatial unit to assess the level of landscape functions in an European wide extent, and thus is considered by the authors an innovative exploratory research. In this work, the concept of function is used as the capacity (stock) of land to produce the goods and services (flows) (figure 2), and the notion – used in other studies – that functions are the goods and services themselves is rejected. The fifteen landscape functions which were considered fall into a ‘classic’ fourfold classification similar to the one used in MA (2005): production, regulation, habitat/support, information/culture functions:

- Production functions: wildlife products; cultivated products; commercial forest products; transportation and housing; energy.
- Regulation functions: Climate regulation; natural hazard regulation; water regulation; waste treatment and nutrient cycling; erosion prevention and biological control.
- Habitat functions: Habitat functions for plants and animals.
- Information functions: Aesthetic information; recreation and tourism; cultural and artistic information.

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[11] Nomenclature of Territorial Units for Statistics (NUTS).

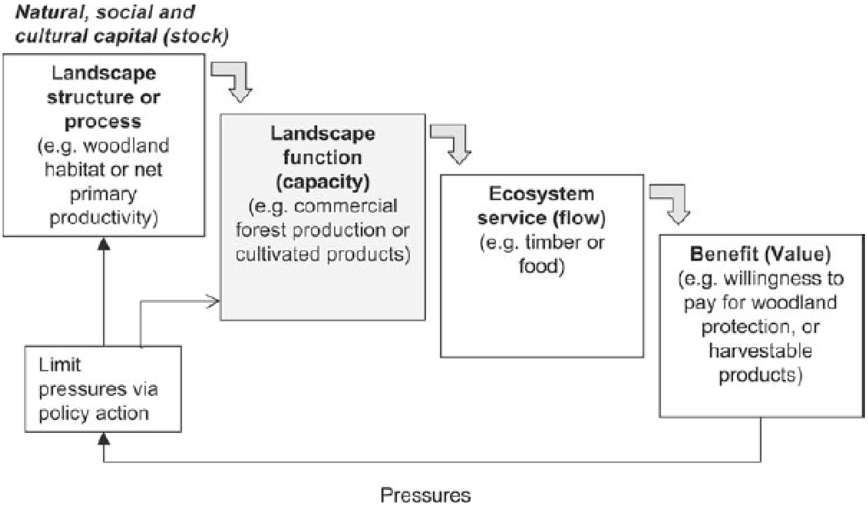


Figure 2. Conceptual framework for analyzing landscape functions (extracted from Kienast *et al.* 2009).

Knowledge gaps are recognized to exist, especially regarding the relationships between the properties of land and its potential to provide goods and services:

> *At the continental scale (…), most of these interrelationships are either not known, or the level of detail of the input parameters does not meet the requirements for a proper up-scaling of the non-linear behavior observed at the lower scale* (Kienast *et al.* 2009: 1101).

The followed approach to make the assessment is based on simple binary links between land use and/or environmental properties and fifteen landscape functions. These binary links are operationalized through look-up tables expressing whether a land characteristic has a supportive or a neutral role, and these links were generated with the aid of an expert panel and scientific literature. The land characteristics considered were mainly land cover percentages within each NUTS-X region, shape indicators derived from land cover patches and some topographic attributes as well (elevation and slope). The final value for the presence/intensity of a given landscape function for each region is computed by a simple sum of the percentages of land characteristics, but only for those land characteristics that were previously linked with the landscape function. The final result is an European map for each landscape function, using NUTS-X as basic spatial unit.

Through comparison of the resulting landscape function maps with reference data/maps, it was considered that the approach produced fair results for 9 of the 15 considered landscape functions.

Land use functions

Within the European project SENSOR, a new concept was drawn to fulfill its needs and purposes. One of the main objectives of the SENSOR project was to build operational tools for ex-ante Sustainable Impact Assessment (SIA) of policies for European regions. It was considered that land use is one of the most relevant factors for sustainability. Thus, policies with impact on land use change were the main focus of the SENSOR's approach. "The basic idea behind the analytical chain in SENSOR is to (i) link policy options with land use changes, (ii) link land use changes with environmental, social and economic impacts and (iii) provide a valuation framework of these impacts in the light of sustainable development" (Helming *et al.* 2008).

