Cities 144 (2024) 104629

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Spatializing Urban Forests as Nature-based Solutions: a methodological proposal

Luca Battisti[a,b,*], Giovanni Giacco[c], Massimiliano Moraca[d], Giacomo Pettenati[b,e], Egidio Dansero[a,b], Federica Larcher[f]

[a] Department of Cultures, Politics and Society, University of Turin, 10153 Torino, Italy
[b] OMERO - Interdepartmental Research Centre for Urban and Mega-Events Studies, Lungo Dora Siena, 100 A, 10153 Turin, Italy
[c] Department of Electrical Engineering and Information Technology (DIETI), University of Naples Federico II, Via Claudio 21, 80125 Naples, Italy
[d] GIS Specialist Freelance, Naples, Italy
[e] University of Eastern Piedmont, Department of Economics and Business Studies, Via Perrone 18, 28100 Novara, Italy
[f] Department of Agricultural, Forest and Food Sciences, University of Turin, 10095 Grugliasco, Italy

ARTICLE INFO

Keywords:
Urban Forest
Urban planning
GIS
Remote sensing
Ecosystem services

ABSTRACT

The Fifth Session of the UNEA-5 defines Nature-based Solutions (NbS) as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits”. A large number of the EU HORIZON 2020 research program projects include the implementation of NbS in urban settings. The proGIreg project implemented several NbS for urban regeneration with and for citizens in its Living Lab in the city of Turin (Italy), among others. Focusing on the NbS of urban forestry, this paper addresses the following question: where can NbS be implemented within the city, in order to maximize their social impact? To achieve this goal, by identifying neighborhoods in need of NbS implementation, the 3–30-300 rule proposed by the International Union for Conservation of Nature (IUCN) was adopted and implemented, taking greater account of environmental and social characteristics. The paper also proposes an index to identify neighborhoods of the city that could have precedence in the implementation of NbS. The results highlight 10 neighborhoods where there is a high need of NbS implementation.

1. Introduction

The Fifth Session of the United Nations Environment Assembly (UNEA-5) defines Nature-based Solutions (NbS) as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits” (UNEP, 2023). Specifically, it emerges that the objective of NbS is to promote and protect biodiversity, supporting the delivery of several Ecosystem Services (ES). If considered superficially, the concept of NbS may present some overlaps with those of Green Infrastructure (GI), as they are both part of the group of metaphors that are mobilized to describe the role and the functions of natural components in urban environments (Escobedo, Giannico, Jim, Sanesi, & Lafortezza, 2019). However, there are key differences, as highlighted by Dorst, Van der Jagt, Raven, and Runhaar (2019). Thus, while on the one hand, GI represents (mainly) a network of green/blue areas, the definition of NBS is broad, encompassing the use of nature to address environmental, social, and economic challenges. Specifically, the literature suggests that NbS should be conceived of as an umbrella concept (Nesshöver et al., 2017; Pauleit, Zölch, Hansen, & Randrup, 2017) that encompasses other concepts such as ES (Escobedo et al., 2019; Fernandes & Guiomar, 2018) and GI (Kong et al., 2021). In addition, scholars recommend that NbS should not be merely a relabelling of previous practices (Pauleit et al., 2017), but a unique concept targeting urban sustainability issues (Kabisch et al., 2016).

NbS are proliferating in the recent plans and projects of several

* Corresponding author at: Department of Cultures, Politics and Society, University of Turin, 10153 Torino, Italy.
E-mail addresses: luca.battisti@unito.it (L. Battisti), giovanni.giacco@unina.it (G. Giacco), info@massimilianomoraca.it (M. Moraca), giacomo.pettenati@uniupo.it (G. Pettenati), egidio.dansero@unito.it (E. Dansero), federica.larcher@unito.it (F. Larcher).

https://doi.org/10.1016/j.cities.2023.104629
Received 1 October 2022; Received in revised form 19 June 2023; Accepted 17 October 2023
Available online 16 November 2023

European cities, as potentially viable means to address the most urgent urban challenges (Almenar et al., 2021; Frantzeskaki, 2019). Also a large number of projects, mostly framed within the EU HORIZON 2020 programme, include the implementation of new NbS in urban contexts among their activities (Cortinovis, Olsson, Boke-Olén, & Hedlund, 2022; Davies, Chen, Sanesi, & Lafortezza, 2021). It is the case of the project "Productive Green Infrastructure for post-industrial urban regeneration" (proGIreg), that is being implemented in the city of Turin (Italy), which uses nature for urban regeneration with and for citizens. The five-year proGIreg project (2018–2023) aims to implement and test NbS to foster environmental, economic and social regeneration processes in urban areas with a strong industrial legacy (Ascione, Cuomo, Mariotti, & Corazza, 2021; Cuomo, 2022).

The need to upscaling and outscaling NbS, in particular those implemented with European funding, is an emerging theme in scientific literature (Cortinovis et al., 2022), where different methods are proposed. Specifically, among the most common techniques for upscaling NbS in urban settings, particular emphasis is placed on scenario analysis techniques. In particular, with regard to the topic of Urban Forestry (UF) in cities, studies have been conducted in Malmö, Utrecht and Barcelona (Barò, Calderon-Argelich, Langemeyer, & Connolly, 2019; Cortinovis et al., 2022). The assessments, which are often based on land cover analysis, allow the distribution of benefits in the city to be mapped, enabling the distributional equity of NbS to also be assessed at a later stage (La Rosa & Pappalardo, 2019). These numerous benefits can be traced back to a multitude of ES provided to the population, including mental benefits (Larcher, Pomatto, Battisti, Gullino, & Devecchi, 2021; Säumel, Hogrefe, Battisti, Wachtel, & Larcher, 2021; Velarde, Fry, & Tveit, 2007), reduction of air pollutants (Battisti, Pille, Wachtel, Larcher, & Säumel, 2019; Battisti, Pomatto & Larcher, 2019), refreshing the city (Bowler, Buyung-Ali, Knight, & Pullin, 2010). However, the need to consider and expand the range of socio-economic and environmental data in order to also assess the social impacts of NBS scaling-up is emphasized (Cortinovis et al., 2022; Cortinovis & Geneletti, 2019; Nesbitt, Meitner, Girling, & Sheppard, 2019). Our research proposes an approach to be conducted prior to or simultaneously with scenario analyses, to overcome this gap by specifically considering social and environmental issues, proposing a method potentially adaptable to any urban context. Not considering exclusively green deficit distribution, and including socio-economic data in the decision-making process about NBS's implementation, our proposal encompasses the main critiques that are moved to the NbS approach, which is considered as 'mechanistic and seemingly apolitical' (Kotsila et al., 2021). In order to eschew the accusations of contributing to green gentrification and to the reproduction of the urban neoliberal model addressed to NBS implementations, the integration of NbS in urban planning necessarily has to include a wide range of socio-environmental factors, as criteria for the localization of urban green, echoing the call for 'just nature-based solutions' (Anguelovski & Corbera, 2023). Our research moves a first step in this direction, linking the identification of suitable areas for new NbS to the implementation of a "socially-oriented" UF localization framework, like the 3–30-300 rule (Konijnendijk, 2022), to more explicitly social and environmental criteria.

Specifically, this article focuses on urban forestry as NbS, intended as the intersection of NBS with UF, rely on UF to address societal challenges as well as playing an important role in human wellbeing and biodiversity (Scheuer et al., 2022).

Reflecting on this theme, the article explores the main debate on the "greening city", trying to address the following question: where NbS can be implemented within the city, in order to maximize their social impact? This specifically regards the upscaling of those punctual NbS implemented and tested by European projects, in order to amplify their impact.

Expanding an existing method, the article develops and tests - in the city of Turin (Italy) - an index aiming to identify the parts of the city that could have precedence in the implementation of NbS.

1.1. Planning and localising green areas and NbS in the city

Expanding and developing the long-standing debate on green spaces planning in urban contexts (Haaland & van Den Bosch, 2015; Wolch, Byrne, & Newell, 2014), NbS - together with ES - represent a recent promising field of integration of urban resilience in the field of urban planning, despite more research is needed to go beyond theory and propose thorough criteria to select the more effective localization of NbS in urban areas (Bush & Doyon, 2019).

Nevertheless, without adequate planning (Ramyar, Ackerman, & Johnston, 2021), the creation of urban green can increase urban social exclusion and stimulate gentrification, as it has been widely discussed (Anguelovski, Connolly, Garcia-Lamarca, Cole, & Pearsall, 2019; Blok, 2020; Haase et al., 2017). Surprisingly, issues related to equity, justice, and reduction of socio-spatial inequalities at the urban and at the neighborhood scale are only marginally considered in the decision-making processes concerning the localization of new urban green areas (Rutt & Gulsrud, 2016). This is also the case with NbS. While there is a long lasting debate on GIS localization and planning in urban areas (Monteiro, Sousa, Natividade-Jesus, & Coutinho-Rodrigues, 2022; Sinnett, Smith, & Burgess, 2015), the recent debate on NbS still lacks significant contributions on how to integrate NbS in urban planning, combining technical criteria with social objectives, with few exceptions (Albert et al., 2019; Bush & Doyon, 2019).

Although some authors argue that planning with NbS should focus on the landscape scale (Arkema et al., 2017; Loiseau et al., 2016), we believe that it is important to plan for NbS at the urban and neighborhood scales as well. Nonetheless, this line of thinking can be found in European policies (e.g., EU Biodiversity Strategy for 2030, EU Green Infrastructure Strategy) aimed at ensuring the supply and quality of green spaces, as well as through the guidance provided by international and European organizations to ensure adequate access to green spaces (World Health Organization recommendation for access to 0.5–1.0 ha green space within 300 m).

Within the roster of recommendations from international organizations, there is a place for the International Union for Conservation of Nature (IUCN) 3–30-300 rule, proposed by Cecil Konijnendijk van den Bosch: at least 3 trees (of a 'decent size') visible from citizens' home; at least 30 % of tree canopy cover in each neighborhood; 300 m from the nearest park or green space. The spatial unity of the rule is characterized by the neighborhood. This is not the only rule that is applied in order to have a positive effect on the structure and diversity of urban forests. Among the most famous, applied and debated is the 10–20-30 rule (Santamour, 1990). However, that rule does not focus attention on the benefits provided by urban forests, as the one proposed by Konijnendijk van den Bosch does.

The 3–30-300 rule (Konijnendijk, 2022) represents a message that policymakers can remember, but takes up research and recent debate about the planning and benefits of green spaces in urban settings. Among the various scientific literature, it appears that it is necessary the importance of nearby, especially visible, green for mental health and wellbeing (Velarde et al., 2007). This assertion was reinforced during the pandemic period, which emphasized the importance of greenery near homes (Larcher et al., 2021). In addition to WHO research and recommendations, van den Bosch et al. (2016) emphasized the importance of proximity to high-quality green spaces that can be used for recreation, generally reachable within 5 min or 10 min, though often the traveled distance to the most used UGS is well beyond a 300–500 m buffer distance (Schindler, Le Texier, & Caruso, 2022). Although this rule is proposed and promoted by the IUCN, to our knowledge no scientific articles have yet been published on its application and modification. This is probably due to the recent dissemination of this information.

