One Ecosystem 3: e25477
doi: 10.3897/oneeco.3.e25477

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Research Article

Mapping and assessing ecosystem services to support urban planning: A case study on brownfield regeneration in Trento, Italy

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Academic editor: Benjamin Burkhard

Received: 03 Apr 2018 | Accepted: 18 Jun 2018 | Published: 25 Jun 2018

Citation: Cortinovis C, Geneletti D (2018) Mapping and assessing ecosystem services to support urban planning: A case study on brownfield regeneration in Trento, Italy. One Ecosystem 3: e25477. https://doi.org/10.3897/oneeco.3.e25477

Abstract

This study explores the use of ecosystem service (ES) knowledge to support urban planning in the assessment of future scenarios. The case study concerns the prioritszation of brownfield regeneration interventions in the city of Trento (Italy). Alternative planning scenarios considering the conversion of existing brownfields into new urban parks are assessed and compared. The assessment focuses on two ES of critical importance for the city, namely microclimate regulation and nature-based recreation. The benefits of the different scenarios are quantified based on the number of expected beneficiaries broken down into different vulnerability classes and then compared through a multi-criteria analysis. Three combinations of criteria and weights reflect different planning objectives and related decision-makers' orientations about what ES and beneficiary groups should be prioritised. The application demonstrates the potential for ES assessments to support urban planning processes in the specific phase of assessment and selection of alternatives, by meeting the requirements in terms of both sensitivity to small-scale changes in land uses or management activities and capacity to capture simultaneous variations in supply and demand of multiple ES. Being coherent with socially-orientated planning objectives, indicators based on ES demand and beneficiaries can effectively convey information about ES in planning decisions. Multi-criteria analysis is an effective way to integrate multiple ES assessments with other information about costs and benefits of planning scenarios, exploring diverse stakeholder perspectives and balancing competing objectives in a rational and transparent way.

Keywords

urban ecosystem services, ecosystem service mapping and assessment, brownfield regeneration, planning scenarios, multi-criteria analysis

Introduction

The mapping and assessment of ecosystem services (ES) can support policy- and decision-making at different levels, from raising stakeholders' awareness to shaping specific decisions (Posner et al. 2016). The most direct impacts are expected when ES knowledge is deliberately used to 'generate actions' and 'produce outcomes', supporting new policies that explicitly consider effects on ES, ultimately promoting human health and well-being along with biodiversity and nature conservation (Posner et al. 2016). Drawing from a set of case studies, Barton et al. (2018) provide some examples of the tasks that ES assessments can perform in these decision-making contexts. ES knowledge can generate actions by supporting the formulation and structuring of the decision problem and the identification of criteria for screening, ranking and spatial-targeting of the alternatives. In the context of spatial planning, preliminary analyses on the state of ES can highlight existing needs that should be addressed during the planning process, while assessments of the expected impacts of planning decisions on ES can support the selection and fine-tuning of alternatives (Geneletti 2015). The inclusion of ES knowledge in spatial planning processes can also produce direct outcomes, for example, by inspiring the definition of standards and policy targets or by setting the basis for the design of implementation tools, including regulations, incentives and compensation schemes (Barton et al. 2018, Cortinovis and Geneletti 2018). These possible applications clearly show the potential benefits of integrating ES assessments into spatial planning processes and decisions, including urban planning and related environmental assessments (e.g. Strategic Environmental Assessment and Environmental Impact Assessement) (Geneletti 2011, McKenzie et al. 2014, Rall et al. 2015).

However, still there are only a few case studies which have demonstrated how ES assessments can support decision-making in the specific phase of comparison and selection of alternative planning scenarios, especially in urban contexts (see Kain et al. (2016) for an exception). In fact, most urban ES mapping and assessment studies lack the identification of specific policy questions and stakeholders to which they might be relevant (Haase et al. 2014). As a consequence, they usually produce generic and abstract recommendations (Haase et al. 2014), failing to close the feedback loop between ES and the planning and management of green infrastructure (Luederitz et al. 2015). The use of

ES knowledge to assess alternative scenarios poses specific requirements to ES assessments. First, appropriate indicators for measuring the expected outcomes of planning actions in terms of changes in human well-being must be identified, which is still a challenge for ES science (Ruckelshaus et al. 2015). Second, while most ES assessments focus on the supply of a single ES (Haase et al. 2014), evaluating planning scenarios requires assessing the consequences of planning interventions on both the supply and the demand of multiple ES, addressing potential trade-offs between different ES and competing land uses (Kain et al. 2016, Sanon et al. 2012, Woodruff and BenDor 2016).

This paper aims to test the use of ES knowledge to support the assessment of alternative planning scenarios. The policy question addressed by the study is a common issue for many cities around the world: the regeneration of brownfield sites produced by the abandonment of previous residential, industrial or infrastructural uses. The presence of brownfields triggers environmental degradation, economic decline and social exclusion, thus representing a key challenge for urban planning (Nassauer and Raskin 2014). In recent years, the strategy of brownfield regeneration as a way to limit land take and sprawl (Baing 2010) has been progressively linked to the adoption of nature-based solutions (European Commission 2015, Raymond et al. 2017), thus making the enhancement of ES one of the main objectives of regeneration interventions. The paper describes the case study of Trento, a medium-sized city in northern Italy characterised by the presence of brownfields in the most-densely populated part of the city. The planning decision, about which of the brownfields should be converted to a new urban park, is supported by the assessment of two relevant ES. Alternative regeneration scenarios are compared with the current condition to quantify the expected benefits produced by the interventions. Then, the results are combined through multi-criteria analysis (Geneletti and Ferretti 2015), which allows the best alternative to be selected according to different planning objectives and priorities. By presenting a real-life application, the paper contributes to the efforts towards mainstreaming ES mapping and assessment in policy-making, specifically addressing the challenge of integrating multiple ES values in decision-relevant and usable assessments (Jacobs et al. 2016, Rosenthal et al. 2014).

Case study

Context and objectives

Trento is a medium-sized city of around 120,000 inhabitants located along the course of the River Adige, in the eastern Italian Alps. The intensely-urbanised valley floor hosts around 70% of the population, as well as most of the industrial areas, commercial units,and transport infrastructures (Fig. 1). The rest of the population live in small villages on the hills, surrounded by agricultural areas, predominantly vineyards and apple orchards. The large municipal territory (around 156 km^2, half of which covered by forests) includes the surrounding mountains up to an elevation of 2,180 m. Natural protected areas account for more than 10 km^2, including seven Natura 2000 sites. The presence of close-by natural areas is a peculiar feature of the city, which affects the type of demand and uses of urban green infrastructure. However, not all neighbourhoods in the city equally benefit from green spaces: the northern suburbs, which host a population mostly composed of low-income families, are the most disadvantaged areas, characterised by an inadequately-planned mixture of industrial, commercial, residential and agricultural uses; disconnection from the city centre; and a scarce presence of services and public spaces. Other key challenges currently faced by the city, notably affecting the urban areas in the valley floor, are the consequences of extreme climate events, especially heatwaves and urban flooding.