The concept of land use functions (LUFs) was built on the roots of the concepts of agricultural multifunctionality, ecosystem goods and services and landscape functions. Ecosystem goods and services and landscape functions were not considered to be broad enough to incorporate the requirements of a full sustainability assessment. In fact, it was considered that the approaches of ecosystem services and landscape functions were substantially biased towards the environmental pillar of sustainability, and did not take into account the other pillars, i.e. economic and social (Perez-Soba *et al.* 2008). Because of this, land use functions concept was an adaptation of the previous ones, towards a more holistic integration of all sustainability pillars, and thus avoiding an "environmental view of the world" (Perez-Soba *et al.* 2008). It also reflected the progress on the concept of multifunctionality, which is now recognized to be a feature of other land uses, rather than just a specificity of the agricultural uses of land. Within the new land use function concept, it is therefore recognized that multiple functions can be attached to each land use typology, for example:

> *Forest land use might have several economic, environmental and societal functions such as provision of wood for forestry and/or for renewable energy, have a recreational function, be part of a cultural landscape, regulate the supply of air, water and minerals, support biodiversity in the form of landscape cohesion and maintain ecosystem processes.* (Perez-Soba *et al.* 2008)

LUFs were hence defined within this European project as “the private and public goods and services provided by the different land uses that summarize the most relevant economic, environmental and societal aspects of a region” (Perez-Soba *et al.* 2008). Because all aspects of sustainability were meant to be captured, nine land use functions were considered, each one of them either being societal, economical or environmental:

- Mainly societal LUFs:
    - Provision of work
    - Human health and recreations
    - Cultural
- Mainly economic LUFs:
    - Residential and land independent production
    - Land based production
    - Transport
- Mainly environmental LUFs:
    - Provision of abiotic resources
    - Support and provision of biotic resources
    - Maintenance of ecosystem processes

In practical terms, each LUF is characterized by a set of indicators, whose values are used to compute a single indicator of the LUF intensity within a region. Each land use function is represented as a regional aggregated value. Thus, spatial explicitness is limited to inter-regional variability.

A chain of model runs within SENSOR project (land use allocation, macro-economic and sectoral models) provide new indicator values for different scenarios and policy alternatives, which will affect the overall intensity of the LUF for a region "by enhancing or hindering the functions, e.g. an increase in forest fire may hinder the support and provision of biotic resources" (Perez-Soba *et al.* 2008). To assess the sustainability of a policy, values of LUF for each region are compared with their correspondent sustainability thresholds, as explained by Perez-Soba *et al.* (2008):

> *The LUFs concept allows therefore translation of the European assessment into an integrated regional impact assessment, i.e. the individual values of the indicators characterizing a region that are obtained from the model chain are aggregated to assess the impact on the LUFs. In other words, the impacts on land use predicted by modeling of policy cases are measured by changes in a set of key indicators that build up the LUFs, and summarized in one single value per LUF (…). The outcomes for sustainability are predicted by comparing the values of the indicator with their correspondent sustainability limits/thresholds and analyzing how the policy option stimulates or hinders the LUF.*

The methodological approach is stepwise. In a first step, economic, environmental and social indicators are collected. For each indicator and each LUF, a relationship is identified through expert knowledge, defining the sign (positive or negative) and strength of the relationship. Finally, a matrix of indicators per LUF is built. In the second step, the European regions (NUTS-2/3) were aggregated using a cluster analysis to form 27 cluster regions relatively homogeneous in biophysical and socio-economic characteristics (Renetzeder *et al.* 2008). These cluster regions were then characterized in detail, including indicator collection. It was then identified the importance of each key impact indicator for the sustainability of the regions. The third step regards the assessment of sustainability limits for the cluster regions. “Sustainability limits are defined as the unacceptable damage of a pressure on a social, economic or environmental system based on current knowledge (…). The rationales for identification of the sustainability limits are based on (i) policy targets, (ii) on statistical distributions of indicator current values, or (iii) on scientific values. They can be quantitative (…) or qualitative” (Perez-Soba *et al.* 2008; see also Bertrand *et al.* 2008). The sustainability limits are defined for each cluster region, and then used to assess, in the fourth and final step, the effect of a policy alternative on the sustainability of a region (NUTS-2/3) or cluster region. In the end, a summarized and straightforward analysis can be delivered in a simple way, easy to interpret by stakeholders and decision makers, and addressing a fairly complete Sustainability Impact Assessment (SIA) (see figure 3).

