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# Urban sustainability: the role of ecosystem services provided by an italian green infrastructure

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*Current population growth, climate change and the increase in derived pollution represent a significant threat to the delicate balance that governs the exploitation of resources on Earth. In recent decades, this balance has been undermined, coming to an over-exploitation condition, or a growing demand for natural raw materials that the planet is no longer able to satisfy, with impacting consequences on human well-being and the health of natural ecosystems. Cities represent the main collectors of such reactions: it is necessary to analyze which mitigation actions can be the best in order to counter their uncontrolled development. This work focuses on a specific tool aimed at achieving the goal: green infrastructures constitute a valid source of sustainability in the urban environment, slowing down the processes derived from climate change and intensifying the recovery of ecological functions. Specifically, the role of the "Le Vallere" park was analyzed, a green area of about 35 hectares that is part of the metropolitan context of the Municipality of Turin, in collaboration with the related management institution ("Ente di gestione delle Aree Protette del Po piemontese", ex "Ente di gestione delle aree del Po torinese"). The main purpose was to quantify the ecosystem services offered by the green infrastructure to the surrounding urban area, through the use of i-Tree, a specific software suite able to evaluate benefits offered by vegetation. Reduction of atmospheric pollutants, carbon storage and sequestration, avoided surface water runoff, improvement of water quality are the main aspects investigated, obtaining an estimate of these parameters also from a monetary point of view. The survey carried out has, therefore, made it possible to obtain an assessment of the sustainability produced by the infrastructure, providing essential information to the related management institution, in view of a future territorial planning.*
**Keywords**: green infrastructure, ecosystem services, urban scale.

***Sostenibilità urbana: il ruolo dei servizi ecosistemici forniti da un'infrastruttura verde italiana.*** *L'attuale crescita della popolazione, il cambiamento climatico e l'aumento dell'inquinamento atmosferico rappresentano una sensibile minaccia al delicato equilibrio che governa lo sfruttamento delle risorse sulla Terra. Negli ultimi decenni, tale equilibrio è stato minato, tanto da poter parlare di sovra-sfruttamento, ovvero una crescente domanda di materie prime naturali che il Pianeta non è più in grado di soddisfare, comportando conseguenze impattanti sul benessere umano e sulla salute degli ecosistemi naturali. Le città rappresentano i principali collettori di tali reazioni: risulta necessario, dunque, analizzare quali azioni di mitigazione possano risultare efficaci al fine di contrastare il loro sviluppo incontrollato. Il presente lavoro si concentra su uno specifico strumento volto al raggiungimento dell'obiettivo: le infrastrutture verdi costituiscono una valida fonte di sostenibilità in ambito urbano, rallentando i processi derivati dai cambiamenti climatici e intensificando il recupero delle funzionalità ecologiche. In modo specifico, si è analizzato il ruolo del parco "Le Vallere", un'area verde di circa 35 ettari che si inserisce all'interno del contesto metropolitano del Comune di Torino, in collaborazione con l'Ente di gestione delle Aree Protette del Po piemontese (ex Ente di gestione delle Aree Protette del Po torinese). Lo scopo principale è stato quello di quantificare i servizi ecosistemici offerti dall'infrastruttura verde all'area urbana circostante, attraverso l'utilizzo di i-Tree, una suite di programmi specifici per la valutazione dei benefici offerti dalla vegetazione. Riduzione di inquinanti atmosferici, stoccaggio e sequestro di carbonio, deflusso idrico superficiale evitato, miglioramento della qualità idrica sono i principali aspetti approfonditi, ottenendo una stima di tali parametri anche da un punto di vista monetario. L'indagine ha consentito di realizzare una valutazione integrata della sostenibilità che l'infrastruttura fornisce all'ambiente circostante, fornendo informazioni fondamentali all'ente suddetto che si occupa della sua gestione, in funzione di una futura pianificazione territoriale.*
***Parole chiave***: infrastruttura verde, servizi ecosistemici, scala urbana.

## 1. Introduction

The current population growth, climate change and the consequent increase in pollution levels raise a series of questions related to both human health and the state of natural and man-made ecosystems. The exploitation of resources has now become over-exploitation, an unsustainable demand for natural raw materials that determines a condition of global deficit, so that the Global Footprint Network currently estimates a use equal to 1,75 times the size of the Earth (W1). This is calculated through the ecological footprint of the various countries of the world and measured in equivalent hectares of productive land necessary to supply demand and absorb the waste generated.

Unfortunately, the consequences of this consumption model are not only the impoverishment of the environmental matrix, but also its damage due to various phenomena: (i) decrease in the ozone layer, (ii) loss of integrity of the biosphere, (iii) chemical pollution, (iv) climate change, (v) ocean acidification, (vi) freshwater consumption and global water cycle, (vii) land use, (viii) nitrogen and phosphorus flows in the biosphere and in the oceans, (ix) atmospheric aerosol load (W2).

