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ANALYSIS

Ecosystem services in urban areas

Per Bolund [a], Sven Hunhammar [a,b,*]

[a] *Environmental Strategies Research Group, Natural Resource Management, Department of Systems Ecology, Stockholm University, Stockholm, Sweden*

[b] *Stockholm Environment Institute, Stockholm, Sweden*

Abstract

Humanity is increasingly urban, but continues to depend on Nature for its survival. Cities are dependent on the ecosystems beyond the city limits, but also benefit from internal urban ecosystems. The aim of this paper is to analyze the ecosystem services generated by ecosystems within the urban area. 'Ecosystem services' refers to the benefits human populations derive from ecosystems. Seven different urban ecosystems have been identified: street trees; lawns/parks; urban forests; cultivated land; wetlands; lakes/sea; and streams. These systems generate a range of ecosystem services. In this paper, six local and direct services relevant for Stockholm are addressed: air filtration, micro climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values. It is concluded that the locally generated ecosystem services have a substantial impact on the quality-of-life in urban areas and should be addressed in land-use planning. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Humanity is rapidly urbanizing, and by 2030 more than 60% of the world population is expected to live in cities (UN, 1997). But even if humanity is increasingly urban, we are still as dependent on Nature as before. Cities are, for example, dependent on the large hinterlands needed to provide input and take care of output from the city. In a study of the 29 largest cities in the Baltic Sea region, it was estimated that the cities claimed ecosystem support areas at least 500–1000 times larger than the area of the cities themselves (Folke et al., 1997).

* Corresponding author. fms, Box 2142, 103 14 Stockholm, Sweden. Tel.: +46-8-4023808; fax: +46-8-4023801.

E-mail address: hunhammar@fms.ecology.su.se (S. Hunhammar)

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When humanity is considered a part of nature, cities themselves can be regarded as a global network of ecosystems. If compared with true, natural ecosystems, the man-made ones are however immature due to features like their rapid growth and inefficient use of resources such as energy and water (Haughton and Hunter, 1994). Odum (1971) even observes cities to be "only parasites in the biosphere".

But there is also a presence of natural ecosystems within the city limits. As will be discussed in this paper, the natural urban ecosystems contribute to public health and increase the quality-of-life of urban citizens, e.g. improve air quality and reduce noise. Most of the problems present in urban areas are locally generated, such as those due to traffic. Often the most effective, and in some cases the only, way to deal with these local problems is through local solutions. In this respect, the urban ecosystems are vital.

The aim of this paper is to analyse some of the ecosystem services generated by urban ecosystems and discuss their importance for the quality of urban life. The emphasis is to identify the services and whenever possible also quantify and value them, with greatest relevance to cities in Europe and North America. Examples will be taken from the city of Stockholm in Sweden.

It is difficult to generalize a discussion like the one in this paper to reflect the importance of ecosystem services in all cities of the world. Both the actual service and its value are site-specific and can vary significantly around the world. Cities differ, since they are built in all kinds of climates, their sizes vary from small towns to huge megacities, and the wealth of city inhabitants ranges from extreme poverty to excessive luxury.

Methodologically, the identification and valuation of ecosystem services could be viewed as an input to a cost-benefit analysis (CBA) aiming at more efficient land-use in urban areas. The benefits of ecosystems are often neglected in ordinary CBAs and if increased values (both monetary and non-monetary) could be allocated to ecosystems, the results of CBAs on new infrastructure or conservation projects could change.

We begin with a general discussion of urban ecosystems and their ecosystem services. A number of local and direct services relevant for Stockholm are then discussed. The paper is concluded by a synthesis and a discussion on the consequences for land use.

2. Urban ecosystems

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). However, the borders between different ecosystems are often diffuse. In the case of the urban environment, it is both possible to define the city as one single ecosystem or to see the city as composed of several individual ecosystems, e.g. parks and lakes (Rebele, 1994). For simplicity, we have chosen to use the term urban ecosystems for all natural green and blue areas in the city, including in this definition street trees and ponds. In reality, street trees are too small to be considered ecosystems in their own right, and should rather be regarded as elements of a larger system.

We identify seven different urban ecosystems which we call natural, even if almost all areas in cities are manipulated and managed by man. The ecosystems are street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea, and streams.

Street trees are stand-alone trees, often surrounded by paved ground. Lawns/parks are managed green areas with a mixture of grass, larger trees, and other plants. Areas such as playgrounds and golf courses are also included in this group. Urban forests are less managed areas with a more dense tree stand than parks. Cultivated land and gardens are used for growing various food items. Wetlands consist of various types of marshes and swamps. Lakes/sea includes the open water areas while streams refers to flowing water. Other areas within the city, such as dumps and abandoned backyards, may also contain significant populations of plants and animals. It should be possible, however, to place most urban ecosystems or elements in one of the above mentioned categories.

