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Urban Forest Digital Cadastre

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Abstract: Urban forests being part of the Natural Capital, they provide goods and services for humans, the ecosystem services that are necessary for their survival. Over recent years, the importance of ecosystem services within urban landscapes has grown steadily. Determining the amount and the value of the ecosystem services provided by the Urban Forest is the main goal of the "Digital Green Cadastre" (DGC), a project in progress of survey, classification and mapping of the urban, agricultural and natural green assets. The DGC records the types of green cover and soil characteristics and utilizes the calculation of the total leaf area for the quantitative analysis of the botanical heritage, environmental performance and ecosystem benefits, such as water runoff management, air pollutant removal and urban heat island reduction. The case study of Abbiategrasso—a small town in Italy—is reported.

Key words: Natural capital, ecosystem services, urban forests, DGC, leaf area index (LAI).

1. Introduction

The Natural Capital is the entire stock of natural assets, living organisms, air, water, soil and geological resources, which provides goods and services—directly or indirectly—for humans and that are necessary for their survival. The flows of goods and services that the Natural Capital offers daily and from which humans benefit are indicated by the term ecosystem services [1]. In recent years, the importance of ecosystem services within urban landscapes has grown steadily [16]. The percentage of people living in cities has increased from about 10 to over 50% in just a few decades [3] and urbanization will continue to shape the future, as new population growth is predicted to take place in urban areas. More than 60% of the total population is expected to live in cities by 2030 [17]. Supporting the well-being of urban populations requires a steady and growing flow of natural resources imported from rural areas, as well as the natural areas needed to treat the waste generated by cities. Ecological footprint analysis documents that this may require non-urban land hundreds of times larger than the area of the city itself [13, 14]. The cities ecological footprint is enormous and the extent to which cities can sustain themselves in even a limited number of ecosystem functions is likely to continue to decline over the next decade. The evolution of this negative trend is accelerated by the growing problems deriving from climate change and by the proliferation of land management models that are putting sustainability at risk, entailing—among others—phenomena of soil consumption and progressive qualitative decline, with heavy environmental, economic and social repercussions [10].

A new model of economic and social development and a new land management model in the cities are thus required. Urban forestry emerged in North America in the 1960s as an innovative model for urban natural resource management [7]. Urban forestry has since evolved to quantify the structure, function and value of urban trees [8, 11], applying forest ecology and ecosystem management concepts to urban trees [15, 12]. Now it is common for large cities to set general urban forestry plans to optimize tree selection criteria, estimate total urban canopy

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coverage and provide long-term goals such as water runoff management, increase in the value of rainwater and urban heat island reduction [6, 12].

Ecosystems designed by urban forestry are one of the most important ecosystem service providers for the world's population. However, they are largely left out of decision making in urban area management, due to the general lack of awareness of how the ecosystem services associated with these systems can be quantified. The failure to give a value to Urban Forests—and related ecosystem services provided—is largely due to ignorance of their value to human well-being and to inadequate socioeconomic valuation mechanisms. To support the choices of planning and management of the territory, it is thus necessary to look for indicators to measure the landscape, naturalistic and environmental functions that plants exert through their hypogeal and epigeal apparatuses. Identification and collection of such indicators enables us both to calculate the ecological benefits and to compare different landscape, urban planning and territorial solutions in terms of the value of the ecosystem services provided [9].

Many products are available for the acquisition and management of Urban Forests data, in particular concerning the management of it. Conversely, there is much less to the acquisition of data aimed at determining the environmental performance of the Urban Forests. To help complete this fundamental step in the process of determining the value of the Urban Forests, from 2014 the "Digital Green Cadastre" platform (hereafter "DGC") is being studied, a project in progress of survey, classification and mapping of the urban green cover, agricultural and natural heritage (http://www.catastodelverde.it) (Fig. 1).

2. Material and Methods

2.1 The IT Structure of the DGC

The DGC platform for the management of urban green information is based on two software pillars that are appropriately put together:

(1) The Google Maps platform, which offers extremely sophisticated geographic information systems (GIS) management procedures—web services in API (application programming interface) mode—and provides a photogrammetric detailed mapping of the entire Italian territory, as well as the Street View overviews of almost all national roads, usable in green survey and mapping.

