MAKING URBAN ECOSYSTEM MAPPING ACCESSIBLE TO THE PUBLIC: THE URBAN NATURE ATLAS OF OSLO (NORWAY)

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1. Introduction

Valuing ecosystem services, their conditions and changes has been highlighted as an important task for informing decision-makers and other stakeholders (Maes et al. 2016) in the light of global change. However, due to the complexity of human-environmental-systems, multiple approaches are available and needed to fulfil a wide range of requirements. Mapping ecosystem conditions and services has been identified as a valuation method of various advantages and an increasing number of studies and projects has published appropriate maps (Burkhard & Maes 2017). Furthermore, plural valuation takes the diverse values of nature given by all stakeholders into account (Pascual et al. 2017). Those results are more in line with sustainable and equitable goals for decision-making (Zafra-Calvo et al. 2020). This adds more complexity to the topic but expectedly less uncertainties in the valuation.

Urban areas with high human population density have high demand per unit area for ecosystem services (Gómez-Baggethun & Barton 2013). Urbanization processes are a global phenomenon which will accelerate in the future with enhanced consequences for the environment. Policy-making and planning processes must take this into consideration. Many people would probably not automatically connect many ecosystem processes and services with urban areas. However, people often feel more interested in and concerned with issues that affect them directly (e.g. place of residence, sense of place) (Raymond et al. 2009). Mapping urban ecosystem services provides the opportunity to put diverse values of people 'into place'. Providing knowledge about the location of prospects - amenities as well as risks - are a key function of maps in socio-ecological systems (Filatova et al. 2013). Since ancient times, maps have been used to display the boundaries of the known world and as a symbol of power and knowledge. The familiarity to read and understand maps is the necessary requirement. For this reason, maps can have an intuitive and strong affective appeal to various users, and their daily use through navigation apps on smartphones is now ubiquitous. A study by Vorstius et al. (2015) concludes that practitioners also require ecosystem services mapping tools which focus on several ecosystem services and scales for planning and decision-making. Co-creating maps with various stakeholders is essential for identifying as many values as possible and the citizens' view is an important aspect to complement the research perspective (Santos-Martin et al. 2017; Jacobs & Burkhard 2017; Fagerholm & Palomo 2017).

Over the past years, many web applications, apps and mobile-ready platforms have been created for citizen science and education and learning about the environment, ecosystems and their services (e.g. MAPNAT[1], birdnet[2], inaturalist[3]). These applications are gaining increasing popularity among scientists and other user groups including citizen scientists. Data gathering conducted by a larger group benefits monitoring and research initiatives and is fostered in projects and programs. Taking this one step further to the use and development of ecosystem accounting and ecosystem service mapping will provide more synergies on the way to achieving the goals society sets to decrease global change. Early development examples of web applications, such as urban forestry inventories, have already combined community-based data collection by using web applications based on Google Maps technology (Abd-Elrahman et al. 2010). The European Environmental Agency (2020) provides free land cover data from Copernicus satellites in their Urban Atlas for three time steps for pan-European functional urban areas (https://land.copernicus.eu/local/urban-atlas). Data has been used for example for indicator performance analysis in urban areas in Germany (Zulian et al. 2017). A planning tool example for ecosystem service trade-off analysis is available in the online Nature Value Explorer tool (https://vito.be/en/nature-value-explorer or https://www.natuurwaardeverkenner.be/#/; Broekx et al. 2013). In this tool, qualitative and quantitative calculations and socio-economic values describe the impacts of planning and land use changes. Another example of a mapping tool is the EnviroAtlas (https://www.epa.gov/enviroatlas/enviroatlas-interactive-map) of which, for example, a dataset is available for the supply of urban ecosystem services from forests in New York City using i-Tree models (US EPA 2020).

[1] https://www.ufz.de/index.php?en=40618

[2] https://birdnet.cornell.edu/

[3] https://www.inaturalist.org/

These various tools point to a number of approaches for disseminating ecosystem service knowledge to the public through maps.