In response to the progressive elimination of the role of the environment from economic considerations, both as recipient of damage and as a source of irreplaceable wealth, the Ecosystem Services

(ES) model was introduced in the 1970s; the quantification of Ecosystem Services, i.e. the benefits that an ecosystem (natural or man-made) provides and which are directly or indirectly linked to well-being and to the quality of human life, appears particularly important (de Groot *et al.*, 2012). From a first pedagogical purpose aimed at underlining the risks represented by the loss of biodiversity, the ES have become a fundamental political and economic tool (Gómez-Baggethun and Martín-López, 2015). This turning point, which took place at the beginning of the new millennium, was marked in particular by the Millennium Ecosystem Assessment (MA), an international research carried out from 2001 to 2005 in order to identify the state of global ecosystems, assess the consequences of changes in ecosystems on human well-being and provide a scientific basis for formulation of actions necessary for conservation and sustainable use (Reid *et al.*, 2005). MA states that: "Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ecosystem services" (Costanza *et al.*, 1997). The MA, together with the literature subsequently developed (Brauman *et al.*, 2007), has identified four categories of services: (i) supply, i.e. consumer goods that can be directly taken from ecosystems such as food, raw materials, fresh water, (ii) regulation: linked to the regulation of the hydrological cycle, climate and hydrogeological instability, (iii) cultural, related to the intangible benefits offered as inspiration for art, music, architecture and, finally (iv) support, necessary for the realization of all other services (creation of soil, support for reproduction).

In the broad panorama just outlined (Montoya-Tangarife *et al.*, 2017), the present work focuses on the urban environment and on the Ecosystem Services related to land use (land use changes in urban residential areas) and water (the mitigation of damage caused by flood events and the containment of pollutant concentrations in surface, sub-surface and groundwater flows). Nowadays urban environments and ecosystems have particular importance due to global demographic changes: the percentage of the population living in urban areas is 55% globally and is projected to increase to 68% by 2050 (W3). This trend of increasing urbanization is visible with respect to all continents, expect for Oceania. In particular, in Italy there was an increase in its percentage from 51% to 71% since 1950 to today. The urban environment is also peculiar from an environmental point of view as, unlike other systems, it is a "functionally incomplete ecosystem", defined by the consumption of ES and by the presence of human beings and their activities (Reid *et al.*, 2005). By virtue of the strong exploitation of the ES, cities represent a major source of ecological pressures that cause changes to the entire earth's ecosystem through resource consumption, greenhouse gas emissions and pollution (Hodson and Marvin, 2010). According to the IPCC (Intergovernmental Panel on Climate Change), cities consume 67% to 76% of global energy and generate about three quarters of global carbon emissions (IPCC, 2014).

To achieve the sustainability of urban areas, a deeper understanding of the relationships with ecosystems, although mainly anthropogenic in nature, is necessary; in particular a study of ES, not derived from the outside but obtained from ecosystems within the wide context of cities, could be instrumental in emphasizing the relationship that man has with these functions: in this sense, urban green infrastructures offer a possibility of study. Nevertheless, in the area of scientific studies, a lack of sufficient research in the field of urban ecology is reported: on a quantitative level, an analysis of the literature in 2014 reported only 217 publications relating to UES (Urban Ecosystem Services), mainly carried out in North America, Europe and China (Haase *et al.*, 2014). Similarly, Caprioli *et al.* (2020) focused the gap in research on urban-type ecosystems compared to others, such as wetlands or forests. In light of these considerations, many authors underlined the importance of broadening the study of cities as ecosystems and as a cause of changes to ecosystems themselves, in order to guarantee urban ecological safety (Hodson and Marvin, 2010; Solecki *et al.*, 2013, McDonnell, 2015; Jennings *et al.*, 2017).

In particular, urban parks are important repositories of urban biodiversity and supplier of UES. The latter are certainly secondary to those obtained from global ecosystems, but offer various educational, moral and practical advantages thanks to their local nature, and allow to better evaluate the direct benefits obtained by the community and to improve cities, integrating ecological considerations into their design (Bolund and Hunhammar, 1999). Furthermore, the type of ES and the quantity of their supply are strongly influenced by the context in which the parks themselves are located and by community use, especially as regards the cultural ES. These can be negatively impacted by a general neglect or dirt of the places, and by the culture of the population in terms of values represented by green areas. Bolund and Hunhammar (1999) highlight how the size of the park is an important factor: larger parks generally offer more regulation services while smaller parks offer more cultural services.

The aim of this work is to highlight the enormous potential of a green infrastructure located in the suburbs of Turin, "Le Vallere" park, justifying numerically (and monetarily) the multiple benefits that the area silently generates on the surrounding city environment, through a recently developed tool, little used in Europe. At the Italian level, few *i-Tree* applications have been implemented and, more generally, scientific research in Italy has so far devoted little attention to the issue of quantifying ecosystem services.

This scientific article is divided into several chapters: chapter 2, called Methodology, contains a presentation of the two *i-Tree* tools (*Eco* and *Hydro*) implemented in the project, with the related equations; chapter 3 presents a description of the considered green area and of the main input data entered into the programs; in chapter 4 the main results obtained are reported and explained, through tables and figures; finally, chapter 5 reports the conclusions drawn from the work carried out, emphasizing the importance of results but also the future developments of the project; in chapter 6 and 7, thanks to the institutions involved in the project and the bibliography of the article are respectively reported.