This article proposes an implementation of the 3–30-300 rule, trying to fill the existing gaps in the debate about NbS planning and localisation (Ruangpan et al., 2021), integrating environmental criteria concerning green spaces distribution and density with social *criteria.*

1.2. The planning of green spaces and NbS in Italy

Analyzing the current situation in Italy, the national Law 10/2013 is the main regulatory reference for the planning and development of urban green spaces. In 2018, referring to this law and to the requests of the European Union, the National Strategy for Urban Green was published, which makes specific reference to the themes of ES, GI and NbS and establishes the criteria and methods with which the administrations involved in the drafting of territorial plans must act. The various strategic actions and lines of intervention include the need to increase the coverage of trees and green areas; to adopt "urban forests" as a reference for the planning and design of the various urban green systems; and to encourage a more equal distribution of green areas among the different areas of the city. The National Strategy indicates the path to be followed in drawing up a Green Plan for the Metropolitan City or Municipality. The City of Turin in December 2020 came up with a Green Infrastructure Strategic Plan (Torino Vivibile, 2020) consisting of 10 sections that address as many issues, including green management and quantification of ES. However, this strategic plan has no particular reference to NbS, and does not propose specific planning of interventions with NbS in the city. However, there are other European projects underway in Turin analyzing the topic of NbS, some with specific reference to urban forestry (CONEXUS), which could bring further interesting results in implementing NbS in the urban setting. It is worth highlighting how in Italy NbS are a relatively new topic in public policy and urban planning even if they are able to provide benefits that simultaneously satisfy Sustainable Development Goals and urban governments' challenges and goals. However, recently some agronomists, geographers and policy analysts offered interesting contributions and delivered useful suggestions for implementing NbS on an urban scale (Ascione et al., 2021; Battisti et al., 2021; Stefanakis, 2019). However, there is a lack of a useful methodology to identify the areas that should have precedence for NbS implementation and thus wisely direct the funds that Italian administrations have in the realization and management of public green. The implementation of the 3–30-300 rule and the proposed application of an index to identify areas in precedence need of NbS attempts to provide a methodology that local administrations can use to implement a Green Plan, considering specific environmental and social characteristics of the city.

1.3. Research aim

The process of upscaling or outscaling NbS is fundamental in many European projects and also in the proGIreg project. In this article, the focus is on UF as NbS. The research question is aimed at understanding: where can NbS be implemented within the city, in order to maximize their social impact? This specifically regards the upscaling of those punctual NbS implemented and tested by European projects, in order to amplify their impact. To achieve this objective, the 3–30-300 rule (IUCN, 2021; Konijnendijk, 2022), was adopted. Specifically, we propose an implementation of the 3–30-300 rule in order to consider also the climatic and social aspects of the city under analysis. Specifically, commonly available climate, land use and land cover (LULC) data were considered. These data are useful for calculating a cooling index by applying the InVEST urban cooling model (InVEST - Natural Capital Project, 2022). Furthermore, social data are also particularly important in identifying where to build or implement NbS. Within the roster of socio-demographic data, special attention is intended to be paid to Population Density, or the number of residents living in a neighborhood.

In addition, in order to consider the parameters added to the rule proposed by Konijnendijk, a precedence index, which is based on a weighted average, is proposed that can return a value highlighting the need or precedence of a neighborhood to implement NbS. The mathematical details concerning the construction of the index can be found in the Method section. As 'one size fits all' solutions are ineffective, especially related to the issue of urban planning that considers population dynamics and climatic contexts (Manoli, Fatichi, Schläpfer, et al., 2019), the objective is to provide decision makers with the possibility to add to the precedence index the parameters they consider crucial to identify the areas of the city where NbS should be implemented in the short term. In this way, our proposed method could be replicable everywhere, tailored to the city under analysis. It is proposed to apply this method to the city of Turin (Italy) in order to identify the neighborhoods that should implement urban forestry as NbS, derived from the proGIreg project.

2. Materials and methods

2.1. Study area

The city of Turin is the capital of the Piedmont region in the northwest of Italy and is located on the western edge of the Po Valley. The city covers 130.2 km^2 in a flat area (239 m a.s.l.) and a hilly area reaching an altitude of 715 m a.s.l., where 878,074 inhabitants live (ISTAT, 2018). The 37 % of the surface area of the City of Turin is composed of green areas (48 km^2 out of a total of 130 km^2), with 55.43 m^2 of green space per inhabitant. Of this 37 %, 5 % is made up of public and private agricultural areas (Torino Vivibile, 2020).

The attention of the city of Turin to its tree heritage is high, so that a web application called Albera.TO used for tree management has been developed (Albera.TO, 2016). In addition, Turin is the capital of the Turin metropolitan area, which comprises 312 municipalities and is characterized by greenways, mainly concentrated along river strips, forming an important ecological network.

Fig. 1 shows the general framing of the study area with respect to the Piedmont region and the entire Italian peninsula. For more information about the relationships between numerical identifier and neighborhood name, please see Table 1. The proGIreg Living Lab 'Mirafiori Sud', is the neighborhood number 23.

2.2. Research methodology

This section explains the implementation of 3–30-300 rule, where environmental and social characteristics have also been considered. Therefore, the presence of: at least 3 trees (of a 'decent size') visible from citizens' home; at least 30 % of tree canopy cover in each neighborhood; 300 m from the nearest park or green space has been analyzed. In order to better consider the climatic-environmental conditions of the city, the Urban Cooling model was considered (Zardo, Geneletti, Prezsoba, & Van Eupen, 2017). Instead, for the social data, the population density of Turin was considered (Battisti, Pomatto, & Larcher, 2020). Fig. 2 shows the workflow methodology applied.

Specifically, the data acquired to conduct the research refer to geospatial datasets that are publicly accessible or provided by the municipal administration. Although the proposed methodology could be easily applied to commercial data, in this work, we focused on using publicly accessible and globally available data in order to propose a practical approach that is easily scalable to other locations.

In addition, a precedence index has been calculated that combines the different parameters into a single score using additive weighting. Data analysis was first performed at the urban scale and then at the neighborhood level. Neighborhoods were ranked according to their precedence index scores, from lowest to highest. The neighborhoods with the lowest scores represent the areas with the most significant needs for NbS implementation.

All data used, refer to the same year, namely 2018. The reasons are as follows: the trees visible, or otherwise planted around the buildings must be of 'decent size', which is the reason we assumed that the trees should be at least 5 years old; the most complete and recent satellite information used for tree canopy cover assessment refers to 2018.

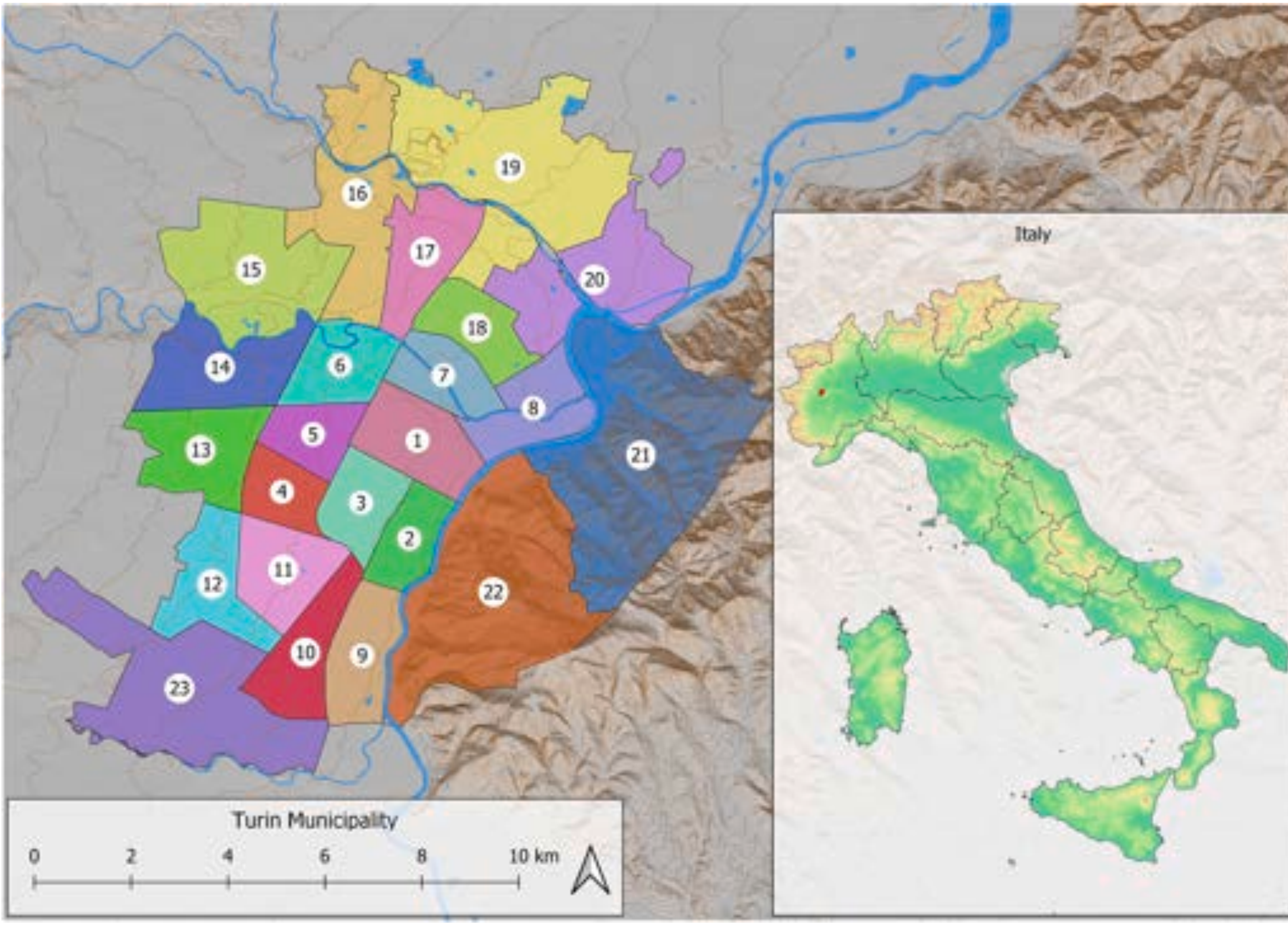

Fig. 1. Location of the city of Turin and subdivision into neighborhoods.

Table 1
Detail of neighborhoods, number of inhabitants, neighborhood surface (data elaboration from WorldPop project, 2021).