In this paper, we introduce the Urban Nature Atlas for the City of Oslo, Norway. The main motivation for the Urban Nature Atlas is to show Oslo residents the results of ecosystem condition and service mapping from various research projects to inform them about qualities of nature where they live, work and spend their time. A motivation for the work is also to inspire Oslo Municipality to make greater use of mapping of ecosystem condition and services in their reporting to the public on Oslo's environmental status. Simple map interaction functions let users explore the maps at different scales and compare maps to explore patterns and correlations between urban form and function. An app within the atlas – the HabitApp – lets residents weight different ecosystem service layers to determine what parts of the city would be most attractive according to their preferences for environmental living conditions or human habitat. Making highly technical map data available to the public is also a strategy to empower civil society to participate in land use planning processes which are otherwise reserved for technical experts. If we as researchers are able to communicate the spatial distribution and temporal changes of urban nature in a way residents understand and care about it, this will also be relevant for urban planners and policy-makers.

2. Case study area

2.1. Status of urban nature

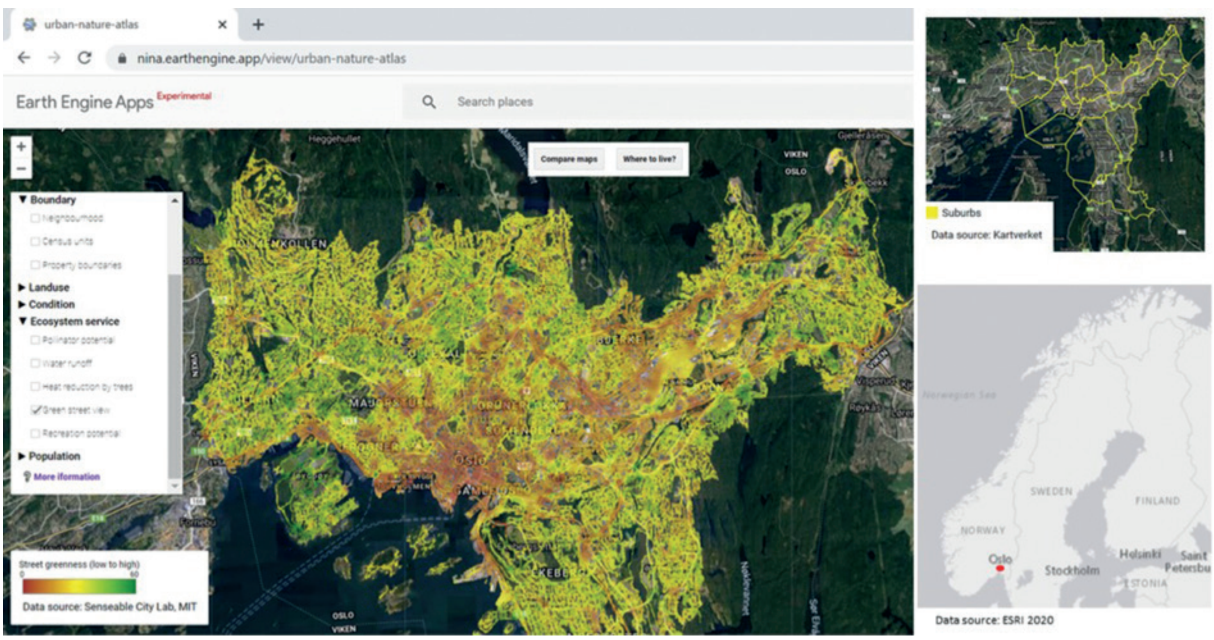
Oslo, Norway's capital, is located at the northern end of the Oslo fjord (Figure 1). A total of 681 071 inhabitants were registered in 2019. The city of Oslo and its surrounding areas have experienced increasing population growth and urbanization during the last decades. The current prognosis is an increase to more than 800 000 inhabitants by 2040. The total area of Oslo municipality is 454 km², of which 300 km² are part of the protected forest area ('Marka'), constraining urban development to the existing built area. Around 98% of Oslo's inhabitants live less than 300m from green areas (Oslo Kommune 2020a). Green space in Oslo municipality amounts to 47%, but it is gradually decreasing over time due to population growth and densification (Oslo Kommune Plan- og bygningsetaten 2018). Oslo was awarded European Green Capital in 2019 (https://www.greencapital2019.com/#gref), promoting ambitious goals for environment and climate until 2030.