In a later study, Reidsma *et al.* (2010) applied SENSOR’s approach based on land use functions to the assessment of land use policies in developing countries, demonstrating the approach with a case study in Taihu basin, on the east coast of China.

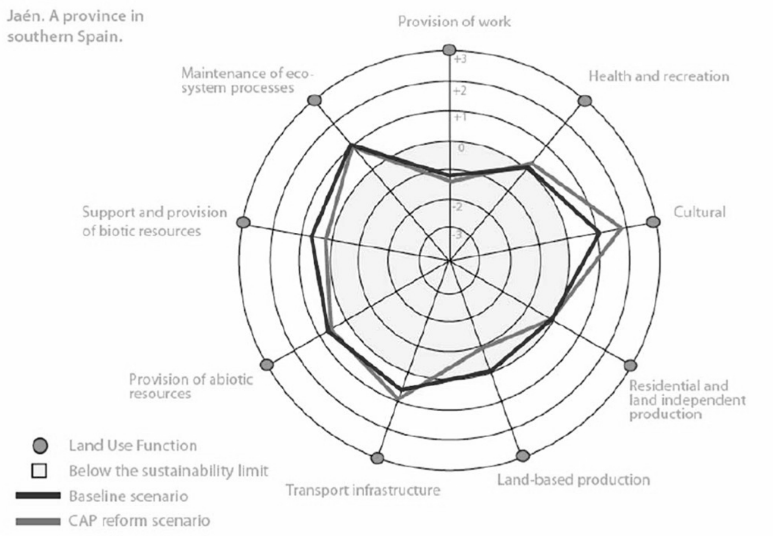


Figure 3. Performance of Land Use Functions under different policy alternatives and its respective sustainability limit, for a Spanish region (extracted from Perez-Soba *et al.* (2009: 25)).

Land function

The concept of land function is a relatively recent derivation of concepts reviewed. Verburg *et al.* (2009) used this term when referring to “the goods and services provided by the land use systems and ecosystems within the landscape”, adding that “land functions not only include the provision of goods and services related to the intended land use (e.g. production of food and wood) but also include goods and services such as the provision of esthetic beauty, cultural heritage and preservation of biodiversity that are often unintended by the owner of the land”. It seems that the idea of the authors was to escape from the “definition debate” by using a term that is broad and flexible enough to comprise all possible interpretations and to, eventually, unify all concepts.

While advocating the evolution from a land cover perspective to a land function one, Verburg *et al.* (2009) recognize that land function characterization and delimitation requires additional data beyond land cover “which, in many cases, can only be achieved at local scales of analysis”. Indeed, land function is a more complex level of analysis of the reality than simple land cover. Representing land function requires that at least part of the complex, fuzzy and dynamic features of the reality (Comber *et al.* 2003) are captured. Additionally to land cover information, quantification of goods and services provided by land, landscape structure, analysis of socio-economic and environmental context (Verburg *et al.* 2009) through census data, field surveys (Winter 2009) and consults to stakeholders (Raymond *et al.* 2009) are necessary.