(2) A spatial geographic database set up on the MongoDB database, which allows particularly complex spatial queries and can guarantee the management of a substantial information asset, always in scalable web mode.

The DGC information set is divided into three classes of objects:

(1) Administrative Zones[1]: define a specific zoning (municipal perimeter of green areas, cadastral parcels, area and basin perimeters, zoning of regulatory plans …).

(2) Surfaces: include all the green surfaces or in any case referable to the green management chapter (woods, cultivated land, lawns, shrubbery, uncultivated land, horizontal and vertical green surfaces on buildings ...).

(3) Punctual objects: include all the botanical entities and the elements related to the theme of green management, which have a precise localization (trees, shrubs, games, benches, poles, fountains ...).

The DGC is geometric in nature. Each registered entity has its own spatial component related to the alphanumeric information component. In addition to absolute data on the specific botanical or dimensional characteristics of the species, punctual objects and

[1] The "Administrative Zones" are space objects that in many cases can be derived and not managed internally in the Land Registry. The municipal boundaries, the cadastral parcels and the zoning of the General Town Development Plan are examples of Administrative Zones that may not be duplicated within the DGC. Unlike the boundaries and the codes of the green areas imposed by the offices for administrative and accounting needs, they are zones that find in the Green Cadastre the most suitable place for their memorization and management.

Fig. 1 The "Digital Green Cadastre" website (http://www.catastodelverde.it).

surfaces, the DGC also records historical data of maintenance, diagnostic and phytosanitary interventions. The three classes of objects are autonomous and unrelated to each other—if not spatially—or with respect to the absolute localization on the map.

2.1.1 Logical Structure of the "Administrative Zones"

The "Administrative Zone" object represented in JSON format, consists of an "_id" identifier, a job parameter that identifies belonging to a cluster, an area, a reference municipality, and a GeoJSON format representation of an area object containing a series of "properties".

These properties are free in their number and in their definition:

- If for example the administrative area is the cadastral theme, the 3 properties that will indicate a single particle within the "Codice Belfiore"[2] are: "Foglio", "Particella" and "Subalterno".
- If the zone is a subdivision of areas for maintenance, there will probably be at least one identifying field with the code or the name of the zone.
- If the area is the organization by districts of the municipality, there will be a field indicating the number or name of the neighborhood.

The administrative zones can be more than one for each project, and only serve to localize an area and create clusters for territorial statistical operations (i.e. how many plants per area, how much lawn for each neighborhood, which species and quantity of plants by species in a park).

Each single node of the network of servers that make up the DGC can choose to encode these areas and make them available to other nodes so that users can use them for their selections.

Between Administrative Zone and Surfaces and/or Punctual Objects there is a dynamic spatial relationship that is not recorded and maintained between the properties of each individual object. The rule according to which this plant belongs to this flower bed arises from the topological relationship of the precise object "plant" which is spatially contained

[2] The Belfiore Code is the Italian National Code (also called: cadastral administrative code or, improperly, Cadastral Code) and is a unique identification code assigned to each Italian Municipality and foreign state.

in the object area "flower bed", and not thanks to a supposed field "zone" in the definition of the parameters that define plant object.

2.1.2 Logical Structure of the "Surfaces"

The "Surface" object represented in JSON format consists of an "_id" identifier, a job parameter that identifies belonging to a context, an area, a reference municipality, and a GeoJSON format representation of an area object containing a series of "properties":

- Genus and Species List (area general): The list of botanical species is taken from any Trees & Shrubs searchable database in REST web service mode, and for which the specifications for free use are provided.
- Area Class List (classe_area): Full Soil, Green Roof, Green Wall, Flowerpot, Waterproof Surface …
- Area Type List (area_type): Sand Mixture, Asphalt, Playground, Self-locking paving, Bare soil, Driveway lawn, Lawn, Group of trees, Group of shrubs, Hedge, Ground Cover Plants …
- Event Type List (type): Pruning, Damage, Phytopathology/Pests, Tree measurements, Planting, Tree Felling, Fertilization, Lawn cutting, Leaves collection …

