

Assessment of Ecosystem Services in Urban Systems for the Example of Karlsruhe

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Abstract In recent times many studies e.g. “The Economics of Ecosystems and Biodiversity” (TEEB) and the “Millennium Ecosystem Assessment” (MEA) have drawn attention to valuing ecosystem services (ESS) not only in natural environment but also in urban systems [The Economics of Ecosystems And Biodiversity (TEEB) Hrsg. Mainstreaming the Economics of Nature 2010, Infodienst Landwirtschaft – Ernährung – Ländlicher Raum Schwäbisch Gmünd Hrsg. Vergleich der Preiswürdigkeit verschiedener Mineraldünger 2011]. The assessment of ESS is an important part of nowadays economic issues and political decision making, especially in ecological urban planning. In this context, a project was launched at the Institute of Geography and Geoecology, KIT, to locate and value ESS for the example of Karlsruhe. Inspired by previous studies like the “Green City Index” (Singapore Index) or “City of Biodiversity” methods of identification, mapping and evaluation of ESS were developed. The mapping of biotope types according to the guideline of the State Ministry for Environment, Measurements and Nature Conservation (Landesanstalt für Umwelt, Messung und Naturschutz Baden-Württemberg (LUBW) Biotoptypenkartierung) was used to identify the different ecosystem types [7]. Five 0.5 km² large areas (tiles) were chosen as representative parts of Karlsruhe to provide a general overview on urban ecosystem types. These ecosystem types can be evaluated with respect to the four ESS (provisioning, regulating, cultural and supporting services) mentioned in the MEA [Infodienst Landwirtschaft – Ernährung – Ländlicher Raum Schwäbisch Gmünd Hrsg. Vergleich der Preiswürdigkeit verschiedener Mineraldünger 2011]. Out of these four services urban relevant ES subservices were picked out to be valued with monetary and non-monetary methods. This study aims at localizing urban ESS and developing and summarizing new assessment tools, which can be used as basis for further studies in Karlsruhe or other urban systems. In addition, the results of this research holistically can be utilized to understand and sum up EES in Karlsruhe in follow-up surveys.

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Fig. 1 Investigated tiles (LGL Baden-Württemberg)

Introduction

Ecosystems in urban systems are under high pressure by various development activities and environment pollution. Nevertheless, especially in urban systems, ecosystems provide indispensable basics for a healthy and worth-living environment. More and above that, in urban systems even the most sealed and developed areas form ecosystems of varying effects on the living conditions. The approach of ESS provides a strong tool to assess the value of ecosystems also in urban systems to improve and optimize the structures of urban developments. Within this study, a method was elaborated in 2011/2012 to value the ESS for the example of Karlsruhe.

Methodology

Five 0.5 km² tiles were chosen as representative parts of Karlsruhe to give a general overview of ecosystems' types occurring in urban systems. The tiles are arranged along transect from west to east in Karlsruhe and show different land uses (Fig. 1). The mapping methodology of biotope types according to the State Ministry for Environment, Measurements and Nature Conservation (LUBW—Biotoptypenkartierung, [7]) served as a guideline to identify the different types of biotopes. These types were evaluated with respect to the four ESS. Specific urban relevant and important services were identified and evaluated with monetary and non-monetary methods.



Fig. 2 Biotope types of the city center (tile J10) in Karlsruhe, aerial photo: Liegenschaftsamt Karlsruhe

The research started with mapping biotope types and drawing biotope maps in GIS (Fig. 2). These biotope maps are essential to locate urban ecosystem services. On that basis, ESS were cartographically expressed in maps (e.g. biodiversity Fig. 3), while other are diagrammed. Table 1 shows the used methods for the assessment of EES.

Results and Discussion

Mapping

The land uses of the urban areas are illustrated by the mapped biotopes (Fig. 2).

As an example the map of biotope types and the map of the ecosystem service biodiversity for tile J10 (city center) are presented in Figs. 2, 3.

Table 2 gives an overview over the main biotope types and the usage of the investigated tiles of Karlsruhe.