Neighborhoods	N° inhabitants (in)	Neighborhood surface (Km^2)
1. Centro	39,651	3.77
2. San Salvario	35,901	2.33
3. Crocetta	34,176	2.77
4. San Paolo	34,955	2.21
5. Cenisia	39,114	2.33
6. San Donato	49,021	3.02
7. Aurora	39,300	2.67
8. Vanchiglia	30,558	3.38
9. Nizza Millefonti	28,207	3.50
10. Mercati Generali	48,803	3.46
11. Santa Rita	56,747	3.57
12. Mirafiori Nord	43,720	3.79
13. Pozzo Strada	57,154	4.22
14. Parella	47,221	4.91
15. Le Vallette	41,400	7.54
16.Madonna di Campagna	41,047	7.40
17. Borgata Vittoria	39,833	3.86
18. Barriera di Milano	48,081	2.83
19. Falchera	26,186	12.62
20. Regio Parco	28,171	6.92
21. Madonna del Pilone	14,167	15.50
22. Borgo Po e Cavoretto	19,541	13.60
23. Mirafiori Sud	35,334	11.43

In this regard, to understand the methodology and the related results achieved, it should be noted that for the city of Turin the neighborhoods of Madonna del Pilone (Fig. 1, number 21) and Borgo Po and Cavoretto (Fig. 1, number 22) will be excluded from the neighborhood focus. These are two hilly neighborhoods characterized by the presence of large forested areas and less by sealed and urbanized areas. In addition, the management of green spaces in these neighborhoods can be likened to forest/woodland management, thus strongly differing from the management of green areas in the remaining neighborhoods.

2.2.1. *Three trees from every home*

In order to verify the presence of three trees visible or otherwise around the buildings, the following procedure was carried out. Building footprints from OpenStreetMap were extracted, and, subsequently, the presence of three trees in a buffer of 30 m from each house in the City of Turin was verified. Trees present for a long time in the City of Turin were considered relevant, considering those that had spent >5 years since planting (data Albera.TO, 2016, based on Battisti et al., 2020). It should be considered that in Turin in the past years, the practice of urban forestation (with young plants 60–80 cm high) was rarely used, and the plants planted were at least 2 years old.

At the urban scale, a buffer area at the distance of 30 m from each building was identified to analyze the distribution of trees. The *Buffer* function present in the *Geoprocessing Tools* of QGIS was used, which generates a polygon vector. Then, using the *Count points in polygon* function present in *Analysis Tools*, a useful count was performed to identify the number of trees per building. Finally, by means of the *Centroids* function present in *Vector Geometry*, the centroids of the

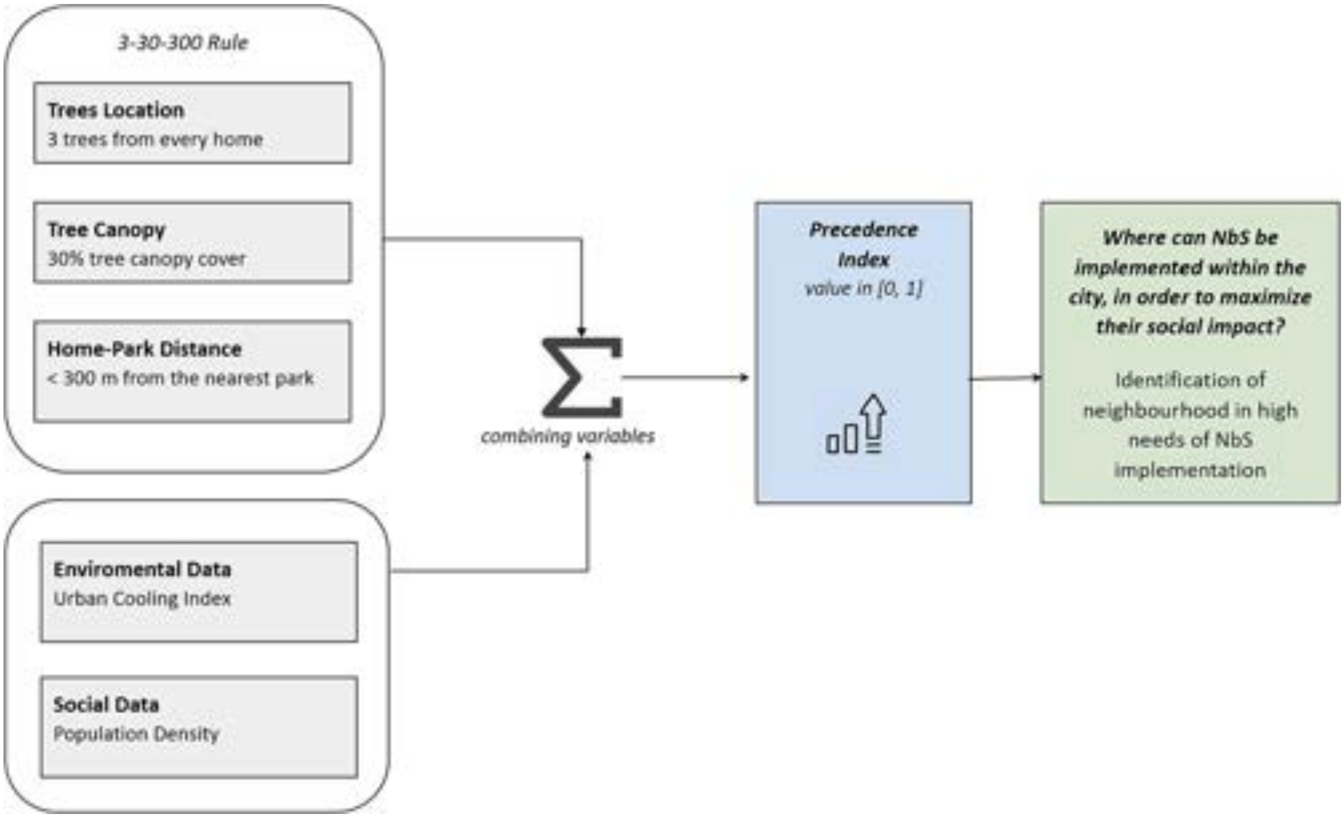

Fig. 2. The research workflow methodology.

buildings were extracted, which were then thematized in order to make the data obtained by the count performed earlier more easily understandable. The *Rule-based* method was used for thematization, which allows each class of values to be associated with a separate visualization. For discussion of the classes, see the results section.

For the neighborhood-scale analyses, the centroids obtained above were interpolated using the column with the tree count as the interpolation weight. The result of the interpolation is a grid-like raster surface. The interpolation algorithm used was IDW (Inverse Distance Weighting) (Lu & Wong, 2008).

The raster was then processed using zonal statistics to identify the distribution of trees at the neighborhood scale using as a reference vector the neighborhoods downloaded from the OpenData portal of the Metropolitan City of Turin. The mean was used as the analysis parameter of the zonal statistics. The thematization of the data was done by dividing the output data into the three intervals previously exposed, by making the ratio between the values of polygons in which at least three trees fall and the number of buildings in the polygon.

2.2.2. 30 % Tree Canopy Cover in every neighborhood

In order to calculate the Tree Canopy Cover in the City of Torino, the data present in the Pan-European High Resolution Layers - Forests (2021) were used and in particular the 2018 data concerning the Tree cover density in 10 m resolution (ranging from 0 to 100 %). The main sources are (since the 2018 reference year) Sentinel-2 and Sentinel-1. For the urban-scale analysis, values were themed into equal 10 % intervals.

For the neighborhood-scale analysis, the zonal statistics algorithm was used by calculating the average cover in each neighborhood. The thematization was performed by dividing the previously calculated data into three quantile classes. See the results section for discussion of the classes.

2.2.3. 300 m from the nearest park or green space

The European Regional Office of the World Health Organization recommends a maximum distance of 300 m to the nearest green space (of at least 1 ha). However, it could be difficult to create new public green spaces of 1 ha in size. In these cases, a decent size of 0.5 ha should be a minimum (WHO, 2017). In the case of Turin, it was considered appropriate to define the reference size of the green area to be reached in 300 m as 0.5 ha.

Parks and gardens data were taken from OpenStreetMap. These data were reprocessed at both urban and neighborhood scales.

Specifically, at the urban scale it was performed using the Proximity algorithm found in Raster Analysis.

The resulting raster was thematized into three classes to make it more intuitive to understand. See the results section for a discussion of the classes.

Neighborhood-scale analysis was conducted by performing zonal statistics on the previously calculated neighborhood raster, using neighborhoods as the reference vector.

2.2.4. Environmental data

An accurate assessment of the capacity of urban green spaces to reduce heat island effect is crucial in planning decisions due to rising thermal pressures on both new and existing urban environments brought on by climate change. This frequently requires data that planners might not have. In this study, we used the InVEST Urban Cooling model, which solves this drawback by employing several readily available factors assigned to a land cover map to create a heat mitigation index (HMI) to estimate the vegetation's ability to cool an area.

The Urban Cooling model generates the heat mitigation index (HMI) based on evapotranspiration from vegetation, the cooling distance of significant urban parks, and albedo given to a land cover (LC) map to measure the average cooling capacity on air temperature.

The model initially calculates the city's evapotranspiration index

(ETI) using a given LULC map:

$$ETI = \frac{Kc\ x\ ET0}{ETmax}$$

It reflects the potential evapotranspiration from plants. For each pixel, it is determined by multiplying the reference evapotranspiration, ET0, the crop coefficient Kc related to the pixel's LULC type, and the highest value, ETmax, of the ET0 raster in the study area.

In particular, the evapotranspiration data provided for the computation was collected using MOD16 global evapotranspiration provided by NASA. This data represent a evapotranspiration estimation from earth land surface by using satellite remote sensing data.

Subsequently, the model computes the cooling capacity index (CCi) for each pixel based on local shade, albedo and evapotranspiration.

$$CCi = 0.6\ x\ shade + 0.2\ x\ albedo + 0.2\ x\ ETI$$

The percentage of tree canopy (>2 m in height) connected to each land use/land cover (LULC) category is represented by the shade factor.

The model then determines the urban HM index: If there are no large green spaces in the pixel's vicinity, HM is equal to CC; otherwise, it is set to a distance-weighted average of the CC values from the large green spaces and the pixel in question.

2.2.5. Socio-demographic data

To assess the socio-demographic characteristics of Turin neighborhoods, data collected by the WorldPop project (2021) were analyzed, calculating the Population Density. This variable was calculated as the number of inhabitants on neighborhood's surface (Battisti et al., 2020). In order to compare the neighborhoods, all the results were grouped into three categories: low, medium and high values.