2.1.3 Logical Structure of "Punctual Objects"

The object "Punctual Object" represented in JSON format consists of an identifier "_id", a job parameter that identifies belonging to a context, an area, a reference municipality, and a representation in GeoJSON format of a punctual object containing a series of "properties":

- Aggregation List (status): Group, Row, Isolated …
- Growth Habitus List (veg): Tree, Shrub …
- Event Type List (type): Pruning, Damage, Phytopathology/Pests, Tree measurements, Planting, Tree Felling, Fertilization …

One of the most relevant objectives of the DGC is to determine the ecological and economic value of ecosystem services provided by Urban Forests. Given the complexity of acquiring precise data, the objective of determining the value of the ecological benefits provided by the plants does not necessarily need to be pursued through the direct measurement of the individual environmental performance, but can be achieved through an estimate of the value of ecosystem services, with an approach by categories and models. In this sense, it is noticeable that some of the most important ecosystem services provided by plants are related to the extension of the leaf apparatus [4, 5]: from the outflow of rainwater to the removal of air pollutants, to the heat absorbed by evapotranspiration, to the reduction of CO_2 and the production of O_2 through the photosynthetic process [9].

The DGC quantifies selected ecosystem services starting from a parameter such as the size of the foliage—in its two-dimensional expression of the projection—and then transforming it into economic value as savings on the management.

The crown projection is a measure that is obtained with acceptable approximation through the interpretation of the aerial photographs. The crown projection, expressed on the surface, multiplied by the leaf area index (LAI) provides an estimate of the Leaf Area for each plant or for groups of plants.

Nevertheless LAI is a complex index to calculate because it depends on numerous factors, from species to growth stage, from soil conditions to microclimate conditions, from maintenance to phytosanitary status, etc. Therefore for the specific purposes a mean LAI has been adopted for each type of plant cover, lawn, shrub and tree, also determining sub-categories to consider the intermediate conditions (Table 1). The DGC uses the average LAI expected for typology of green cover which ranges from 0 of the bare ground to 18 of some conifers. Being a relationship between two surfaces, LAI represents a pure numerical parameter; it is therefore dimensionless, being measured in m^2/m^2. LAI therefore represents the amount of leaf material in an ecosystem and is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area [2].

$$\text{Total leaf area } (m^2) = \text{Crown projection } (m^2) \times \text{LAI}$$

Table 1 LAI applied in the DGC for typology of plant cover.

LAI	Typology of plant cover
0	Bare ground
0.2	Almost bare ground
0.5	Very degraded lawn, armed lawn with self-locking devices
0.8	Slightly degraded lawn
1.0	Lawn in fairly vegetative state, extensive meadows and natural areas (cuttings < 3)
1.2	Non-irrigated lawn in fairly vegetative state (cuttings 3-6)
1.5	Irrigated lawn in good vegetative state (cuttings 6-10)
2.0	Valuable irrigation lawn and sports turf (cuttings > 10)
2.8	Carpeting shrubs (plant density > 10 p/m^2)
3.0	Small shrubs (plant density 3-10 p/m^2)
3.2	Medium-sized shrubs (plant density 1-3 p/m^2)
3.5	Large bushes (plant density < 1 p/m^2)
4-6	Isolated broad-leaved deciduous trees: small-size trees, columnar trees or trees maintained with short pruning
5	Broad-leaved deciduous wood
6-7	Isolated broad-leaved deciduous trees: medium-size trees, large columnar trees or large trees maintained with short pruning
7-8	Isolated medium-size broad-leaved evergreen trees
7	Deciduous needle-leaved wood
8	Isolated large broad-leaved deciduous trees
9	Evergreen needle-leaved wood
10	Isolated evergreen broad-leaved large trees
12-14	Isolated evergreen needle -leaved large trees

A further refinement of the data can be obtained by introducing an index of vigour that takes into account the state of health of the crown. The Index of Plant Vigour (IPV) ranges from 0 of the almost dead tree to 1 of the healthy plant. Therefore, given the same species and crown projection, a different total leaf area may correspond.