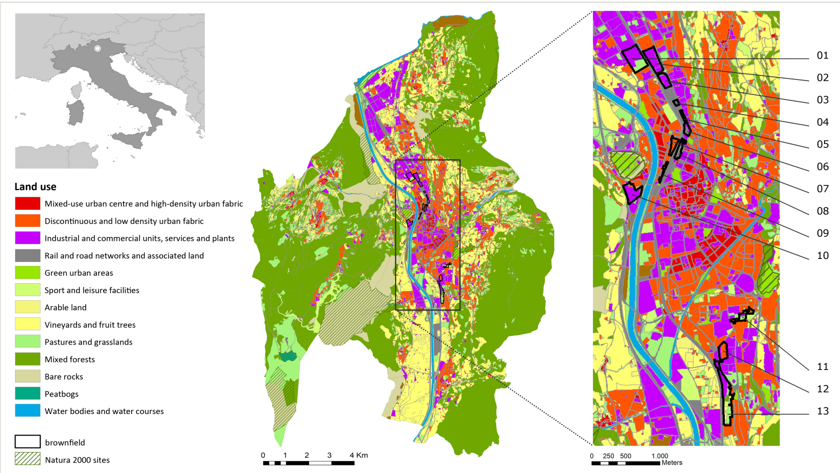

Figure 1.

Main land uses in Trento, Natura 2000 sites and the 13 brownfields identified by the urban plan as ‘urban redevelopment sites’. Source: Comune di Trento (2017a).

The presence of brownfields in the most dense and populated part of the city is one of the main planning issues in Trento. Amongst the existing brownfields, the current urban plan identifies 13 areas called ‘urban redevelopment sites’, whose regeneration is considered a priority to prevent or counteract the emergence of social, economic and environmental problems. The 13 sites range in size from 0.5 to 9.9 ha and cover a total area of 44 ha (Fig. 1). Until now, the costs - especially in the case of contaminated sites - and the bureaucratic burden associated with interventions, as well as the sometimes contrasting interests of public administration and private owners, have hindered their regeneration. Given these premises, it is reasonable to assume that only some of the brownfields will be converted to new industrial or residential areas in the next years. A greening intervention can thus be advanced as a possible, perhaps temporary, solution. Building on Geneletti et al. (2016), this study is aimed at supporting the decision about which of the existing brownfields should be converted into a new urban park based on the benefits produced for the surrounding inhabitants.

Selection of key ES

Two key urban ES for Trento are considered in the assessment of brownfield regeneration scenarios, namely microclimate regulation and recreation. The selection of microclimate regulation is linked to the growing concerns of the local administration for summer heatwaves, particularly intense in the city due to the low altitude and the narrow nature of the valley. As demonstrated by the 2003 event, Trento is more vulnerable to heatwaves compared to other Italian cities (Conti et al. 2005). Heatwave effects combine with the urban heat island in the valley floor, the most urbanised and sealed part of the city (Giovannini et al. 2011), causing peaks in energy demand for cooling (Grimmond 2007) and posing serious threats to citizens' health and well-being (Kenny et al. 2009). Considering the increased frequency and intensity of heatwaves expected in the coming decades (Fischer and Schär 2010), effective solutions to mitigate their negative effects and to provide cool areas for heat relief during the hot season are seen as one of the most pressing needs by citizens and administration.

The focus on recreation is in line with the main planning objectives of the city administration. In the last years, the enhancement of public green areas has been targeted toward gaining a more balanced distribution over the city, hence providing equal opportunities to all citizens for recreation and relaxation. However, understanding these opportunities for nature-based recreation, i.e. outdoor recreational activities that imply physical or experiential interactions with natural components of the environment (Haines-Young and Potschin 2018, Zulian et al. 2013) being equally distributed, is not an easy task. In Trento, besides urban parks, citizens also benefit from the proximity to other typologies of green areas where they conduct a wide range of activities, including hiking, mountain-biking, skyrunning and climbing. Indicators based on the availability of and accessibility to urban parks are not enough to capture this variety (Paracchini et al. 2014). Assessing recreation as an ecosystem service, considering different providing units and different levels of demand, could provide planners with useful information for achieving an equal distribution of recreational opportunities over the city (Kabisch and Haase 2014).

The regeneration of existing brownfields through their conversion to new urban parks is an opportunity to enhance several key ES for urban areas (Collier 2014, McPhearson et al. 2013), including the two ES selected for the study. Urban green areas, especially when carefully designed (e.g. shape, vegetation density, presence of water), not only reach an internal temperature significantly lower than built-up areas, but can also produce a cooling effect on the surroundings (Zardo et al. 2017). From this point of view, the location of the thirteen 'urban redevelopment sites' in the valley floor (Fig. 1) represents an opportunity to mitigate the combined effects of heatwaves and the urban heat island. At the same time, the regeneration of these brownfields strategically located close to the city centre can provide new recreational opportunities for citizens living where both the availability of urban parks and the proximity to natural areas are low (De Sousa 2004).

Material and methods

Mapping and assessing the cooling effect of urban green infrastructure

To map and assess the cooling effect of urban green infrastructure, we adopted a method specifically designed to support planning and management decisions at the urban and sub-urban scale. The method is described in Zardo et al. (2017) and Fig. 2 provides an overview of the main stages. The method accounts for the two main ecosystem functions involved in microclimate regulation, i.e. shading and evapotranspiration and assesses them based on three properties of green infrastructure components, namely soil cover, canopy coverage and size. Once the green infrastructure component is classified according to the three properties, the model provides the corresponding cooling capacity score, depending on the climatic region of the study area (see Zardo et al. (2017)and Fig. 2 for further details on the model). Then, the cooling capacity scores can be classified and each class can be linked to an expected temperature difference between the analysed area and a reference area with the lowest cooling capacity (i.e. a sealed surface with no trees). For the present application, we adopted a version of the model with the range of scores scaled up to a maximum value of 172 and six final classes of cooling capacity, from A+ to E, as in Geneletti et al. (2016). Finally, the cooling effect produced on the surroundings can be mapped using decay functions. The model accounts for the effect of evapotranspiration by assuming linear decay functions that vary depending on the size of the area, whilst the effect of shading is approximated by a local buffer around canopies. The cooling effect can be mapped using the same classes defined for the cooling capacity, with the same range of expected temperature difference (Geneletti et al. 2016).

