URBAN SOCIAL-ECOLOGICAL ATLAS PROJECT

SYNOPSIS

At our workshop in Stockholm April 18, 2008, we decided that the first common deliverable of the urban network research will be the "**Urban Social-Ecological Atlas"** presenting the perspective, focus and work characteristic of each of the participating urban sites but also providing lessons learnt and methodologies useful for scaling up and replication. Participants agreed that building on a common methodology to make cross-site comparisons possible, the group would construct a basis for comparison instead of doing just a synthesis. The Atlas would map the spatial extent of selected **ecosystem services** and to what extent different socio-economic groups have **access** to the services. The Atlas would also include temporal changes and provide guidelines for where in the urban landscape specific management interventions, protection, restoration or creation would be most needed from a public interest point of view. The following joint methodology was agreed upon for the mapping project:

Ecosystem services

Focus on three services across all sites:

1) Freshwater services;
2) Carbon sequestration; and
3) Recreation and other cultural services.

It was agreed that each site will add ecosystem service(s) viewed as relevant and important depending on priorities and capacity to participate in the Atlas project.

Scales and boundaries

We decided to base our analyses on three scales:

1) The administrative (municipal);
2) The relevant ecological scale; and
3) A larger more coarse scale which takes into account distant flows of services.

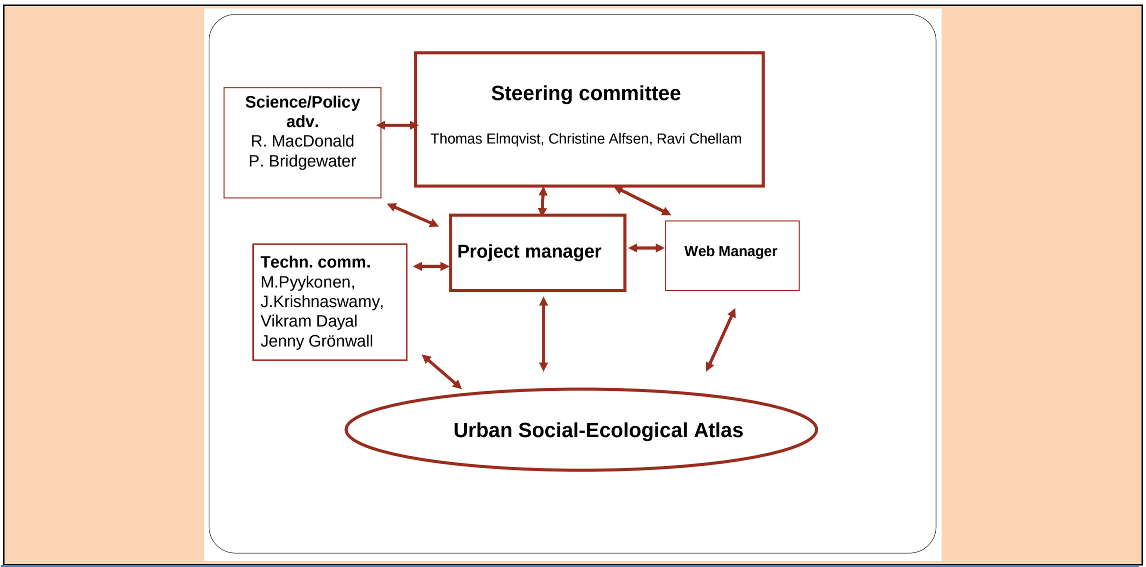
Participating cities:

Bangalore, Canberra, Cape Town, Chicago, Helsinki, Istanbul, Johannesburg, New Delhi, New Orleans, New York City, Phoenix, Stockholm

Time period

The project will run through 2008 and 2009 and result in a book finished during 2010.

Project organization:



1. URBAN SOCIAL-ECOLOGICAL ATLAS

Overall aim: The main outcome of the Atlas will be maps and classification of the urban landscape (green and selected brown areas) based on GIS and on the following matrix where examples of actions, interventions and sets of policy are indicated:

Ecological values (incl. diversity of ecosystem services)	Social values (incl. diversity of stakeholders involved) — Low	Social values (incl. diversity of stakeholders involved) — High
Low	**1** **Example:** remnant green areas, road verges etc. or brown field areas **Ecosystem services:** few **Example of action:** restoration, creation of both social and ecological values	**2** **Example:** large lawns **Ecosystem services:** few **Example of action:** User-contracts for stakeholder involvement in management
High	**3** **Example:** wetlands, small patches of vegetation, remnant forests **Ecosystem services:** many **Example of action:** formal protection	**4** Areas providing a high diversity of ecosystem services with high user-values and high degree of social fencing

The maps will in the first stage consist of areas with four colors describing the matrix above. To do this we need to quantify ecological values through analyzing biodiversity and ecosystem services (water services and carbon sequestration) and social values through analyzing recreation and other cultural services. Then we will successively complicate the picture, deal with different spatial and temporal dimensions and build scenarios and analyze transitions. For example:
Transition from 1 to 4 and 2 to 4. Such transitions will build on innovations based on both ecological and social research and urban design (e.g. 1 to 4) and social innovations in management and governance (1 to 4, 2 to 4).
Transition of 3 to 4 may sometimes be desirable, sometimes not depending on the fragility of the area.
Transition from 1 to 3 is perhaps desirable for areas with high value for landscape connectivity.
In the following we will describe the methodology for creating the maps and also a template for the narratives that have to go with the maps.

The manual is intended as a first foundation for framing our collaborative work and will develop over time in detail.

What are Ecosystem Services?

Ecosystem services are "the components of nature, directly enjoyed, consumed or used to yield human well-being" or "benefits provided by ecosystems that contribute to making human life both possible and worth living". The **Millennium Ecosystem Assessment (MA 2005)** represented a major international effort to assess ecosystem changes and the consequences for human well-being, at scales from the global to the local. MA recognized four distinct categories of services: supporting (nutrient cycling, soil formation and primary production); provisioning (food, fresh water, wood and fibre and fuel); regulating (climate, flood and disease regulation and water purification) and cultural (aesthetic, spiritual, educational and recreational). The MA findings conclusively prove that society is exhausting the planet's ecosystem services, and the current decline of these services presents a serious obstacle in meeting the Millennium Development Goals for many developing countries. The MA emphasis on ecosystem services and trade-offs and their links to human well-being have been welcomed by the conservation and development community as a bridge to development efforts focused on poverty reduction. Because most ecosystem services are public goods, markets are seldom available to provide clear units of account.