Total leaf area (m^2) = Crown projection (m^2) × LAI (from DB) × IPV

The amount of the tree leaf area has been used:

- to estimate the volume of meteoric water intercepted by the canopy before reaching the ground; this value provides the basis for all the outflow calculations and, ultimately, savings for adaptation and maintenance of the sewage system;
- for the evaluation—through simulation models—of the amount of energy in kWh implied by the presence of vegetation;
- to calculate the interception surface of pollutants, providing the basis for estimating to removal of pollutants present in the atmosphere or dissolved in meteoric waters;
- to calculate the quantity of photosynthesizing tissue, providing the basis for estimating the reduced CO_2 quantity in the photosynthesis process.

In the present survey, the ecosystem services provided by plants have been estimated with reference to USDA Forest Service's i-Tree™ (https://www.itreetools.org/)[3] and expressed in terms of savings in the management cost for rainwater interception, microclimate mitigation, air pollutants removal and CO_2 reduction.

2.2 Data-Entry in Abbiategrasso (Milan, Italy)

The DGC was applied for the first time in 2014 in the municipality of Abbiategrasso, where the following updates of the project were tested (Fig. 2).

[3] USDA Forest Service's i-Tree™ (https://www.itreetools.org/) is a set of free tools built on science that quantifies the benefits and values of trees around the world, aids in tree and forest management and advocacy, shows potential risks to tree and forest health and is based on peer-reviewed, USDA Forest Service Research in the public domain.