## 2. Methodology

A complete assessment of ecosystem services can be based on various tools: interviews with inhabitants of the neighborhood, on-site inventories of vegetation but, above all, the use of specific softwares. In the following case study, a quantitative analysis of the environmental benefits generating by "Le Vallere" Park has been carried out, through a specific SE assessment tool for vegetation. The suite *i-Tree* is a collection of analysis and assessment tools designed and developed by the United States Forest Service, part of United States Department of Agriculture (USDA), to quantify the ES provided by a green area (i.e. street-lined, park, neighborhood, city or whole region). The choice fell on this software, born in the current century, although there are several tools, more popular and born earlier, designed to carry out a SE evaluation; the reason is related to the specificity of *i-Tree* on vegetation, with an appropriate approach to the purpose of this work.

The project is particularly focused on *Eco* and *Hydro* functionality, two flagship tools of *i-Tree* supported by *Database* and *Canopy* respectively. While *Hydro*, based on urban hydrology model, allows to simulate the effects of changes in tree cover at the urban level on local hydrology, *Eco* provides information on the urban green structure and its environmental effects (Treeconomics and Trädkonsult, 2019). Both tools base the ES assessment on the collection (and often on-site retrieval) of different types of data: geographic location information, topographic data, precipitation time series, species information, pollution data, hydrological parameters and more.

### 2.1. i-Tree Eco

Table 1 provides a summary of the main input data required and output that the program is able to furnish. Regarding the input data, they vary according to the size of the studied area: for small areas, a "complete inventory" methodology is applied, through a precise inventory of tree species and shrubs, defining land use and cover. On the other hand, the analysis of larger areas can be carried out through a statistical sampling of the parameters and characteristics, that is called "plot-based sample inventory".

The purpose of *i-Tree Eco* is to analyze and quantify the benefits offered by the green area to the context in which it is located, in terms of $CO_2$ storage and sequestration, atmospheric pollutants removal, Volatile Organic Compounds (VOC) emissions and avoided water runoff. The precision with which these outputs are provided by the program depends, in turn, on the quantity and quality of the input data, many of which are not necessarily mandatory and which require a site inspection for their retrieval. The monetary evaluation associated with each ecosystem service allows to estimate an overall impact value of the area and derives from the definition, in the input phase, of unitary benefit prices, as shown in Table 1. For each category considered (electricity, eating, carbon and avoided runoff) an unitary benefit price is defined: *Eco* includes default values, linked to an average condition in US but the user can enter their own, relatively to the place where such analysis is carried out.

*Eco* is based on a mathematical model, validated by countless experiments and with which the tool has been programmed: the Urban Forest Effects (UFORE) model. It allows to monitor urban forest structure and to estimate its ES, using a random sampling technique, with known standard deviation, integrating local environmental data such as pollutant concentration and hourly meteorological data to return estimates of the aforementioned outputs. The greater the knowledge of the forest structure, the greater the accuracy of the benefits estimate.

Five modules make it up: (i)

Tab. I – Summary of *i-Tree Eco* (a) input and (b) output data.

| (a) Input | | (b) Output |
|---|---|---|
| Weather station | $CO_2$, $NO_2$, $O_3$, $SO_2$, PM 2.5 concentration [ppm]<br>PAR [W/m$^2$]<br>Rainfall [cm/h]<br>Temperature [°C] | Dry deposition of pollutants per canopy cover unit [g/m$^2$/h]<br>DBH distribution:<br>- Leaf area [ac]<br>- Leaf biomass [ton]<br>VOC [lb/yr]:<br>- Monoterpene<br>- Isoprene |
| Inventory | Specie<br>DBH<br>Land Use/Ground Cover<br>Tree Height/Height to crown base<br>Tree crown dimension and condition<br>Crown light exposure<br>GPS coordinates | Stored carbon [ton]<br>Gross sequestered carbon/Equivalent in $CO_2$ [ton/yr]<br>Potential evapotranspiration, Evaporation, Transpiration, Intercepted rainfall [m$^3$/yr]<br>Monetary values [€]:<br>- stored carbon<br>- gross sequestered carbon<br>- avoided runoff<br>- pollutants removal |
| Benefit prices | Electricity [€/kWh]<br>Eating [€/therm]<br>Carbon [€/ton]<br>Avoided runoff [€/m$^3$] | |

UFORE-A: Anatomy of the Urban Forest; (ii) UFORE-B: Biogenic Volatile Organic Compound (VOC) Emissions; (iii) UFORE-C: Carbon Storage and Sequestration; (iv) UFORE-D: Dry Deposition of Air Pollution; (v) UFORE-E: Energy Conservation (Nowak, 2008).

