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URBAN ECOSYSTEM SERVICES: LITERATURE REVIEW AND OPERATIONALIZATION FOR THE CASE OF BRUSSELS

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Urban ecosystem services: literature review and operationalization for the case of Brussels

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Abstract

We summarise the literature on urban ecosystem (ranging from individual trees to extensive green spaces) and examine how urban ecosystems can be linked to the four main types of ecosystem goods and services. We then propose an empirical strategy for measuring urban ecosystem services in Brussels. We argue that a feasible approach consists in focusing on changes to urban ecosystems induced by neighbourhood revitalisation programmes. We conclude that there is sufficient empirical material allowing to assess, at least in a first approximation, the impact of neighbourhood revitalisation programmes on the provision of ecosystem services within the city of Brussels.

JEL : Q57, Q51, R14, R22

1 Introduction

Although ecosystem goods and services and ecosystems in general are traditionally associated with more natural environments than with anthropogenic systems such as cities, a quickly expanding literature in fields such as Ecological Economics and Applied Ecology has recognised the importance of ecosystem service provision in urban contexts. In the wake of increasing urbanisation of human populations and unsustainable strain on natural resources, the social-ecological resilience of cities is widely associated with their capacity to cater the enormous demand for ecosystem goods and services by producing some of them locally. Indeed, in many cases such as micro-climate regulation there is often no alternative to providing these services locally through urban ecosystems. The increased awareness of the importance of urban ecosystems and their beneficial impact on the quality of life within cities is, however, not matched by satisfactory knowledge about how such ecosystems can be maintained, managed and expanded so as to create resilient and efficient cities.

The aim of this paper is twofold. The first objective is to summarize the literature on urban ecosystems and the provision and distribution of ecosystem goods and services in urban contexts.

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The second objective is to present a strategy how ecosystem goods and services could be analysed in a specific urban context, namely in the region-city of Brussels, Belgium.

The paper is structured as follows. We first summarize the state of the art related to urban ecosystems (Section 2) and ecosystem goods and services (Section 3). We then examine how ecosystem goods and services could be measured at the neighbourhood level in Brussels (Section 4). The final section concludes.

2 Urban ecosystems

The notion of ecosystems has traditionally been associated with natural environments; interactions and disturbances between social systems and ecosystems have been studied more recently (Ervin et al. 2012). This being said, an increasing proportion of human populations is concentrated in urban settlements: according to global projections more than two thirds of humanity will live in cities within three decades. Current urbanisation rates in North America and Europe are already much higher. Although cities produce only a small amount of total ecosystem services, large cities claim extensive ecosystem support that can be 500-1000 times larger than their own surface (Folke et al., 1997). Indeed, the globalisation of production chains allows city dwellers to access resources and to affect ecosystems that are far removed from their residence (Ervin et al, 2012).

An ecosystem can be defined as “a set of interacting species and their local, non-biological environment functioning together to sustain life” (Moll and Petit, 1994), but the “borders between different ecosystems are often diffuse” (Bolund and Hunhammar, 1999). In urban environments it is particularly difficult to distinguish different ecosystems as they are both fractioned and invariably interacting with social systems. As a consequence, some authors frame these interactions as “social–ecological systems” and define them as “integrated system of ecosystems and human society with reciprocal feed- backs and interdependence” (Folke et al, 2010). On any account, it should be noted that urban ecosystems are characterised by a high degree of complex interactions with human systems so that philosophical questions about what constitutes “human” and “nature” frequently resurface (e.g. is a vegetables garden “nature”?). While the lens of social-ecological systems allows for a humans- in-nature perspective, it also opens the possibility for a nature-in-society perspective.

The scale at which ecosystems are studied in urban settings also merits scrutiny. Advances in GIS technology such as high-resolution imagery has led to the recognition of small patches of green space as being an important part of urban ecosystems (Gaston et al., 2012). Indeed, one can view the city as forming a single ecosystem but also as a collection of smaller, interacting ecosystems (Rebele, 1994). A pragmatic approach that we will also adopt here has been proposed by Bolund and Hunhammar (1999) who apply the notion of urban ecosystems to “all natural green and blue areas in the city, including street trees and ponds in this definition – even if street trees are too small to be considered as separate ecosystems. In their analysis of ecosystem service flows in Stockholm, Bolund and Hunhammar (1999) identify seven different urban ecosystems:

- street trees (including surrounding patches of unsealed land);
- lawns/parks (managed areas with grass, tress and herbaceous strata);
- urban forests (less managed with higher tree density);
- cultivated land (included gardens, orchards);
- wetlands (marshes and swamps);
- lakes/sea (open water areas).
- and streams (flowing water)
Given that each city is characterised by its specificities (climate, geological and hydrological conditions, urban configuration etc.), it should be noted that the relevant types of urban ecosystems are site-specific. In cities like Detroit, but to a smaller extent also in Brussels, the extensive patches of unused land such as brownfields and abandoned backyards can also be considered as ecosystems given their role of refuge and harbour for biodiversity. The relevant urban ecosystems in Brussels therefore necessarily differ from the one proposed by Bollund and Hunhammar (see Section 4.2.2 below).

Although the field is relatively young, a range of studies of urban ecosystems is available (Folke et al, 2010, Ervin et al, 2012). The most important opportunities and challenges of study of urban ecosystems are presented in Alberti et al (2003). There is a large consensus in the literature that the complex and dynamic interactions and feedback loops between natural ecosystems and human systems warrant transdisciplinary approaches to urban ecosystems: interactions and feedbacks typically “transcend” any individual discipline.

While urbanisation undeniably poses important challenges in terms of human footprints and alternative metrics, cities are also increasingly seen as the focal point for possible solutions to environmental problems ranging from global climate change to micro-climate regulation. In line with this more positive stance to the environmental impact of cities, Ervin et al. (2005) argue that “urban landscapes may be ‘hot spots’ for global environmental solutions”. Another argument why cities play a crucial role to solving environmental problems is that many challenges cannot be solved at any other level than locally. For instance, noise reduction and air filtration often cannot be provided at a distance so that the associated services have to be produced within the boundaries of human settlements (Bolund and Hunhammar, 1999). As a consequence, the governance of such environmental phenomena is likely to be more efficient if it is locally anchored. In other words, there should be a “correspondence between phenomena and their mode of management” (Vanderstraeten et al, 2009). Due to their relatively higher cultural diversity, cities are also a privileged scene for experimentation regarding the management of environmental assets, which in turn could foster biodiversity and social-ecological resilience (Colding and Barthel, 2013). In line with this assessment, Bolund and Hunhammar (1999) argue that “it can be advantageous to generate ecosystem services locally for pure efficiency reasons”.