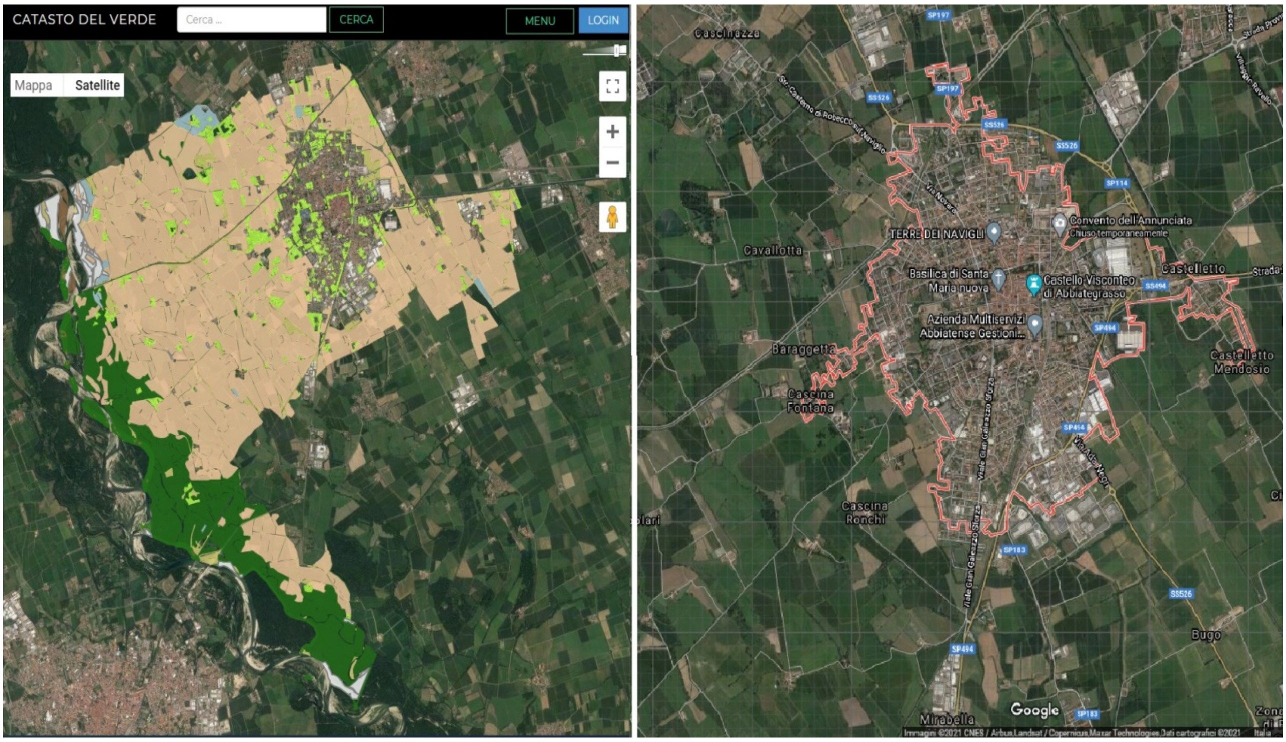

Fig. 2 Abbiategrasso municipality boundaries on the left (dark green: naturalistic, yellow: agricultural, pale green: urban and gardens) and Abbiategrasso City boundaries on the right; from the "Digital Green Cadastre" website (http://www.catastodelverde.it) and Google Maps.

2.2.1 Administrative Data

- Area Code (given automatically by the software).
- Green Space Category (Gardens, Parks, Lawns, Road Green, Extensive Green, Residential Green, Playgrounds, Dogs Area, Sports Area, Parking Area, Vegetable Gardens, Cemetery Green, Green Roofs, Green Walls, Uncultivated Areas, Woodland, Shrubs and Shrubland, Orchards, Vineyards, Wood Arboretum, Waterway Banks, Arable Land, and others).
- Ownership (Public/Private).
- Management (Public/Private/Private for public use).
- Maintenance (Enter name of the Company).

2.2.2 Area Data

- Area Surface.
- Soil characteristics (Full Soil, Green Roof, Green Wall, Flowerpot, Waterproof Surface).
- Types of surface cover (Mineral/Vegetal).
- Types of mineral material (Asphalt, Decomposed Granite, Self-binding Limestone, Self-binding Gravel, Sand Mixture, Playground, Self-locking Paving).
- Types of vegetation cover (Trees in row, Trees in group, Woodland i.e. Trees in group surface > 2,000 m^2, Shrubs in group, Hedge, Ground Cover plants, Lawns, Bare ground).
- Lawns: non-irrigated extensive lawn (No. of cuts < 3), non-irrigated lawn (3-6 cuts), irrigated ornamental lawn (6-10 cuts), fine irrigated ornamental lawn (No. of cuts > 10), irrigated sports turf (No. of cuts > 10), non-irrigated sports turf (No. of cuts > 10).
- Ground Cover Plants: planting layout < 10 plants/m^2, > 10 plants/m^2.
- Shrubs in group: planting layout < 1 plant/m^2, > 1 plant/m^2.
- Trees in group: planting layout 1-3 plants/100 m^2, 3-10 plants/100 m^2, > 10 plants/100 m^2.
- Vegetation cover height (m).
- Ground cover vegetation genus and species or type (pre-digit enter from any Shrub & Trees database).

• Events/Notes: date and operation (Pruning, Damages, Phytopathology-Pest, Plant height, Planting, Plant removal, Fertilization, Lawn cutting, Leaf collection, and others).

2.2.3 Punctual Data (Tree/Shrub)

• Object number (given automatically by the SW).
• Status (Group/Row/Isolated).
• Habitus (Tree/Shrub/Other).
• Genus and Species (pre-digit enter from any Shrub & Trees DB).
• Height (m).
• Trunk diameter (cm).
• Crown diameter (m).
• Events/Notes: date and operation (Planting, Fertilization, Lawn cutting, Leaf collection, Pruning, Suckering, Damages, Phytopathology/Pest, VTA Class, Plant height, Trunk diameter, Crown diameter, Tree removal, and others).

3. Results and Discussions

The city of Abbiategrasso was used as a test area of the DGC.

The polygons of the public green areas in charge of the public administration and related characteristics have been inserted into the platform, followed by the areal elements (lawns, trees and shrubs in groups) and punctual elements (isolated trees and shrubs) (Fig. 3).

The Green Balance Sheet of the public urban forest of Abbiategrasso in charge of the Municipal Administration (http://www.urbanplan.it/amaga/#) can be generated in real-time by clicking “STAT.” on and then “SCHEDE BILANCIO DEL VERDE”. The results of the data uploaded to the platform up to March 2021 are reported and analyzed (Fig. 4).