Our classification is crude and has to be adopted to site-specific conditions.

Stockholm has a large and varied ecological structure. In the City of Stockholm, parks and green space occupy 56 km^2 (26%), and water areas cover 28 km^2 (13%) of the total area of 215 km^2 (Miljöförvaltningen, 1995). This is considerably more water and green space than possessed by most other cities, and gives Stockholm its unique character. The city is situated on a number of islands between the fresh water lake Mälaren and the brackish Baltic Sea. Stockholm also has a special feature with a number of green wedges pointing towards the city centre. This allows the ecosystems close to the city centre to be linked with larger ecosystems outside of the city. The City of Stockholm has about 700 000 inhabitants. Greater Stockholm has 1.5 million inhabitants.

3. Locally generated ecosystem services

Ecosystem services are defined as "the benefits human populations derive, directly or indirectly, from ecosystem functions" by Costanza et al. (1997) and they also identify 17 major categories of ecosystem services. A number of these ecological 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. Another aspect of ecosystem services is that they have different spatial cover. Services can be available on the local or global scale according to the scope of the problem they are connected to and the possibility of transferring the service from where it is produced to the city where humans benefit from it. Such a transfer can take place both by man-made transport and by natural means (e.g. atmospheric transport). Easily transferred services with a global scope, like CO_2 sequestering, do not necessarily have to be produced close to the source of the problem. Services which are impossible to transfer must, however, be generated close to where they are consumed (e.g. noise reduction).

Since this paper focuses on issues relevant for urban areas, the attention is on direct and locally generated services relevant for Stockholm. From the 17 groups of services listed by Costanza et al. (1997), six are considered to have a major importance in urban areas: air filtering (gas regulation), micro-climate regulation, noise reduction (disturbance regulation), rainwater drainage (water regulation), sewage treatment (waste treatment), and recreational/cultural values. Other services, such as food production and erosion control, could also have been included, but are not considered significant for Stockholm. For each of the addressed services the following aspects are discussed:

- Which kind of problem does the service contribute to the solution of?
- What ecosystems are involved in the generation of the service, and how?
- Quantification and valuation of the service with examples from the literature.
- Examples from Stockholm.

3.1. Air filtering

Air pollution caused by transportation and heating of buildings, among other things, is a major environmental and public health problem in cities.

It is clear that vegetation reduces air pollution, but to what level seems to depend on the local situation (Svensson and Eliasson, 1997). The reduction is primarily caused by vegetation filtering pollution and particulates from the air. Filtering capacity increases with more leaf area, and is thus higher for trees than bushes or grassland (Givoni, 1991). Due to the larger total surface area of needles, coniferous trees have a larger filtering capacity than trees with deciduous leaves (Stolt, 1982). This capacity is also greater because the needles are not shed during the winter, when the air quality is usually worst. However, coniferous trees are sensitive to air pollution and deciduous trees are better at absorbing gases (Stolt, 1982). A mix of species therefore seems to be the best alternative. In general, vegetation is much better than water or open spaces for filtering the air.

The location and structure of vegetation is important for the ability to filter the air. Bernatzky (1983) reports that up to 85% of air pollution in a park can be filtered out, and in a street with trees, up to 70%. Thick vegetation may simply cause turbulence in the air while a thinner cover may let the air through and filter it (Bernatzky, 1983). According to some estimates (Tolly, 1988; Bramryd and Fransman, 1993), 1 ha of mixed forest can remove 15 t of particulates per year from the air while a pure spruce forest may filter two or three times as much. The trees of the Chicago region have been estimated to remove some 5500 t of air pollutants, providing more than US$9 million of air quality during 1 year (McPherson et al., 1997).

In Stockholm the percentage of vegetated area, as well as of water area, is clearly above the European average (Eurostat, 1995). In fact, approximately 10% (22 km^2) of the land area in the City of Stockholm is forested. Such a large amount of forest has a significant air filtering capacity which leads to an improvement of air quality. The total filtering service of Stockholm vegetation has not been estimated.

3.2. *Micro-climate regulation, at street and city level*

Local climate and even weather are affected by the city. In studies of US cities, some of these differences have been quantified, and expressed as changes compared with surrounding country-side: air temperature is 0.7°C higher measured as the annual mean, solar radiation is reduced by up to 20%, and wind speed is lowered by 10–30% (Haughton and Hunter, 1994). The phenomenon, sometimes called the urban heat island effect, is caused by the large area of heat absorbing surfaces, in combination with high amounts of energy use in cities.