Nowak (1996) states "Accurate estimates of tree leaf area and leaf biomass in both urban and surrounding natural areas are critical in assessing evapotranspiration, atmospheric deposition, biogenic volatile organic emissions, light interception, and other ecosystem processes". On this principle UFORE-A, fundamental model for the implementation of a *Eco* project, is based trough the Equations (1) and (2). These regression equations were produced to calculate total leaf area and total leaf dry-weight biomass of "open-grown urban trees" (Nowak, 1996): Eq. 1 is a function of the DBH (Diameter at Breast Height) while Eq. 2 varies according to the height (H) and width (D) of the crown.

$$\ln(Y) = b_0 - b_1 \cdot DBH + b_2 \cdot S \qquad (1)$$

$$\ln(Y) = b_0 - b_1 \cdot H + b_2 \cdot D + b_3 \cdot S + b_4 \cdot C \qquad (2)$$

where $Y$ is leaf area (m$^2$) or leaf dry-weight biomass (*g*); $b_0$, $b_1$, $b_2$, $b_3$, $b_4$ are regression coefficients; *S* is a species-specific shading factor defined as the percentage of light intensity intercepted by the canopy of trees; *C* is the canopy external surface (Gacka-Grzesikiewicz, 1980) calculated as:

$$C = \pi \cdot D(h + D))/2 \qquad (3)$$

A further important variable for the *Eco* simulations is the leaf area index (LAI)

$$\text{LAI} = -\ln (I/(I_0)/k \qquad (4)$$

where I is the light intensity under the canopy while $I_0$ is the light intensity above it; k is the light extinction coefficient (0.52 for conifers, 0.65 for hard woods). The ratio between I and $I_0$ represents the shading factor. The LAI is a dimensionless index that represents the leaf area (m$^2$) per surface unit (m$^2$) and that is defined on the basis of Beer-Lambert law (Nowak, 1996).

The parameter on which UFORE-D is based, fundamental for the analysis carried out, is the flow of atmospheric pollutants removed (g/m$^2$/s$^1$), (Hirabayashi *et al.*, 2011).

$$F = V_d \cdot C \qquad (5)$$

where $V_d$ is the deposition rate (m/s) and C is the pollutant air concentration (g/m$^3$). The deposition rate for CO, $NO_2$, $SO_2$ and $O_3$ is calculated as the reciprocal of the sum of resistances to pollutant transport (s/m), (Baldocchi *et al.*, 1987).

$$V_d = 1/(R_a + R_b + R_c) \qquad (6)$$

where $R_a$ is the aerodynamics resistance, that is the resistance opposed by the air to the passage of the pollutant molecules; $R_b$ the quasi-laminar layer resistance, or the resistance encountered by the particles at the air-leaf interface surface; $R_c$ is the canopy resistance, or rather the resistance opposed by the plant tissues and the stomal openings. In Baldocchi *et al.* (1987) an insight into how these three resistance types can be calculated is present.

## 2.2. *i-Tree Hydro*

As mentioned at the beginning of the chapter, *i-Tree Hydro* is a flagship tool based on urban hydrology model specific for vegetation and allows to simulate the effects of changes in tree cover at the urban level on local hydrology. In other words, it is a desktop-based program aimed at studying the hydrogeological impact of different type of coverage. It is based on a hydrological topographically-based model, UFORE-*Hydro*, still in development, composed by the division into *Hydro* and *Hydro*+; the latter is a new advanced version subjected to research. UFORE-*Hydro* has been developed through the OBJTOP (Object-oriented, Topographic) structure and it is based on algorithms which work with interception, storage, infiltration, evaporation and runoff data, modifying them slightly. It is an easy-to-use model for researchers, urban planners or environmental technicians, who are required to insert minimal input data (Wang *et al.*, 2008). The version used, on which all the model updates depend, involves the use of an urban scheme of soil-vegetation-atmosphere exchanges represented by vertical layers. Furthermore, the surface is recognized as permeable or impermeable and coverage percentage due to the presence of albedo is quantified.

The flow model provides, as inputs, NED (National Elevation Data) as raster with each pixel corresponding to an area with a user-definable size and NLCD (National Land Cover Data). Therefore, from these two data sets, the following information can be obtained: Topographic Index (TI) from NED and estimates of Impermeable Cover (IC) and Tree Crown (TC) from NLCD (Yang *et al.*, 2003). TI is calculated as the quotient between the area by the length of the contour and the tangent to the slope of the local pixel; IC and TC are defined for each block of TI, i.e., groups of pixels with the same Topographic Index. Other input data are: (i) initial groundwater level, (ii) chemical composition of soil and its physical parameters, (iii) meteorological data, required with hourly time interval or less and (iv) potential evapotranspiration.

Then, main output data are: (i) amount of precipitation intercepted by the vegetation, (ii) infiltration, (iii) evapotranspiration, (iv) surface runoff and (v) lateral flows of the aquifer.

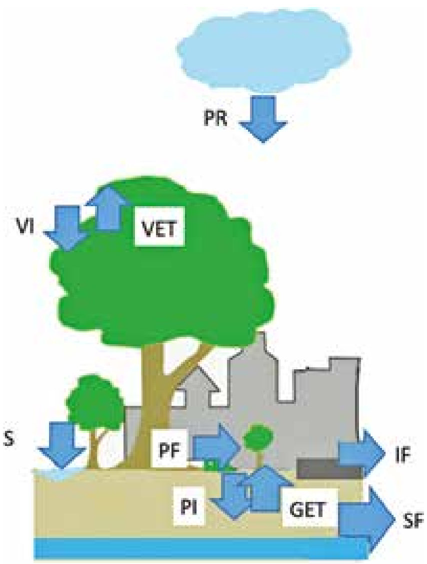


Fig. 1 – *i-Tree Hydro* water balance.