2.2. Status of urban nature reporting in Oslo

Until 2017 the City of Oslo provided an annual report containing detailed information on the state of the city's environment and climate. The aim was to provide the inhabitants with information on the progress towards the city's climate and environment goals (Oslo Kommune 2020b). After 2018, a new website has provided online information on Green Oslo. However, the online information contains little communication on the state of Oslo's nature in the form of maps. The only exception is the information on the location of recreation areas. The website from the City of Oslo provides information for recreational activities, as well as related guidelines and regulations (Oslo Kommune 2020c). National environmental authorities also provide datasets on environmental quality status (Miljødirektoratet 2020a), but spatial resolution of the data is mostly not adequate for comparison across areas at neighbourhood level within the cities' built zones. National authorities also collate maps on nature (Miljødirektoratet 2020b) and biodiversity (Miljødirektoratet 2020c) but datasets mostly cover rural and peri-urban areas with little resolution of green space within urban built zones.

In this paper, we argue that the very limited use of maps for reporting and public communication at municipal and neighbourhood level resolution is disadvantageous for citizen engagement in urban planning. Increasing knowledge of the city's natural qualities may

Figure 1. The Oslo Urban Nature Atlas focuses on the built zone of Oslo



also support educational activities. To address what we see as a communication gap, the URBAN EEA project[4] has developed the Urban Nature Atlas which compiles spatial data from various research projects and authorities on the city's ecosystem extent, condition and services, in an easy to use map interface (Figure 1).

3. Methods and data

3.1. Background

To better detect the contributions from urban ecosystems to human wellbeing and to reveal changes in the urban green infrastructure, a combination of mapping of urban ecosystem services and experimental ecosystem accounting (EEA) for the city of Oslo and surrounding areas has been carried out within several international and national projects[5]. Usually, maps generated by projects are confined to project-specific spatial databases and platforms with limited public access and to mapping formats mainly designed for scientific purposes. The results of these research activities and available maps from authorities were therefore compiled in the Urban Nature Atlas to establish a platform where researchers on Oslo's nature can update the public as mapping products become available. A secondary and longer-term aim is also to generate synergies across different research and planning institutions in Oslo by making potential partners aware of available data.

3.2. Google Earth Engine functionality

Oslo's Urban Nature atlas was developed in the Google Earth Engine JavaScript API (https://earthengine.google.com/) which is a cloud-based computing platform for processing and analysing global data from satellite imagery and geospatial datasets. Google Earth Engine has a library of functions aimed at serving data outputs to end users via an online web application. Researchers are thus able to leverage Google's efficient and scalable computing infrastructure to process geospatial queries and render map results on-the-fly.

Oslo's Urban Nature Atlas is available here: https://nina.earthengine.app/view/urban-nature-atlas

The atlas is published in Norwegian and English. The main map categories are: boundary, land use, condition, ecosystem services and population. Further data and documents are available from the open source Geospatial Content Management System, GeoNode (http://urban.nina.no/). Functionality of the Urban Nature Atlas includes the ability to navigate using basemaps from Google satellite imagery and street map. The HabitApp ("Where to live") is a modified multi-criteria decision analysis, where users can make their own weighting of nine environmental criteria (e.g. green streets, tall trees, noise level). These criteria are based on the condition and ecosystem services maps. Users can explore these and weight personal preferences for residential areas or other areas of interest. The area of preference matches all stated criteria on a scale from 0-1. The resulting map shows users where their preferred areas are based on their preferences for urban nature qualities and ecosystem services. Playing around with the weights of the map layers, comparing maps and zooming to areas of local interest combines three functionalities for increasing interactivity with the data in an intuitive way.