All natural ecosystems in urban areas will help to reduce these differences. Water areas in the city will help even out temperature deviations both during summer and winter. Vegetation is also important. A single large tree can transpire 450 l of water per day. This consumes 1000 MJ of heat energy to drive the evaporation process. In this way city trees can lower summer temperatures of the city markedly (Hough, 1989). Vegetation can also decrease energy use for heating and air conditioning substantially in urban areas by shading houses in summer and reducing wind speed in winter.

120 gal. per day

In Chicago it has been shown that an increase in tree cover by 10%, or planting about three trees per building lot, could reduce the total energy for heating and cooling by US$50–90 per dwelling unit per year. The present value of long-term benefits by the trees was found to be more than twice the present value of costs (McPherson et al., 1997).

The micro-climate in Stockholm is regulated to a great extent by the large bodies of water in the city, as the city is situated on a number of islands. Mean annual temperatures are reported to be 0.6°C higher in downtown Stockholm as compared to areas outside the central city (Alexandersson et al., 1991). Stockholm also benefits from the vegetation, for example by reduced heating costs.

3.3. *Noise reduction*

Noise from traffic and other sources creates health problems for people in urban areas. The overall costs of noise have been estimated to be in the range of 0.2 –2% of GDP in the EU (Kommunförbundet, 1998). In Sweden, maximum noise levels of 55 dB(A) outside and 30 dB(A) inside buildings have been established as the long-term goal (Naturvårdsverket, 1996).

The distance to the source of the noise is one key factor, and a doubling of the distance decreases the equivalent level by 3 dB(A). Another key factor is the character of the ground. A soft lawn, rather than a concrete pavement, decreases the level by another 3 dB(A) (SOU, 1993). Vegetation also contributes to the decrease, but at what level is uncertain. One source states that a dense shrubbery, at least 5 m wide can reduce noise levels by 2 dB(A) and that a 50-m wide plantation can lower noise levels by 3–6 dB(A) (Naturvårdsverket, 1996). Another source claims that 100 m of dense vegetation is only reported to decrease noise by 1–2 dB(A) (Kommunförbundet, 1998). Sounds propagate long distances on water (Naturvårdsverket, 1996).

Society is prepared to pay large sums for lowered noise levels. Technical solutions to decrease noise include, for example, 3–5-m high walls at a cost of at least 5000 SEK (8 SEK ≈ US$1) per m (Kommunförbundet, 1998). A wall like this decreases the noise by 10–15 dB(A) immediately behind it. However, the urban visual landscape would be destroyed if such walls were built everywhere. Another example of a technical solution is insulated windows in houses, but they are only effective for indoors.

In Stockholm, about 20% of the population is exposed to noise levels of over 55 dB(A) outside their homes, the maximum recommended level by the Swedish Environmental Protection Agency. Some 630 km of streets have average roadside noise levels of 60 dB(A) or more (Miljöförvaltningen, 1995). Increasing the areas with soft ground and vegetation may decrease these noise levels. Vegetation may also contribute by shielding the visual intrusion of traffic and thus making it less disturbing: Evergreen trees are preferred in this case.

3.4. Rainwater drainage

The built-up infrastructure, with concrete and tarmac covering the ground, results in alterations of water flow compared to an equivalent rural catchment. A higher proportion of rainfall becomes surface-water run-off which results in increased peak flood discharges and degraded water quality through the pick-up of e.g. urban street pollutants (Haughton and Hunter, 1994). The impervious surfaces and high extraction of water cause the groundwater level of many cities to decrease.

Vegetated areas contribute to solving this problem in several ways. The soft ground of vegetated areas allows water to seep through and the vegetation takes up water and releases it into the air through evapotranspiration.

Even if the built city surface primarily seals the ground from rainwater, it has been suggested that urbanization also creates some new, unintended pathways for recharge. These include leaking water mains, sewers, septic tanks, and soakways (Lerner, 1990).

In vegetated areas only 5–15% of the rainwater runs off the ground, with the rest evaporating or infiltrating the ground. In vegetation-free cities about 60% of the rain water is instead led off through storm water drains (Bernatzky, 1983). This will of course affect both the local climate and the groundwater levels. Valuation of this service depends on the local situation. Cities with a high risk of flooding will benefit more from green areas that take up water than do other cities.

The drinking water in Stockholm is supplied by lake water. Therefore, the ground water levels in the city are not heavily affected. Stockholm could however benefit from improved rainwater drainage through soft ground since the building and maintenance of the storm water drainage system involve large costs. Using the ecosystem service could lower the cost.