2. DEALING WITH SPATIAL AND TEMPORAL SCALES

Attempts of integrated analyses of biophysical and socio-economic and political data have so far been severely constrained because of the manner in which data are available or generated for these two components. Data on abundance and distribution of ecological resources on one hand, and social-economic data on the other, seldom are available at comparable scales. This causes serious problems in data interpretation and on the availability and cross-compatibility of official data for detailed modeling and analysis. Furthermore, biophysical data from remote sensing (raster data) on natural resources will be available at regular intervals from weeks to years, for a grid of pixels varying in size ranging from meters to kilometers, whereas socio-economic data will be available for polygons (vector data) corresponding to administrative or political boundaries at relatively infrequent intervals.

Scale for the purposes of this common urban project will be defined from the landscape ecology perspective and will consist of grain and extent. Grain is the fundamental unit of observation e.g. size of a pixel of a remotely sized imagery, size of clusters of households sampled, size of observation plots and so on. The extent is the size of the study area, which will be a nested set of two boundaries determined by:

1) The administrative (municipal/urban district/city government);
2) The relevant ecological/biophysical scale which take into account flows of some important services such as from a nearby watershed or river system;
3) A larger scale, only for a conceptual model or discussion with respect to import of ecosystem services from great distances or migration of labor etc.

When performing mapping for the final “Urban Social-Ecological Atlas Project” it should preferably be based on scalable vector graphic maps at the scale at appr. 1:10000 to 1:20000. The minimum mapping unit should not be smaller than 1 ha. Classified satellite images can also be used in which cells are aggregated into zones not smaller than 1 ha. Each polygon or zone cannot be assigned more than one single unique value for each parameter, which in practice means that there will be a certain amount of generalization which will vary between different areas.

Typically scale 1 extent will be 100-1000 sq km^2, and scale 2 extent will be 1000-5000 km^2. For each of these scales, we need a corresponding choice of grain. For scale 1, this will be raster satellite multi-spectral data of a pixel resolution not exceeding approximately 100 m. The vector equivalent will be digitized polygons that define landscape units such as parks and permanent water bodies for which we recommend a minimum mapping unit of 1 ha. These can be digitized from a classified remotely sensed image or from an available vector map.

The grain for scale 2 will be *no coarser* than 1 km. This scale is meant for assessing biophysical fluxes for the larger study area, and that cut across the municipal boundaries. Examples of such flows would include a nature reserve or a water body that straddles boundaries 1 and 2, or a nearby catchment that provides water to the city. This same coarse pixel resolution should be used for assessing temporal change in land-cover over time (see Bangalore example in Appendix). The data for this type of analyses could be 500 m to 1 km NDVI or CVI data that are available from various sensors (AVHRR, SPOT and MODIS). For scale one, field data collection is needed of a variety of bio-physical and socio-economic variables. These data points can be located within individual remotely sensed pixels or within individual polygons scattered throughout the city using a stratified sampling approach with the classified image as the basis. If the purpose is to test the effectiveness of the remotely sensed variable (e.g. NDVI-vegetation index) or the classified image to act as a surrogate for the biophysical variable (e.g. carbon sequestration), then all data points can be assumed to generate a regression model, after ensuring that issues of spatial dependence are addressed (contact Jagdish Krishnaswamy for assistance or help). On the other hand, if the purpose of the field data collection for a specific variable is to help categorize a whole landscape unit such as a park or a water body, then all data points falling within one such polygon would be aggregated. Thus, if any field data sampling is done (for example carbon or biomass measurement, or water quality) one single value of the measured attribute should finally be generated, even if there are more than one sampling unit within the polygon. Similarly, for socio-economic data (e.g. assessing employment potential, equity or access or recreation value of the water body or park), one final aggregated data value should be generated for each such polygon.

Methods 1
Scales

1. The administrative (municipal/urban district/city government); Typical extent = 100-1000 km^2 based on either satellite imagery with pixel size not exceeding 100 m or vector maps with scale 1:10 000-1:20 000. Minimum mapping unit = 1 ha.
2. The relevant ecological/biophysical scale which take into account flows of some important services such as from a nearby watershed or river system; Typical extent = 1000-5000 sq km^2 with pixel size not exceeding 1 km
3. Only for a conceptual model or discussion (not ordinary map) with respect to import of ecosystem services from great distances or migration of labor etc.

3. REMOTE SENSING AND GIS

REMOTE SENSING

If no other base data or satellite images/aerial photos are available the most convenient solution will in most cases be either to purchase or to download free Landsat TM imagery with ca. 30 m resolution via Internet, especially if the end result will be at a course resolution. This imagery provides a good base for time series analysis since data is available from 1980. Prior to 1979, Landsat MSS data with resolution of 79 m is accessible.

For more detailed level and subject to availability of resources, Quickbird or Ikonos can be recommended. QB offers a resolution of 0.65 m in panchromatic mode and 2.5 m resolution in multispectral mode, whereas Ikonos offers 1 m and 4 m respectively. This makes it possible to map individual trees and hedgerows. However, the prize still tends to be too high for studies at a larger scale. The recent versions of Indian IRS satellite imagery (LISS4 and P-6) is another option with resolutions at 2.5 m and 5.8 m respectively and at a lower cost.

A number of commercial software for classification of satellite images are available of which can be mentioned IDRISI, ERDAS Imagine and ER Mapper or Image Analysis Extension for ArcGIS 9.x or ArcView 3.x. One suggested freeware software is MultiSpec offered by Purdue University in USA. Out of many different methods for classification of an urban environment we recommend either unsupervised classification using ISO-DATA clustering or some rule based method, such as CTA in IDRISI (eg see Krishnaswamy et al, 2004). We do not recommend a supervised classification using maximum likelihood algorithm as it may be difficult to meet the assumptions of multi-variate normality for heterogeneous urban classes. . We also do not recommend use of filters such as majority filters in dealing with salt and pepper effects and reclassification of isolated pixels during post-classification image processing as there are often considerable and scattered or isolated pixels of a certain class embedded in other classes in urban areas. Using filters is likely to result in information loss from critical classes that are composed of scattered, isolated pixels.