2.2.6. Identification of Turin neighborhoods that need precedence in NbS implementation

A precedence index (PI) is proposed to identify neighborhoods with a high need of NbS implementation.

$$sum = \sum_i w_i \times variable_i \tag{1}$$

$$min\ (sum) = \sum_i min\ (variable_i\ ) \tag{2}$$

$$max\ (sum) = \sum_i max(variable_i\ ) \tag{3}$$

$$PI = \frac{sum - min\ (sum\ )}{max\ (sum\ ) - min\ (sum\ )} \tag{4}$$

The index was made by summing the variables reported in the mathematical formula, giving each variable a value of 0 (low); 1 (medium); 2 (high). In order to apply it in different urban contexts, the index also provides a weight to apply to each variable, i.e. w_i . In this article, all the identified factors have been equally weighted with a value of 1. Next, the index has been normalized, which consists of limiting the range of a set of values within a certain predefined range. After summing variables values (formula (1)), a min-max normalization is performed to obtain a precedence index between 0 and 1. This procedure ensures that the values of the variables are comparable with each other as they are reported on the same scale and, with the same variables, it is possible to compare the values of precedence indices calculated on different neighborhoods.

By summing the variable values, the results were divided into three categories: $0 \leq x < 0.25$ (high intervention priority); $0.25 \leq x < 0.5$ (medium intervention priority); $0.5 \leq x < 1$ (low/no intervention priority).

This index provides an initial graphical representation of the neighborhoods that should be affected by interventions with NbS.

Neighborhoods falling in ranges characterized by numerical values close to zero, have a precedence for intervention with NbS, subsequently the other ranges, have a decreasing need for intervention with NbS.

Should the number of variables increase, the methodology and approach used would still be applicable in other contexts.

3. Results

The results of the variables analyzed at urban and neighborhood scale are presented below.

3.1. 3 trees from every home

The results show the presence of the tree component within a buffer of 30 m from every building in Turin. To better distinguish buildings, and subsequently neighborhoods, that comply with the 3 trees from every home rule, the results were divided into 3 classes (low, medium, high).

Fig. 3A shows the centroid for each building. The class 'low' is associated with buildings with a number of trees within 30 m radius <3; the class 'medium' is associated with buildings with number of trees equal to 3; the class 'high' is associated with buildings with number of trees >3.

Fig. 3B shows the results at the neighborhood level. The results were obtained by averaging the values of centroids falling within the individual neighborhood.

It is possible to highlight that about 40 % of the neighborhoods are able to meet the rule of potentially having 3 trees visible from each building, while only one neighborhood has strong deficiencies in this regard.

3.2. 30 percentage of Tree Canopy Cover in every neighborhood

The results show the percentage of Tree Canopy Cover in Turin. To better distinguish neighborhoods that comply with the 30 % of Tree Canopy Cover, the results were divided into 3 classes (low, medium, high).

Fig. 4A shows the values of tree canopy cover at the urban scale. The City of Turin has a Tree Canopy Cover percentage of 19.43 %, also considering the hillside area. Focusing on the neighborhoods under investigation, the minimum value of percentage cover is 4.8 %, while the maximum value is 14.7 %. Given the results obtained, it was deemed inappropriate to graphically render a map showing a division of classes according to the benchmark of 30 % tree canopy cover. However, it was considered to investigate this further, in order to understand whether any particular differences emerged between the various neighborhoods.

In order to differentiate the neighborhoods in terms of the % of Tree Canopy Cover, Fig. 4B shows the classification of Tree Canopy Cover into the three classes (low, medium and high). Specifically, the average value of tree canopy cover for each neighborhood was calculated, and the identification of the extremes for the three classes was done through a subdivision into 3 quantiles. The three classes emerge from a proposed subdivision into equal percentages. For the low class the interval 0–5 % was used, for the medium class the interval is 5–10 %, for high the interval is 10–15 %. Fig. 4B presents a division of the data into 3 classes, but the 'high' class refers to tree canopy cover values that are never higher than 14.7 %.

The results underline that the City of Turin to date is far from being able to comply with the 30 % Tree Canopy Cover rule in every neighborhood.

3.3. 300 m from the nearest park or green space

The results show the distance between buildings and green areas of at least 0.5 ha, in Turin. To better distinguish neighborhoods that comply with the '300 metres from the nearest park or green space' rule, the results were divided into 3 classes (low, medium, high).

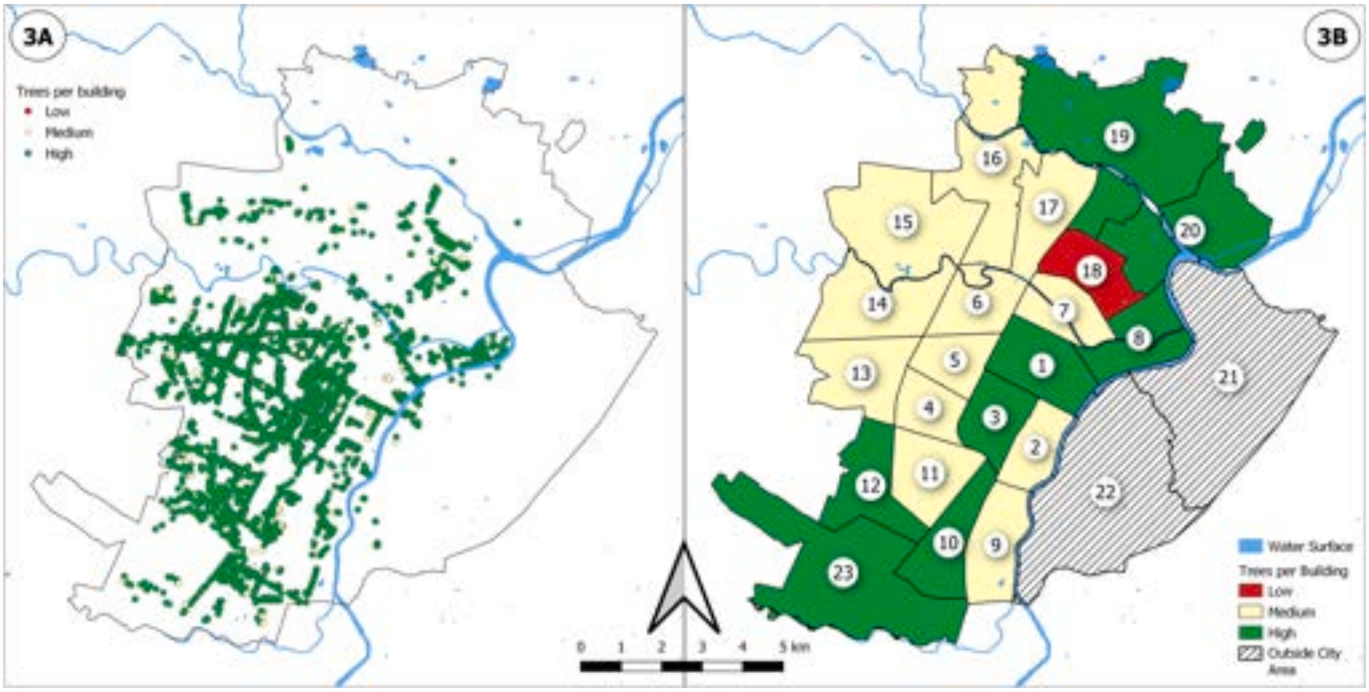

Fig. 3. Differentiation of buildings according to compliance with the '3 trees from every home' rule (3 A); differentiation of neighborhoods according to compliance with the '3 trees from every home' rule (3B).

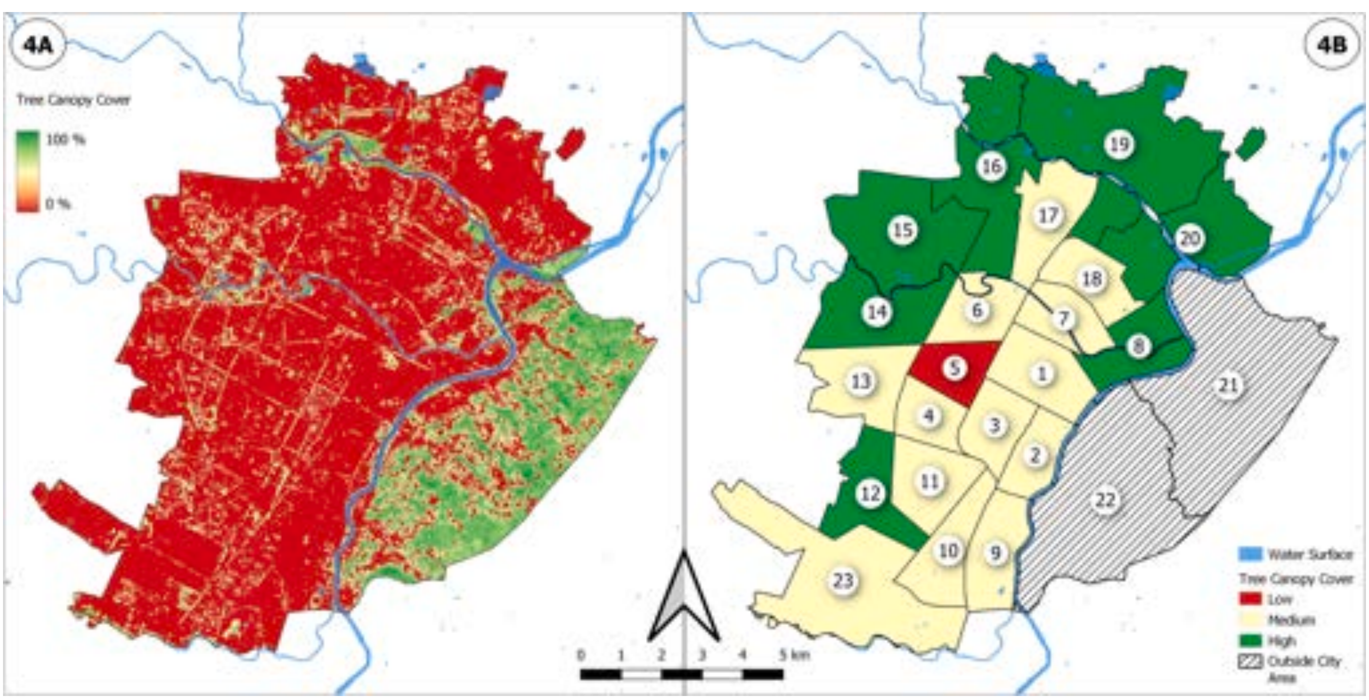

Fig. 4. Analysis of the % Tree Canopy Cover of the city of Turin (4 A); the subdivision of neighborhoods according to the % Tree Canopy Cover (4B).

Fig. 5A show the proximity map at urban scale. A classification in low, medium and high was applied, using the following intervals: low: (> 500); medium (≥300; 500); high (0; 300).

Following the same classification, Fig. 5B show averaged data at neighborhood level.

The results show that the majority of neighborhoods in Turin have a green area of at least 0.5 ha within 300 m of buildings. Exceptions are the 'Crocetta' and 'Madonna di Campagna' districts, which have green areas within 500 m. The district with the lowest values is 'Falchera'.

3.4. Environmental variable results

The results estimate the heat mitigation based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (e.g. parks). To better distinguish neighborhoods which have different heat mitigation values, the results were divided into 3 classes (low, medium, high).