3.5. Sewage treatment

Stockholm sewage treatment plants annually treat more than 150 million m^3 of sewage (Stockholm Vatten, 1998). Taking care of sewage costs cities large amounts of money, and the nutrients that are still released contribute to eutrophication of the surrounding water ecosystems.

In many cities, large scale experiments are taking place where natural systems, mainly wetlands, are being used to treat sewage water. The wetland plants and animals can assimilate large amounts of the nutrients and slow down the flow of the sewage water, allowing particles to settle out on the bottom.

Up to 96% of the nitrogen and 97% of the phosphorous can be retained in wetlands, and so far wetland restorations have largely been successful, increasing biodiversity and substantially lowering costs of sewage treatment (Ewel, 1997). The cost of nitrogen reduction through wetland restoration has been calculated to 20–60 SEK while the cost in a sewage treatment plant is 33–350 SEK (Gren, 1995). Other benefits of wetlands, e.g. biomass production and biodiversity, have not been included in these figures.

Stockholm has very few natural wetlands available for sewage treatment, but it is possible to construct more wetlands for cleaning sewage water. If all converted wetlands of the Stockholm catchment were restored, the cost of halving the nitrogen load to the archipelago could be lowered by 20% (Gren, 1995).

3.6. Recreational and cultural values

A city is a stressful environment for its citizens. The overall speed and number of impressions cause hectic lifestyles with little room for rest and contemplation.

The recreational aspects of all urban ecosystems, with possibilities to play and rest, are perhaps the highest valued ecosystem service in cities. All ecosystems also provide aesthetic and cultural values to the city and lend structure to the landscape. Botkin and Beveridge (1997) argue that "Vegetation is essential to achieving the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment". According to the Swedish economist Nils Lundgren, a good urban environment is an important argument for regions when trying to attract a highly qualified workforce (N. Lundgren, Nordbanken, personal communication).

The appearance of fauna, e.g. birds and fish, should also be accounted for in recreational values. In Stockholm, a central stream of water provides excellent opportunities for fish to spawn and the area is one of the best places to fish in the entire country. Approximately 30 different species are found here (Stadbyggnadskontoret, 1995).

Green spaces are also psychologically very important. One example is a study on the response of persons put under stress in different environments (Ulrich et al., 1991). This study showed that when subjects of the experiment were exposed to natural environments the level of stress decreased rapidly, whereas during exposure to the urban environment the stress levels remained high or even increased. Another study on recovery of patients in a hospital showed that patients with rooms facing a park had 10% faster recovery and needed 50% less strong pain-relieving medication compared to patients in rooms facing a building wall (Ulrich, 1984). These studies imply that green spaces can increase the physical and psychological well-being of urban citizens.

The scientific values of ecosystems are also included in this group, e.g. providing information services. The urban ecosystems can function as indicators of the state of the urban environment. Lichens, for example, cannot grow in areas with polluted air, and can thus be used to indicate the air quality (Miller, 1994).

The citizens of Stockholm highly value their green spaces: more than 90% visit parks at least once during the year, 45% do so every week, and 17% more than three times a week (Stadbyggnadskontoret, 1994). In a stated preference study, performed in Stockholm and a few other Swedish cities, people were willing to pay 360–530 SEK/month to live near a park, they were prepared to pay 370–540 SEK/month to live close to a larger urban forest and 330–570 SEK/month to live close to water areas (Transek, 1993).

4. Synthesis

In the previous section, the ecosystem services were listed individually. It is however obvious that each ecosystem generates a number of different services simultaneously. This is shown in a matrix (Table 1) where we can see that all ecosystems contribute to climate regulation as well as providing recreational and cultural values. Wetland also seems to be a valuable ecosystem type since it contributes to all services. This corresponds to the study by Costanza et al. (1997) where wetlands were ranked as the most valuable terrestrial ecosystem per ha.

If the aim is to assess the total value of ecosystems in urban areas, it is important to add the value of all cells in a matrix of this kind. The individual values might be small, but taken together the total value of urban ecosystems is potentially significant. It should also be remembered that the services discussed in this paper are only a subset of the existing services.