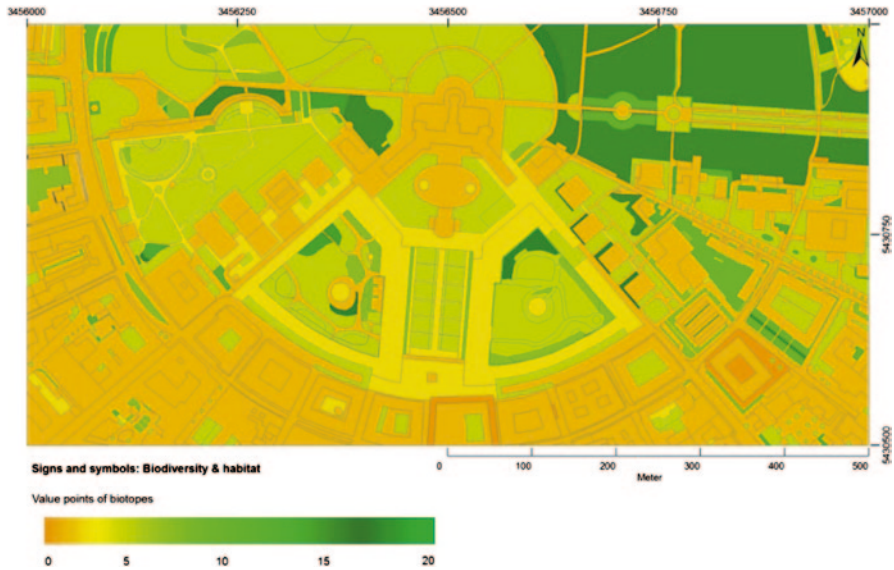


Fig. 3 Biodiversity of the city center (tile J10) in Karlsruhe

Table 1 Methodology of assessed EES

Ecosystem Service	Method
Biodiversity	Value points of biotope value (the higher the points, the more biodiversity), guidance of LUBW [5], non-monetary
Food supply	Price and earnings for agriculture crops
Pollination	Value of bee colony, according to TEEB Case Study [2]
Cultural and spiritual inspiration	Cemetery maintenance costs per m ²
Recreation	Costs for maintenance of green areas and allotment
Climate regulation (climatic balance, dust bounding capacity)	Categories of ground cover [7], non-monetary
Groundwater renewal	Grade of sealing, precipitation charges and runoff coefficient
Nutrient element regulation	Estimated by valuing nutrient content in soils (N, P, Ca, K, Mg, S) based on the actual price of fertilizers [5]
Value of trees	Calculating capacity of wood, current price of forestry wood
Carbon storage	Value of carbon storage per ha with carbon certificate [6]

Table 2 Details of mapped tiles

Tile	Biotope types/utilization
J3 (Industry area)	Agriculturally used areas, sealed paths, buildings, lawns, forest and floodplain areas, industrial area (30%)
J5 (Port settlement)	Buildings, sealed places, cemetery; river Alb (natural biotope type, floodplain-band)
I7 (West City)	Anthropogenic biotope types (90%), buildings, lawns, gardens, allotments, sport fields
J10 (City Center)	Green spaces, biotope type represents the cityscape (radiate streets around castle) outward, recreation areas, lawns, urban forest, buildings, streets and paths
K16 (Suburban Area)	Buildings (6,5%), lawn, cobbled streets and squares, gardens (12%), largest area by agriculture crop research institute "Augustenberg", cemetery

Biodiversity

The conducted assessment of biotopes provides a good overview and a reasonable introduction to the ecosystem service biodiversity. However, it did not take wildlife or connection between biotopes and is based solely on valuing the biotopes by points according to the guideline of the State Ministry for Environment, Measurements and Nature Conservation [7].

Tiles' Details

In tile J3 the transition between rural and urban area becomes evident. Anthropogenic influenced industrial areas directly adjoin more rural biotopes and natural floodplains. A settlement of industrial and commercial areas is rather typical, because the use of riverine areas as a residential area was unthinkable before mosquito control.