Table 1: Urban ecosystems generating local and direct services, relevant for Stockholm,

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<thead>
<tr>
<th>Air filtering</th>
<th>Micro climate regulation</th>
<th>Noise reduction</th>
<th>Rainwater drainage</th>
<th>Sewage treatment</th>
<th>Recreation/cultural values</th>
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Source: Bolund and Hunhammar (1999).
3 Urban ecosystem goods and services

The notion of ecosystem services was introduced in the Study of Critical Environmental problems (1970) and captures a broad range of outputs associated with natural ecosystems. Costanza et al. (1997) propose a division of these outputs into ecosystem goods and services\(^2\), on the one hand, and ecosystem functions on the other hand. They define ecosystem services as “the benefits human populations derive, directly or indirectly, from ecosystem functions” and propose a classification of 17 major categories. As Bolund and Hunhammar (1999) note, several goods and services “are not consumed by humans directly, but are needed to sustain the ecosystems themselves. Such indirect services include pollination of plants and nutrient cycling, but the classification is not obvious.”

Despite the intrinsic complexity of ecosystems, the notion of “goods and services” proved to be fruitful for research into the interactions between natural ecosystems and anthropogenic needs and has been adopted by a rapidly expanding community of environmental scholars.\(^3\) Daily (1997) provides an overview of the terminological issues associated with ecosystem services; de Groot et al. (2002) propose a typology of ecosystem functions and services in ecological economics. According to Norgaard (2010), ecosystem services was initially a “humble metaphor to help us think about our relation to nature” and notes that this metaphor “has become integral to how we are addressing the future of humanity and the course of biological evolution”.

Ecosystem services gained significant academic clout when a large number of scientists from different countries and fields collaborated on the Millennium Ecosystem Assessment (2005) that aimed at a synthesis of the relationships between ecosystems and human well-being (Keune et al., 2012). Since then, the concept has become mainstream vocabulary and appears frequently in media coverage and civil society discussions about environmental issues, albeit still rarely applied to urban contexts.

Following Costanza et al. (1997) the literature typically distinguishes between four broad types of ecosystem goods and services (Davies et al., 2011):

- supporting (e.g. soil formation and nutrient cycling),
- provisioning (e.g. game, lumber),
- regulating (e.g. local climate and flood regulation) and
- cultural (e.g. aesthetic, sense of place and health benefits of green space and wildlife).

The precise content and range of ecosystem goods and services varies considerably among different applications, mainly because ecosystems themselves are characterised by extreme heterogeneity. In other words, the notion of ecosystem services has proved to be rather malleable and remains heuristically useful in a variety of contexts. This is arguably one of the reasons why the scientific community and policy makers have discovered it as structuring element of international research

\(^2\) Costanza et al (1997) include goods in the term ecosystem services (cf. Bolund and Hunhammar, 1999). Other authors prefer the term ecosystem goods and services (e.g. Gaston et al., 2013). We will use the term ecosystem goods and services whenever we want to stress the role of certain goods, for instance in the provision of foodstuffs; for brevity, we will refer to ecosystem services whenever goods play a minor role.

\(^3\) Although ecosystem services has received much more attention, there are also ecosystem disservices. Bolund and Hunhammar (1999) cite the emission of volatile organic compounds that may contribute to urban smog and ozone problems; disturbing noises of birds and frogs; mosquito hatching and bad odors of wetlands. An increase of vegetation within cities could also be associated with allergical reactions in some individuals.
networks, such as the EU Working Group on Mapping and Assessment of Ecosystems and their Services (MAES) and the network The Economics of ecosystems and biodiversity (TEEB)\(^4\).

In Belgium, ecosystem services also emerge as novel focus of scientific attention in several disciplines combining environmental, economic and sociological perspectives (Keune et al, 2012). Between 2009 and 2012, for instance, the Belgium ecosystem services (BEES) project brought together the leading research institutions in this area in order to set the agenda for research on ecosystem services in Belgium. The BEES project has subsequently been consolidated as an informal “community of practice” and an “open and flexible network that serves as interface between different social actors” interested in ecosystem service research (Keune et al., 2012).

Among the relevant research projects carried out by Belgian scientists is the Valuation of Terrestrial Ecosystem Services in a multifunctional peri-urban space (VOTES), involving researchers from the University of Namur, VUB, ULg and the Flemish Research Institute for Nature and Forest (INBO). Another project is ECOFRESH, which evaluates freshwater ecosystem services and brought together the Ecosystem Management Research Group (ECOBE) of University of Antwerp, KU Leuven, and the Flemish Institute for Technological Research (VITO), Ghent University and INBO. Moreover, the Flemish Land Organisation (VLM) used the lens of ecosystem service delivery to coordinate the development of a programme in De Wijers in the province of Limburg. Next, the Environment Administration of the Flemish government (LNE) commissioned a study aiming to quantify and monetize different types of (semi-) natural land use by applying the framework of ecosystem services. This study was carried out by VITO, ECOBE, and the Free University of Amsterdam (IVM). Finally, Planning for ecosystem services (ECOPLAN) started in 2013 and aims at providing heuristic instruments for ecosystem service assessment and valuation. Partners are ECOBE, the Leuven Sustainable Earth Research Centre (LSUE) from the KU Leuven, the Environmental Modelling Division (RMA) and the Earth Observation Unit (TAP) from VITO, the Aquatic Ecology Research Unit (AECO) from Ghent University and INBO. In Brussels, research on ecosystem service research is mainly carried out by the Vakgroep Menselijke Ecologie of the VUB, the Institut de Gestion de l’Environnement et d’Aménagement du Territoire (IGEAT) and the Centre d’études économiques et sociales de l’environnement (CEESE) of the ULB.

Research on ecosystem services in Belgium is not exceptional in that it predominantly focuses on areas outside of cities, although the VOTES project clearly integrates urban issues by looking at the impact of urban sprawl on ecosystem service flows. Indeed, the literature has focused on the substantial magnitudes of goods and services that arise from large natural ecosystems such as oceans or forests (Ervin, 2012). This being said, there is an increasing consensus that urban environments are becoming vital arenas to ensure ecosystem service provision for future generations. In light of secular trends towards urbanisation of human populations in Europe and elsewhere, the social-ecological resilience of cities is gaining recognition as both research object and policy objective. In this context, the magnitude and quality of locally provided ecosystem services is recognised an integral element of urban transitions (Schäffler and Swilling, 2013).