4. Results

In the current test version of the Urban Nature Atlas, map themes are organized to correspond core themes of ecosystem accounts: "landuse" covering data relevant to ecosystem extent, "ecosystem condition" and "ecosystem services". "Boundaries" and "population" offer relevant background information for identifying use and distribution.

Under "Boundary", the three different administrative units (neighbourhood, census unit and property boundaries) are depicted to facilitate orientation for users and they act as units for reporting accounting data. Furthermore, these are the spatial units which are relevant for policy-making for the municipality level.

"Population" density gives an overview of the population distribution over the case study area with the most densely populated areas in the city centre.

"Land use" contains layers on protected areas and as the most important aspect of urban nature, parks and green spaces are available as separate layers. The separated layers for parks and green space are available as they are managed by different authorities.

Under "Ecosystem condition", spatial data sets for terrain slope, drainage, soil type, nature types, noise pollution and land surface temperature are available together with time series for land cover (2015-18), greenery (2015-18) and tree crown heights (2011-17). The time series of the tree crown heights show the changes in the years 2011-2017. Figure 2 is a zooming into an area of Oslo with significant increase in tree crown height and extent as one example.

Green infrastructure contributes to a wide range of ecosystem services (e.g. air quality regulation, local climate and water regulation, recreation and landscape aesthetics). There are five urban "ecosystem services" map themes available. Stange et al. (2017) tested the policy relevance of the ESTIMAP model for urban honeybee keeping and the potential consequences for bumblebee and solitary bee species. Research results are available in the layer "pollinator potential". Taking into consideration climate change, "heat reduction by trees" was assessed and mapped (Venter et al. 2020) and integrated as the layer with the same name. Suárez et al. (2020) mapped the outdoor "recreation potential" for individual user groups by applying a spatially refined version of the ESTIMAP tool in the Oslo metropolitan area. The results are compiled in the layer "recreation potential". The layer "stormwater runoff" shows the results of the REO hydrological model using the rational formula developed for assessing annual runoff per property unit for the purpose of calculating a stormwater runoff fee (Sælthun et al. 2020). The "green street view" is based on available data from Treepedia to compare the green canopy of selected cities globally (MIT Senseable City Lab 2020).

[4] https://www.nina.no/english/Fields-of-research/Projects/Urban-EEA

[5] OpenNESS, ENABLE, URBAN SIS, URBAN EEA

Figure 2. Urban ecosystem condition - tree crown height layer for comparing the changes from 2011-2017.