To provide a general overview the following four classes should be derived:

- Natural and semi-natural land (forest, grassland, (incl. grazing land), scrub/bush land, wetland, parks and golf courses)
- Urban - Artificial surface (residential, industrial, hard made ground such as parking lots, roads etc.)
- Agricultural land
- Water bodies

The images can be classified and thereafter imported into any GIS package. The possibilities of utilizing satellite imagery for generation of vegetation indices are discussed in the chapter about carbon sequestration.

GIS

The base mapping itself must be done at high resolution utilizing either vector maps at the scale of 1:20000 or better or satellite imagery with 30 meter resolution or less. The reason for not using maps at scale of 1:50000 or smaller is that the typical error could be as least 20 m, which is very close to the pixel size and could potentially introduce an unwanted error. Using data from two time periods (15-20 years apart) bi-temporal urban sprawl maps can be produced at a general level, which also gives an early indication of land use/land cover changes. For the time-series analysis a raster based approach is preferred since polygons (areas) in a vector based analysis will very seldom match each other perfectly, giving overlapping areas and/or gaps and slivers between areas. If converting existing vector based data to raster format and performing the base analysis with ca. 25–30 m grid resolution, these problems can be avoided and the grids can thereafter be resampled to desired resolution. All resampling to larger grids inevitably leads to a generalization and important details in built up areas might be lost.

Crucial for all mapping is a final ground truthing of selected areas where uncertainties can be expected. A mobile GIS system connected to a GPS (Global Positioning System) facilitates this task and is also a good aid in all other data collection in the field. This system could consist of a handheld computer with inbuilt GPS and the software ArcMap from ESRI, which however requires that also ArcGIS is installed on the main GIS office computer.

Methods 2
Mapping and classification:

Satellite images:

Landsat TM – 30m resolution – many images freely available
Ikonos or **Quickbird** – high resolution – expensive
IRS – high resolution – alternative to Ikonos or QB

Maps: Vector maps should have a scale of 1:20 000 or better and converted to raster format

Classes derived:
Natural and semi-natural land (forest, grassland, (incl. grazing land), scrub/bush land, wetland, parks and golf courses)
Urban Artificial surface (residential, industrial, hard made ground such as parking lots, roads etc.)
Agricultural land
Water bodies

4. ANALYZING AND MAPPING ECOSYSTEM SERVICES

4. 1 FRESHWATER SERVICES AND ACCESS

Benefits to human life provided by freshwater systems comprise rivers, lakes, aquifers, reservoirs and wetlands (liquid or 'blue' water), but here we also include the 'green' water fluxes (water vapor flows, evapotranspiration, soil moisture). Dependence on the services from these systems is steadily increasing. At the same time, the capacity of the ecosystem to sustain freshwater provisioning services is strongly compromised due to the efficiency in tapping the water resources and the anthropogenic influence on their physical and chemical character (Vörösmarty, C.J., C. Lévêque and C. Revenga 2005).

The MA employs the term 'freshwater' rather than talking about 'hydrological services', so does Fitzhugh and Richter (2004) and Daily et al. (1997).[1] Freshwater and freshwater services can further be defined in the following ways:

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[1] Alternatively, we could use the term 'ecohydrology', which is described by UNESCO as "a new integrative science that involves finding solutions to issues surrounding (fresh)water, people, and the environment. One of the fundamental concepts involved in ecohydrology is that the timing and availability of freshwater is intimately linked to ecosystem processes, and the goods and services provided by fresh waters to societies. This means that emphasis is placed on the hydrological cycle and its effects on ecological processes and human well-being". http://typo38.unesco.org/en/ecohydrology.html.

- Freshwater contains less than 0.5 parts per thousand dissolved salts;
- The services fall into three broad categories: supply of water for drinking, irrigation and other consumptive purposes; supply of goods other than water, such as fish; and supply of non-extractive 'instream' benefits, such as recreation, transportation, dilution and flood control (Postel and Carpenter 1997).
- It is also possible to explain these services as benefits produced by terrestrial ecosystem effects on freshwater, preferably organized into five categories: improvement of extractive water supply; improvement of in-stream water supply; water damage mitigation; provision of waterrelated cultural services; and water-associated supporting services. (Brauman et al. 2007).
- It is difficult to define 'freshwater services' as a distinctly *provisioning, regulating, cultural or supporting* service, because the hydrological cycle plays so many roles in the climate, chemistry and biology of Earth (Vörösmarty, C.J., C. Lévêque and C. Revenga 2005). For instance, the water-related *supporting* services of terrestrial ecosystems include water for plant growth (Brauman et al. 2007), i.e., green water.

In the urban environment, water bodies and wetlands are often beneficial for transportation, recreation, dilution, and purification. The main service is, without doubt, the freshwater provided for drinking and like consumptive uses.

Water quality and liquid waste assimilation and transformation is included in our definition of freshwater services in the urban context. Further, many water bodies in cities store water that /can/ recharge groundwater, provide habitat for biodiversity and recreation, and provide water for domestic use, sanitation and liquid and solid waste assimilation and transformation **within certain limits.**

Access to drinking water

The concept of 'access to water' has been defined as access to safe drinking water,[2] which in turn includes water for preparing food at home and for basic health protection (WHO and UNICEF 2000). Unsafe water and non-existing or under-dimensioned sanitation services are directly and indirectly causing the death of some 4,000 children daily around the world, and make millions of people suffer from water-borne diseases.

Aspects of equity and stakeholder diversification

UN has crudely estimated that 35-50 percent of urban dwellers in Asia and Africa lack adequate provision of water, whereas the equivalence is 20-30 percent in Latin America and the Caribbean (UN-HABITAT 2003). Slum dwellers are practically always underserved, a fact linked to poverty, power inequalities, social stigmas, infrastructure

[2] 'Safe' water and 'improved' provision of drinking water are concepts defined by Howard and Bartram (2003).

deficits and political factors. Stand posts, taps and other public water sources are most often shared with hundreds, sometimes thousands, of others and the reliability of the supply is seldom assured (Vörösmarty, C.J., C. Lévêque and C. Revenga 2005; Grönwall 2008). Apart from the household's purchasing power, the location in the city will have a large impact on what quantities of freshwater are served, and the quality of this water. It will be pertinent to take the level and strategies of access into account when mapping water supply.