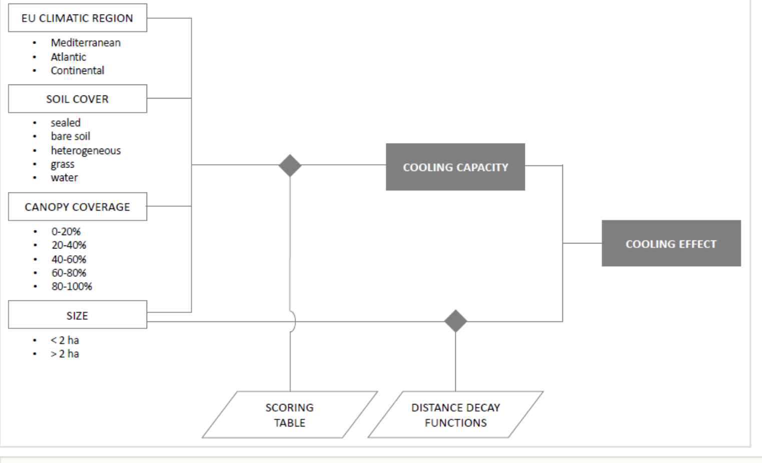

Figure 2.

Flow chart of the model for mapping and assessment of the cooling capacity and cooling effect of urban green infrastructure, building on Zardo et al. (2017). Input data are listed on the left. For model parameters (i.e. scoring tables and distance decay functions) refer to Geneletti et al. (2016), Zardo et al. (2017).

To assess the improvement in micro-climate regulation under the planning scenarios, the new urban parks obtained by the regeneration of existing brownfields were modelled as areas covered by grass, with 80% to 100% canopy coverage. Maps of the cooling effect were produced for the baseline condition and considering the conversion of each brownfield (i.e. each scenario) independently. Then, we computed the difference between each scenario and the baseline condition and intersected the resulting maps with a map of population distribution. The final indicator for each scenario was defined as the number of affected residents weighted by the intensity of change in the class of the cooling effect of their location (i.e. residents experiencing an improvement of two classes are counted twice). Young children (<5 years) and the elderly (>65 years) were selected as the most vulnerable groups, based on their higher sensitivity to heat stress (Basu 2002, Kabisch et al. 2017, Kenny et al. 2009) and counted separately.

Mapping and assessing opportunities for nature-based recreation

To map and assess the potential and opportunities for nature-based recreation in the city, we applied a locally-adjusted version of ESTIMAP-recreation. The model is part of the ESTIMAP suite, originally developed by the European Commission's Joint Research Centre for the purpose of mapping ecosystem services at the European scale (Zulian et al. 2013, Paracchini et al. 2014) and later adjusted for the application to different contexts and scales (Zulian et al. 2018). The model is composed of two modules, as summarised in Fig. 3. The first module assesses the Recreation Potential (RP), i.e. the suitability of different areas to support nature-based recreational activities based on their intrinsic characteristics and produces a raster map with relative values ranging from 0 (no recreation potential) to 1 (maximum recreation potential in the analysed area). The second module assesses the Recreation Opportunity Spectrum (ROS) by combining the RP with information about the availability of infrastructures and facilities to access (e.g.cycle paths, bus routes, parking areas) and to use (e.g. playgrounds, sport fields, park furniture) the area, thus providing an assessment of the opportunities offered to the citizens. The module produces a raster map classified into 9 categories resulting from the cross-tabulation of high/medium/low RP and high/medium/low availability of infrastructure and facilities. The different elements that contribute to the values of RP and ROS, listed in Fig. 3, are combined according to scores assigned by the user. For the described application, the scores were elicited from a pool of local experts, as detailed in the 'Data' section.

To assess the enhanced opportunities for nature-based recreation under the planning scenarios, the new urban parks obtained by the regeneration of existing brownfields were assigned to the land use class ‘green urban areas’ and assumed to be equipped with the same infrastructure and facilities as other parks with comparable dimensions. People living within 300 m from the new parks were considered as the main beneficiaries of the transformation (Kabisch et al. 2016, Stessens et al. 2017). Children and teenagers (<20 years) and the elderly (>65 years) were selected as the most vulnerable groups, based on the higher demand for close-to-home recreation and relaxation areas (Kabisch and Haase 2014). Furthermore, we distinguished the beneficiaries already served by high-level opportunities for nature-based recreation in the baseline scenario (i.e. living within 300 m from areas classified in the highest class of ROS) and counted them separately.

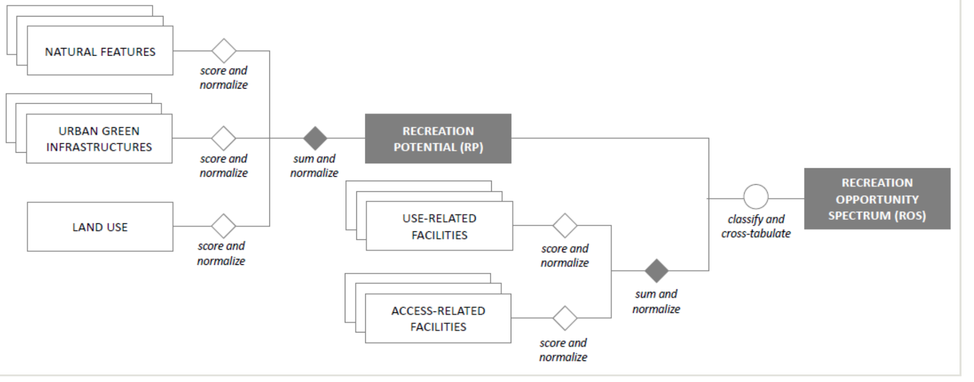

Figure 3.

Flow chart of the ESTIMAP-recreation model adjusted for the application to Trento. Modified after Zulian et al. 2013.

Integrating ES assessments to evaluate planning scenarios

A multi-criteria analysis was used to combine the results of the two ES assessments. The 13 scenarios simulating the regeneration of the different brownfields were considered as alternatives. The two ES and the different categories of beneficiaries based on the level of vulnerability were used as criteria and sub-criteria, respectively (Table 1). We applied three illustrative combinations of weights, corresponding to three hypothetical policy perspectives and related objectives (Table 1). The 'cool air for the elderly' perspective favours improvement in the cooling effect in areas with a high share of older population. The 'every child needs a park' perspective favours opportunities for recreation to people, especially children and teenagers, who are not served in the present condition. The 'balanced' perspective promotes both ES equally, but gives more weight to the most vulnerable beneficiaries (see Table 1 for details on the weights). Values for each criterion and sub-criterion were normalised according to the maximum and a ‘weighted summation’ approach was used to calculate the overall score for each alternative, hence defining the final rankings for the three perspectives. Finally, a sensitivity analysis was conducted to explore the robustness of the rankings to variations in the weights assigned to criteria and sub-criteria.