Equation 7 represents the water balance taken as model in *Hydro*, whose components are represented in Figure 1.

$$PR = VET + VI + S + PI + PF + IF + SF + GET \qquad (7)$$

with mm as unit of measure for all terms and where, in particular, PR is the precipitation; VET and GET are respectively vegetation and soil evapotranspiration; VI is vegetation interception; S is storage in soil depressions; PI is infiltration on permeable soil; PF, IF and SF are respectively permeable, impermeable and subsurface runoff.

## 3. Study Area and Data

The proposed i-Tree tools have been applied to an urban park located in Moncalieri, in the Metropolitan City of Turin (Italy N O). The city covers a surface of 4753 hectares and has a population of 57528 inhabitants (W5). It is located at 262 meters above the sea level and it has a warm and temperate climate. Moncalieri receives annual precipitation of 700-750 mm spread in 75 days with a minimum in winter and a maximum in spring and autumn. The average temperature is 12°C with the warmest month in July. According to Köppen and Geiger this climate is classified as Cfa (Humid subtropical climate) (W6).

The selected area is "Le Vallere" park, an extensive semi-urban green space located at the confluence of two rivers, Po River and Sangone Torrent with an extension of 130 ha. "Le Vallere" term was given by French to the embankments built in 1541 during the first French occupation of Piedmont. In 1960s this area was partially saved from the urbanization and the overbuilding which led to the construction of the main street "Corso Trieste" and the residential neighborhood located west of it. Subsequently, "Le Vallere" park became Piedmont Region's property and in 1990's the large eighteenth-century farmhouse became the headquarters of the park management institution, ex "Ente di gestione delle aree protette del Po torinese". On 29th June 2009, Piedmont Region enacted a regional law with which the park was protected as Nature Reserve; nowadays it is open to the public and available with regulation. The regional law n.11/2019 established that all individual protected areas along the Po river in Piedmont, in the section from Casalgrasso to the border with Lombardy, constituted a single protected area: the "Piedmontese Po Natural Park" ("Parco Naturale del Po Piemontese") (W7).

The designed land use has been turned from a merely agricultural use to an alternation of intensive forage cultivation and clearings with groves. The coexistence of