Other services from freshwater systems are not likely to be influenced by what stakeholder group one belongs to.

Green water

Traditionally, the green water services were ignored in ecosystem service evaluations. Both surface water and groundwater resources are part of the blue water services. (cf. Rockström et al. 1999). Zhang et al. (2001) developed a simple two-parameter model that relates mean annual evapotranspiration to rainfall, potential evapotranspiration, and plant-available water capacity. Recent work on remotely sensed surrogates for biodiversity and ecosystem services now makes it possible to adapt the Zhang et al. map watershed services of different green areas such as grass covered areas, forest or tree-covered surfaces and open barren areas. Global estimates of evapotranspiration from green areas in urban settlements are approx. 100 km^3/yr (Postel et al. 1996). To this comes vapor flows from lakes.

Freshwater services – example from Bangalore

The Bangalore Water Board takes most of the water supplied to the city from River Cauvery. Water is pumped over a distance of 100 km and against an elevation of c. 1000 m. The river is subject to an inter-State conflict and a special Tribunal has ordered a limit to how much can be pumped, much in favor of irrigation purposes downstream. Further, it has declared that only the third of the city which is situated within the watershed is entitled to water from the river.

A reservoir that has previously provided 148 million liters daily (MLD) has now practically dried out. Many Bangaloreans – up to 40 percent – rely on groundwater, much of which is delivered by private water vendors. However, the hydrogeological conditions being hard bedrock mean that the water table is dropping rapidly and the area is over-exploited. Regulation that is in force to curb the situation is not yet implemented to the necessary extent.

Due to the inherent lack of property certificates, slum dwellers are formally excluded from the possibility to apply for connections to the public distribution network. Recent pilot projects under the auspices of the Water Board to connect poor areas have not been scaled up in spite of showing promising results (Grönwall 2008).

Methods 3

Measuring fresh water services and issues of access

To measure fresh water services and issues of access to those services, it is necessary to look at the existing data bases, available land use and geological maps and secondary materials – but also to generate new data where so is needed. Supplementing information may, for instance, be important for analyzing the social value of blue and green water. The following information will thus be needed:

- Indicators should be derived to address freshwater services as well as the issue of access to water sources;
- Types and physical availability of water sources (incl. water sharing, cost of water supply);
- Size and volume of surface water bodies;
- Level of the groundwater table, related to 'normal' level, and the rock and soil conditions;
- Data on wells;
- Land use pattern and proportions (classification);
- Quality of both surface and groundwater (incl. the issue of liquid waste assimilation potential of water bodies);
- Bio-diversity scenario (species-richness and their social value, if any); and
- Evapotranspiration (rainfall, potential evapotranspiration, plant-available moisture).

To fill up the missing information, especially to address the issue of access, some primary methodologies could be employed which includes:

- GIS mapping, remote sensing and statistical packages (SPSS) for regression model. A land use/land cover classification is needed using simple assumptions based on proportion of built-up land, connectivity of water bodies to non-built up areas and open areas using 1 km grid cells or smaller. *Cf. the Bangalore study in Appendix A below.*
- Field observations to cross-check the real situation with data and maps.
- Statistical analysis of data from municipal water supply boards, companies or the like that are in charge of supplying citizens with water – on the raw water intake from respective sources, environmental flow, how the raw water is treated, number of costumers reached by the water supply networks, etc.
- Field surveys to collect specific information of a particular area.
- Interviews and surveys to map who are accessing (potable) water via a supply network, from public standposts, and via private vendors. Distinction to be made between sources, i.e. surface or groundwater. *Cf.* Raju, K.V. et al.
- Focus group discussion with stakeholders to collect indigenous, innovative and different ideas from local people and provide for a certain amount of people's participation.
- Zhang's et al. two-parameter model for green water assessment that relates mean annual evapotranspiration to rainfall, potential evapotranspiration, and plant-available water capacity.
- Method(s) for liquid waste assimilation assessment.

The Water Poverty Index may be useful to measure water scarcity and stress at household level (Sullivan et al. 2003), but ecosystem conditions and capacity measures need to be better incorporated (Vörösmarty, C.J., C. Lévêque and C. Revenga 2005).

5. CARBON SEQUESTRATION

Carbon: In a city environment, carbon sequestration can occur across a diversity of spatial scales and vegetation structure, ranging from road side avenue trees, small private gardens to large parks and reserves. In addition at all these scales, there will be a below ground and soil carbon storage potential.

NDVI and other vegetation indices from remotely sensed imagery in combination with available equations (e.g. Riumy et al. 1994, Hunt et al. 1994) and some site specific ground measurements from will enable estimation of above-ground net primary production, leaf area index and carbon sequestration. However most of these have been developed for large forest areas, and we suggest that for the urban project, we take a two pronged approach. Use NDVI based approximations for large (1 ha or more) pieces of tree-covered and grass covered areas (e.g. golf courses). In addition, we need an estimate of tree-density and age in different parts of the city along roads and squares, based on a stratified sampling approach or taken from very fine scale imagery such as IKONOS, to estimate carbon sequestration potential for individual trees.

Methods 4

Carbon sequestration

NDVI and other vegetation indices from remotely sensed imagery in combination with available equations will enable estimation of carbon sequestration.

Two scales – 1 ha and individual trees

The specific method for NDVI indexing will be presented later.

Key references:

Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution Journal*. volume 116. No. 3. March 2002. pp 381–389.

Nowak, D.J. 1993. Atmospheric Carbon Reduction by Urban Trees. *Journal of Environmental Management* 1993 volume 37 pp 207-217. http://www.fs.fed.us/ne/syracuse/Pubs/Downloads/93_DN_Atmospheric.pdf

6. SOCIAL AND CULTURAL SERVICES

The importance and concepts of recreation, aesthetic values, etc.