The purpose of this paper is to analyze the benefits received from ecosystems, but ecosystems can also cause problems. The main reason for building houses, as well as cities, has been to

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

	Street tree	Lawns/parks	Urban forest	Cultivated land	Wetland	Stream	Lakes/sea
Air filtering	X	X	X	X	X		
Micro climate regulation	X	X	X	X	X	X	X
Noise reduction	X	X	X	X	X		
Rainwater drainage		X	X	X	X		
Sewage treatment					X		
Recreation/cultural values	X	X	X	X	X	X	X

protect humans from nature. The ecosystems kept in cities contribute to urban well-being but may also create negative aspects. Some common city tree species, for example pine (*Pinus* spp.), oak (*Quercus* spp.), and willow (*Salix* spp.), emit volatile organic compounds that may contribute to urban smog and ozone problems (Slanina, 1997). Animals, such as birds at municipal solid waste dumps or frogs in wetlands, could cause disturbing noise and the restoration of wetlands could cause problems such as increased mosquito hatching and bad odors. The parks could be dangerous places during the dark hours. In a complete cost-benefit analysis of land use and urban ecosystems, such negative aspects should also be reviewed.

5. Land use

One important issue in the debate on sustainable cities is whether expansion should be directed at increasing urban density or rather allowing urban sprawl. Sprawled cities can produce more urban ecosystem services while occupying a larger amount of land. Even if a number of problems are created by the urbanization process, e.g. disrupted nutrient cycles and concentration of pollutants, urbanization also creates opportunities. If people live in dense concentrations, environmentally benign solutions like public transport and district heating become feasible (Rees and Wackernagel, 1996). European cities are often dense and to a large extent dependent on ecosystem services from the outside. Some Chinese cities on the other hand are reported to recycle organic waste efficiently and produce much of their own food (Yufang et al., 1994). However, it is not evident that more self-sufficient urban areas are simultaneously more sustainable.

Urban ecosystems are threatened by the process of increasing the density of buildings. Trees are sometimes lost at a faster rate than they are replanted. The American Forestry Association found in a survey quoted in Moll (1989) that New York City had a net loss of approximately 175 000 street trees, or 25% of its total tree stand, during 1977–1987. In Stockholm about 8% of the green space was lost during the 1970s, 7% during the 1980s and, the process still continues in the 1990s (Länsstyrelsen, 1996).

Urban ecosystems are also often of poorer quality than their rural equivalents. By studying an urban-to-rural gradient in New York City, a scientific team discovered that forests at the urban end of the gradient exhibited reduced fungal and microarthropod populations and poorer leaf litter quality than the more rural forests (McDonnell et al., 1997).

For the preservation of fauna, the size and nature of the urban green areas are also important. An area with a variety of biotopes will have a large number of ecological niches that can be occupied by many different species, and will thus increase biodiversity. To have a high diversity of plants and species in the city requires that the connections between the ecosystems surrounding the city and the green spaces in the city are not disrupted. The small city parks and urban forests are often too small to sustain a varied flora and fauna in themselves. Through the migration of organisms from larger core areas outside the city, the diversity in urban ecosystems can still be maintained. For example, Italian cities have been shown to contain almost 50% of all species of the total Italian avifauna (Dinetti et al., 1996) and over 1000 different vascular plant species have been identified in central Stockholm (Länsstyrelsen, 1996). However, the roads and railroads and large built-up areas around cities often cause major barrier effects to the migration of many species, and can thus lower the stabilizing effect of outer core areas (Bolund, 1996).

Since land is so valuable in urban areas, a combination of different land uses on the same piece of land is probably needed in order to safeguard and improve the generation of ecosystem services. Different strategies can be used to increase vegetation, e.g. trees in parking spaces or narrow lawns as lane-separators. Some creative thinking is needed.

6. Concluding discussion

We have tried to identify, and whenever possible also quantify and value, the ecosystem services generated in urban areas. For most general ecosystem services, the share generated by ecosystems within the urban area is expected to be limited compared to the total service. However, even if the generation of the services can often be made at a distance from the city, there are reasons why part of the services should be produced locally. It can be advantageous to generate ecosystem services locally for pure efficiency reasons, but also on ethical and educational grounds.

It is also clear that urban ecosystem services contribute to the quality of urban life even if urban citizens are still dependent on global ecosystem services for their survival. The quality of life for urban citizens is improved by locally generated services, e.g. air quality and noise levels that cannot be improved with the help of distant ecosystems. It should however be remembered that it is only the effects of these problems that are decreased, not the cause of the problem that is solved. It is necessary to work to both ends.

Hopefully, an increased awareness of the ecosystem services could contribute to a more resource-efficient city structure and design. The urban ecosystems could then be fully appreciated for their contribution to urban life and valued accordingly when the land is claimed for exploitation. An understanding of the importance of ecosystem services could also mean that unexploited urban areas can be maintained or even expanded. As cities are expected to grow at a rapid rate in the coming decades, it is important that the ecosystem services in urban areas and the ecosystems that provide them are understood and valued by city planners and political decision-makers.

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