Although not always labelled as such, ecosystem services are already driving an array of human interventions in their immediate urban environment (Ervin et al, 2012; de Groot et al, 2010). In their overview of the literature on urban ecosystem services, Gaston et al (2013) cite many examples of human interventions that affect locally provided ecosystem outputs: the creation of new green spaces, landscaping developments, managing vegetation in existing or newly created green spaces (e.g. grazing, mowing, tree planting and surgery, coppicing, growing fruit and vegetables), managing green waste (e.g. composting, wood chipping), installation of green roofs and walls, and ‘wildlife gardening’ (e.g. provision of nectar-rich plants, bird feeders, nest boxes, bat boxes, ponds). There is a

\(^4\) www.teebweb.org
growing literature that studies the impact of one or several of these interventions on ecosystem service flows (Snep and Opdam 2010; Douglas and Ravetz 2011; Rowe 2011; Sadler et al. 2011; Hale and Sadler 2012). There is a related and dynamic literature on the valuation of green infrastructure (Mell et al, 2013; Vandermeulen et al, 2011) that has also given rise to international research programmes looking at beneficial outputs of urban ecosystems, such as the European Interreg IV project VALUE, “in which scientists together with policy stakeholders are analysing different ways to value landscape within an urbanizing environment” (Vandermeulen et al, 2011). In the VALUE consortium, Belgium is represented by the Ulg, the Vlaamse Landmaatschappij (VLM), and the Services Promotion Initiatives en province de Liège.

There is little uncertainty about the fact that cities provide ecosystem goods and service and that the proportion of total services provided by cities is increasing. According to Gaston et al. (2011), “the ecosystem goods and services provided within their bounds will inevitably constitute a growing proportion of their regional and global provision” due to the spread of urban forms. The production of ecosystem goods and services within cities hinges of course on the availability of permeable surfaces, vegetation and blue/green infrastructure, all of which tend to be present in most cities (Churkina, Brown & Keoleian 2010; Davies et al. 2011b). The local provision of ecosystem services within urban agglomeration is typically associated with “much more functional and more pleasant places to live” (Gaston et al., 2011). Unsurprisingly, scholarly attention has focused on mapping the level of ecosystem goods and services but also on the inequalities between socio-economic groups associated with their provision (Jo and McPherson 2001; Hope et al. 2003; Kinzig et al. 2005; Grove et al. 2006; Barbosa et al. 2007; Tratalos et al. 2007; Davies et al. 2011, 2012; Fuller et al. 2012). In the context of urban revitalisation, the impact of greening projects can, for instance, have an impact on the socio-economic composition of neighbourhoods and lead to an unequal distribution of gains and losses (Dessouroux et al, 2009; Van Criefingen, 2009).

Due to the density of anthropogenic pressures and high incidence of impermeable surfaces, not all ecosystem services identified by Constanza et al. (1997) are provided in urban forms. For the case of Stockholm, Bolund and Hunhammar (1999) observed six local and direct services that arise from the different types of urban ecosystems in the Swedish capital (see Table 1): air filtration (gas regulation), micro climate regulation (reduction of heat island effects at street and city level), noise reduction (disturbance regulation), rainwater drainage (water regulation), sewage treatment (waste treatment), and recreational and cultural values. To the extent that urban agriculture is gaining momentum in many cities - including Detroit, Toronto, Chicago, Havanna, but to a smaller extent also Brussels - food production and erosion control could also constitute sizable urban flows (Bonfiglio et al., 2008; Verdonck et al., 2012).

One of the main challenges of studying ecosystem service flows in urban environments is the complex interaction between human and natural systems (Norgaard, 2010). Indeed, urban ecosystems differ from other ecosystems such as national or regional forests or wilderness areas due to the strong presence of built forms and human pressure. In order to take this distinction into account, Ervin (2012) propose to study ecosystem services by distinguishing between different sources of services:

- Natural ecosystem sources (e.g. national/regional forests, rivers, wilderness area activities, lakes, streams, watersheds, wetlands)
- Intermediate (natural/built) sources (urban parks, greenways, street trees, reservoirs, green spaces, restored wetlands and streams)
- Built replacement sources (green roofs, air conditioning, hatcheries, indoor facilities, wastewater treatment, artificial wetlands)
In practice, the three categories describe a continuum and not a discrete classification. In urban forms, intermediate (natural/built) sources and built replacement sources typically predominate, although some cities also harbour natural ecosystems such as extensive surface water (Stockholm) or forests (Johannesburg, Brussels). It should also be noted that the distinction between intermediate and replacement sources of ecosystem services is relatively fuzzy and has to be dealt with on a case-by-case basis. Replacement services are largely considered as attractive opportunities for local business development (e.g. in the construction sector), but there is also increasing into the relationship between other ecosystem services and business development (TEEB, 2010; World Resources Institute, 2008).

Building on the distinction between supporting, provisioning, regulating and cultural services, we will now briefly review the state of the art regarding their measurement and analysis in urban environments.

### 3.1 Supporting services

Supporting services such as soil formation, nutrient cycling and biodiversity maintenance are typically connected to the extent of vegetated spaces, either as permeable green spaces or other intermediate natural/built forms such as gardens or green rooftops (Rowe, 2011). For the case of urbanised regions in England, Dallimer et al. (2011) observed that green space increased in 13 out of 14 English cities between 1991 and 2006, but also that most of these increases occurred before 2001. In Brussels, the area of impermeable surfaces increasing slowly but steadily and constitutes today roughly half of the Regional surface (Vanhuysse et al, 2006; Hamdi et al, 2009).