Ecosystem services include such benefits as aesthetic inspiration, recreation, and cultural, religious and spiritual services provided. These are regarded to have a range of positive impacts on human health and social well-being. People's own experiences and perceptions of *meaningfulness* and functionality have been emphasized (Tyrväinen, et al. 2007). The nature of the services is described in short below.

The concept of cultural services has been defined as
- the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, *recreation*, and *aesthetic* experience, including, e.g., (traditional) knowledge systems and social relations (MA).

In turn, the concept of 'recreation' can be defined as and linked to
- refreshment of strength and spirits after work, tourism, relaxation, fun, helps counteract stress;
- the expenditure of time in a manner designed for therapeutic refreshment of one's body or mind… Recreation commonly occurs during an individual's discretionary, or free, time (Wikipedia).

Aesthetic qualities and responses may be individually different and culturally conditioned (and change over time and place) but in general, the values can be defined as and linked to:

- preference or like-dislike affect in association with pleasurable feeling and neuro-physiological activity elicited by visual encounter with an environment (Ulrich, 1986);
- in people's views, natural environments are preferred over built-up ones, healthy and lush landscapes and forests are preferred over those perceived as unhealthy and sick (i.a., Ulrich 1986), and park-like settings[3] are rated highest both by Europeans, Asians and North Americans (Kellert 1993). Accordingly, land prices tend to be higher where a real estate is surrounded by or situated adjacent to beautiful natural parks or like objects.
- The *savanna hypothesis* predicts that some of the positive aesthetics that people have are based on innate knowledge of productive human habitats; humans are genetically predisposed to seek out natural settings that were most likely to offer necessities of food, water, security and exploration (Heerwagen and Orians 1993). *Cf.* Wilson's *biophilia hypothesis*; our innate affinity with nature. Accordingly, the natural environment has a positive effect on the human mind and body and gives a sense of place.
- Like recreation, aesthetic services help counteract stress and fatigue.

Aspects of equity and stakeholder diversification

The parameters for the recreational and aesthetic services will have to vary somewhat with the geographical, cultural etc. context. For instance, the characteristics of 'recreation' imply that certain values are enjoyed to a higher degree in wealthier regions of the world, and the city, than in others. It is thus important to make the analyses and mapping class, caste, gender, and age sensitive. Income levels, type of housing, geographical area, etc. are some aspects that need to be taken into

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[3] Some characteristics of 'park-like' setting preferred were depth, (half-) openness, uniform grassy coverings, presence of water, absence of threat, and scattering of trees.

account to attain this objective. Perceptions of safety, social norms and physical boundaries are other issues in this respect.

Different stakeholder groups will have different degrees of access to social, cultural etc. services and may value them differently. Whereas the ecological value has some potential of being increased, the social value may change much more slowly in developing and newly industrialized countries such as India, due to the social stigma attached to various groups of citizens. Similarly, a planned-for park or children's playground will mainly be at the disposal of certain groups, namely those from the middle- and upper classes. The parts where slum dwellers and other poor strata live tend to be neglected in respect of planning.

In the city landscape, occasional trees, alleys and the like give services that are beneficial to all. Almost everyone can on a daily basis enjoy the aesthetical and refreshment aspects of greenery, plants, clean water bodies, open spaces and areas with forest sense, peacefulness, etc., where such services are at hand.

It should also be remembered that an increase of aesthetic values in an area can lead to a (direct or indirect) increase of its economic value.

Social and cultural values

Example from Bangalore

The example of Bangalore shows that only a minority of the population has the opportunity to take vacation from work. Many people however visit parks during weekends and declared holidays, but also during lunch breaks. Some use paths in parks for walking and jogging in the mornings. People from the lower middle class will typically prioritize visiting temples and other places of worship on their free time. Visits to the Bannerghetta Zoological Park, and Lal Bagh are popular with the lower and middle classes from and outside Bangalore. The poor constitute at least a quarter and maybe even a third or more of the population in Bangalore and it can be assumed that the majority of this group has neither time nor economical means to spend on 'recreation'. Instead, religious, spiritual, aesthetical and other social values will be of importance and need to be classified. The existence of squares (and various brown areas) that function as meeting places and playgrounds are examples.

Stress levels are high in Bangalore, mainly due to factors such as noise and air pollution, traffic infarcts, unemployment, poverty, increasing gaps between the have and have-nots, etc. The city has been dubbed the Diabetes Capital of India.

Example from Stockholm

A classification of social and cultural values regarding recreation was performed for the pilot study within the "Urban Social-Ecological Atlas project", based on the "Sociotope map" of Stockholm City. In total 35 parameters are evaluated in the base map in terms of their social value and classified with numeric values 0 or 1 (see App. B for all parameters).

The Sociotope map has been created in the following way: First open spaces > 1 ha were defined and named, on basis of basic city-landscape categories like parks, nature, squares, shores and quays. Also open spaces < 1ha in built-up areas were defined depending on density and open space quality. Secondly, professionals (landscape architects) valued the open spaces under observation with protocols, developed from international and national research on open space life and evaluations. Park experts such as park- and garden historians were also engaged.

In total 35 variables, such as rollerblade skating, playgrounds for children and market places were mapped and valued. For the pilot study within the “Urban Social-Ecological Atlas project” where focus is on recreational values, variables such as green oasis, forest sense, peacefulness, walking and jogging etc. were more relevant to use. 16 parameters were selected and their values summarized and brought into a GIS system. This approach gives zero values for built-up areas whereas the green areas totals resulted in values ranging from 1 to 9 (see App. B)

Methods 5
Measuring social and cultural values

Citizen's participation is an important component to collect data on social and cultural values of ecological services which can later be integrated into various urban planning processes. To collect information following methods could be used appropriately:

- *Questionnaire Survey (either structured or open) /field survey/ postal survey/ through email/ perception survey*
- *Focus Group Discussion (FGD) / Public Meetings/ Small Dialogues among stake-holders/*
- *Interviews with various stakeholders*
- *Observation*
- *Case studies/ personal experiences*

It is very important to derive indicators which would be helpful for guiding the questions for any survey, discussion or interview. The social and cultural services which affect human well-being would be considered as indicators in this case to assess the socio-ecological relation of selected urban areas.