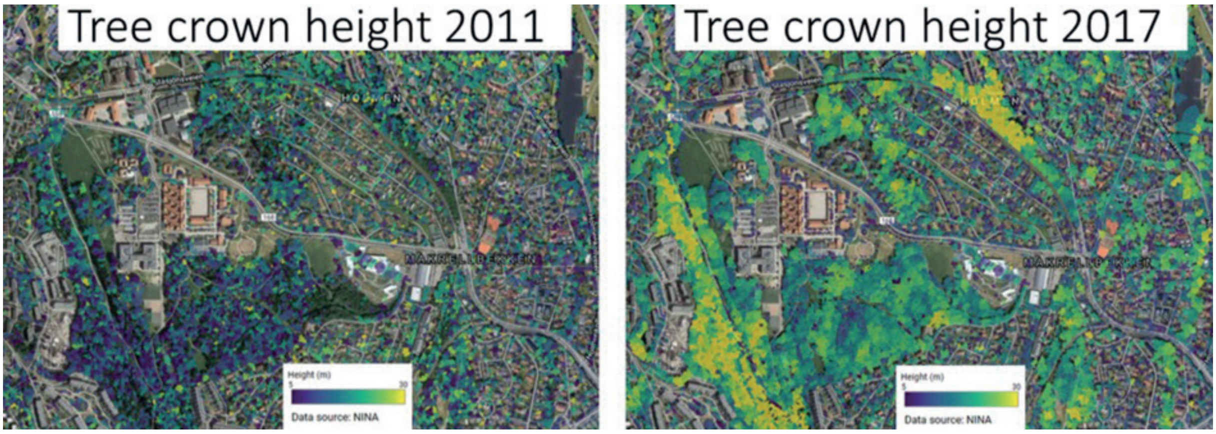


Figure 3. HabitApp example with high values for green infrastructure-related options.

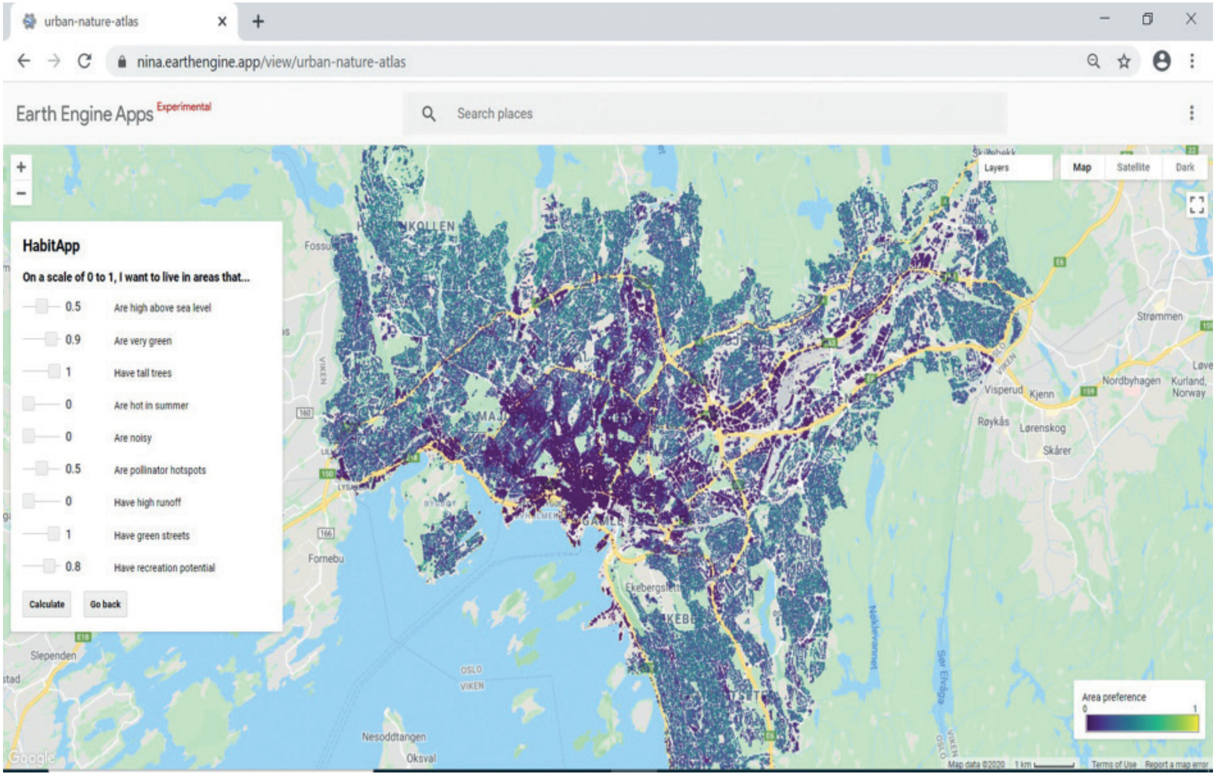


Figure 3 shows the resulting map for an exemplary preference selection of the nine criteria of the HabitApp ("Where to live"). The location of the matching residential areas are distributed from the city centre to the edge of the case study area.