Green spaces vary considerably with respect to their capacity to provide supporting services. Within cities, cultivated land such as gardens has been shown to harbour substantial biodiversity. Davies et al (2009), for instance, have established an inventory of resource provision for biodiversity within domestic gardens, a category that comprises a total area of around 432,924 ha in the UK. Based on survey data, the authors estimated that approximately 12.6 million households provide supplementary food for birds, 7.4 million of which specifically use bird feeders. In addition, a minimum of 4.7 million nest boxes are located within gardens, along with 2.5–3.5 million ponds and 28.7 million trees. In light of these figures, Davies et al (2009) conclude that “the important contribution domestic gardens make to the green space infrastructure in residential areas must be acknowledged, as their reduction will impact biodiversity conservation, ecosystem services, and the well-being of the human population.” Related to the study of biodiversity within gardens (Gaston et al., 2005), ponds have also been recognised as a source of urban ecosystem services (Gledhill et al, 2008).

A feature of urban ecosystems with potentially strong influence on supporting services is their embeddedness in the wider urban metabolism, a catch-all concept that refers to the substantial flows of organic and inorganic matter within cities. Especially the management of compost has been – and could resurface in the future as – an important vector of supporting services in urbanised areas (Gaston et al, 2010). The harnessing of urban metabolism for supporting services requires, however, a rethinking of flows in what Erkman (1998) refers to as “industrial ecology”. For the case of Brussels, Vanderstraeten et al (2009) point out that the transformation of the urban metabolism calls for the
development of new infrastructures and an economy based on functionality and services rather than products.

### 3.2 Provisioning services

Cities have historically been prominent locations of provisioning services linked to urban ecosystems. Especially in the long-term, the resilience of human settlements has been shown to be closely related to the availability of food and water within city boundaries (see Barthel and Isendahl (2013) for a seminal discussion of provisioning services in the case of Maya civilisations and Constantinople). Brussels is no exception given that prior to the industrialisation in the 19th century a considerable portion of food was produced in green spaces within the limits of the historic city fortifications (Billen et al., 2012).

Since the 1990s, provisioning services have reappeared in many cities with extensive patches of unused land, especially in the United States. Bonfiglio et al. (2008) takes stock of this development for the case of Detroit, one of the epicentres of this movement, and documents the substantial size of associated flows and how they affect the quality of life in the city. Gaston et al. (2010) also mention provisioning services as a key output of urban ecosystem in most European cities, whereas Bolund and Hunhammar (1999), writing a decade earlier, do not include provisioning services in their review of urban ecosystem services in Stockholm. On any account, Sonnino (2009) correctly emphasises that “cities are emerging as prominent food chain actors”.

In the Brussels-Capital Region, provisioning services have appeared in urban landscapes relatively recently and partly in the framework of CdQ after 2010, although a significant number of spatially dispersed gardens have been active for decades. Since the mid-2000, local initiatives supported by dedicated civil society organisations have sprung up all over the region, responding to a renewed interest in gardening and sustainable lifestyles (Verdonck et al, 2012). This trend has subsequently influenced regional policy agendas, with the Regional Ministry in charge of the environment declaring the local provision of food as one of its priorities.

Given that provisioning services are related to supporting services in that they require soil and nutrients, the urban metabolism plays a central role in the underlying ecosystems. As a consequence, many commentators call for identifying the potential to close loops in the nutrient cycle, for instance by using locally created compost in urban agriculture initiatives. Given that the connected economic services provide sizable potential employment but have yet to be developed (Verdonck et al, 2012), there is hence scope for regional economic development in this domain of industrial ecology (Erkman, 1998; Vandersraeten et al, 2009).

### 3.3 Regulating services

Compared to supporting and provisioning services, the regulatory effects of urban ecosystems have received relatively more attention in the scientific literature. We can distinguish between two broad
types of regulatory services: those who are provided locally but have regional or global impact; and those whose provision and benefits are both local.

Regarding the first type of regulating service, several studies have estimated the amount of above-ground biological carbon storage within urban forms. Gillespie et al (2012) trace the evolution of urban forestry in Los Angeles over time, while Churkina et al (2010) look at human settlements in the United States in general. Edmondson et al (2012) and Davies et al. (2012) include other types of vegetation beside trees in order to quantify aboveground carbon storage in urban ecosystems. This allows the authors to draw conclusions on the comparative performance of a range of urban ecosystems with respect to regulating services in the city of Leicester: they notably conclude that 97.3 percent of the total above-ground carbon storage (231 521 tonnes) is associated with trees rather than herbaceous and woody vegetation. For instance, gardens are measured to store only 0.76 kg C m2 compared to 28.86 kg C m2 in areas of tree cover on publicly owned/managed sites (Davies et al, 2011). Such estimations have important repercussion for the management of vegetated areas if cities are to contribute to this type of ecosystem service. Moreover, the method used in these studies allow for relatively unproblematic (qualitative) extrapolations to the Brussels region to the extent that different types of land cover can be distinguished in available orthophotoplans such as the UrbiIS database. Other studies focusing on regulatory services of global reach use the method for assessing urban forest structure and ecosystem services by Nowak (2008) and the analysis of urban forest landscapes by McPherson (1995). The evaluation of carbon storage by the significant stock of city trees in Johannesburg by Schäffler and Swilling (2013) is potentially relevant for the case of the Brussels region due to the presence of the Sonian Forest on the regional territory, but also because of the spatial distribution of trees in the South African city. Similarly to the East-West opposition that is echoed in many socio-economic cleavages in Brussels, the provision of regulatory ecosystem services in Johannesburg is marked by clear socio-economic divisions between the North and the South of the city, with the density of trees being much higher in the wealthier and traditionally white neighbourhoods in the North (Schäffler and Swilling, 2013).

Among the regulatory ecosystem services whose provision and benefits are both local, one can include air filtering and noise reduction due to endemic vegetation. For instance, McPherson et al. (1997) have estimated that the trees in the Chicago region remove approximately 5500 tons of air pollutants per year and evaluate this service at 9 million US dollars of air quality. A regulatory service that can only be locally provided is noise reduction. Different types of vegetated surfaces have been shown to differ in their capacity to absorb sounds and produce more quite environments (Bolund and Hunhammar, 1999).

A regulatory ecosystem service that has received substantial public attention in Brussels\(^5\) is rainwater drainage through permeable green spaces, while impermeable surface lead to increased water run-off and peak floods (Haughton and Hunter, 1994). The water quality is also negatively related to the extent of impermeable surfaces given that run-off water will pick up relatively more pollutants that are present in urban forms (Bollund and Hunhammar, 1999). Vegetated surfaces, on the other hand, provide an attractive solution to rainwater drainage through a mix of local seeping, transpiration and evaporation that largely avoids run-off. Indeed, Bernatzky (1983) estimate that vegetated areas produce only 5-15 percent of rainwater run-off, compared to 60 percent in cities without vegetation.