- *Physical establishments and value (aesthetical value, heritage, social value, cultural value, religious value, forest, open space, green patches, agricultural land, amusement parks, etc)*
- *Accessibility (consumption pattern, distance, transport availability, cost of travel, entrée fee, gender aspect, aspect of economical aspect)*
- *Sense of Security (encroachment, crime situation, safety net)*
- *Opportunities of activities (park, picnic spot, recreation facilities, golf course, fishing, play ground, agricultural land etc.)*
- *Social relation (community activities)*
- *Freedom of choice (equity, social norms)*

It is assumed that there is no market for cultural services in urban areas. However, a properly managed eco-tourism industry can enrich cultural services and amenities. In this connection, encouraging eco-tourism can ensure the market for cultural services for urban residents.
Some indicators of managed eco-tourism can thus be included in the above-mentioned list of indicators.

Data Analysis

7. USING NARRATIVES TO INCORPORATE THE COMPLEXITY OF REALITY

The cross-site comparisons of services in the form of an atlas need to be supplemented by *narratives*, descriptions of the cities that tell their stories in words. Each narrative is thought to provide a richer context and point to the relevant complexities behind the hard data.

The aims of the narratives are as follows:

- To counteract simplification and avoid misinterpretation of the data presented in the maps;
- To understand the socio-economic and environmental trends (background, diversity and changes) of each city; and
- To identify the existence and roles of various stakeholders groups.

Certain criteria should be fulfilled *briefly* for the selected cities

- Environmental history of the landscape of the city;
- Equity issues and social assimilation over time and space;
- Conflict of interests (political, economic, social and environmental); and
- Stakeholder analysis (roles and responsibilities – in theory and practice).

Finally, we need to find ways of accounting for the value of very small green spaces or even individual trees, which are of importance for human well-being.

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USEFUL INTERNET LINKS

Swiss Federal Institute of Technology, Zurich
http://www.uns.ethz.ch/res/irl/ecosystemservices.
Effects of Urban Forests and their Management on Human Health and Environmental Quality. USDA Forest Service http://www.fs.fed.us/ne/syracuse/studies.htm.
Urban Forest Mapping's CityGreen: http://rsgl.gis.umn.edu/citygreen.html; http://www.americanforests.org/downloads/citygreen/CG_GIS_Brochure_small.pdf.
Rajanet Yegneswaran Charitable Trust, plants trees in Bangalore: http://www.treesforfree.org/

GLOSSARY AND ABBREVIATIONS

Afforestation: Planting trees in areas where trees have been absent in recent times.
Agroforestry: Planting and managing trees in conjunction with agricultural crops.
Aquifer: A water-bearing stratum of permeable rock, sand, or gravel.
Blue water: Liquid, 'visible' water – surface and groundwater. Cf. '**Green water**'.
Carbon Sequestration: A method or process of keeping carbon (CO_2) from reaching the atmosphere by capturing, isolating, and diverting it to secure storage, and/or to remove CO_2 from the atmosphere by various means and store it.
Carbon Sink: A terrestrial or aquatic repository for atmospheric carbon.
CBD: Convention on Biological Diversity.
CCS: CO_2 capture and storage.
CDM: Clean Development Mechanism.
Domain: In modeling, the area which is being modeled.

Downscaling: Applying data gathered and/or aggregated at a large scale to a smaller-scale assessment, such as to examine the effects on a single air basin.
Dynamical Model: There are two meanings of dynamical (or *dynamic*) in the context of economic modeling: (1) A *dynamic model* represents the economy over a period of years or decades. The paths of variables such as prices and quantities are represented as they change over time, in contrast to a static model that represents a market or an economy only at one point in time. (2) In another context, *dynamic model* also refers to a type of model that incorporates taxation and fiscal policy into its analysis. In this context, the term *dynamic* means that both direct and indirect effects of taxes are represented in a model. For example, the government-levied tax will result in a certain quantity of revenue being raised (the direct effect). However, it will also (in general) result in indirect changes in consumers' and firms' choices regarding consumption, employment, and investment.
Ecological Indicator: A key attribute of an ecosystem that is used to gauge the health of the whole
ecosystem.
EIA: Environmental Impact Assessment.
Endogenous Technological Change: Technological change brought about by changes in prices or policy variables.
ETo: Reference evapotranspiration. A measure of the amount of water evaporated and transpired by well-maintained, well-watered turf grass. This amount is measured weekly in California at various California Irrigation Management Information System (CIMIS) facilities throughout the state.
Evapotranspiration: Water loss from a combination of evaporation from the soil and transpiration from vegetation.
Extent: The size of the study area, which will *here* be a nested set of two boundaries determined by three scales
Freshwater: Water that contains less than 0.5 parts per thousand dissolved salts.
Geographic Information Systems (GIS): A computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system.
Grain: The fundamental unit of observation, e.g. size of a pixel of a remotely sized imagery, size of clusters of households sampled, size of observation plots and so on.
Green water: 'Invisible water'; vapor flows, evapotranspiration, soil moisture.
Humus: see **Soil Organic Carbon**.
Hydrological: Having to do with the study of water on the Earth and its atmosphere.
IKONOS: A commercial earth observation satellite, 1- and 4-meter resolution.
IDRSI: A GIS program for the analysis and display of digital spatial information.
Institution: norms and rules in use
IRS: Indian Remote Sensing Satellite.
IWRM: Integrated Water Resources Management.
JMP: Joint Monitoring Program.
LEK: Local Ecological Knowledge.
MA: The Millennium Ecosystem Assessment.
MDG: Millennium Development Goal.
MS: Multispectral imagery.
NDVI: Normalized Difference Vegetation Index. A simple numerical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not.
NGO: Non-Governmental Organization.
PPP: purchasing power parity; *also* public-private partnership
PAN: Panchromatic (black & white) imagery.