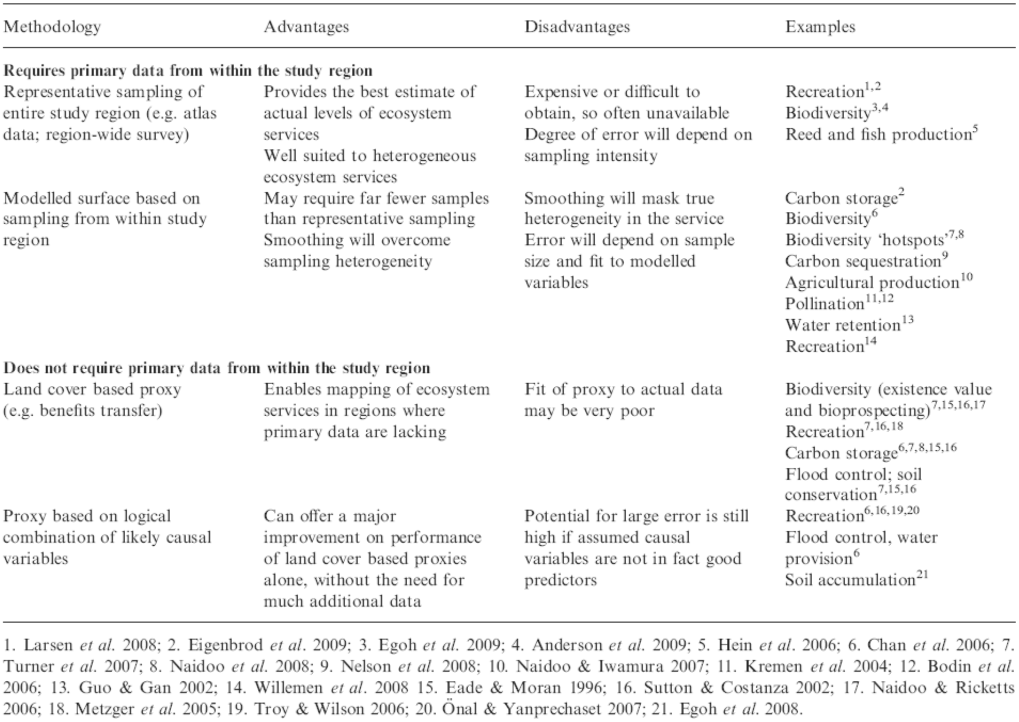
Mapping and assessing ES and LF

As reviewed by Eigenbrod *et al.* (2010), and synthesized in table 1, different approaches are being used by different authors in the recent effort to make land functions spatially explicit. Besides the previously mentioned work developed by Willemen *et al.* (2008), others exist. Egoh *et al.* (2008) mapped five ecosystem services, namely surface water supply, water flow regulation, soil retention, soil accumulation and carbon storage, at national scale, for South Africa, and using 4th order river basins as spatial unit to compute and visualize the ecosystem service values. The mapping methodology used proxies to estimate the distribution of ecosystem services. For instance, soil depth and litter cover were the variables used as proxies for the soil accumulation service.

Chen *et al.* (2009) demonstrated a GIS-based methodology to estimate the spatial distribution of the direct economic value of three goods/services derived from land/ecosystems: agricultural products, forest products (value of stumpage) and tourism services (accounted as the park entrance fees). Different assumptions were used to map the value of each land function at each pixel. To account for services derived from agricultural systems, yield, production and an average net value of each type of product were combined with land use/cover data. For forest products, only the value of stumpage was considered. A map of forest species and the market prices information were used to make the estimation. Finally, tourism service value was considered to be a function of proximity and visibility of scenic spots. This study was applied to a small Chinese county (1,424 km^2), and the spatial resolution was 25 meters. While the authors allow themselves to make strong conclusions on the value and distribution of ecosystem services, and emphasizing that the approach "indicated that the valuation and mapping of direct use value of ecosystem services would help to protect the area, and make holistic policies", we think that the simplistic assumptions used should refrain much of their enthusiasm.

Lastly, the approach of Raymond *et al.* (2009) was rather distinct. A wide range of ecosystem services were mapped for an Australian region (56,000 km^2). The approach was to use the knowledge and subjective value perception obtained through in-depth interviews to a sample of 56 regional decision-makers. During the interviews, participants were asked to place dots in a regional map, marking and identifying both values and threats of several ecosystem services. This information was later transferred into GIS, and used to produce spatial distributions of the intensity of values and threats for natural capital assets and ecosystem service types (provisioning, regulating, cultural and supporting). The results of this study were helpful in the revision of the Regional Natural Resource Management Plan. Although the methodology seems interesting in the sense that tries to capture the values of nature in the way local people perceive it, it also shows some drawbacks: the delimitation is too much dependent on subjective analysis and all the heavy interview process needs to be carried out for every region under analysis/mapping. Nonetheless, the methodology would fit for validating other more automated and proxy-based methods.