Table 1.

The three illustrative perspectives and respective combinations of weights considered in the multi-criteria analysis for the two ES (criteria) and the different categories of beneficiaries based on the level of vulnerability (sub-criteria).

CRITERIA sub-criteria	**Perspective 1 "balanced"**			**Perspective 2 "cool air for the elderly"**			**Perspective 3 "every child needs a park"**		
COOLING	0.50			0.80			0.20		
< 5 years		0.40			0.29			0.40	
> 65 years		0.40			0.57			0.40	
others (less vulnerable)		0.20			0.14			0.20	
RECREATION	0.50			0.20			0.80		
< 20 years		0.40			0.40			0.57	
served			-			-			0.20
not served			-			-			0.80
> 65 years		0.40			0.40			0.29	
served			-			-			0.20
not served			-			-			0.80
others (less vulnerable)		0.20			0.20			0.14	
served			-			-			0.20
not served			-			-			0.80

Data

Information about green infrastructure in Trento were mostly retrieved from municipal data, including a land use map published in 2017 (Comune di Trento 2017a) and the municipal database for the management of public green areas and trees (Comune di Trento 2010), which provides detailed information about their typology and location (including data about tree species, age and dimension) and about the presence of facilities in urban parks (e.g. benches, fountains, playgrounds). To assess the micro-climate regulation, first the land use map was integrated with more detailed information available from other sources for specific areas (e.g. municipal database of public green areas, map of community gardens). Then, each land use class was assigned to one of the five soil cover classes identified by the model (Table 2). Canopy coverage was mapped by combining the land use map with the provincial and municipal maps of forested areas and the municipal database of public green areas and trees.

Table 2.

Land use classes of the municipal map (Comune di Trento 2017), respective class of soil cover assigned for the cooling assessment and score resulting from the expert consultation about recreation. * Green urban areas and watercourses are included in other components of the ESTIMAP-recreation model, hence they are not assigned a score in the land use component. ** A score of 0.7 was assigned to community gardens.

Land use class	Soil cover class (Zardo et al. 2017)	Score
Mixed-use urban centre, continuous high-density urban fabric	sealed	0.6
Discontinuous urban fabric	sealed	0.6
Discontinuous low-density or sparse urban fabric	heterogeneous	0.7
Industrial units	sealed	0.2
Commercial units	sealed	0.4
Large areas for public and private services	sealed	0.4
Areas for technological systems and plants	sealed	0.2
Rail network and associated land	sealed	0.1
Road network and associated land	sealed	0.2
Parking areas	sealed	0.3
Airports	sealed	0.3
Mineral extraction sites	bare soil	0.3
Dump sites	sealed	0.1
Construction sites and other non-classified artificial areas	bare soil	0.1
Green urban areas	grass	*
Sport and leisure facilities	sealed	0.9
Sport and leisure facilities -ski areas	grass	0.9
Arable land	heterogeneous	0.4
Vineyards	grass	0.5
Fruit trees and berry plantations	grass	0.5
Pastures	grass	0.8
Complex cultivation patterns	heterogeneous	0.6**
Mixed forest	heterogeneous	0.9
Natural grasslands	grass	0.7
Other grasslands	grass	0.7
Bare rock	sealed	0.7
Peatbogs	grass	0.6
Watercourses	water	*
Water bodies	water	0.9

Input data for the ESTIMAP-recreation model were retrieved from both institutional databases and Open Street Map (Open Street Map Contributors 2017). The scores were elicited through an on-line questionnaire from a pool of experts selected with the collaboration of a municipal officer. The questionnaire was sent to 19 experts who had previously agreed to collaborate to the project and 17 valid responses were collected within the deadline (December 2017). Respondents include personnel of different provincial (3) and municipal (7) departments with an interest in recreational areas and activities, local practitioners (1) and academics from the University of Trento (3) and other research centres in the city (3). The experts were asked to assign to each element a score from 0 to 5 based on the role of the element in supporting or promoting nature-based recreational activities. The scores were then averaged, excluding the highest and the lowest scores and converted to a 0-to-1 scale. The final scores used to run the model are listed in Table 2 and Table 3.

Table 3.

Input data of the ESTIMAP-recreation model divided by model component and respective scores assigned by the experts.

	Source	Spatial entity	Score
Natural features			
local reserve	Provincia Autonoma di Trento 2017	point	0.8
Natura 2000 sites	Provincia Autonoma di Trento 2017	polygon	0.8
monumental tree	Lando and Gadotti 2016, Open Street Map Contributors 2017	point	0.7
mountain pass or saddle	Open Street Map Contributors 2017	point	0.7
mountain peak	Open Street Map Contributors 2017	point	0.8
rock or stone	Open Street Map Contributors 2017	point	0.7
karstic area	Provincia Autonoma di Trento 2017	point	0.5
canyon	Provincia Autonoma di Trento 2017	point	0.8
sites of geomorphological interest	Provincia Autonoma di Trento 2017	point	0.7
cave	Provincia Autonoma di Trento 2017	point	0.7
paleontological site	Provincia Autonoma di Trento 2017	point	0.7
site of stratigraphic interest	Provincia Autonoma di Trento 2017	point	0.6
spring	Open Street Map Contributors 2017	point	0.5
valuable landscapes	Provincia Autonoma di Trento 2017	point	0.8
viewpoint	Open Street Map Contributors 2017	point	0.9
river areas with landscape value	Provincia Autonoma di Trento 2006	polygon	0.8
river or watercourse - primary	Comune di Trento 2017a	polygon	0.8
river or water course - secondary	Comune di Trento 2017a	polygon	0.7

Urban parks			
>2 ha	Comune di Trento 2010	polygon	1
>0.5 ha	Comune di Trento 2010	polygon	0.9
<0.5 ha	Comune di Trento 2010	polygon	0.8
historical garden	Comune di Trento 2010	polygon	0.7
Access-related facilities			
parking area	Open Street Map Contributors 2017	point	0.7
bus stop	Open Street Map Contributors 2017	point	0.8
cycle path – local	Comune di Trento 2010	line	0.9
provincial road	Comune di Trento 2017b	line	0.7
local road	Comune di Trento 2017b	line	0.8
forest track	Provincia Autonoma di Trento 2013	line	0.6
Use-related facilities in non-urban context			
alpine hut	Open Street Map Contributors 2017	point	0.9
rock climbing route	Open Street Map Contributors 2017	point	0.8
picnic area	Open Street Map Contributors 2017	point	0.7
cycle path – long distance	Provincia Autonoma di Trento 2010	line	0.9
forest track	Provincia Autonoma di Trento 2013	line	0.7
hiking trail	Società Alpinisti Tridentini 2017	line	0.9
MTB track	Open Street Map Contributors 2017	line	0.8
Use-related facilities in urban parks			
playground	Comune di Trento 2010	point	0.9
sport field	Comune di Trento 2010	point	0.7
dog area	Comune di Trento 2010	point	0.7
benches and tables / picnic area	Comune di Trento 2010	point	0.7
water feature / fountain	Comune di Trento 2010	point	0.7