Particulate Matter (PM): Airborne particles or droplets from emissions that can be inhaled and lodged in the lungs. PM is regulated as a criteria pollutant.
QB: QuickBird, a high-resolution commercial earth observation satellite that collects panchromatic (black & white) imagery at 60-70 centimeter resolution and multispectral imagery at 2.4- and 2.8-meter resolutions.
Regional Climate Model: A computer model capable of modeling potential climate changes in a small, focused region.
Soil Organic Carbon: Also known as *humus.* Partially decomposed plant or animal matter that makes up the organic part of the soil.
Stochastic: Something characterized by chance, probability, or randomness.
Variabilization Policy: A policy of charging a surcharge on a product or service based on the amount of that product or service used. For example, annual payments of a gasoline tax would cost more for the driver of an inefficient vehicle than they would for the driver of a more efficient vehicle, because the vehicle would need more gas.
Virtual water: The embedded or embodied water used for the production of goods and services (Allan 1997). The volume depends on climatic conditions and agricultural practice. There is a green and a blue component in the total virtual-water content of a product, referring to evaporation (Falkenmark 2003). A grey component in the total virtual-water content of a product refers to the volume of polluted water. Cf. **Water footprint**.
Water footprint: Statistics indicating both direct and indirect water use, taking the demand and consumer perspective, http://www.waterfootprint.org/?page=files/Concept. Cf. **Virtual water**.
Watershed: The land area that drains to a local water body.
WHO: World Health Organization.
WPI: Water Poverty Index.
WTP: Willingness to Pay.

Sources: the California Energy Commission (http://www.westcarb.org/pdfs/Glossary.pdf); Wikipedia; MA (2005).

APPENDICES

A. BANGALORE STUDY

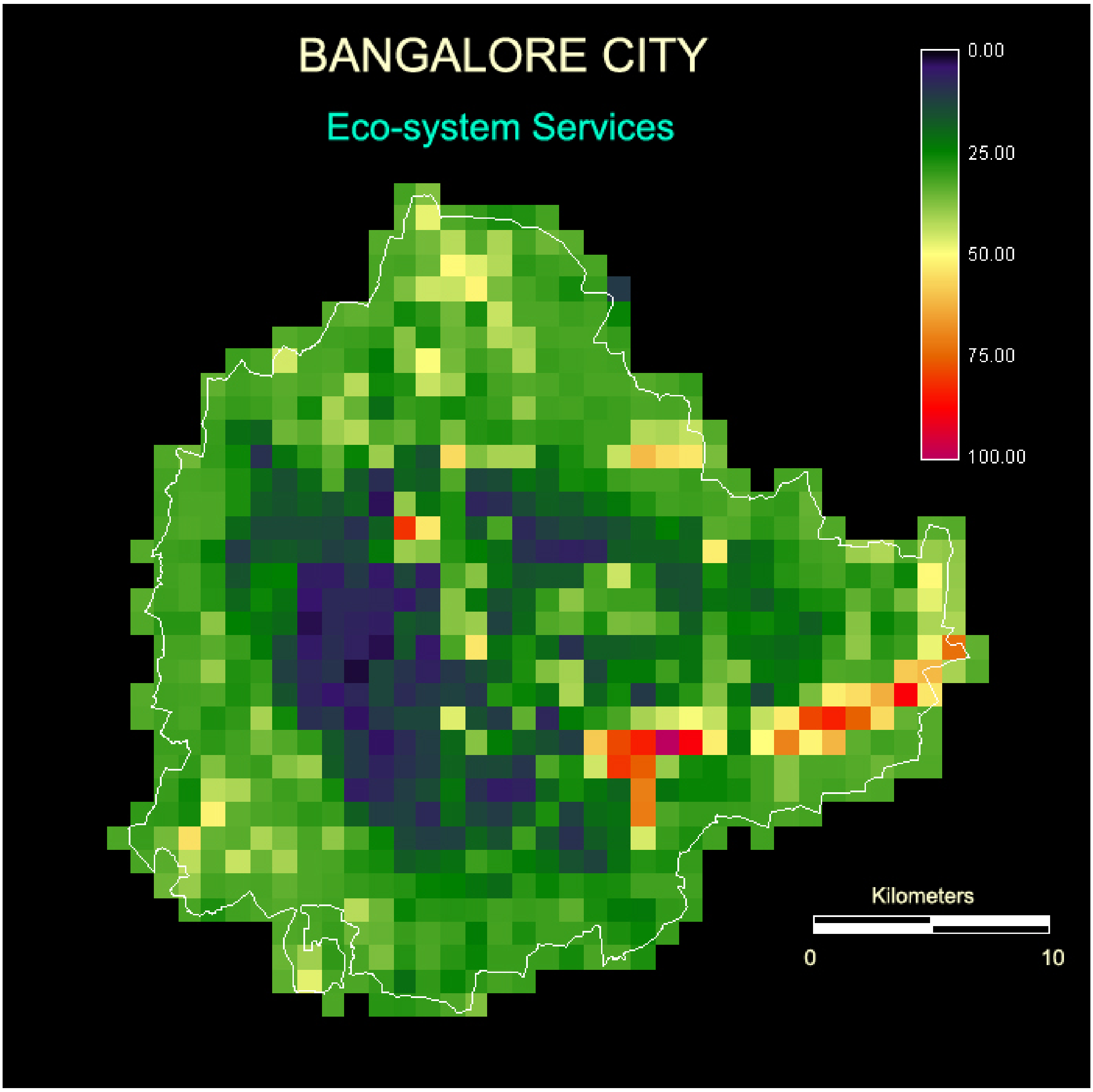
Land cover classification: Land cover map was prepared using IRS P6 LISS III image acquired on May 10, 2007. The spatial resolution is 23.5m. Supervised classification procedure using maximum likelihood classification algorithm was used. The accuracy assessment of this layer is still in progress. The classification scheme is as follows

- Green Areas : Tree covered areas
- Built-up
- Water bodies
- Open Areas: Include barren and fallow lands, seasonal agriculture, etc.