It can be highlighted from Fig. 6 A, how about 80 % of the area of Turin is in critical situations from an environmental point of view. This

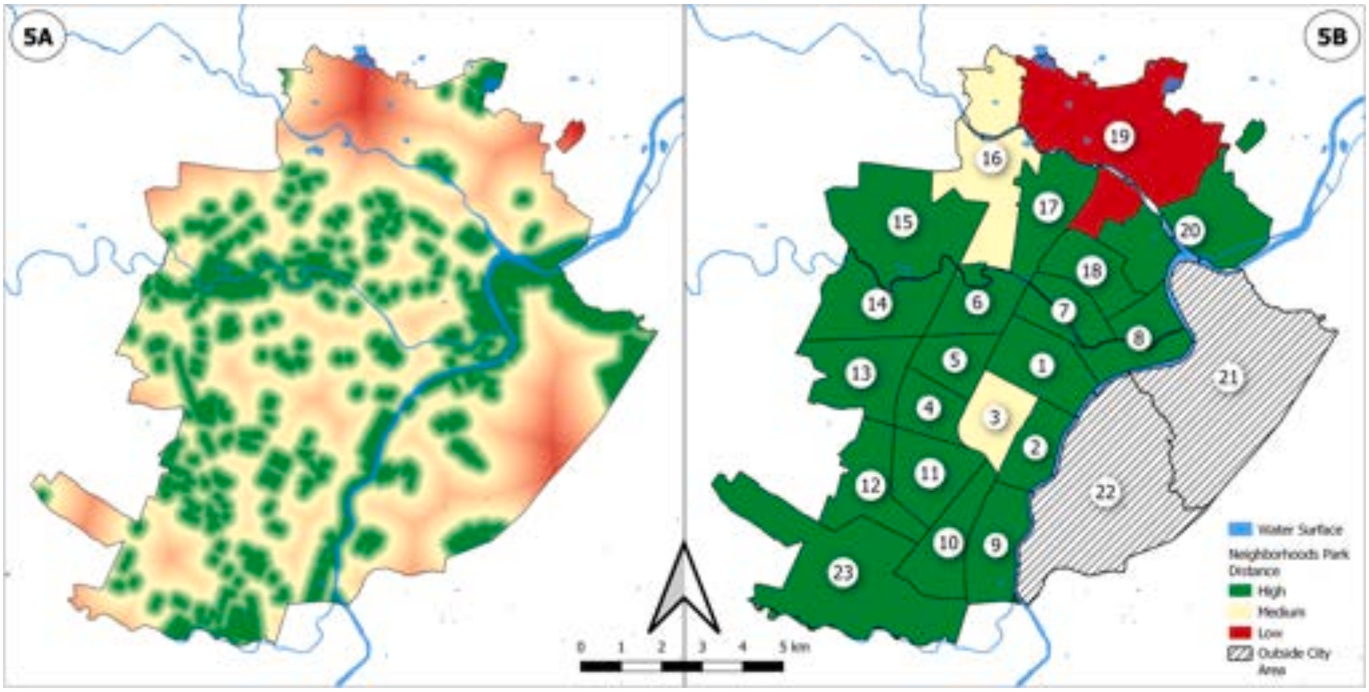

Fig. 5. Proximity map concerning urban green areas at urban level (5 A); Subdivision of neighborhoods according to their potential to comply with the '300 m from the nearest park or green space' rule (5B). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

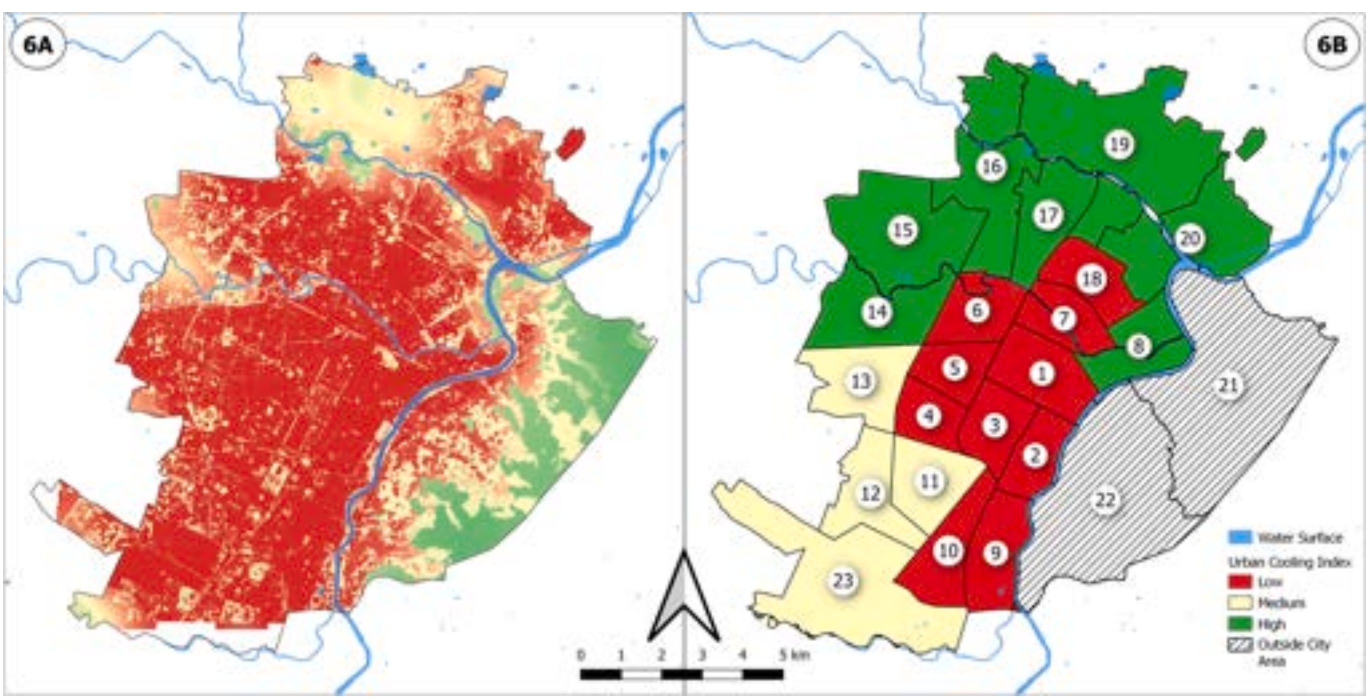

Fig. 6. The results of the Urban Cooling Index at the urban level (6A). The subdivision of neighborhoods which have different heat mitigation values (6B).

observation is represented by the red and yellow colors, which indicate low values of the Urban Cooling Index.

Only 5 % of the area of the City of Turin has a high value of Urban Cooling Index, found mainly in the hilly areas.

The Urban Cooling Index has its foundation in key scientific references. In particular, Zardo et al. (2017), identify scores/benchmarks useful for dividing areas with different index values.

However, as can already be seen in Fig. 6 A, the city of Turin has homogeneously low values. As in the case of the Tree Canopy Cover, the Urban Cooling Index subdivision has not been shown graphically because all the neighborhoods fall within the low class of values.

However, here too, an attempt was made to gain a deeper understanding of any differences between neighborhoods. Fig. 6B highlights the Urban Cooling Index values referable to the City's neighborhoods. Specifically, the following division of values into quantile classes was used: low (0–0,1); medium (0,1 - 0,15); high (0,15 - 0,3).

3.5. Population Density

The results show the Population Density of the Turin' neighborhoods (Table 2). To better distinguish neighborhoods which have different Population Density, the results were divided into 3 classes (low, medium, high), reported in Fig. 7.

Fig. 7 shows the subdivision of neighborhoods according to the Population Density value. The values are in the range 913–20,000 (Battisti et al., 2020) and have been divided into three classes: low (≥ 913; 5000); medium (> 5000; 10,000); and high (> 10,000–20,000).

It can be observed from the results that about 60 % of the neighborhoods have a high Population Density value, mainly concentrated in the central area of the city. Interestingly, the three neighborhoods in red color, which in the past were the industrial neighborhoods (numerous manufacturing establishments, including the former FIAT plants) or neighborhoods where blue collar workers lived, now have a lower Population Density. This could be due to less industrial/economic activity in these areas.

3.6. Identification of Turin neighborhoods that y need precedence in NbS implementation

Following the application of the proposed index (see Section 2.2.6), the neighborhoods in the City of Turin that need precedence of interventions with NbS, are highlighted.

Specifically, the results are returned in two different detail levels.

Fig. 8A, shows the neighborhoods in Turin that have different priorities for intervention with NbS. Specifically, the results correspond to a division of values into 3 categories (low, medium, high). However, Fig. 8A shows a first graphical representation of the neighborhoods that should be affected by interventions with NbS.

The results therefore show the need for numerous NbS interventions in the city. In order to suggest to politicians the neighborhoods where they should focus their attention and funds in a timely manner, Fig. 8B shows the 3 neighborhoods (Cenisia, Nizza Millefonti, Barriera di Milano) that have a precedence for NbS implementation.

4. Discussion

Since the steps of planning NbS should follow five key guiding principles (Albert et al., 2021), in this article, we focused on Place specificity, analyzing the green characteristics, together with the environmental and social characteristics of the city. Therefore, the promotion of NbS requires a preliminary investigation of the area available for the specific NbS to be implemented and scaled up (Bradfer-Lawrence et al., 2021). In this study, we propose a methodology for the implementation of NbS in urban settings, especially for climate-change adaptation, which also takes social aspects into account. In order to respond to these challenges, we have proposed an implementation of the 3–30-300 rule. The intent of the 'rule' seems more to serve as a guideline that prompts discussion and can help cities set targets. It therefore provides a discussion tool to understand where green spaces are adequately provided and where there are gaps. Thus, the rule is more a tool to discuss the importance of trees with the ambition to be reported for example in a policy brief. It is not so much a benchmarking tool per se and certainly not between cities, perhaps a touch more within cities, in order to reduce social inequalities between neighborhoods. According to Konijnendijk (2022) the 3–30-300 rule, in parallel with other possible targets and indicators, may in the future also help benchmarking with other cities nationally and internationally, as is already done with specific international green city benchmarking schemes (European Green City Award or the Tree City of the World programme). Our proposed revision of the rule is intended to trigger a debate on the inclusion of the concept of UF as NbS (Scheuer et al., 2022). Thus, we propose a PI to identify city neighborhoods that need of NbS implementation, or more precisely a method of suggesting to politicians where to direct funds for the implementation of new UF as NbS in the city. Therefore, we discuss the data on the basis of the research carried out and point out some synergies/differences with different methods (Cortinovis et al., 2022) used in the implementation and upscaling of NbS in urban areas.