Comparatively, tile J5 scores the highest total biodiversity points of all tiles. This is caused by many natural biotopes with a very high rating, though they are not classic city biotopes. While high value points were awarded, biotopes can be further improved (e.g. by containment of invasive species). Nevertheless, by having these high-quality biotopes inside the city of Karlsruhe, it becomes clear that even in cities sufficient natural areas can exist if they are adequately protected and maintained.

As mentioned above, in tile I7 (West City) rather low assessed and anthropogenic influenced biotopes are found. High-quality biotopes are only found on a very small scale, which indicates that urbanization and anthropogenic use shaped I7. Thus, it is not surprising that I7 achieves the lowest biotope value of all the selected tiles. However, this area is enhanced by a high number of trees.

The extremely low values of biotopes in tile J10 (City Center) reflect that this part is strongly influenced by human beings. By a high degree of development and sealing many plant species have been pushed back. The downtown area is heavily affected by non-indigenous or intentionally planted plants. Spontaneous vegetation

occurs almost nowhere in this district. For this reason, the mapped biotope types and biodiversity are rather inferior in comparison to the other tiles.

Unlike tile J3 and J5, tile K16 (suburban area) has less dense developed areas, but still the overall biotope value is lower. This is because although a high number of natural biotopes were found, most of them have a low value. The agricultural land on Augustenberg is characterized by monocultures (orchards) and thus has only a poor biodiversity value.

Food Supply

For the evaluation of the ESS food supply the average crop in dt/ha has been used. The applied market rates are from 2010 since market prices for the diverse groceries in the same reference period were not available. In the calculation merely the area of cultivable land was used. Information such as age, quantity and height of the trees or shrubs was not considered. This might affect the results, since especially in orchards the density of trees per area differs. However, the exact recording of these data is extremely time consuming. A specific of tile K16 is that there is a crop research institute and almost all crops have to be abolished, so there is only marginal direct marketing.

Pollination

The evaluation of the monetary value of pollinating service is based on estimations from Switzerland [2]. Several factors, such as location, climate, annual production or world market price can lead to regional and annual fluctuation of the monetary value. For that reason a detailed interrogation of Karlsruhe's beekeepers has to be started to get an advance in this evaluation. However, the chosen evaluation method is adequate for the first approximation.

Cultural and Spiritual Inspiration

As already mentioned in the MEA, these ecosystem services are difficult to map and to evaluate [9]. In the TEEB it is suggested to use "willingness to pay"-surveys, but in the framework of the study, such an investigation was not conducted [3]. It is in common ground that a cemetery is an important green area to the European culture and, moreover, it is easy to map. This is only a tiny part of what this service can offer, but it definitely requires further research in how it could be mapped and valued, before these ecosystem services can be surveyed at the same degree as the others. Annual fees, using rights, funeral expenses and maintenance costs have been used for calculation of the ESS.

Recreation

Green space, especially lawns, is mapped and attributed with recreation in this study. Tiles with many allotments and green space are the most valuable areas. The tile at the city center (J10) hosts the Castle Park, a large recreation area. Tile I7 in the west is rich in allotments, giving both tiles the best results for recreation. For public green maintenance costs were used for ESS calculation, for allotment gardens the respective fees for renting such gardens from for Germany typical allotment garden clubs.

Climate Regulation and Groundwater Renewal

Climate regulation comprised the factors of mitigating the urban heat effect and dust filter capacity. Both are expressed non-monetary as percentage between no heat island mitigation respectively no dust filter capacity and maximum effects of heat island mitigation and dust filter capacity [1, 3, 8]. The ESS groundwater renewal was expressed as monetary value calculated via surface runoff coefficient, respective area and the fee that has to be paid if precipitation cannot percolate and becomes surface runoff. This fee was 5.06 € per 10 m² in Karlsruhe in 2012. With this evaluation method of climate control and groundwater renewal it is relatively simple to compare the tiles with each other. However, the assessment results only from the categories of ground cover. Other factors such as climate and surface structure were not considered. For a more detailed assessment measures in these fields are necessary as differences between the surrounding areas (such as cold-air-lanes) are not displayed by this method. Furthermore all studied biotope types (in total 97) are classified in only 10 categories of ground cover and not every biotope type was easy to classify. For the monetary valuation of groundwater renewal all sealed and partly sealed areas were considered. However, the split precipitation charge of Karlsruhe only considers precipitation, which is canalized. Sealed areas without a connection to the canalization were not assessed separately.