General Data (Census data)	
Population	32,537
Abbiategrasso total surface (m^2)	47,805,402
Built surface (m^2)	1,758,966
Road surface (m^2)	1,632,990
Surface with vegetation (m^2)	44,413,446
Composition of green surface	
Agricultural (m^2)	26,240,819
Naturalistic (m^2)	7,554,037
Urban* (m^2)	1,524,000
Urban Green Surface per inhabitant (m^2)	46.76

* estimated

Fig. 3 Abbiategrasso (Milan, Italy) (http://www.urbanplan.it/amaga/#).

Fig. 4 Urban green areas under investigation.

4. Urban Green Data (from DGC)

The Urban Green areas in charge of the administration and object of the present survey are shown in Fig. 4. They have a total surface of 723,972 m^2 and 552,911 m^2 are classified "lawns" as far as management is concerned with 67.2% in the class of "Extensive lawns", low maintenance lawns requiring less than 3 cuts per year (Table 2).

Within these areas 6,535 isolated trees are counted in total. Trees belonging to the following 15 genus represent 90.52% of the population as follows: Tilia 19.35%, Acer 9.87%, Populus 9.04%, Prunus 7.85%, Platanus 7.38%, Aesculus 7.12%, Celtis 5.97%, Cedrus 4.20%, Quercus 4.01%, Pinus 3.69%, Fraxinus 3.62%, Ailanthus 2.46%, Robinia 2.06%, Lagerstroemia 1.95%, Liquidambar 1.95%. The remaining 9.48% is divided into the following genus: Betula, Fagus, Carpinus, Ulmus, Picea, Magnolia, Sophora, Abies, Albizia, Cupressus, Chamaecyparis, Morus, Taxus, Acacia, Araucaria, Eriobotrya, Hibiscus, Ilex, Juglans, Laurus, Ligustrum, Liriodendron, Olea and Punica.

The great proportion of trees and shrubs are broad-leaved deciduous, respectively 88.0% and 78.0%. The difference is a higher proportion of broad-leaved evergreen shrubs (12%) in comparison to broad-leaved evergreen trees (2%) (Table 3). The preponderant size class (Fig. 5) of tree population is the 2nd (63%) and with respect to tree species origin (Fig. 6) 52% of the trees are from naturalized species. The actual class diameter and height are in Tables 4 and 5.

Table 2 Lawns.

Extensive lawn (No. of cuts < 3)	67.2%
Extensive lawn (No. of cuts 3-6)	29.4%
Ornamental lawn (No. of cuts 6-10)	3.2%
Fine ornamental lawn (No. of cuts >10)	0.1%
Sports turf (No. of cuts > 10)	0.1%

Table 3 Trees and shrubs.

	Trees	Shrubs
Deciduous broad-leaved	88.0%	78.0%
Evergreen broad-leaved	2.0%	12.0%
Deciduous conifers	1.0%	1.0%
Evergreen conifers	9.0%	9.0%

Table 4 Tree trunk circumference.

< 50 cm	9.31%
50-100 cm	86.51%
100-200 cm	3.22%
200-300 cm	0.76%
> 300 cm	0.16%

Table 5 Tree height.

< 6 m	83.06%
6-12 m	12.19%
12-20 m	4.59%
20-30 m	0.12%
> 30 m	0.03%

Table 6 Total leaf area.

Plant cover (canopy)	m^2	%
Lawns	540,064	35.17
Isolated trees	842,544	54.87
Trees in row	93,496	6.09
Trees in group	37,445	2.44
Woods	16,865	1.10
Isolated shrubs	354	0.02
Shrubs in group	520	0.03
Hedges	3,894	0.25
Ground covering shrubs	293	0.02
Bare ground	164	0.01
Total	1,535,639	

The DGC calculates the total leaf area using the surfaces of the lawn areas and the projection of the foliage of trees and shrubs multiplied by the LAI according to Table 1. The estimated total leaf area is 1,535,639 m^2 (Table 6). Trees contribute for about 58% of the total leaf area (Fig. 7).