Another regulating service is sewage treatment through urban ecosystems, although in many cities this type of water treatment is still in an experimental phase. Bolund and Hunhammer (1999)

\(^5\) For instance in the context of the remodelling of the Place Flagey in Ixelles after the construction of storm water recipients underneath the public square.
highlight that cities can use wetland plant and animals in order to “assimilate large amounts of the nutrients and slow down the flow of the sewage water, allowing particles to settle out on the bottom.”

Micro-climate regulation is another service that can only be provided locally. There is a large body of literature that documents higher surface temperatures in cities, partially captured with the notion of “heat island effects”. This effect can be substantially reduced by the presence of different types of urban ecosystems, notably city trees. McPherson et al. (1997) has calculated that increasing the tree cover of Chicago by 10 percent would reduce annual energy spending by city dwellers for heating and cooling by 50–90 US dollars per dwelling unit, which equals more than twice the present value of the costs associated with tree planting and maintenance. In addition to trees, other intermediate natural/built ecosystem can also contribute to micro-climate regulation. Alexandri and Jones (2008) show that green walls and roofs can substantially reduce surface temperatures. So-called “living walls” indeed represent a promising venue for replacement services in urban contexts and is receiving increasing policy support, for instance by the DG Environment of the European Commission.

For the case of Brussels, Hamdi et al (2009) have studied the effects of historical urbanization trends on surface air temperature. The study links changes in microclimate to the secular rise in impervious surfaces in Brussels. Their results show that between 1960 and 1999, the isolated effect of urbanisation led to a rise in the mean temperature of 0.62°C and attribute 45 percent of the overall warming trend to intensifying urban heat island effects rather than to changes in the regional climate. The provision of regulatory ecosystem services that curb heat island effects is therefore both measurable and highly relevant in the context of the Brussels-Capital Region.

3.4 Cultural services

While the measurement of supporting, provisioning and regulating ecosystem services relies predominantly on biophysical indicators, the nature of cultural services has given rise to a series of often methodologically heterogeneous approaches. While the general precept that urban ecosystems contribute to the quality of life within cities is relatively unproblematic (Folke et al, 1997; Gaston et al; 2012), the identification and measurement of different types of cultural services poses intricate epistemological challenges as to how these services should be quantified and valued. For instance, the beneficial repercussions of green spaces can be apprehended by either subjective indices using cardinal or ordinal metrics of well-being or by monetised indicators of willingness to pay. Both types of evaluations are present in the literature and have their advantages and caveats.

An example of subjective assessments that does not rely on monetisation is the study by Dallimer et al. (2012) examining the impact species richness in public parks on self-reported well-being. While actual biodiversity is not significantly related to subjective well-being, the perceived level of biodiversity increases well-being. This is an illustration of why the evaluation of cultural ecosystem services is fundamentally different from biophysical services due to the presence of several layers of sociological interference.

Ervin et al (2012) underline that urban ecosystem services therefore give rise to concerns for environmental justice: “Interest in and capacity to make decisions that support ecosystem services are often closely correlated with the socioeconomic profile of a community (education, income, race/ethnicity). (…) Densely populated areas with substantial built environments, though, pose socio-political challenges for the delivery of ecosystem services (e.g., clean air). Relatively wealthy and well-educated citizens tend to value a broad range of ecosystem services, from the tangible (i.e., with easily assigned monetary values) to intangible (e.g., a beautiful landscape). Less economically and
educationally advantaged citizens, in contrast, tend to be less able to pursue sustainable uses of ecosystems, but this is not always the case.” Inequalities between socio-economic groups have been shown to be empirically related to both ecosystem service provision and consumption (Jo and McPherson, 2001; Hope et al. 2003; Kinzig et al, 2005; Grove et al., 2006; Barbosa et al. 2007; Tratalos et al; 2007; Fuller et al, 2012). Among the variables used to capture cultural ecosystem services are crime (Kuo and Sullivan, 2001), social ecology (Kuo, 2003), willingness to pay for tree canopy (Netusil et al, 2010) and birth outcomes (Donavan et al, 2011). An important aspect of cultural services related to the observation that their provision is often spatially constrained and tightly linked to socio-economic inequalities within urban settlements. Indeed, Gaston et al (2011) observe that the “majority of ecosystem goods and services show much more spatially constrained flows than in many other environments”, which potentially reproduces and exacerbates other socio-economic cleavages by transcending them into the domain of cultural ecosystem services.

An area that has received considerable attention in the empirical literature on cultural ecosystem services is the relationship between green spaces and the real estate market, mostly by using the willingness-to-pay approach. For instance, Ervin et al (2010) highlight the impact of “cultural ecosystem services through improvement in property values and neighbourhood aesthetics”. Transek (1993) found that city dwellers in Sweden were willing to pay 360–530 SEK per month to live near a park, 370–540 SEK per month to live close to a larger urban forest and 330–570 SEK per month to live close to water areas. Estimates of the relationship between community gardens on property values have been computed by Been and Voicu (2006), who conclude that the presence of a community garden within 1000 feet has a significantly positive impact on the value of real estate. The study by Vigdor (2010) is also related to the proposed research as it examines the link between urban revitalisation and housing prices. The author concludes that the observed price increases “associated with revitalization are smaller than most households’ willingness to pay for neighbourhood improvements” and that for most people “neighbourhood revitalization is beneficial and decline detrimental”.

For the case of Brussels, existing empirical material studying the relationship between urban revitalisation, for instance through the creation of new green spaces, is extremely thin. This being said, Van Criekingen (2009) reports findings suggesting that increases in housing prices that can at least partially be attributed to cultural ecosystem services often exceed willingness to pay, with the result of tenants spending a bigger proportion of their income on rent. This perverse effect of neighbourhood revitalisation projects in the centre of Brussels can thus be likened to a special kind of gentrification that Van Criekingen describes as a blend between exclusionary displacement and in situ impoverishment. In general, the idea that cultural ecosystem services in the form of parks and other green spaces reproduces other socio-economic cleavages embedded in the East/West and centre/periphery oppositions in Brussels is regularly criticised by civil society organisation such as the IEB or the ARAU.
4 Analysis of ecosystem services at neighbourhood scale

In this section we examine one way to analyse urban ecosystem service provision in an urban context. More specifically, we focus on an empirical evaluation of the impact of a specific urban revitalisation instrument (the Contrat de Quartier, CdQ) on ecosystem functions, goods and services in the affected neighbourhoods in the Brussels-Capital Region. Several elements of the CdQ framework are likely to affect urban ecosystem service flows: for instance, new housing developments or the creation of community infra structures typically increase the proportion of impermeable surfaces and thereby potentially hamper rainwater drainage regulation; the creation or restructuring of green spaces, on the other hand, can be associated with higher quality ecosystems of different sizes and types (street trees, parks, gardens, rooftops, etc) and associated ecosystem service delivery; the renovation of old buildings and the ecodesign of new structures can potentially reduce pressure on ecosystems by the provision of replacement services. Although urban revitalisation programmes such as the CdQ appear to provide important leverage to improve local ecosystems and their different outputs, so far no systematic study has evaluated their consequences in terms of ecosystem service flows.