Population data for each census tract, including 5-year age groups, were also provided by the municipality (last update: 31st December 2014). To be as accurate as possible in the analysis, the population in each census tract was distributed only on the surface covered by the footprint of residential buildings. Spatial data were analysed and elaborated using the GIS software QGIS 2.18.9 (QGIS Development Team 2017) and GRASS GIS 7.2.1 (GRASS Development Team 2017), while the multi-criteria analysis was conducted using the free version of the software Definite (SPINlab Vrije Universiteit Amsterdam 2016).

Results

Cooling effect of urban green infrastructure in Trento

The assessment of the cooling effect produced by green infrastructure in Trento was carried out for the most urbanised area of the city, i.e. the valley floor, where all the brownfields are located (Fig. 4). Overall, the highest classes of cooling effect prevail there, due to the presence of close-by forests and of the River Adige and its tributaries that contribute to lower the temperature of the surroundings. The most disadvantaged areas are in the dense neighbourhoods close to the city centre and in the northern suburbs. Here, the mix of residential and industrial areas, with little green infrastructure, as well as the high rate of soil sealing generated by the concentration of major transport infrastructures, have a negative impact on the cooling performance of the city. Most of the brownfields appear to be strategically located in areas that scarcely benefit from the cooling effect of both urban green infrastructure and the surrounding natural and semi-natural areas.

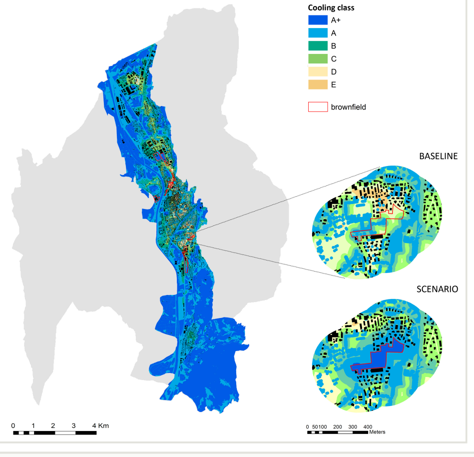

Figure 4.

Map of the cooling effect of urban green infrastructure in the most urbanised part of the city of Trento (baseline condition) and an example of a planning scenario related to the regeneration of brownfield 11. The zoom shows the maximum distance potentially reached by the cooling effect generated by the converted brownfield.

An example of how the conversion of brownfields into new urban parks would affect the cooling effect is provided in the right side of Fig. 4 for the case of brownfield 11. Due to the change in the soil cover from partly sealed to grass and to the intense plantation, the site would reach the highest class of cooling effect. The immediate areas would also be affected by the transformation. In the present condition, most of the surrounding residents gain very little or no thermal benefit at all from the presence of green infrastructure, which is almost exclusively limited to single shading trees. In the regeneration scenario, an improvement is noticeable in the major part of the area. In the neighbourhood to the north, some households would shift from class E to class A of the cooling effect.

The performance of the different scenarios in terms of microclimate regulation is summarised in Fig. 5, where brownfields are compared according to the number of people that would benefit from their regeneration. Brownfield 11, a potentially large green area inside a densely built-up and populated part of the city, is by far the best performing one: more than 2,000 citizens would benefit from the enhanced cooling effect produced by the transformation. The regeneration of the other brownfields is expected to affect much less people, within the range of some hundreds for most scenarios.

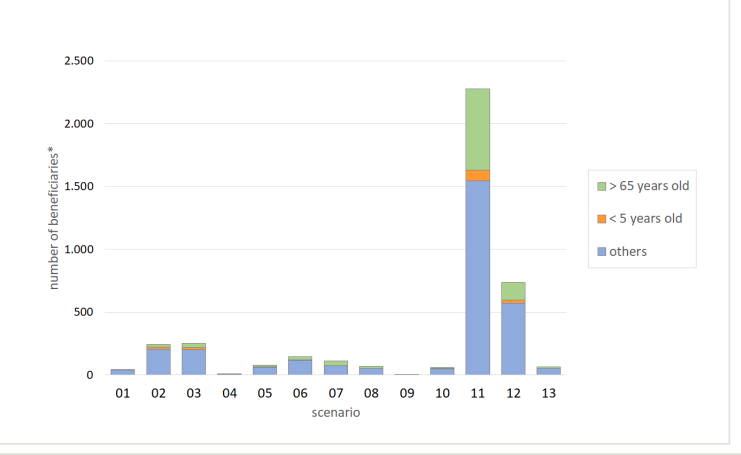

Figure 5.

Expected benefits produced by the different scenarios in terms of enhanced cooling effect by urban green infrastructure: number of beneficiaries broken down into different vulnerability classes.

Opportunities for nature-based recreation

The map of the Recreation Opportunity Spectrum (ROS) in the city of Trento, as obtained from a cross-tabulation between Recreation Potential (RP) and the level of availability of infrastructures and facilities, is shown in Fig. 6. The valley floor, though mostly characterised by low values of RP, presents the highest concentration of infrastructure and facilities that provide access and support the use of green areas. The best-performing areas in this part of the city are urban parks and the river banks, which host an important touristic cycle path, intensely used by Trento citizens for running, cycling and skating. In the extra-urban areas, different opportunities for nature-based recreation characterise the two sides of the valley. Forests on the east side are characterised by a higher density of forest tracks, hiking trails and facilities dedicated to specific activities such as climbing routes and MTB trails, especially near the settlements. On the west side, the settlements are more sparse and the connections with the valley floor are more difficult, which determines a lower availability of infrastructure and facilities.

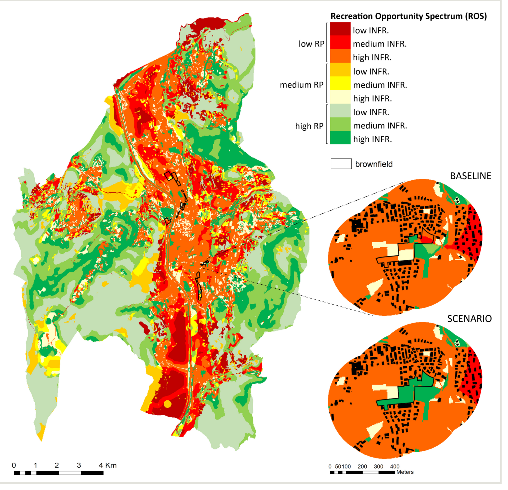

Figure 6.