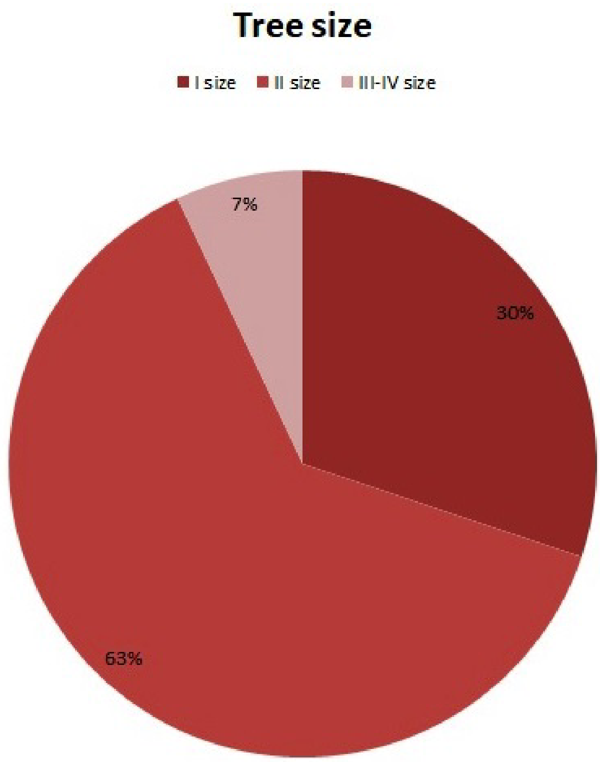

Fig. 5 Dimensional class (expected growth: I = very large tree species, IV = small tree species).

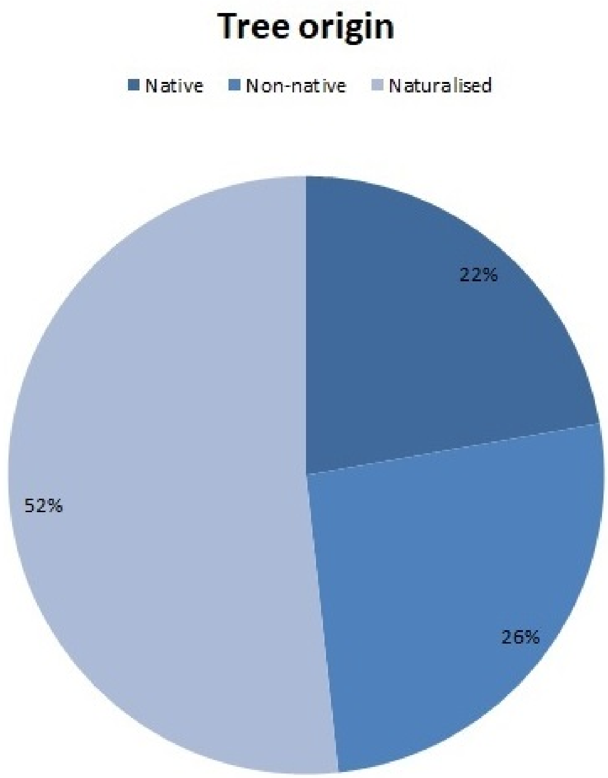

Fig. 6 Tree species origin.

Table 7 Total leaf area.

	Ecosystem services per year	Savings per year
Stormwater interception, runoff management	85,422 m^3	€203,303.49
Air pollutants removal	15,074 kg	€149,538.11
Micro-climate mitigation, heath absorbed by evapotranspiration	18,424,274 kWh	€2,026.670.14
CO_2 fixed	5,024,802 kg	€33,314.44
Total		€2,412,826.17