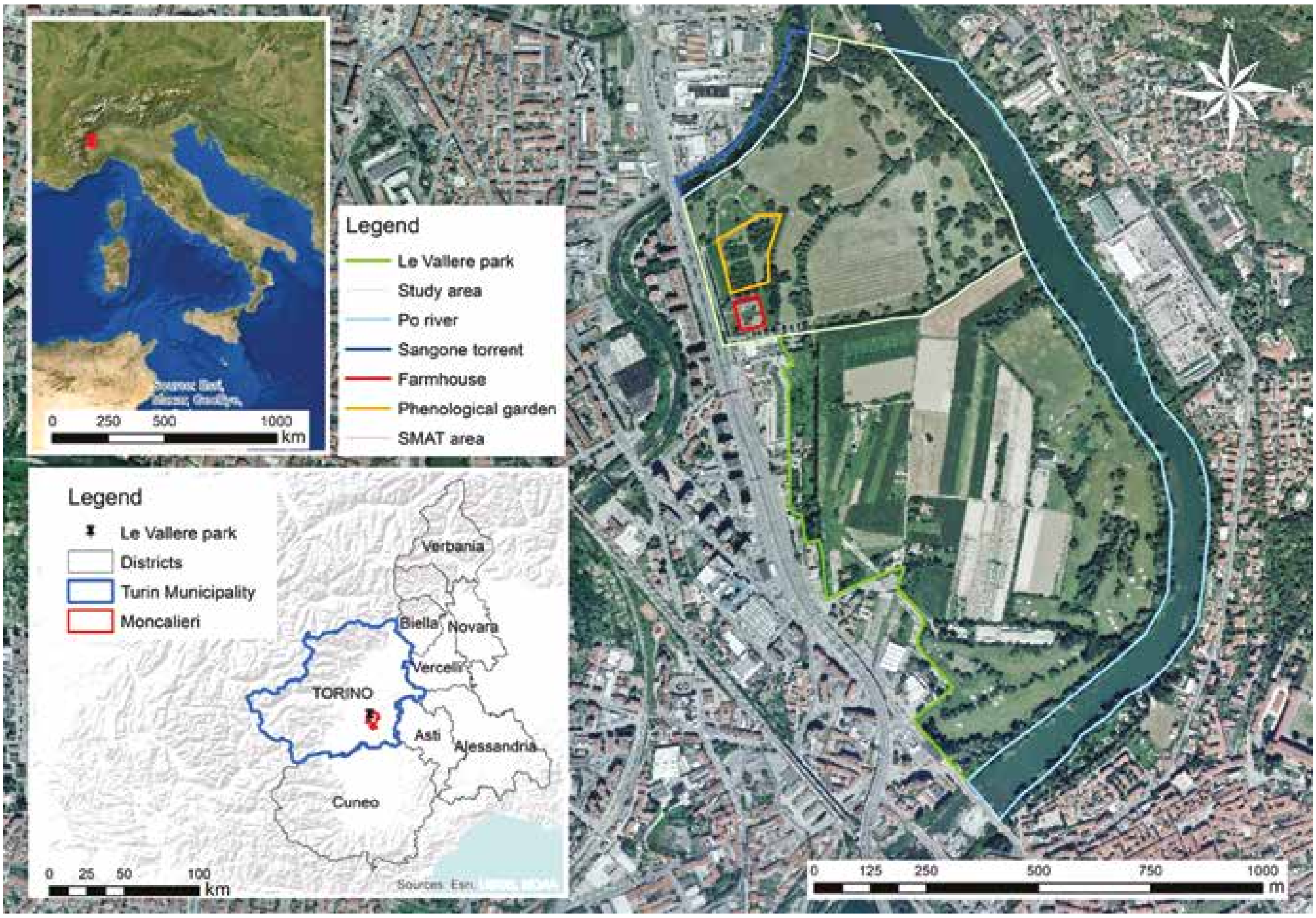


Fig. 2 – Geographical framework of case study "Le Vallere" park.

agricultural landscape and public park and the environmental and landscape recovery measures of Po River's banks allowed to re-enact a section of ecological network of Turin metropolitan area, underling its important role as an element of biodiversity conservation and for migratory flows. The alternance of agricultural activities and public park represents the distinguishing feature between "Le Vallere" park and the other green areas located in the surrounding urban context, increasing the environmental quality of the city.

The present work has been developed on a portion of park managed by "Ente di gestione delle aree protette del Po torinese" (now become part of "Ente di gestione delle aree protette del Po piemontese) which covers a surface of 34 hectares (Fig. 2). Within this area, recreational activities are common: it includes children playground, sport area, picnic areas, two plots for dogs, a botanical-phenological garden and different paths for mountain biking, walking and horse riding. The botanical-phenological garden has been created between 2000 and 2002, it is named in honour of Carlo Allioni and it aims to evaluate the impact that thermal anomalies, parasites and air and soil pollution have on typical species of a continental climate regions (W8). "Le Vallere" park also encloses a building managed by SMAT S.p.A., the water management society of the metropolitan city of Turin.

The partnership with the aforementioned institution has allowed to get reliable and up-to-date technical data. A measurement campaign has been conducted in July 2020 in order to retrieve datasets on tree population required by *Eco* and *Hydro* tools such as arboreal species, tree diameters, health crown condition, land use and land cover. The entire study area has been subdivided into 192 circular plots fixed grid distributed; the plot size is one twentieth of a hectare with a radius of 12.62 m. It has been decided to sample a single tree for each plot, since mostly plants falling within each plot had similar dimensional characteristics; 102 trees have been analyzed.

Concerning meteorological and air quality data, we gathered them from sources provided by regional authorities. In particular, for *Eco* simulation, we had to refer to data collected by "Bric della Croce" weather station (ID 160610-99999) located in Turin (45°02'N 07°44'E) because it was the only station close to study area with validated datasets from USDA Forest Service. Conversely, *Hydro* simulation has allowed to customize climate data selecting a weather station that was representative of the entire study area: we referred to "Torino Vallere" weather station (ID 249) located inside the park itself, run by ARPA Piemonte, and to datasets surveyed by the "Observatory of Carlo Alberto College, Italian Metrological Society" in Moncalieri. All weather and air quality data implemented in *Eco* simulation refer to 2015, while those used in *Hydro* simulation refer to 2019. Table 2 shows input data required to carry out *Eco* and *Hydro* simulations.

## 4. Results and discussion

### 4.1. i-Tree Eco

#### 4.1.1. Tree population and carbon storage and sequestration

The first output provided by *i-Tree Eco* is a valuation of composition and structure of the urban forest based on field data. Concerning "Le Vallere" park, it assesses a number of 487 (±29) trees belonging to 25 different species, covering about 31% of park's surface. The most common species are (i) *Tilia x europaea* (67), (ii) *Salix alba* (62), (iii) *Tilia cordata* (43) and (iv) *Populus nigra* (38) which present a percentage distribution of tree stem diameters in 45.7-61 class (50% *Tilia x europaea,* 66.7% *Tilia cordata*), in 30.5-45.7 class (53.8% *Salix alba*) and in 106.7-121.9 class (37.5% *Populus nigra*).

Based on previous results, *i-Tree Eco* estimates leaf area and leaf biomass for each species (see Paragraph 2.1, Eq. 1 and Eq. 2) and, according to those factors, assesses the contribution of carbon storage and gross carbon sequestration of trees by species. Total estimates of the first one are 437 metric tons with a leaf biomass of 14 kilograms and a monetary value of about 40 thousand euros, while the gross carbon sequestration amounts to about 13 metric tons compared to a leaf area of 21.3 hectares, economically equivalent to about 1.2 thousand euros. The monetary value refers to benefit prices in Table 2, according to the Italian context.