Map of the Recreation Opportunity Spectrum (ROS) in Trento calculated through the locally-adjusted version of the ESTIMAP-recreation model (baseline condition) and example of planning scenario related to the regeneration of brownfield 11. The zoom shows the 300-m buffer used to identify potential beneficiaries of enhanced close-to-home recreational opportunities.

Considering the brownfields and their surroundings, all of them are in areas with high availability of infrastructure and facilities. Some are close to existing urban parks, as in the case of brownfield 10, while others, e.g. brownfields 01, 02 and 03, are far from any area of high RP. Hence, they represent opportunities to enhance the condition of people that currently have no or very few close-to-home opportunities for nature-based recreation.

Regeneration interventions would convert existing brownfields into new urban parks, thus increasing the opportunities for nature-based recreation in the neighbourhoods. Fig. 6 shows the case of brownfield 11 that, once regenerated, would fall into the best class of ROS, with high RP and high availability of infrastructure and facilities. The map also highlights the possibility of connecting the new park to an adjacent open-air soccer field, already classified in the best class of ROS. Despite being already served by other parks and green areas close by, all the households, included in the map, would benefit from an additional space for recreation within walking distance from their location.

The performance of the different scenarios in terms of recreation opportunities is summarised in Fig. 7, where brownfields are compared according to the number of people that would benefit from their regeneration. Brownfields 07 and 08 produce the highest absolute number of beneficiaries. However, only the scenarios that consider the regeneration of brownfields 01, 02 and 03 would serve people that, at present, have no access to close-to-home nature-based recreational opportunities. The ratio between total beneficiaries and specific vulnerable groups is not the same across scenarios, due to the uneven distribution of population groups across the city. For example, the share of children and teenagers is higher for scenarios 01 and 02 compared to the others, while the share of people aged more than 65 is the highest for scenario 11.

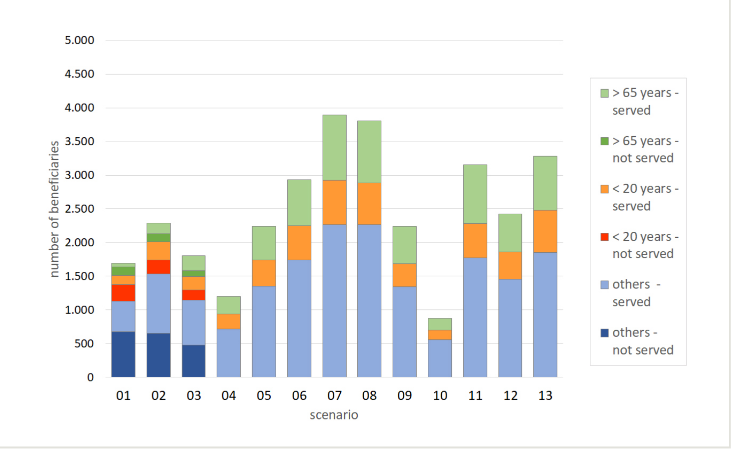

Figure 7.

Expected benefits produced by the different scenarios in terms of enhanced opportunities for nature-based recreation: number of beneficiaries broken down into different vulnerability classes.

By comparing Fig. 7 with Fig. 5, the performance across scenarios appears more balanced in the case of recreation than in the case of microclimate regulation. Moreover, excluding scenario 11, the number of people that would benefit from increased opportunities for nature-based recreation is much higher compared to the number of citizens that would experience an improved cooling effect. Although some of the beneficiaries overlap between the two ES, due to the spatial relationship between providing units and benefitting areas, the information is important for defining the weights of the different criteria in the multi-criteria analysis.

Integrated assessment of planning scenarios

The information about the number of beneficiaries of the two ES in the different scenarios was combined through a multi-criteria analysis according to the three perspectives described in Table 1. The results of the analysis are summarised in Fig. 8. When assuming a 'balanced' perspective, with the same weight assigned to the two ES and a double weight assigned to vulnerable compared to non-vulnerable groups, brownfield 11 ranks first. The second perspective, consistent with the objective of improving the cooling effect in areas with a high share of older population, leads to the same first-ranking scenario. Although the other positions change between the two perspectives, all scenarios gain a very low score compared to brownfield 11. Under the third perspective, the final ranking changes significantly and the first positions are occupied by the three brownfields (01, 02 and 03) located in the northern part of the city. In such neighbourhoods, the population is comparatively younger and the opportunities for recreation are scarcer.

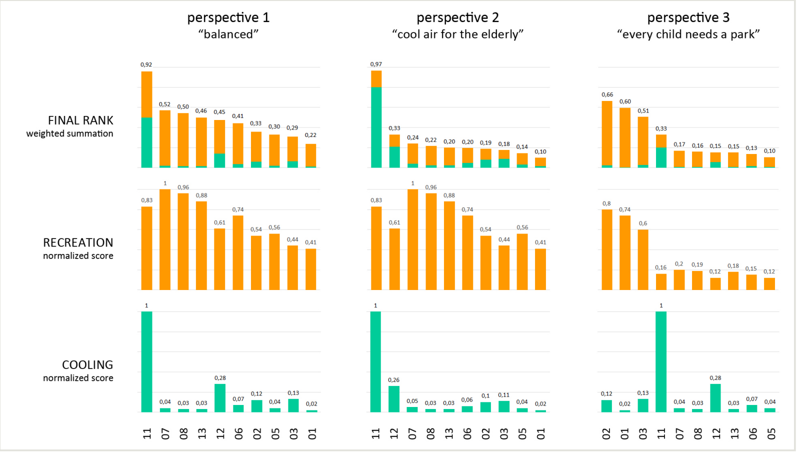

Figure 8.

Final rankings of the regeneration scenarios according to three perspectives considered in the multi-criteria analysis. The weights assigned to the different ES and the different categories of beneficiaries are reported in Table 1. Scenarios 04, 09and 10 were identified as sub-optimal alternatives and excluded from the multi-criteria analysis.