1. **Water bodies** : Water bodies greater than 2 ha area were selected from the classified land cover map. Topo sheets were used to verify the accuracy of the classification. 55 water bodies were selected for final analysis.
2. **DEM**: 90m DEM from Shuttle Radar Topographic Mission (SRTM) was used.
3. **Watershed Delineation**: Watersheds were delineated from the DEM through an automated procedure using the software IDRISI. The original extends of the selected lakes digitized from the topo sheets were used to improve the efficiency of the watershed delineation.
4. **Landcover Change**: SPOT satellite data of 1 km resolution was used to analyze the land cover change from 1998 to 2004. The annual maximum NDVI for each 1km pixel was calculated from monthly NDVI data sets. Slope for each 1km pixel was calculated to quantify the trend of the change.
5. **Regression analysis**: Available data environmental and water quality data for the water bodies were collected. Environmental parameters such as shore line and depth characteristics, presence of floating and fore shore vegetation, islands and various threats for 10 lakes were collected. Water quality data include dissolved oxygen and BOD was available for 17 lakes. Bird species for 14 lakes were also available. These parameters were regressed against the proportion of green areas and proportion of built-up areas within each catchment. The relationship between the proportion of built-up areas within the catchment and BOD was found significant.
6. **Water Quality Score**: Two indices were derived for the water quality of selected water bodies. The proportion of green areas within each catchment was used as a water quality index. The projected BOD for all the catchments using the regression equation was used as another index for water quality. Both indices were rescaled to 100. BOD was inversed before rescaling as high BOD is low water quality. The average of both the indices was used as the final Water Quality Score.
7. **Surface Water Score:** The area occupied by each water body was used as a Surface Water Score. The values were scaled to 100.
8. **Ground Water Recharge Score:** A 1 km grid was overlaid on the city area. The proportion of green areas, open areas and water bodies together within each 1 km grid cell was considered as the Ground Water Recharge Score. The values were rescaled to 100.
9. **Carbon Storage Score** : Green areas with more than 15 ha area were selected. There were 105 patches. The patches were sub-divided according to ownership and finally there were 112 patches (parcels ?). The average NDVI of each patch were found from the above mentioned satellite image and rescaled to 100. This value is used as Carbon Storage Score.
10. **Biodiversity Score**: Two indices were generated to represent biodiversity. The bird species richness was available for a subset of water bodies and green areas. A Biodiversity Score was generated for these areas using the bird species richness.

For the sites where species data not available, the area of the site was used as an indicator of biodiversity. The Biodiversity Score was generated by rescaling the area of the sites to 100. Water bodies and green areas were rescaled separately and then combined to form the final layer.

11. **Total Ecosystem Services**: The ecosystem service scores such as water quality, surface water, ground water recharge, carbon storage, biodiversity based on birds and biodiversity based on area were summed up to find the total ecosystem service at the pixel level. The pixel level ecosystem service values were summed up for each cell of a 1km grid. This was rescaled to form the final Ecosystem Service Score.



Result of pilot mapping of ecosystem services in Bangalore

B. STOCKHOLM STUDY

1. Land cover classification: Land cover maps were prepared using Landsat satellite images from 1985 and 2002. Classification was performed in the software IDRISI.

The following classes were derived:
- Natural and semi-natural land
- Urban-artificial surface
- Agriculture
- Water

2. Social values were derived from a sociotope map from the mapping unit in Stockholm city. Areas with high recreational values were summarized and classified.

3. Ecological values were derived from a biotope map from the mapping unit in Stockholm city. The different vegetation and land cover classes were reclassified to ecological values.

4. Hot spots and cold spots were derived using a GIS where social and ecological values were summarized after converting all maps to raster format.

SOCIOTOPE Mapping - Working order/structure:

How the original map was prepared:

1. Planning phase.
2. Identification, delineation and naming of the open/built up areas based on an open space typology.
3. Valuation of each area by landscape architects, based on observations and in dialog with experts and planners in Stockholm
4. User evaluation through web-/letter questionnaires, interviews, meetings, group discussions.
5. Compilation and analysis by planners. Reflection on goal, aims, naming and map design.
6. Input to a GIS system.
7. Results can be used as a base for planning of the city and open space development. Continuous follow up needed.

Sociotope: Asks questions such as: For whom? For what purpose? Out from a qualitative interest/user perspective-how can it be described in terms of quality, perception value, meaning, character, function …?
A sociotope tells us how biotopes are valued and how it is to live in and together with the biotope (together with the people within it).

Open space typology

Open space is defined as a non built up area, not used for transportation/terminal usage.

Open /free space is divided into four main groups:

Larger open space (such as Djurgården)
Separate open spaces (e.g. parks and market places)
Within built up areas (such as back yard gardens and sidewalks)
Transportation and terminal areas (e.g. marina/ferry areas)

For northern and southern Djurgården areas the following subareas were encountered:
Forest > 5 ha
Semi open ground and park area >3 ha
Agricultural area is small gardens or other agriculture > 3 ha
Open grassland with tall grass >3 ha
Grassland with mowed short grass > 3ha
Wetland, bog, bog forest >3 ha
Canal and hard made rivulets >3 ha
Beach within a park or natural beach >3 ha
Quay is hard made beach > 3 ha
Open water body and lakes > 5 ha

Planner's evaluation

Experienced planners evaluates the open spaces as the first sociotope study, through observations of environments and users and in dialogue with experts in the community such as park and garden historians, traffic engineers, and researchers in green structures and milieu psychology. The most important values should have been caught at this stage (March-July)
Three different observation periods were done in March, May and August, consisting of 14 walks, each 5 km and 3-4 hours long.

One of the main objectives with the questionnaire to the public is to find out what is important for them regarding the open spaces.

The child questionnaire asks which areas in the city and outside that are perceived as important for playing and what other qualities that are important.

Parameters used for the "Urban Social-Ecological Atlas" Stockholm pilot study:
Green oasis
Forest sense/feeling
Peacefulness
Nature sense
Livestock / Pasture
Cultivation
Riding
Walking / Hiking
Jogging
Water contact
Flower splendor
Cultural milieu
Golf
Playing ground (kids)
Playing in nature (kids)
Picnic

Not used parameters

Downhill sports
Swimming
Swim-gymnasium
Ball games
Ball play
Skating
Rollerblade skating
Boating
Events (concerts etc.)
City life (people gathering)
Market places
Athletics grounds
Play ground for children
Play ground for children (park)
Water play
Outdoor cafes and restaurants
Nice view
Land forms
Ancient remains, monuments

Result of the pilot mapping of social and ecological values connected to green areas I Stockholm