Focusing on the Turin case study, our approach allows to identify those neighborhood where to implement the urban forest, in order to upscale the NbS realized through the proGIreg project. The number of trees and the tree canopy cover are now two important indicators to classify cities according to the green spaces they have. "Treepedia" developed by Senseable City Lab of the Massachusett Institute of Technology (MIT), which measures the canopy cover in cities, places Singapore at the top of its the 'Green View Index' with 29 % coverage, referring to cities with high population density (Treepedia, 2022). The idea is not to do the 'Green Olympics', but to check what is happening within a reality and the results are particularly useful to verify, monitor changes over time and bring information to politicians and citizens. Turin, according to MIT calculations, has a Green View Index value of 16.2 %. Nevertheless, Treepedia proposes an interesting result based on Google Street View Images and contemplating only street trees. However, the results presented in this paper, show a value of the tree canopy cover of Turin of 19.7 %, based on the Pan-European High Resolution Layers - Forests, considering also the hilly area. So, different methods of evaluating this variable could lead to different results and thus slightly different planning goals for green areas and NbS. However, the minimum limit of the tree canopy cover should be 30 % to reduce air pollution and noise and foster mental health (IUCN, 2021), so even results using different methods show a clear need for tree canopy cover. Despite the scarce presence of tree canopy cover, the proximity to green areas in Turin is relatively satisfactory. Of course, the actual accessibility of such spaces and the quality of green areas are not taken into account here. However, in Turin, >60 % of citizens have a green area within a 300 m radius. This information allows a comparison with other cities, including for example Sheffield, where green areas are less close to inhabitants (Barbosa et al., 2007), or Berlin and ſódź where very large green spaces are nearby homes (Kabisch, Strohbach, Haase, & Kronenberg, 2016). The application of the Urban Cooling model is growing in numerous researches related to city planning. This model has made it possible to estimate the average cooling capacity of air temperature, also associated with the presence of vegetation. The application of this model in the city of Turin shows that in the summer period the value relative to the cooling capacity of the air is low, i.e. that the city is subjected to high temperatures, which can affect the well-being of its citizens. These

Table 2
Detail of neighborhoods and related Population Density.

Neighborhoods	Population Density (in/km^2)
1. Centro	10,517
2. San Salvario	15,371
3. Crocetta	12,335
4. San Paolo	15,759
5. Cenisia	16,764
6. San Donato	16,223
7. Aurora	14,733
8. Vanchiglia	9041
9. Nizza Millefonti	8043
10. Mercati Generali	14,101
11. Santa Rita	15,879
12. Mirafiori Nord	11,532
13. Pozzo Strada	13,526
14. Parella	9616
15. Le Vallette	5489
16.Madonna di Campagna	5543
17. Borgata Vittoria	10,309
18. Barriera di Milano	16,984
19. Falchera	2075
20. Regio Parco	4068
21. Madonna del Pilone	913
22. Borgo Po e Cavoretto	1435
23. Mirafiori Sud	3089

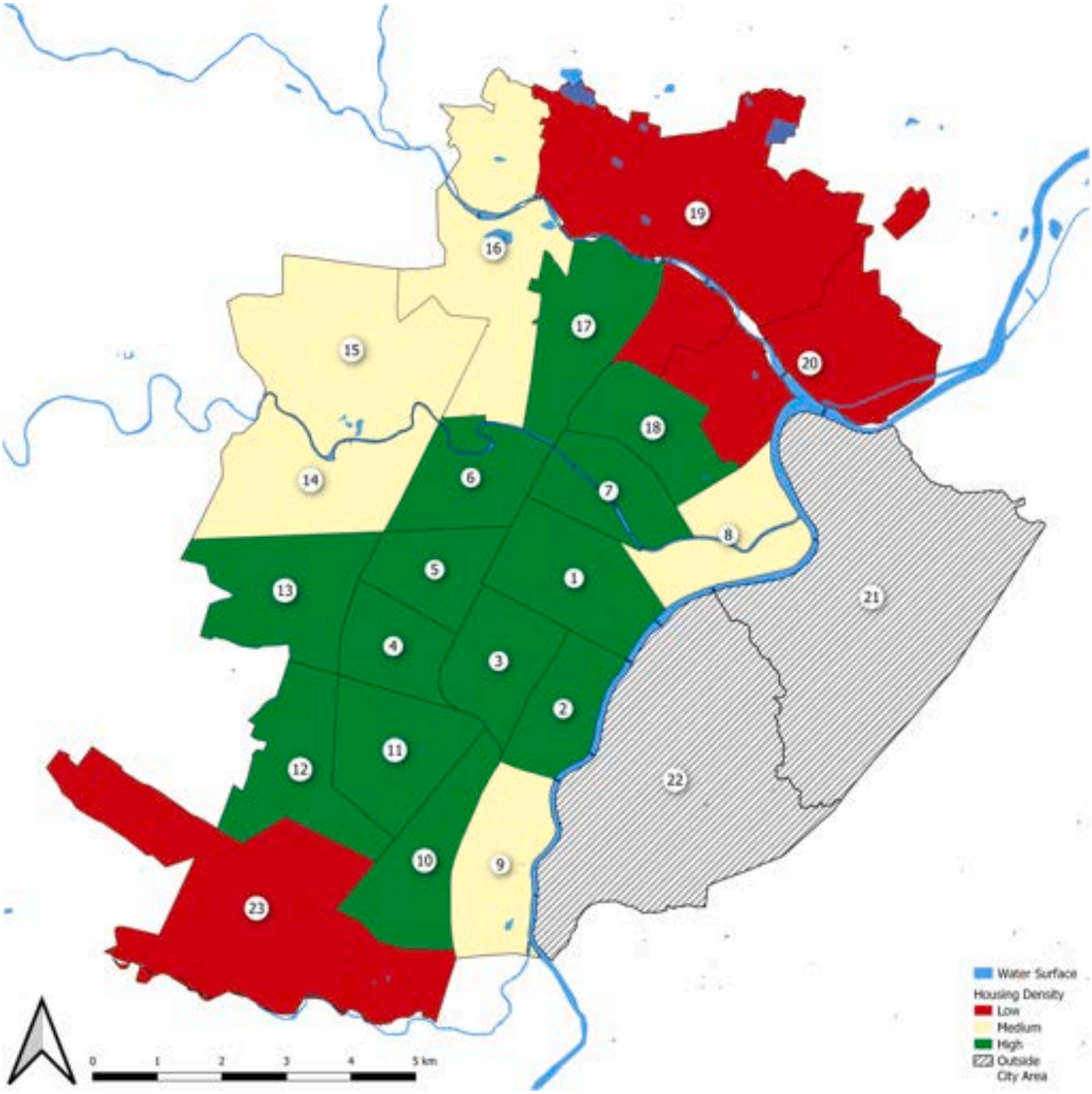

Fig. 7. Subdivision of neighborhoods according to Population Density values.

results are comparable with those of Milan (Ronchi, Salata, & Arcidiacono, 2020), although critical situations have emerged in cities in central-northern Europe (Cortinovis et al., 2022), in England (Zawadzka, Harris, & Corstanje, 2021), but also in non-EU countries such as India (Das, Das, & Momin, 2022) and China (Cheng, Guan, Zhou, Zhao, & Zhou, 2019). Although the whole city of Turin is characterized by low values, from the more detailed analysis (Fig. 6B) it can be noted that the neighborhoods that characterize the historic center are the most suffering from a climate-environmental point of view. All these parameters, together with the population density that has to be specific to the city under analysis, have been considered in the PI proposal that allows for a fair analysis of data of different nature, including climatic, ecological and social data. In particular, the application of the PI in Turin shows how precedence must be given to action in 10 neighborhoods that are located from north to south of the city and that affect the historic center and neighborhoods with an industrial past. In particular, the proposed study (Fig. 8B) suggests to decision makers 3 neighborhoods from which to start considering the implementation of NbS and on which to concentrate the available funds. The proposal and application of the PI is also reflected in the research carried out in the Banjarbaru City, where the method used to prioritize the implementation of green areas in various areas of the city considered the use of vegetation density, temperature humidity index, population density data among the indicators (Humaida, Prasetyo, & Badriyah Rushayati, 2016). However, it should be noted that typology and differences in data quality can lead to variations in results (Le Texier, Schiel, & Caruso, 2018). Precisely for this reason, since a single approach for all cities under analysis does not work (Manoli et al., 2019), the proposed PI

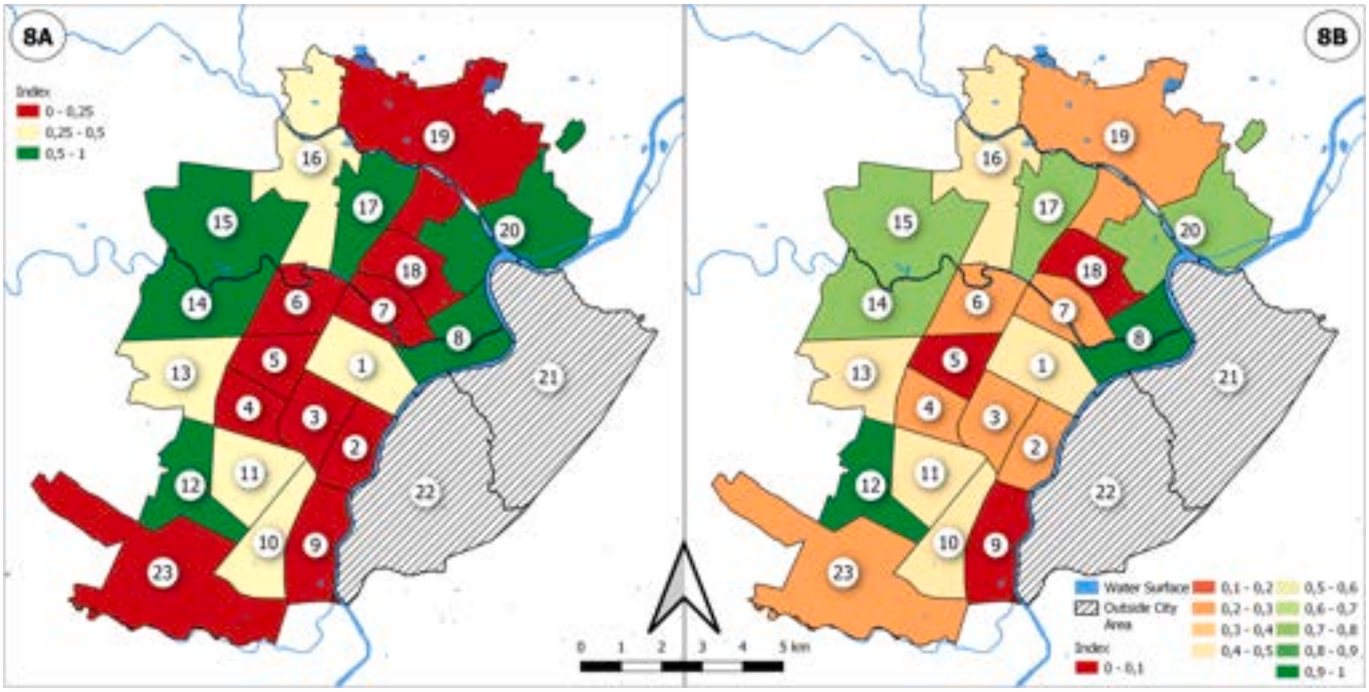

Fig. 8. Identification of neighborhoods that need precedence of NbS implementation (8A). Detail on the neighborhoods in order to identify those in which the municipality should start investing immediately by implementing NbS (8B).

allows the inclusion of several aspects (at least social and environmental), depending on the city under consideration. This aspect makes it possible to replicate our approach almost everywhere, also finding an important basis in the rule proposed by Konijnendijk (Konijnendijk, 2022) and promoted by the IUCN. However, it is important to emphasize that the possibility of applying the PI in different places does not mean that it is correct to compare the results of very different cities with different climates, but rather serve as a guideline to direct policy choices concerning the planning of UF as NbS within cities.