4.1 Contrats de Quartier and ecosystem services

While the ideological and political underpinning of the CdQ developed over several decades (Lenel, 2013), its legislative basis was written relatively swiftly in the early 1990s: the instrument was officially created in 1993 with the Ordonnance du 7 octobre 1993 organique de la revitalisation des quartiers. As implied by its name, the CdQ has been conceived a contract between the regional and communal public authority and covers a project phase of 4 years, preceded by nine months during which the programme is established and succeeded by two years to finish all works. The total duration of an individual CdQ is therefore around 7 years.

In order to target the neighbourhoods that are most in need of urban revitalisation, the regional authorities used a series of socio-economic criteria to define a priority zone from which each year neighbourhoods are selected. This Espaces de développement régional du logement et de la rénovation (EDRLR) covers neighbourhoods situated in the communes of Anderlecht, Auderghem, Bruxelles-Ville, Etterbeek, Forest, Ixelles, Jette, Koekelberg, Molenbeek-Saint-Jean, Saint-Gilles, Saint-Josse-ten-Noode, Schaerbeek.

There is spatial and temporal variation between different CdQ programmes given that their design and implementation depends to some extent on the vision and capabilities of the local commune of the selected neighbourhood. Each commune typically calls upon a specialised commercial planning bureau for the implementation of the different phases, but it should also be noted that many communes have built up extensive in-house expertise, especially Bruxelles-Ville and its Délegation au Développement du Pentagone (DDP) later transformed into the Délegation au Développement de la Ville (DDV) and then into the Délegation au développement durable de la de la Ville (DDDV) (Dessouroux et al, 2009). There are several studies and monographs that document how the CdQ has affected local policies in the domain of urban renovation, for instance Sacco (2010) on Cureghem; Hilgers (1995) on Saint-Gilles.

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While the CdQ undeniably induced sizable changes in communal policy and the affected neighbourhoods, in its 20 years of existence the instrument itself also underwent several modifications (Guérin, Maufroy, Raynaud, 2007). The first of these changes concerns the budget of the CdQ instrument; the second the role of the socio-economic and participatory elements that are stipulated in its regulation; the third change relates to the role of the environmental aspects of the programmes.

The budget of the different CdQs stems from the region, but the initial set-up also foresaw a co-financing of the instrument by the selected municipalities of 30 percent. This was soon perceived as a heavy burden on the finances of the EDRLR communes, which is why this quota was reduced to 10 percent in 2001 and was then further reduced to today’s value of 5 percent. Parallel to this development, the federal funding of the instrument increased over time and another urban policy, the Quartier des Initiatives, was absorbed and incorporated into the CdQ framework with the Ordonnance du 20 juillet 2000 (Thibaut, 2001). Today, 44 Contrats de Quartiers that started between 1994 à 2006 have been completed. The total budget of these programmes was 388,189,243 euros. There are twelve programmes that started between 2007 and 2009 and are still active: their cumulative budget equals 192,186,850 euros. 12 Contrats de Quartiers Durables have been initiated since 2010 for a total budget of 201,851,410 euros. Four programmes are currently being defined. This accumulates to a total of 68 active or completed programmes to the tune of 782,227,508 euros.

A second change concerns the role of socio-economic elements in the CdQ framework. Indeed, the initial set-up foresaw actions favouring the social cohesion in the selection neighbourhoods (volet 5). However, the performance of these actions has been widely regarded as unsatisfactory and in 2001 the underlying legislation attempted to improve the conception and implementation of social cohesion initiatives in the CdQ. Comhaire and Sacco (2007) go as far as describing the corresponding modifications as the “socio-economic turn” of the CdQ. Parallel to the stronger role of social cohesion elements in the programmes, the different modes of participation have been systematically improved and extended (Berger, 2009). Partly, the improving performance of the participatory element in the different programmes can also be attributed to the learning effects and the accumulated experience of administrations, planners and civil society actors with the overall CdQ framework (Moritz, 2011).

Finally, during the past 20 years environmental aspects of neighbourhood revitalisation have moved from the periphery of urban strategy to their very core. While the initial objective of the policy did not include any explicit reference to sustainable development criteria (Rossy, 2004), since 2010 the latter have been declared as the transversal backbone of the entire framework, which consequently has been renamed Contrats de Quartier Durable.

Although the initial ambition of the CdQ was therefore not chiefly environmental, there is a range of potential channels through which the neighbourhood programmes impacted from the outset on local ecosystem services. The absence of explicit sustainable development criteria was in practice often replaced with implicit criteria, in many places through the knowledge and vision of the involved actors (see the interviews with administrators and planners by Rossy, 2004). But more importantly, from the beginning the CdQ adopted a voluntaristic stance on replacement services in buildings, notably by reducing the energy demand through ecological heating systems, insulation and rainwater management. Moreover, the conception of new or re-conception of existing green spaces within the
neighbourhood has obvious impacts on local ecosystems, for instance through the choice of vegetation, their extent and envisaged use. Another potentially negative impact are new developments, for instance for social housing, that have often been integrated in CdQ programmes. These developments typically increased the impervious surfaces in the neighbourhood, with consequences for supporting and regulating ecosystem services.

Since 2010, the environmental dimension of the CdQ framework was re-enforced by adopting “sustainable development” as transversal criterion for all of its elements. The series of programmes that started after 2010 are therefore bound to integrative elements that are potentially relevant for the provision of ecosystem services, including:

- replacement services through the “construction of new passive buildings” and “low-energy renovations”;
- the creation of public spaces that improve the “management of rainwater run-off”, “conserve or increase local biodiversity”, the “creation of green spaces” and “collective vegetable gardens” and the systematic “soil depollution”;
- the promotion of industrial ecology through socio-economic projects that areas including “sustainable material flows”, “eco-construction”, “renewable energies”, “gardening” and “urban agriculture”.