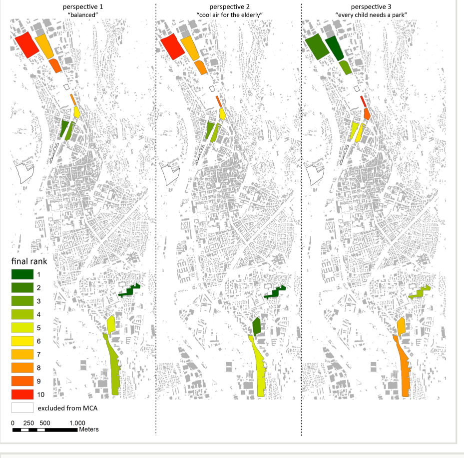

Figure 9.

Map of the priority level of brownfield regeneration scenarios according to three perspectives considered in the multi-criteria analysis.

Overall, the three illustrative perspectives show how priorities for brownfield regeneration change based on the relative importance attributed to the different ES and the respective categories of beneficiaries (Fig. 9). To assess the stability of the ranking and the robustness of the results with respect to possible variations in the assigned weights, we conducted a sensitivity analysis. Considering the weights assigned to the main criteria, i.e. the two ES, the rakings produced by perspective 1 ('balanced') and 2 ('cool air for the elderly') are very stable: the first-ranking alternative (brownfield 11) maintains its position even for large fluctuations of the weight (up to the weight of the ‘recreation’ criterion equal to 0.85). In the case of perspective 3 ('every child needs a park'), the ranking is less stable and a weight of 0.58 assigned to the ‘recreation’ criterion is sufficient for scenario 02 to reach the first position.

Discussion

The case study shows one of the possible tasks that ES mapping and assessment can perform to support urban planning, i.e. the assessment of alternative planning scenarios (Barton et al. 2018). The analysis considered different brownfields in the city of Trento that could be converted to new urban parks and assessed the expected effects of the transformations in terms of ES benefits. The presence of brownfields and abandoned areas is a key issue for today’s cities, with strong economic and social implications (Nassauer and Raskin 2014), hence their regeneration is promoted amongst the strategies for sustainable urban development (European Commission 2016). Recent studies have analysed how, depending on their actual conditions, brownfields are or may be turned - through interventions that range from simply changing the management of the areas to demolishing, de-paving and regreening - into sources of ES for the urban population (Beames et al. 2018, Collier 2014, Geneletti et al. 2016, Mathey et al. 2015, McPhearson et al. 2013). Our analysis focused specifically on the expected benefits in terms of improved cooling effect by vegetation and enhanced opportunities for nature-based recreation, thus addressing two of the most critical issues for citizens’ well-being in Trento.

The comparison of alternatives considered three perspectives that simulate different decision-makers’ orientations. In the analysis, the relative importance of different planning objectives, hence ES, is reflected by different combinations of criteria and weights. In the case of perspective 1, a balanced weighting was performed by assigning the same weight to the two ES. In the case of perspectives 2 and 3, one ES received a weight significantly higher than the other and specific vulnerable groups were identified as the main targets of policy interventions. The results clearly show how priorities change with changing policy goals, as already demonstrated in other applications (Grêt-Regamey et al. 2013, Kremer et al. 2016, Sanon et al. 2012). This finding highlights the need for a strategic approach to ES and for the inclusion of explicit ES-related objectives in urban plans, an aspect still mostly neglected in current planning documents (Cortinovis and Geneletti 2018). Simply providing ES knowledge as part of the information base for urban plans is not enough to guarantee that it is used to guide decisions, if it is not perceived as relevant to the problem at stake (Cash et al. 2003, Saarikoski et al. 2016). Formulating objectives and targets for ES provision helps to identify the values against which the effectiveness of planning actions should be measured, hence also to clarify the possible role(s) of ES knowledge within the process.

Previous applications of multi-criteria analysis to the assessment of urban ES have mostly focused on trade-offs amongst different ES and how they can be minimised in the context of planning interventions (Grêt-Regamey et al. 2013, Sanon et al. 2012). Here, we considered a case in which all scenarios are expected to improve the existing conditions and to generate benefits that decision-makers aim to maximise. This situation is not an unusual one in the context of ecosystem-based actions and nature-based solutions, often characterised by synergies rather than trade-offs amongst ES and related multiple benefits for nature, society and the economy (Albert et al. 2017, Demuzere et al. 2014, Raymond et al. 2017). In the analysed case, potential trade-offs could be related to competing uses of the existing brownfields (Kain et al. 2016) or other non-ES criteria, for example, the costs of intervention (Koschke et al. 2012), which were not considered in the study. However, multi-criteria analysis provides a platform where multiple information about costs and benefits for planning scenarios can be easily integrated (Saarikoski et al. 2016) and where different planning objectives can be balanced with the conservation and enhancement of green infrastructure (Adem Esmail and Geneletti 2018).

Although limited to ES-related objectives and indicators, in the described application, multi-criteria analysis allowed results about two different ES categories to be combined: namely regulating and cultural ES. While most urban ES studies have focused on a single ES (Haase et al. 2014), the integration of multiple value dimensions and related indicators, especially across different ES categories, is still a challenge (Jacobs et al. 2016). In this context, multi-criteria analysis was demonstrated as a useful tool for planners (Adem Esmail and Geneletti 2018, Saarikoski et al. 2016). However, a fundamental issue, which also affects the quality and usability of multi-criteria analysis results, is that the single indicators are perceived as meaningful and informative for decision-makers. From this perspective, the focus of ES assessment methods and practices on biophysical aspects limits their relevance (Bagstad et al. 2014, Olander et al. 2018), especially in decision-making contexts where social and economic objectives prevail over ecological concerns, as is often the case in urban planning. On the contrary, indicators based on beneficiaries, explicitly linking ES provision with changes in human well-being, are a promising way to integrate ES knowledge into decision-making processes (Geneletti et al. 2016, Olander et al. 2018) and to communicate ecological knowledge to planners and politicians primarily interested in enhancing citizens' well-being and quality of life (Schleyer et al. 2015).

Part of the challenge of integrating different ES assessments lies in finding common indicators to express benefits and associated values across the whole range of ES. So far, this has mostly been done through monetary units, whose popularity is probably also linked to this capability. However, several authors have already highlighted limitations and potential drawbacks for monetary valuation of ES in real-life decision-making contexts (Ruckelshaus et al. 2015, Saarikoski et al. 2016). In the described application, different ES have been assessed through the same units of measurement based on the number of beneficiaries produced by each planning scenario. The results confirm the potential of 'benefit relevant indicators' (Olander et al. 2018) to provide a common ground for assessing multiple ES in a way that is relevant for making decisions (Olander et al. 2017).