4.1. Future perspectives

The research places great emphasis on the tree component, even though the provision of many ES is provided by all vegetation. A future consideration of this data could be useful for accurately quantifying selected ES provided by urban green spaces.

Trees considered in the '*3 trees from every home*' rule are those within a 30 m radius and not necessarily visible from building windows. An additional methodology to collect this data could be useful for planning urban green spaces in even more detail. It is also worth noting that in this study, we considered the need for NbS by the amount of green spaces without addressing the difference in quality. Furthermore, tree species composition was not considered. This information has a strong impact at the ecological and management level, since an urban forest dominated by monocultures, in the case of invasion events, often requires high costs for treatment, removal and/or replacement of diseased, dying or dead trees (Nitoslawski & Duinker, 2016).

In addition, this study does not consider the health conditions of plants, a variable that could also affect ES supply. The issue of implementing new NbS, especially related to urban forestry, should also consider aspects related to the management of such solutions over time. This statement is even more important when considering the ES provided by NbS and in particular by trees. In a study conducted in Chicago in 2016, it is shown that a tree goes from being a carbon emitter to being carbon neutral many years after planting, depending on the management practices applied for care and maintenance (Petri, Koeser, Lovell, & Ingram, 2016). Moreover, not all plant species survive after planting. A study conducted in 2015 estimated that about 67 % of the trees planted as part of the Million Trees Los Angeles programme did not survive (McPherson, Kendall, & Albers, 2015). Even earlier, a study conducted from southern Berkeley through western inner-city Oakland (California) shows that 34 % of trees died after the first two years of planting, also indicating that trees close to apartments and public greenspaces have a higher mortality rate than trees that are close to single family houses and rapid transit stations (Nowak, McBride, & Beatty, 1990).

Then, an issue that needs to be explored further is related to the social acceptance of NbS by citizens, also trying to understand whether and which ES are perceived and whether citizens obtain a real benefit (Larcher et al., 2021; Velarde et al., 2007). Finally, the aspiration of this paper is to raise awareness of NbS among citizens and politicians focus is not on UF (referring to the classical, purely technical concept with a mainly environmental focus), but on UF as NbS, intended as the intersection of NBS with UF, relying on UF to address societal challenges as well as playing an important role in human wellbeing and biodiversity (Scheuer et al., 2022). We clarified this concept in the introduction and reported in the discussions. A first step in this direction is thus being attempted, but a future step (suggested in the Discussion section) could certainly include what you envisioned, about a multi-criteria framework for NbS implementation.

5. Conclusions

NbS should be place-based, and its success depends on its sensitivity to socio-spatial context (Haase et al., 2017). Thus, NbS interventions must be tailored to their environment and actors involved, and a mismatch with the socio-spatial context means that the proposed NbS solution is no longer valid. The concept of NbS is framed in policy and practice as a deliberate and targeted use of natural features to deal with sustainability challenges, with examples including urban forests. The proposal for a different reading of the rule 3–30-300 and the application of the PI makes it possible to replicate our approach everywhere, taking into account climate-environmental and social aspects. This allows decision-makers to plan and schedule the implementation of NbS in the medium to long term, in order to increase the supply of ES in the city, reducing any social inequalities.

Focusing on the NbS of urban forestry, the research addressed the question: where can NbS be implemented within the city, in order to maximize their social impact? This specifically regards the upscaling of those punctual NbS implemented and tested by European projects, in order to amplify their impact. In particular, neighborhoods that should have precedence in NbS implementation were highlighted. These findings could help local governments in implementing the City' Green Plan with a methodology useful to achieve environmental objectives. In addition, the authors want to emphasize that all green areas, and even NbS, bring benefits if there is special care and attention from the planning and (co)design stage to the planting of plant species and subsequent care. The proposed methodology can be considered an important basis for NbS planning in cities, which can be enriched by participatory approaches, fieldwork data collection, and land-use decision-making processes. Furthermore, it is of paramount importance to monitor NbS over time, assessing the provision of ES and ecosystem disservices, in order to ensure human wellbeing. However, NbS, to be truly nature-based, should not have a primarily anthropocentric approach (Randrup, Buijs, Konijnendijk, & Wild, 2020). Therefore, the approach to planning and design of NbS, and thus also improvements to the methodology proposed in this paper, should also consider the needs of nonhumans (Maller, 2021; Pineda-Pinto, Frantzeskaki, & Nygaard, 2022). NbS in the urban landscape thus turn out to be crucial to living in more resilient and sustainable cities, especially when planned in a way that provides specific benefits where there is the greatest need.

Author's statement

This manuscript has not been published and is not under consideration for publication elsewhere.

All authors have approved the manuscript and agree with its submission to Cities.

We remain available to clarify any further issue or answer that Editor or Reviewers may raise.

Funding

The research leading to these results has received funding from the European Union's Horizon 2020 innovation action program under Grant Agreement no. 776528. The sole responsibility for the content lies with the proGIreg project and in no way reflects the views of the European Union.

CRediT authorship contribution statement

Luca Battisti: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Giovanni Giacco:** Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Visualization. **Massimiliano Moraca:** Methodology, Software, Validation, Formal analysis, Data curation, Visualization. **Giacomo Pettenati:** Writing – original draft, Writing – review & editing. **Egidio Dansero:** Supervision, Funding acquisition. **Federica Larcher:** Project administration, Supervision, Writing – original draft.

Declaration of competing interest

We have no conflicts of interest to disclose.

No human-beings or other life forms were directly involved in this research.

We attest that all authors contributed significantly to the creation of this manuscript, each having fulfilled criteria as established by the ICMJE.

We confirm that the manuscript has been read and approved by all named authors.

We confirm that the order of authors listed in the manuscript has been approved by all named authors.

Data availability

Data will be made available on request.

Acknowledgments

The authors would like to thank Laura Ribotta (Municipality of Turin), Mauro Manente (Latitudo40) and Torino City Lab for their research support. Special thanks also go to Stefano Marrone (University of Naples 'Federico II') for his revision of the proposed index.

The research leading to these results has received funding from the European Union's Horizon 2020 innovation action program under Grant Agreement no. 776528. The sole responsibility for the content lies with the proGIreg project and in no way reflects the views of the European Union.

References

Albera.TO (2016). Retrieved from http://www.comune.torino.it/verdepubblico/2016/alberi16/nasce-alberato-applicativo-gestione-patrimonio-arboreo.shtml. Accessed June 6, 2019.

Albert, C., Brillinger, M., Guerrero, P., Gottwald, S., Henze, J., Schmidt, S., Ott, E., & Schröter, B. (2021). Planning nature-based solutions: Principles, steps, and insights. *Ambio, 50*, 1446–1461. https://doi.org/10.1007/s13280-020-01365-1

Albert, C., Schröter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, C., & Matzdorf, B. (2019). Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? *Landscape and Urban Planning, 182*, 12–21. https://doi.org/10.1016/j.landurbplan.2018.10.003

Almenar, J. B., Elliot, T., Rugani, B., Philippe, B., Gutierrez, T. N., Sonnemann, G., & Geneletti, D. (2021). Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy, 100*, Article 104898.

Anguelovski, I., Connolly, J. J., Garcia-Lamarca, M., Cole, H., & Pearsall, H. (2019). New scholarly pathways on green gentrification: What does the urban 'green turn'mean and where is it going? *Progress in Human Geography, 43*(6), 1064–1086.

Anguelovski, I., & Corbera, E. (2023). Integrating justice in nature-based solutions to avoid nature-enabled dispossession. *Ambio, 52*, 45–53. https://doi.org/10.1007/s13280-022-01771-7

Arkema, K. K., Griffin, R., Maldonado, S., Silver, J., Suckale, J., & Guerry, A. D. (2017). Linking social, ecological, and physical science to advance natural and nature-based protection for coastal communities. *Annals of the New York Academy of Sciences, 1399*, 5–26. https://doi.org/10.1111/nyas.13322

Ascione, G. S., Cuomo, F., Mariotti, N., & Corazza, L. (2021). Urban living labs, circular economy and nature-based solutions: Ideation and testing of a new soil in the City of Turin using a multi-stakeholder perspective. *Circular Economy and Sustainability, 1*, 545–562.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, K. J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban planning, 83*(2–3), 187–195.

Barò, F., Calderon-Argelich, A., Langemeyer, J., & Connolly, J. J. T. (2019). Under one canopy? Assessing the distributional environmental justice implications of street tree benefits in Barcelona. *Environmental Science and Policy, 102*, 54–64. https://doi.org/10.1016/j.envsci.2019.08.016

Battisti, L., Larcher, F., Vercelli, M., Bonelli, S., Martelli, F., Paradiso, F., … Ribotta, L. (2021). NbS E Biodiversità nelle aree urbane: il progetto progireg a torino. *Reticula, 28*, 58–70.

Battisti, L., Pille, L., Wachtel, T., Larcher, F., & Säumel, I. (2019). Residential greenery: State of the art and health-related ecosystem services and disservices in the City of Berlin. *Sustainability, 11*, 1815. https://doi.org/10.3390/su11061815

Battisti, L., Pomatto, E., & Larcher, F. (2019). Assessment and mapping green areas ecosystem services and socio-demographic characteristics in Turin neighborhoods (Italy). *Forests, 11*(1), 25.

Battisti, L., Pomatto, E., & Larcher, F. (2020). Assessment and mapping green areas ecosystem services and socio-demographic characteristics in Turin neighborhoods (Italy). *Forests, 11*, 25. https://doi.org/10.3390/f11010025

Blok, A. (2020). Urban green gentrification in an unequal world of climate change. *Urban Studies, 57*(14), 2803–2816.

van den Bosch, M., Mudu, P., Uscila, V., Barrdahl, M., Kulinkina, A., Staatsen, B., Swart, W., Kruize, H., Zurlyte, I., & Egorov, A. I. (2016). Development of an urban green space indicator and the public health rationale. *Scandinavian Journal of Public Health, 44*, 159–167. https://www.jstor.org/stable/48512637.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning, 97*(3), 147–155.