All of these elements are tightly related to urban ecosystem service flows, which is why the CdQ programmes make up a fertile ground for the study of the relationship between urban revitalisation policy and different types of ecosystem services.

So far several in-depth evaluations of the CdQ framework have been published: the 1994-1998 series was evaluated by Deloitte & Touche and Aries in cooperation with Benoît Moritz; the period 1997-2003 was evaluated by Archi+i: the series 1999-2001 by an academic team from UCL and ULB; Guérin et al (2007) is an overall overview over the entire period between the early 1990s until the mid 2000s; Berger (2009) documents the participatory elements of the CdQ; Rossy (2004) is a first study on the integration of sustainable development criteria. Yet none of these evaluations has focused on the impact that neighbourhood interventions have on local ecosystems. This gap could be overcome by means of a systematic evaluation into how the different CdQ programmes affected the most relevant locally provided urban ecosystem services.

4.2 Available data on changes in ecosystem service flows due to CdQ programmes

Extensive qualitative and quantitative data on the different features of CdQ programmes is available in the documentation that planning companies in charge of these programmes have to provide to local and regional authorities. What is more, important elements of this documentation, such as the neighbourhood assessments documents - including high-resolution maps and detailed descriptions of buildings and green spaces - are relatively homogenous across different CdQ programmes given that their content and features are defined by regional regulations.

7 http://www.quartiers.irisnet.be/fr/contrats-de-quartiers-durables/dimension-environnementale
In particular, many of these documents are defined by the Ordonnance du 7 octobre 1993 organique de la revitalisation des quartiers and the Arrêté du GRBC du 3 février 1994 portant exécution de l'ordonnance organique du 7 octobre 1993 sur la revitalisation des quartiers. There is also a detailed description of the “mission d'étude concernant un programme de revalorisation” that has been defined by the regional authorities in 1998 and that has been subsequently updated (Rossy, 2004).

As a consequence, not only the scope of the local interventions in terms of the size of the affected area and the allocated budgets but also the available data for each programme render the CdQs much more homogeneous and comparable than other urban revitalisation policies that give rise to a range of heterogeneous one-off interventions. Wherever necessary, information that is not available in the individual programmes will be completed with the help of additional data sources (such as the different high-resolution aerial campaigns in UrbIS, Monitoring des Quartiers, Registre National, etc). After assessing the impact of each CdQ programme in the sample on the extent and quality of local ecosystems, the corresponding potential flows of ecosystem goods and services will be computed with state-of-the-art models in applied ecology and ecological economics.

A preliminary list of urban ecosystem services is provided in Table 2. The table is divided into supporting, provisioning, regulating and cultural services. It also includes replacements of ecosystem services through the built environment (Ervin et al., 2012), the indicators associated with the measurement of each service, the main data sources for each service, and a selection of empirical applications in the scientific literature. As can be seen the CdQ programme documentation constitutes the main source of quantitative and qualitative data, but other sources can provide valuable external information.

We will adopt an environmental approach based on biophysical indicators wherever this is possible and sensible; however, it appears to be heuristically useful to monetize cultural goods and services given the literature on the links between these flows and several economics variables such as property values in the neighbourhood and the associated changes in socio-economic inequalities (Dessouroux et al, 2009: van Criekingen, 2009).

In order to illustrate the type of geospatial information contained in the CdQ programme documentation, Figure 1 shows extracts from maps provided by Arsis in the preparatory phase of the CdQ Maison Rouge in Bruxelles-Ville. As can be seen in Figure 2, these maps, based on data by UrbIS and completed with ground observations, contain a series of data on urban ecosystems and, by extension, on associated ecosystem goods and services such as:

- Surfaces of non impervious soil inside blocks (in % of interior of blocks)
- Surfaces of impervious soil inside blocks (in % of interior of blocks)
- Number of trees inside blocks
- Number of street trees
- Detailed information on types of surfaces: green spaces (lawns, gardens), tarmac, asphalt, cobblestone, concrete, etc

As can be seen in Figure 2, in the CdQ neighbourhood Maison Rouge, a relatively dense set of blocks with no public green spaces, there were nevertheless 423 trees in the public domain and an approximate 262 trees within block interiors, hence a total of 685 trees. Other information available in the mandatory CdQ programme documentation includes:

- Links with other urban renovation programmes (other CdQ, Objectif II)
- The quality of each building (new, currently under renovation, good, average, degraded etc), as shown in the lower panel of Figure 1
- The current use of each building (housing, commerce, etc)
- Empty buildings, abandoned buildings, vacant lots

For some biophysical and monetary indicators it may be necessary to collect additional data that is not contained in the CdQ programme documentation. Relevant sources of data on ecosystems at the neighbourhood level include, for instance, the UrbiS database that is provided by the Centre d’Informatique pour la Région Bruxelloise (CIRB). UrbiS contains high-resolution aerial images that allow assessing soil vegetation and built forms in 1996, 1999, 2004, 2009 and 2012. In addition, detailed orthophotoplans are available as of 2004. Another provider of extremely precise plans is the Institut géographique national (IGN), but the precisions of IGN maps often comes at the cost of lower periodicity and are therefore less useful for comparisons across time. There are also several European databases that could be used to complete the information on neighbourhoods, such as the URBAN ATLAS or CORINE compiled with a harmonized methodology by the European Environmental Agency. Bolund and Hunhammar (1999) used Eurostat “Europe’s Environment: Statistical Compendium for the Dobris Assessment” to quantify city trees.

For socio-demographic and socio-economic variables, the “Monitoring des Quartiers” compiled by the Institut Bruxellois de Statistique et d’Analyse (IBSA); complementary information is contained in the “Atlas de la Santé et du Social” provided by the Observatoire de la santé et du social de Bruxelles (OSSB). Data on rent prices and real estate evolutions are published in the Observatoire régional de l’habitat by the SLRB. Contrary to the UrbiS data however, the variables published by the IBSA, OSSB and SLRB typically employ a classification of neighbourhoods that are often larger that the geographical scope of CdQ neighbourhoods. Only variables that are provided at the level of the finer statistical sectors allow computing precise socio-economic and socio-demographic variables. This is of instance the case for fiscal data on income or cadastral revenue collected by the Registre National and the different fiscal administrations in Belgium.