5. Discussion

The use and success of the ecosystem services concept as a communication tool for conservation is heavily discussed (e.g. Schröter et al. 2020; Chan & Satterfield 2020; Klein et al. 2014; Kranz 2000). More and more studies document the application of the concept in various contexts and case studies for planning and decision-making. Bekessy et al. (2018) argue that the ecosystem services concept had only limited success in engaging the public for ecosystem services and biodiversity conservation. A number of assumptions are required. Thompson et al. (2016) conclude in their study that the public trusts scientific research results but has difficulties in understanding the specific language, especially if it is presented in a condensed manner. Maps are a widely used visual communication tool for identifying hotspots and coldspots and mismatches of ecosystem service supply and demand. However, it is important to prepare the corresponding spatial data carefully to avoid misinterpretation of maps. Different map layers may have been prepared for different purposes, extents and time periods (Schröter et al. 2020) and this must be made clear to the user. User-friendly tools are key for a successful implementation. The tools and resulting maps must be easy to understand and data must be available for use. Klein et al. (2014) point to the important fact of "guiding users through such systems". The increasing number of such web applications in recent years goes hand in hand with the digitalization of society.

Some challenges exist in the successful operation of an online platform such as the Urban Nature Atlas presented in this paper. It is necessary to keep not only the content of the atlas and related applications up-to-date and user-friendly but also to follow technological development. This causes extra effort which needs to be taken into account in such projects. Broekx et al. (2013) point to the difficulties in meeting all these requirements during the development of their web application the Nature Value Explorer which is for example continuously under development. Further limiting effects are the context-specific publication of case studies in other languages except English, which hampers the dissemination of results and knowledge. However, stakeholders might have difficulties in using applications and interpreting results in languages other than their mother tongue. Plural valuation is in particular necessary when these values are mapped in relation to people's location. We developed the HabitApp within the Urban Nature Atlas to help the public engage with maps and determine which ones are significant to them. The interpretation of the validity and relevance of ecosystem service mapping locally is a neglected part of ecosystem accounting.

Zhao & Sander (2018) analysed the effect of data and method selection on the accuracy and validation of urban ecosystem service maps. There is an assumption that remote sensing data and classification is accurate and reliable for aggregate accounting purposes, but the secondary use of the input data is not evaluated at higher spatial resolutions relevant to local users of the landscape. Ecosystem (service) classification accuracy is an important additional piece of information which needs to be communicated when map results are presented to stakeholders and users. Functions of online applications do not always have the expected results of the user. For example, zooming into a data set does not necessarily result in higher resolution or better information. This fallacy is associated with the discussion on data accuracy.

Online applications show the wide ranges of application areas, technical solutions, opportunities and limitations. Due to its basic idea and use of open source data from Google Earth Engine, Oslo's Urban Nature Atlas has the flexibility to add more topics and layers to the spatial extent. We believe the Urban Nature Atlas can be relatively easy transferred to other urban areas or ecosystems and their specific characteristics and needs. Additional data can be added based on availability. Further work includes adapting the Urban Nature Atlas as a reference for the reporting of the City of Oslo and exploring further practical applications in municipal policy-support.

6. Conclusion

High-resolution remote sensing data and advanced modeling of urban ecosystem condition and ecosystem services are combined in the Oslo Urban Nature Atlas. These maps are made available in a Google Earth Engine interface that requires only basic technical capabilities of users similar to the Google Maps application. Spatial representations of green infrastructure and related ecosystem services in digital online maps facilitate communication with various users at the local level. It gives local communities a tool to participate on a more equal 'knowledge footing' in policy and planning in urban areas. Inhabitants, local communities and civil society with limited technical capabilities and data are enabled to monitor and evaluate urban planning and development by means of the Urban Nature Atlas. Oslo's Urban Nature Atlas is a work in progress. It will evolve based on user feedback to integrate more updated and additional map layers and develop further interactive tools for both inhabitants and planners to fulfil a wider range of applications.

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