Table 1. Major approaches to producing maps of ecosystem services (extracted from Eigenbrod *et al.* 2010)



Methodology	Advantages	Disadvantages	Examples
Requires primary data from within the study region			
Representative sampling of entire study region (e.g. atlas data; region-wide survey)	Provides the best estimate of actual levels of ecosystem services Well suited to heterogeneous ecosystem services	Expensive or difficult to obtain, so often unavailable Degree of error will depend on sampling intensity	Recreation[1,2] Biodiversity[3,4] Reed and fish production[5]
Modelled surface based on sampling from within study region	May require far fewer samples than representative sampling Smoothing will overcome sampling heterogeneity	Smoothing will mask true heterogeneity in the service Error will depend on sample size and fit to modelled variables	Carbon storage[2] Biodiversity[6] Biodiversity 'hotspots'[7,8] Carbon sequestration[9] Agricultural production[10] Pollination[11,12] Water retention[13] Recreation[14]
Does not require primary data from within the study region			
Land cover based proxy (e.g. benefits transfer)	Enables mapping of ecosystem services in regions where primary data are lacking	Fit of proxy to actual data may be very poor	Biodiversity (existence value and bioprospecting)[7,15,16,17] Recreation[7,16,18] Carbon storage[6,7,8,15,16] Flood control; soil conservation[7,15,16]
Proxy based on logical combination of likely causal variables	Can offer a major improvement on performance of land cover based proxies alone, without the need for much additional data	Potential for large error is still high if assumed causal variables are not in fact good predictors	Recreation[6,16,19,20] Flood control, water provision[6] Soil accumulation[21]

1. Larsen *et al.* 2008; 2. Eigenbrod *et al.* 2009; 3. Egoh *et al.* 2009; 4. Anderson *et al.* 2009; 5. Hein *et al.* 2006; 6. Chan *et al.* 2006; 7. Turner *et al.* 2007; 8. Naidoo *et al.* 2008; 9. Nelson *et al.* 2008; 10. Naidoo & Iwamura 2007; 11. Kremen *et al.* 2004; 12. Bodin *et al.* 2006; 13. Guo & Gan 2002; 14. Willemen *et al.* 2008 15. Eade & Moran 1996; 16. Sutton & Costanza 2002; 17. Naidoo & Ricketts 2006; 18. Metzger *et al.* 2005; 19. Troy & Wilson 2006; 20. Önal & Yanprechaset 2007; 21. Egoh *et al.* 2008.

As seen, much of the effort to map ecosystem services is quite recent. During the second half of the 20th century, mapping efforts of natural systems were mainly driven by human need. For instance, agricultural capability maps were produced in some countries, and they required "prodigious amount of survey work (…). And the capability in question is agricultural capability, not carbon storage, biodiversity, flood prevention or any other of what are now called ecosystem services" (Winter 2009). Winter suggests furthermore that a historic legacy effect is constraining the datasets that we have now, mainly the cartographic ones. Land use/cover datasets, recently produced with the help of satellite imagery, have thus been used as one of the core proxies to land functions/services (Eigenbrod et al. 2010). However, "attempts to put functionality into the equation clearly require much more than spatial data on land type and land cover" (Winter 2009).

Eigenbrod *et al.* (2010) agree. Their study on "the impact of proxy-based methods on mapping the distribution of ecosystem services" clearly led to the conclusion that "land cover based proxies provide a poor fit to primary data surfaces", and that proxies are only useful to produce coarse broad-scale patterns, with very little or no potential for high scale planning. In fact, as stated by Verburg *et al.* (2009: 1328),

> *there is no one-to-one relation between land cover and functionality. Functionality is often determined by both local and contextual factors synchronously. In addition, land function may not be observed and monitored by standard techniques used in land cover observation. In many cases land function may drastically change without any change in land cover and vice versa. Attempts to quantify land functions based on land cover information are often limited since land cover is not always a good indicator for the actual functions performed by the land at that location.*

Thus,

> *any attempt by stakeholders to plan or strategize for land use in order to strike an optimal balance between the various regulatory, market and public pressures requires data.* Winter (2010: S218)

3. Why Land Function?

After this extended review, a summary of the main differences between LC, LU and LF are shown in table 2, and some examples are given for clarification purposes. The ideas summarized in the table may help us to justify the pertinence of adding this new level of analysis to the existing ones (LC and LU). The LF concept is inherently quantitative due to its definition: the *capacity* of land to provide goods and services. It must be noted that capacity is a quantitative term intended to be measured. In this sense, land function (or the capacity of land to provide goods and services) is meant to *measured*, while land use is meant to be *described*.