A third set of complementary data are related research projects that study a specific aspect of urban ecosystem and the associated services. Several of these projects have been or are currently carried out at the ULB by the IGEAT, for example the European project “Design and implementation of Urban Public Spaces for Sustainable Cities” (DRUPSSuC), the project “Amélioration de l'interprétation de l'occupation du sol de différents types de paysages belges”, the project “Belgium Ecosystem Services: a new vision for society-nature interactions” (BEES) and “Cartographie, évolution et modélisation de l'occupation du sol en milieu urbain : le cas de Bruxelles”. The latter project has led to a series of relevant application regarding changes in urbanised surfaces in the Brussels region (Hamdi et al., 2009; Leignel et al., 2010; examples are shown in Figures 4 and 5).
<table>
<thead>
<tr>
<th>Type of ES</th>
<th>Supporting Service</th>
<th>Provisioning</th>
<th>Regulating</th>
<th>Cultural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example of urban ecosystem service</td>
<td>Biodiversity in urban ecosystems (gardens, ponds, parks etc)</td>
<td>Occurrence of edible plants</td>
<td>Air filtering</td>
<td>Above-ground biological carbon storage</td>
</tr>
<tr>
<td>Example of replacement service</td>
<td>Nutrient recycling through composting</td>
<td>Urban agriculture production</td>
<td>Construction of passive or low-energy buildings</td>
<td>Grey infrastructure</td>
</tr>
<tr>
<td>Indicators</td>
<td>Changes in surface cover and quality of urban ecosystems areas due to CdQ</td>
<td>Production of foodstuffs in gardens, orchards, shrubbery, rooftops, bee hives etc</td>
<td>Changes in stock of street trees, tree stock in parks and block interiors, emission reductions through renovation</td>
<td>Reduction of carbon emissions</td>
</tr>
<tr>
<td>Data sources</td>
<td>Programme documentation, UrbIS high-resolution GIS, IGN</td>
<td>Programme documentation, IBGE, WORMS database</td>
<td>Programme documentation, UrbIS high-resolution GIS, Services Verts</td>
<td>Programme documentation, UrbIS high-resolution GIS</td>
</tr>
</tbody>
</table>

**Table 2: Overview of proposed ecosystem service evaluation for CdQ programmes**
Figure 1: Details of a map produced by Arsis in the framework of the CdQ Maison Rouge in Brussels.

The percentages indicate pervious/impervious surfaces, the numbers in green circles are estimates for trees within block interiors.

The colours indicate the quality of the built environment (e.g. dark green represents new buildings, orange buildings indicate degradation).
Figure 2: Development plan from CdQ and aerial image of Place de Houffalize

The left panel shows the new design of the Place de Houffalize by D+A Consult as shown by Moritz (2011). The right panel an aerial image of the Place de Houffalize after the implementation of the new design.

Figure 3: Aerial image from Anderlecht (8km x 5km)
Note: Resolution of 2.5m. Grey areas = no urban change; yellow = detected urban change; pink = ground truth for the new urban area; other = area out of interest. Source: Leignel et al. (2012)
Figure 4: Evolution of impervious surfaces in the Brussels region (1985-2006)

Percentage of impervious surfaces in 1-ha grid cells: 1985

Percentage of impervious surfaces in 1-ha grid cells: 2006

Source: Hamdi et al. (2006)
5 Conclusion

Paul Duvigneaud, one of the precursors of ecosystem science, is widely recognised for having combined different scientific strands in his analysis of ecosystems, notably the botanical, chemical and biological methods that his research team had at its disposable during the second half of the 20th century. His landmark publication “La synthèse écologique” is a seminal overview of this effort.

Duvigneaud, whose intellectual influence is still strongly felt in different departments of the ULB and beyond, is less known for his work on urban ecosystems. This is unfortunate given the tremendous amount of empirical and conceptual material that he collected and summarized with remarkable concision in publications such as “L’écosystème Bruxelles”, published in 1975 and today mostly forgotten. While his work on different flows and cycles within the urban ecosystem focused on the concepts of scientific ecosystem analysis (the nitrogen cycles, the carbon cycle, the oxygen cycle, the water cycle etc), Duvigneaud also stressed the importance of the interactions between environmental and anthropogenic variables. In a well-known schematic presentation of his ecological synthesis one even finds “hope” as one of the central variables of the ecosystem... By and large, however, the main thrust of Duvigneaud’s ecosystem research is situated within the natural sciences. More than two decades after Duvigneaud’s last publications, a synthesis between approaches of the natural and social sciences to ecosystems still remains missing.

Ecosystem goods and services are a promising step in this direction, and the application of the underlying concepts to urban ecosystem constitutes a priviledged venue for research on the integration between ‘hard’ and ‘soft’ sciences. The anthropogenic nature of urban systems is so strong that it can be difficult to identify ecosystems within cities – and yet urban ecology has shown that the built environment is not only a habitat for humans but are also harbours great biodiversity. The promise of research on urban ecosystem services is to provide an analytical framework allowing to link theoretically and empirically the functioning of cities and the well-being of its inhabitants to the ecosystem of which they are a part and parcel.

Applying the ecosystem service approach to urban contexts requires both conceptual innovation and new forms of data collection. In this paper we have summarised the state of the art in the literature on urban ecosystem and identified typologies of ecosystems within cities ranging from individual trees to extensive green spaces. We then examined how the different elements of urban ecosystems can be linked to the four main types of ecosystem goods and services that are conventionally cited in the literature. Finally, we have examined how the provision of urban ecosystem services could be studied empirically. Focussing on the case of Brussels, we proposed an identification strategy that does not attempt to account for the total production of ecosystem services by all aspects of the urban ecosystems. Instead, we argue that a more feasible approach consists in focusing on changes to urban ecosystems induced by neighbourhood revitalisation programmes (the Contrats de Quartiers) and how these changes affect the provision of urban ecosystem services. Our overall conclusion of this exercice is that there is sufficient empirical material allowing to assess, at least in a first approximation, the impact of neighbourhood revitalisation programmes in Brussels on the provision of ecosystem services within the city. We argue that a careful analysis of this empirical material would allow to significantly improve the management of the city’s ecosystem.
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