Nutrient Element Regulation

The important difference between the investigation areas is the level of sealing of the soil surface. Because of that, the downtown areas are of less value than the peripheral ones. The nutrient contents (N, P, K, Mg, Ca, S) were estimated on the basis of available information on occurring soils and monetarily expressed according to respective fertilizer prices. Including more soil functions and variables important to soil fertility, such as the buffer and filter function of soils, would increase the value of the soil. Additionally, valuing may not be limited just to unsealed areas, because roots can reach underneath sealed areas as well.

Table 3 Ecosystem services of Karlsruhe

ESS	Tiles total	Tile average
Total area	2,500,703 m ²	50 ha
Sealed surface	-	45%
Biodiversity (Biotope value)	13,662,355 value points	54,634 value points/ha
Food supply	283,978 €/a	1,136 €/(a*ha)
Pollination	1,846 €/a	7 €/(a*ha)
Cultural and spiritual inspiration	4,191,222 €	16,760 €/ha
Recreation	1,282,604 €	5,129 €/ha
Climate regulation		
Dust bounding capacity		26%
Climatic balance		52%
Groundwater renewal		
Groundwater recharge		35%
Precipitation charges	500,249 €/a	2,000 €/(a*ha)
Nutrient element regulation	60,755 €	243 €/ha
Tree value		
Tree value-single trees	376,994 €	1,508 €/ha
Increase of tree value-forests	16,702 €	67 €/ha
Carbon storage		
Carbon storage-single trees	42,376 €	169 €/ha
Carbon storage-forests	8,136 €	33 €/ha

The Value of Trees (Timber and CO₂)

For trees, the diameter in breast height was measured, the height was estimated and the trees were categorized whether they are coniferous or deciduous trees. The volume was calculated according the method described by Nagel (2009) [10]. Average market prices from 2011 were used to calculate the monetary value of timber.

In addition, the amount of stored CO₂ in the trees was calculated. The sample zones do not represent the mean forest area of the city; therefore the extrapolated value for the whole urban area is lower than the one measured by Kändler et al. (2011) [6]. For monetary evaluation the average price for CO₂ at the European Energy Exchange was applied.

All used prices are highly variable over time and are thus not reliable in long-terms. In comparison to the other evaluated ESS, the monetary account of urban trees is comparatively low. It can be assumed that the value would be much higher if all ESS of urban trees (and not only timber and CO₂) would have been considered.

Summary of Ecosystem Services

Table 3 provides an overview over the evaluation of the tiles and the ecosystem services occurring in them. Not for all ESS monetary values could be produced. However, it is noteworthy that the services cultural and spiritual inspiration and

recreation are the most valuable ones if expressed in Euro. The transfer of biotope value points into Euro is still under discussion and has not been carried out here.

Conclusions

The localized urban EES and the developed assessment tools can be used as a basis for further studies in Karlsruhe or other urban systems. In addition, the results of this study can be utilized for a holistic understanding and serve as a building block for future surveys on EES. Elaborating the methodology for the assessment of ecosystem services based on biotope type mapping was a main part of this study. Since urbanization is correlated with changes to biodiversity, this is an important aspect when considering EES. Nevertheless some major points could not be considered in this study. For example, the ecosystem service of biodiversity was only conducted qualitatively (non-monetary). Moreover, because the topography of the studied areas was not considered, the actually mapped space is bigger than the GIS based surfaces. Another point is the relatively small extension of the mapped tiles, with only provide an overview and no results for Karlsruhe as a whole. Besides that, “multifunctional biotope types” could be of interest, as overlapping ecosystem services could create a “multi-talented” biotope type by providing e.g. climatic compensation function, recreation and pollination. These “multi-talented” biotope types should be considered even higher in worth.

The whole research results, maps and discussion are unpublished in a report of the Institute of Geography and Geoecology, KIT. The calculated equations and a full list of all references are available on enquiry.

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