The most performing species for the ES evaluation is *Populus nigra* due to the unusually large diameter structure and to the fair crown health. As expected, *Tilia* and *Salix* genus also concur positively to the process of carbon fixation in plant tissues and to the removal of carbon dioxide from the atmosphere through chlorophyll photosynthesis. Although plants belonging to *Tilia* and *Salix* genus hold a higher number of individuals than *Populus* genus (approximately twice), it results they have less influence on carbon storage and carbon sequestration quantification.

#### 4.1.2. Air quality

Another interesting output produced by *i-Tree Eco* is the quantification of annually atmospheric pollutants removed by tree population

Tab. 2 – *I-Tree Eco* and *i-Tree Hydro* input data for case study "Le Vallere" park.

| | Eco | Hydro |
|---|---|---|
| Project configuration | Plot – based sample inventory, unstratified sample | Non – watershed |
| n. of plots sampled | 192 (one tree for each plot) | - |
| n. of trees sampled | 102 | - |
| Weather data | Bric della Croce (2015) | Torino Vallere, Observatory of Carlo Alberto College (2019) |
| Air quality data | Bric della Croce (2015) | - |
| DTM | - | CTRN 1:10000 |
| Land cover parameters | - | Grass/herbaceous (57.1%), Impervious ground (3.8%), Tree impervious (1.6%), Tree pervious (33.9%), Soil/bare ground (3.5%), Water (0%) |
| DCIA (Directly Connected Impervious Area) | - | 10.1% |
| LAI | - | 1.74 |
| Annual average flow of project area | - | $9.98 \cdot 10^{-3}$ m³/s |
| National pooled EMCs and NURP EMCs | - | As default |
| Benefit prices | Energy (0.17 €/kWh), Heating (2.87 €/therm), Carbon (91.92 €/ton), Avoided runoff (1.902 €/m³) | - |

and the resulting improvement in air quality. Ozone ($O_3$), sulfur dioxide ($SO_2$) and nitrogen dioxide ($NO_2$) removal made by the green area turns out to be much larger compared to particulate matter (PM2.5), as reported in Table 3. It also points out the non-linear relationship between pollutants quantities removed and their monetary value. One possible reason for that disparity can be the impact that each pollutant have on environment quality and human health, taken into account by *i-Tree Eco*.

In order to correctly quantify ES provided by "Le Vallere" park, it is necessary to take into account the emission of biogenic volatile organic compounds (BVOCs) produced by plants. They significantly affect atmospheric chemistry and climate, especially monoterpene e isoprene emissions that represent a possible source of atmospheric pollution through the formation of $O_3$, CO and other tropospheric aerosols. Therefore, it has been necessary to consider these compounds in the overall balance of pollutants removal provided by the study area. What has been deduced is that the pollutants removal process strongly depends on trees' intrinsic characteristics, their size and vegetative cycle, not only on their numerical quantity. The economic value assigned to air pollution removal is equal to 95 thousand euros, resulting from a pollutants quantity equal to 437 kilograms per year.

*Eco* tool provides other hydrological outputs (such as evaporation, evapotranspiration, flows interception by vegetated covers and avoided runoff) intentionally not examined as they have been evaluated with *Hydro* tool as it is based on more robust hydrological models that allow greater precision in runoff calculation and in plant-specific hydrological processes.

### 4.2. i-Tree Hydro

Concerning *i-Tree Hydro*, outputs provided by simulation assess the effects of changes in urban tree cover and impervious surface on stream flows and water quality. In order to compare different scenarios, the current configuration of park has been defined as *Base case*, while it has been assumed an increase in impermeable surface of 25%, 50% and 75%, respectively as *Alternative case S1, S2, S3*. It has been taken 25% of these percentages out of "Pervious under tree cover" class and the remaining percentage out of "Herbaceous" class, assuming that the reduction of permeable soil involves a decrease in tree cover. Percentages of "Impervious under tree cover" and "Bare soil" have been kept unchanged.

The first output belongs to *water quantity* results: more specifically, it has compared the analyzed scenarios in total flows generated by precipitation fallen in 2019, subdivided into (i) base flow, (ii) pervious flow and (iii) impervious flow. As expected, the comparison has shown an important increase in impervious runoff component related to *Alternative cases*, especially in *S3* in which it represents the 72% of the total flow (Tab 4). Quantities related to Base flow show a decrease of about 225 $m^3$ per year each 25% increase in impermeable cover.

The second output provided by *Hydro* is related to *water quality*, examined through ten different type of pollutants: total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), soluble phosphorus (soluble P), total Kjeldahl nitrogen (TKN), nitrite and nitrate ($NO_2$, $NO_3$), copper (Cu), lead (Pb). As shown in Figure 3, the more impermeable surface increases, the more runoff quality gets worse.