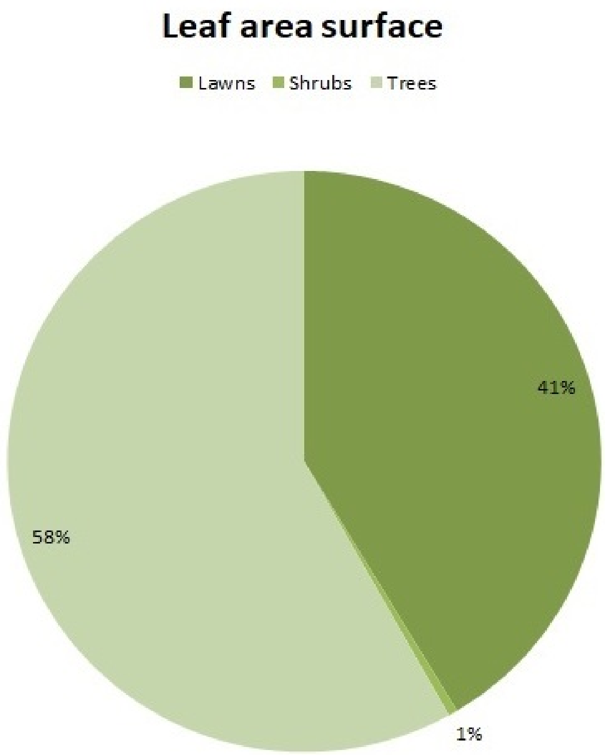

Fig. 7 Leaf area surface.

In Table 7 some of the benefits related to the total leaf area of herbaceous, shrub and tree plants area reported. The DGC estimation is as follows: 85,422 m^3/year of stormwater interception, 15,074 kg/year of air pollutants removal, 18,424,274 kWh/year of equivalent heath absorbed by evapotranspiration and 5,024,802 kg/year of CO_2 reduced. The environmental effects are economically evaluated in terms of yearly savings on city management as follows: runoff management €203,303.49, air pollutants removal €149,538.11, micro-climate mitigation €2,026,670.14 and CO_2 removal €33,314.44.

5. Conclusions

The DGC is a project of survey, classification and mapping of the public and private urban, agricultural and natural urban forest, which introduces some important elements of originality and innovation.

The DGC has moved from a quantitative analytical criterion to a systematic performance model that has taken as a first reference the ecosystem control of green facilities, overcoming the computational/taxonomic criterion in favour of the formation of final balances and the monitoring of evolutionary dynamics of the urban forest.

The DGC was therefore shown:

- to be an easy application tool for the acquisition of botanical data and able to use the most up-to-date survey and data processing technologies;
- to recover the censuses performed with traditional methodology and the measurement of the urban forest;
- to deal with other territorial databases;
- to produce a quantitative balance of public and private urban forest, standardized at national level, in response to the increasingly pressing demands of environmental quality, in particular urban;
- to calculate the quantity and economic value of the ecosystem services provided by the urban forest;
- to support the choice of development models that recognize the environmental and economic value of the urban forest and the soil, through the estimate of the asset value of the urban forest;
- to keep alive the botanical data collected daily in the area.

The novelty of the DGC approach does not lie in the IT management and the sharing and publication on the web of data—which is based on procedures already widely tested and successfully applied in other contexts—but in identifying the performance parameters and the classification model able to constitute a reference standard for the municipal urban green balance [9].

The DGC project identifies in the measurement of the total leaf area one of the main parameters for the quantitative analysis of the botanical heritage, environmental performance and ecosystem benefits. Using the Leaf Area as the parameter for the measurement of the botanical heritage and of the ecosystem benefits makes it possible, for example, to estimate with acceptable approximation the quantity of urban greenery. This parameter can be used for a single plant, but also for larger surfaces covered by vegetation, in order to measure radically different situations in terms of ecosystem services provided.

The Abbiategrasso Urban Forest data uploaded on the DGC have been used to produce on-time the Green Balance. The Green Balance is crucial for evaluating not only the amount but—most of all—the environmental performances of the urban forest. A very interesting consideration is that, with an annual cost of maintenance of the public botanical heritage of around €800,000.00, including leaves collection, the botanical heritage generates a multiplicity of ecosystem benefits that should be equally monetized. On the basis of bibliographic data deriving from studies that are multiplying in many cities of the world, the DGC calculates the value of four ecosystem benefits linked to the total leaf area in terms of saving on the management of rainwater, reduction of air pollutants, energy consumption for air conditioning of buildings and CO_2 removal, which amounts to about €2,400,000.00 per year.

The format of the Green Balance can be tailored to the requirements of the administration or other stakeholders.

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