Such indicators refer to the stage of the ES Cascade that describes how ES 'appropriation' (Spangenberg et al. 2014) generates benefits, i.e. contributes to specific aspects of human well-being (Haines-Young and Potschin 2010). Despite the link with ES demand, 'benefit relevant indicators' are not necessarily the result of socio-cultural methods aimed at eliciting preferences from stakeholders (Harrison et al. 2018), which may be difficult to integrate into planning processes. As shown by the assessment of the cooling effect, simple beneficiary-based indicators can be obtained through the combination of biophysical modelling with information commonly available to planners, such as the distribution and generalised level of demand of the actual and potential beneficiaries. What is needed, though still challenging, is to follow the whole 'production chain' of ES, from urban ecological structures and functions to ES benefits (Luederitz et al. 2015, Olander et al. 2018), which requires synthesising multiple inputs into a true trans-disciplinary assessment (Jacobs et al. 2016, Potschin-Young et al. 2018).

The two methods, adopted in the case study, are specifically aimed at assessing urban ES for decision support (Zardo et al. 2017, Zulian et al. 2018). Accordingly, they work at the city scale and have the necessary resolution to capture the heterogeneity and fragmentation of urban green infrastructure and the limited dimension of the resulting service benefitting areas (Gómez-Baggethun and Barton 2013). However, not all ES assessment methods, suitable for city-wide applications, can be successfully adopted to compare planning scenarios. Assessing and comparing urban planning scenarios requires methods which are responsive to small changes in land uses (Kain et al. 2016) and which are able to measure variations in ES due to changes in management that may not be reflected by land use changes. The ESTIMAP-recreation model adjusted for the described application, with a component specifically devoted to assessing the presence of infrastructure and facilities, is a good example of how management interventions that affect ES provision can be taken into account even when land uses do not change.

However, both the methods and their application are characterised by some limitations that must be acknowledged. Due to the classification of soil cover and canopy coverage on which it is based, the model for assessing the cooling capacity and cooling effect of urban green infrastructure is sensitive to classification errors and the different resolutions of input data may have produced inaccurate results, particularly in private areas where detailed data were not available. Moreover, the assessment was limited to the valley floor, since the model is suitable only to applications in urban areas and does not account for the direct (i.e. temperature gradient) and indirect (i.e. wind intensity and reduced urban heat island due to land cover change) effects of elevation on the local climate (Zardo et al. 2017). Due to the location of the brownfields, this limitation was irrelevant to the case study, but it must be taken into account by potential users. The application of the ESTIMAP-recreation model was partly driven by the availability of spatially-explicit data, especially regarding the 'natural features' and the 'use-related infrastructure and facilities' components. Data from Open Street Map (Open Street Map Contributors 2017) allowed the lack of information in the municipal databases to be overcome, but poses issues of completeness and reliability. Furthermore, the involvement of experts from different departments and sectors does not guarantee that citizens' needs and preferences are reflected in the assessment.

A final limitation involves the use of population data to identify ES beneficiaries and their classification into vulnerability groups. Age represents just one of the factors that determine the level of vulnerability to heat stress, which also depends on health conditions and socioeconomic aspects (Basu 2002, Kenny et al. 2009) and is only a proxy for the level of demand for recreational opportunities, which is context-specific and is affected by indvidual preferences and lifestyle (Bertram and Rehdanz 2015, Hegetschweiler et al. 2017). Similarly, surrounding residents may represent only a part of the users of an area and methods that take into account the real distribution of people (including non-residents and commuters) across the city and its variations during the day would represent a significant advancement in the quantification of ES beneficiaries.

Conclusions

The case study explored the use of ES assessments to support urban planning in the specific phase of the planning process where decisions amongst alternative scenarios are to be made. Specifically, it addressed the issue of brownfield regeneration in the city of Trento, focusing on the expected benefits that different planning scenarios could generate in terms of improved cooling effect by vegetation during hot days and enhanced opportunities for nature-based recreation for the surrounding residents. In the case study, the presence of thirteen brownfields to be regenerated determines the need for a rational approach to prioritise interventions. The proposed methodology allowed the alternative sites to be compared, based on the number of beneficiaries that the conversion into new urban parks would produce, hence selecting the best scenario depending on specific planning objectives and decision-makers' orientations. While, in terms of cooling effect, one of the scenarios performs much better than all the others, in terms of opportunities for nature-based recreation, the number of beneficiaries is similar across different scenarios and three of them, despite a lower number of beneficiaries, would answer the need of people currently not served by any urban park. The final ranking is therefore sensitive to the relative weights assigned to the two ES and the different categories of beneficiaries. Starting from this result, a more complete decision support system could be built by integrating the two ES assessments with other relevant criteria (including non-ES criteria such as, for example, the cost of intervention).

The case study demonstrates that beneficiary-based indicators, combined through multi-criteria analysis, are a promising methodology to assess planning scenarios involving changes in green infrastructure. In these contexts, accounting for the multiple ES that are affected, considering changes triggered by planning actions in both the supply of and the demand for ES, is essential for making informed decisions (Langemeyer et al. 2016). Contrary to strictly biophysical measures and to monetary values, beneficiary-based indicators are coherent with urban planning objectives directed to pursue public interests and societal benefits (von Haaren and Albert 2011), hence potentially effective in integrating ES knowledge in the assessment of planning actions (Olander et al. 2018). However, ES assessment methods, usable for planning and able to produce beneficiary-based indicators with the required level of detail, are not common in ES literature. In the study, two ES mapping and assessment methods specifically developed for the urban scale were applied (Zardo et al. 2017, Zulian et al. 2018) and combined with a spatially-explicit analysis of population groups. The use of multiple methods highlights the need for trans-disciplinary efforts to link ecological values with social benefits (Potschin-Young et al. 2018).

Multi-criteria analysis was adopted as a tool to integrate ES assessments, moving from scientific results about the single ES to the selection of the best performing scenario. On the one hand, multi-criteria analysis allows multiple sources of information and value dimensions to be combined, disregarding the indicators that are used to express them, which makes it suitable to address ES-related issues (Saarikoski et al. 2016). On the other hand, it offers a structured way to explore different stakeholder perspectives and related objectives, balancing diverse and sometimes competing interests in a rational and transparent way (Adem Esmail and Geneletti 2018). While the presented application was mainly a scientifically-driven exercise, the proposed methodology demonstrated the potential for making ES assessments usable and relevant to real-life urban planning decisions.

Acknowledgements

Research for this paper has been partly conducted for the project ESMERALDA, receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642007.

The authors gratefully acknowledge the support of Dr. Grazia Zulian (European Commission's Joint Research Centre) for adjusting the ESTIMAP-recreation model and applying it to the case study and the collaboration of Arch. Giovanna Ulrici (Comune di Trento) for providing useful input and organising the expert consultation. The authors also thank all the experts who answered the questionnaire, as well as Claudia Dworczyk and Nadja Kabisch for their valuable comments on the manuscript.

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