Finally, as *i-Tree Hydro* is a vegetation-specific urban hydrology model, it has been possible to make a few general observations on results from sub-routines such as interception by vegetation, storage on vegetation surfaces and throughfall from them (*Vegetation Hydrology* outputs). The simulation has shown a strong correlation between processes that occur at tree canopy level, intensity and duration of precipitation events and vegetative period of arboreal individuals. In terms of soil hydrology, the program refers to quantities that reach the ground exceeding the maximum accumulation capacity of the leaf cover: some of these volumes seep into subsurface zones, others evaporate from root zone. The comparison conducted between *Base case* and *Alternative cases* has shown that both components decrease as permeable cover decreases.

Tab. 3 – Removed pollutants quantity with related monetary benefit (*i-Tree Eco*).

| | $NO_2$ | $O_3$ | PM 2.5 | $SO_2$ |
|---|---|---|---|---|
| Removed quantity (kg/year) | 89.3 | 305.6 | 8.9 | 32.2 |
| Monetary value (€/year) | 2040.6 | 46747.6 | 47432.8 | 268.2 |

Tab. 4 – Water quantity outputs (*i-Tree Hydro*).

| | Total flow $m^3$/year | Base flow $m^3$/year | Pervious flow $m^3$/year | Impervious flow $m^3$/year |
|---|---|---|---|---|
| Base case | 217763,2 | 852,5 | 215357,4 | 1517,4 |
| S1 | 233829,3 | 627,2 | 197332,3 | 35833,8 |
| S2 | 250383,0 | 401,9 | 148645,2 | 101299,9 |
| S3 | 267187,5 | 176,7 | 74845,0 | 192129,8 |

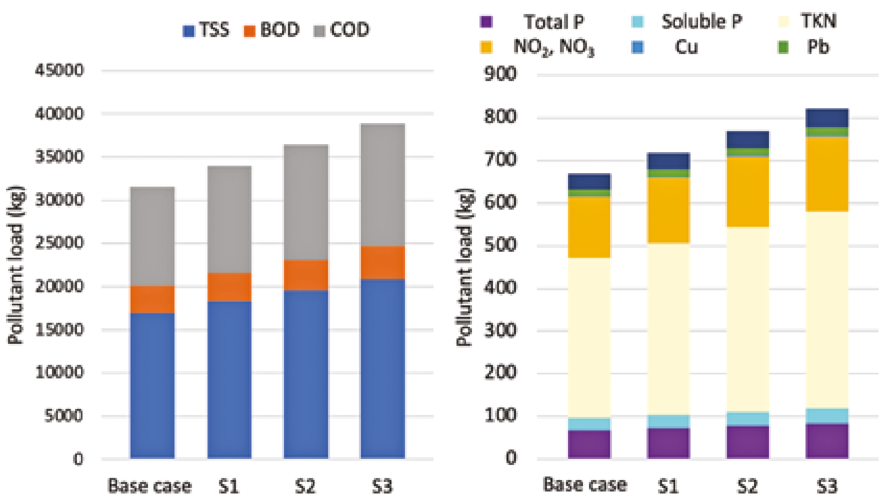


Fig. 3 – Yearly water quantity outputs: on the left, main pollutants; on the right, secondary pollutants (*i-Tree Hydro*).

The results proposed by *Eco* and *Hydro* tools highlight the importance role of the "Le Vallere" park as permeable area, underling the avoided runoff and the improved water quality of surface runoff compared to a waterproofed land cover with same size.

## 5. Conclusions

The project is part of the complex theme of ES, analyzed through an application on an urban green area with the aim of investigating whether and how the presence of the aforementioned area can contribute to make the surrounding metropolitan environment more resilient and sustainable.

In particular, through the use of i-Tree software suite, the ES offered by "Le Vallere" park, the green lung of the urban area between the municipalities of Moncalieri and Turin, were quantified. The methodology used is based on the availability of data, in part already accessible and in part detected on site, while the accuracy of the analysis is inextricably linked to the quantity and quality of such data. The results proposed by *Eco* and *Hydro* tools highlight the role of the green infrastructure as permeable area, underlying the avoided surface runoff and the improvement of water quality compared to an impervious area with same size. Furthermore, the green area has a significant impact on improving air quality and carbon storage.

The quantified benefits provide a useful tool to guide the future planning and planting choices of the management institution "Ente di gestione delle Aree protette del Po piemontese", with which a pleasant collaboration was held. In this regard, in the future it will be crucial to analyze more specifically the role that each species could play in determining each ecosystem service. The project is in progress to analyze a further fundamental aspect for future urban environmental sustainability: the role of climate change. A *i-Tree* project is being implemented on "Le Vallere" park, in order to take into account the effects that future climate changes (temperature and precipitation) will entail, analyzing two possible scenarios: RCP 4.5 and RCP 8.5, respectively the scenario for which it is planned to implement mitigation actions and the scenario for which it is not planned to fight climate change. As a mitigation action hypothesized in this work, a detailed future planting plan is being defined, in agreement with the park technicians, which can be implemented through the "Forecast" function of *i-Tree Eco*. Through such a study, it is expected to obtain a valid tool for evaluating the evolution of the ES system offered by the park and on this basis, possibly, proceed with some changes.

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