Bradfer-Lawrence, T., Finch, T., Bradbury, R. B., Buchanan, G. M., Midgley, A., & Field, R. H. (2021). The potential contribution of terrestrial nature-based solutions to a national 'net zero' climate target. *Journal of Applied Ecology, 58*, 2349–2360. https://doi.org/10.1111/1365-2664.14003

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities, 95*, Article 102483.

Cheng, L., Guan, D., Zhou, L., Zhao, Z., & Zhou, J. (2019). Urban cooling island effect of main river on a landscape scale in Chongqing, China. *Sustainable Cities and Society, 47*, Article 101501.

Cortinovis, C., & Geneletti, D. (2019). A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services, 38*, Article 100946.

Cortinovis, C., Olsson, P., Boke-Olén, N., & Hedlund, K. (2022). Scaling up nature-based solutions for climate-change adaptation: Potential and benefits in three European cities. *Urban Forestry & Urban Greening, 67*, Article 127450.

Cuomo, F. (2022). Urban living lab: An experimental co-production tool to Foster the circular economy. *Social Sciences, 11*(6), 260.

Das, M., Das, A., & Momin, S. (2022). Quantifying the cooling effect of urban green space: A case from urban parks in a tropical mega metropolitan area (India). *Sustainable Cities and Society, 87*, Article 104062.

Davies, C., Chen, W. Y., Sanesi, G., & Lafortezza, R. (2021). The European Union roadmap for implementing nature-based solutions: A review. *Environmental Science & Policy, 121*, 49–67.

Dorst, H., Van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions–key characteristics of an emerging concept. *Sustainable Cities and Society, 49*, Article 101620.

Escobedo, F. J., Giannico, V., Jim, C. Y., Sanesi, G., & Lafortezza, R. (2019). Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? *Urban Forestry & Urban Greening, 37*, 3–12.

Fernandes, J. P., & Guiomar, N. (2018). Nature-based solutions: The need to increase the knowledge on their potentialities and limits. *Land Degradation and Development, 29*, 1925–1939.

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy, 93*, 101–111.

Haaland, C., & van Den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening, 14*(4), 760–771.

Haase, D., Kabisch, S., Haase, A., Andersson, E., Banzhaf, E., Baró, F., & Wolff, M. (2017). Greening cities–to be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat International, 64*, 41–48.

Humaida, N., Prasetyo, L. B., & Badriyah Rushayati, S. (2016). Priority assessment method of green open space (case study: Banjarbaru City). *Procedia Environmental Sciences, 33*, 354–364. https://doi.org/10.1016/j.proenv.2016.03.086

InVEST - Natural Capital Project. (2022). Retrieved from: https://naturalcapitalproject.stanford.edu/software/invest. (Accessed 12 June 2022).

ISTAT. (2018). Retrieved from: http://demo.istat.it/bilmens2018gen/index.html. (Accessed 6 July 2020).

IUCN (2021). 3-30-300 rule. Retrieved from: https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/#:~:text=300%20metres%20from%20the%20nearest%20park%20or%20green%20space&text=The%20European%20Regional%20Office%20of,both%20physical%20and%20mental%20health. Accessed July 6, 2022.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., et al. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*. https://doi.org/10.5751/ES-08373-210239

Kabisch, N., Strohbach, M., Haase, D., & Kronenberg, J. (2016). Urban green space availability in European cities. *Ecological Indicators, 70*, 586–596.

Konijnendijk, C. C. (2022). Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *Journal of Forestry Research, 1-10*. https://doi.org/10.1007/s11676-022-01523-z

Kotsila, P., Anguelovski, I., Baró, F., Langemeyer, J., Sekulova, F., Connolly, J. T., & J.. (2021). Nature-based solutions as discursive tools and contested practices in urban nature's neoliberalisation processes. *Environment and Planning E: Nature and Space, 4* (2), 252–274.

La Rosa, D., & Pappalardo, V. (2019). Planning for spatial equity - a performance based approach for sustainable urban drainage systems. *Sustainable Cities and Society, 101885*. https://doi.org/10.1016/j.scs.2019.101885

Larcher, F., Pomatto, E., Battisti, L., Gullino, P., & Devecchi, M. (2021). Perceptions of urban green areas during the social distancing period for COVID-19 containment in Italy. *Horticulturae, 7*, 55. https://doi.org/10.3390/horticulturae7030055

Le Texier, M., Schiel, K., & Caruso, G. (2018). The provision of urban green space and its accessibility: Spatial data effects in Brussels. *PLoS One, 13*(10), Article e0204684.

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., Leskinen, P., Kuikman, P., et al. (2016). Green economy and related concepts: An overview. *Journal of Cleaner Production, 139*, 361–371. https://doi.org/10.1016/j.jclepro.2016.08.024

Maller, C. (2021). Re-orienting nature-based solutions with more-than-human thinking. *Cities, 113*, Article 103155.

Manoli, G., Fatichi, S., Schläpfer, M., et al. (2019). Magnitude of urban heat islands largely explained by climate and population. *Nature, 573*, 55–60. https://doi.org/10.1038/s41586-019-1512-9

McPherson, E. G., Kendall, A., & Albers, S. (2015). Life cycle assessment of carbon dioxide for different arboricultural practices in Los Angeles, CA. *Urban Foret & Urban Greening, 14*, 388–397.

Monteiro, J., Sousa, N., Natividade-Jesus, E., & Coutinho-Rodrigues, J. (2022). Benchmarking City layouts—A methodological approach and an accessibility comparison between a Real City and the Garden City. *Sustainability, 14*(9), 5029.

Nesbitt, L., Meitner, M. J., Girling, C., & Sheppard, S. R. J. (2019). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning, 181*, 51–79. https://doi.org/10.1016/J.LANDURBPLAN.2018.08.007

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., et al. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *The Science of the Total Environment.*. https://doi.org/10.1016/j.scitotenv.2016.11.106

Nitoslawski, S. A., & Duinker, P. N. (2016). Managing tree diversity: A comparison of suburban development in two Canadian cities. *Forests, 7*(6), 119.

Nowak, D. J., McBride, J. R., & Beatty, R. A. (1990). Newly planted street tree growth and mortality. *Journal of Arboriculture, 16*, 124–129.

Pan-European High Resolution Layers - Forests (2021). Retrieved from: https://land.copernicus.eu/pan-european/high-resolution-layers/forests Accessed July 6, 2022.

Pauleit, S., Zölch, T., Hansen, R., & Randrup, T. B. (2017). Nature-based solutions and climate change – Four shades of green. In A. Kabisch, N. Korn, H. Stadler, & J. Bonn (Eds.), *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice* (1st ed., pp. 29–49). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5.

Petri, A. C., Koeser, A. K., Lovell, S. T., & Ingram, D. (2016). How green are trees? — Using life cycle assessment methods to assess net environmental benefits. *Journal of Environmental Horticulture, 34*(4), 101–110.

Pineda-Pinto, M., Frantzeskaki, N., & Nygaard, C. A. (2022). The potential of nature-based solutions to deliver ecologically just cities: Lessons for research and urban planning from a systematic literature review. *Ambio, 51*, 167–182. https://doi.org/10.1007/s13280-021-01553-7

Ramyar, R., Ackerman, A., & Johnston, D. M. (2021). Adapting cities for climate change through urban green infrastructure planning. *Cities, 117*, Article 103316.

Randrup, T. B., Buijs, A., Konijnendijk, C. C., & Wild, T. (2020). Moving beyond the nature-based solutions discourse: Introducing nature-based thinking. *Urban Ecosystem, 23*(4), 919–926.

Ronchi, S., Salata, S., & Arcidiacono, A. (2020). Which urban design parameters provide climate-proof cities? An application of the urban cooling InVEST model in the city of Milan comparing historical planning morphologies. *Sustainable Cities and Society, 63*, Article 102459.

Ruangpan, L., Vojinovic, Z., Plavšić, J., Doong, D. J., Bahlmann, T., Alves, A., & Franca, M. J. (2021). Incorporating stakeholders' preferences into a multi-criteria framework for planning large-scale nature-based solutions. *Ambio, 50*, 1514–1531.

Rutt, R. L., & Gulsrud, N. M. (2016). Green justice in the city: A new agenda for urban green space research in Europe. *Urban Forestry & Urban Greening, 19*, 123–127.

Santamour, F. S. (1990). Trees for urban planting: Diversity, uniformity and common sense. In *, 7. Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance (METRIA)* (pp. 57–65). http://www.ces.ncsu.edu/fletcher/programs/nursery/metria/metria07/m79.pdf.

Säumel, I., Hogrefe, J., Battisti, L., Wachtel, T., & Larcher, F. (2021). The healthy green living room at one's doorstep? Use and perception of residential greenery in Berlin, Germany. *Urban Forestry & Urban Greening, 58*, Article 126949.

Scheuer, S., Jache, J., Kičić, M., Wellmann, T., Wolff, M., & Haase, D. (2022). A trait-based typification of urban forests as nature-based solutions. *Urban Forestry & Urban Greening, 78*, Article 127780.

Schindler, M., Le Texier, M., & Caruso, G. (2022). How far do people travel to use urban green space? A comparison of three European cities. *Applied Geography, 141*, Article 102673.

Sinnett, D., Smith, N., & Burgess, S. (Eds.). (2015). *Handbook on green infrastructure: Planning, design and implementation*. Edward Elgar Publishing.

Stefanakis, A. I. (2019). The role of constructed wetlands as green infrastructure for sustainable urban water management. *Sustainability, 11*(24), 6981.

Treepedia (2022). Retrieved from: http://senseable.mit.edu/treepedia/ Accessed August 6, 2022.

UNEP (United Nations Environmental Program). (2023) About UNEA-5. Retrieved from: https://www.unep.org/environmentassembly/about-unea-5.

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening, 6* (4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

Torino Vivibile, 2020. Retrieved from: https://www.torinovivibile.it/aree-tematiche/torino-green-print/ Accessed July 6, 2022.

WHO, 2017, Urban green spaces: a brief for action, World Health Organization Regional Office for Europe, Copenhagen. Retrieved from: https://www.euro.who.int/__data/assets/pdf_file/0010/342289/Urban-Green-Spaces_EN_WHO_web3.pdf Accessed July 5, 2022.

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning, 125*, 234–244.

WorldPop project. (2021). Retrieved from: https://www.worldpop.org/methods/populations. (Accessed 6 July 2022).

Zardo, L., Geneletti, D., Prezsoba, M., & Van Eupen, M. (2017). Estimating the cooling capacity of green infrastructures to support urban planning. *Ecosystem Services, 26*, 225–235. https://doi.org/10.1016/j.ecoser.2017.06.016

Zawadzka, J. E., Harris, J. A., & Corstanje, R. (2021). Assessment of heat mitigation capacity of urban greenspaces with the use of InVEST urban cooling model, verified with day-time land surface temperature data. *Landscape and Urban Planning, 214*, Article 104163.