Moreover, in LU terminology a single dominant use and coexistent secondary uses are considered per unit of measurement. In the LF framework, functions are analyzed independently of any preconceived hierarchical reasoning, and any given number of functions may coexist in time and space. This two different perspectives result in the interesting fact that often LU is described through a single map (one layer) of mutually exclusive dominant LU classes, while LF is described through a series of overlapping maps (n layers, n = number of considered LF). This quantitative multilayer LF analysis opens new possibilities for land value assessment within a cross-sector context.

Finally, we tend to agree with Perez-Soba *et al.* (2008), that terms such as *ecosystem services* or *ecosystem functions* are biased towards environmental goods and services, thus marginalizing those goods and services provided by non-natural systems. On the other hand, the term *landscape functions* incorporates systems strongly influenced by humans taking also into account the spatial arrangement of different systems. However, the word *landscape* has a very specific meaning within the scientific community. Lastly, the term designed for the SENSOR project – *land use function* – directly connects function to the land use, which may not always be the case. Therefore, we propose that all the previous terminologies are unified into the simpler term *land function*. In fact, it shares the same broad definition (*the capacity of land to provide goods and services*) and it is broad enough to be used independently of spatial scales or units of measurement.

In future publications, we hope to contribute to the development of the theoretical background needed to support the concept of land function. This will mainly be done 1) by proposing a classification structure of land functions based on a two branch subdivision (socio-economic land functions and biophysical land functions) and 2) by introducing the concept of dynamic land functions.

Table 2. Synthesis of the main differences between LC, LU and LF.

	Land Cover (LC)	**Land Use (LU)**	**Land Function (LF)**
General definition	*The observed biophysical cover of the Earth's surface* (Di Gregorio and Jansen 1998)	*The description of land in terms of its socio-economic purpose* (Duhamel 1998)	*The capacity of land to provide goods and services* (Verburb *et al.* 2009; Kienast *et al.* 2009)
Overlap in time and space	No. LC classes are mutually exclusive.	Yes. Primary and secondary LUs can be identified*.	Yes. More than one LF can be present in the same place at the same time.
Units of measurement	Pixels of different sizes; survey points.	Zone (cadastral parcel, administrative unit, statistical unit, LC polygons); survey points.	Zone (cadastral parcel, administrative unit, statistical unit, LC polygons); pixels of different sizes**; landscape unit.
Type of data used to describe	Categorical	Categorical	Quantitative
Methods for measurement	Direct observation from various sources (human eye, aerial photographs, satellite sensors).	Inference from observation of LC, landscape and presence of structural elements; field interviews.	Inference from observation of LC, landscape and presence of structural elements; field interviews; socio-economic statistics; field measurements.
Examples	Grassland	Agriculture (grazing)	Water regulation; soil retention; aesthetic information; leisure; food provision.

	Forest	Forestry	Gas regulation; water regulation; soil retention; provision of wood and wood-related products; provision of jobs; leisure.
	Built-up land	Commercial	Retail trade and basic services; leisure; provision of jobs.
	Built-up land	Residential	Provision of accommodation (residential or tourism); aesthetic information.
	Greenhouses	Agriculture	Provision of food; provision of jobs.

* Primary land use is more closely associated with a land cover. Primary land use controls land cover while the secondary does not (Bakker and Veldkamp 2008).

** Assessing some land functions may require analysis at larger extents. For example, a building with significant architectonical/historical value may not provide, alone, a measurable LF (such as aesthetic information or leisure), but a whole group of buildings of the same kind may generate a LF. Therefore, to assess LF at a given point in space, the characteristics of vicinity areas may have to be considered.

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