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Urban green infrastructure valuation: an economic method for the aesthetic appraisal of hedges

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Abstract. The paper presents a parametric approach to quantify the economic value of hedges in urban green spaces. The model integrates indexes that allow for an aesthetic estimate of green infrastructure. Both field and desk phases are developed to depict and sample hedgerows in a case study in Italy (Cascine Park, Florence). Street view and Google Maps applications are used in the preliminary steps to spatialize hedges. An equation, incorporating nine variables including financial, dendrometric, and correction factors, is developed to appraise economic value. The results highlight the relevance of species, plant height, and the number of hedge rows for the unitary and total value of green infrastructures. Phytosanitary condition, the presence of gaps in linear traits, and the degree of tree canopy coverage also influence the economic performances of hedges. The technique facilitates application for both researchers and practitioners, potentially allowing for damage estimates and calibrated management of urban green in different locations.

Keywords: hedges, parametric technique, economic analysis, cultural ecosystem services, urban forest, Florence (Italy).
JEL codes: Q51, Q57.

1. INTRODUCTION

Urban Green Infrastructure (UGI) or Urban Green Spaces (UGS) play a vital role in providing various ecosystem services (ES), which enhance urban resilience to climate change and mitigate natural hazards like droughts and floods, contributing also to human health and well-being (Lampinen et al., 2023; Morpurgo et al., 2023). According to Tzoulas et al. (2007:169), UGI can be defined as "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales". Gardens, parks, green walls, urban forests, green alleys and streets, and hedges, both public and private, can be ascribed as examples of

UGI. Even if different type of UGI provide different ES, it is possible to group ES in four major categories: provisioning, regulating, cultural, and supporting services (La Notte et al., 2017). The provisioning function relates to the possible material goods provided by the ecosystem, such as food or water. The regulating role pertains to functions like temperature, noise, pollution, erosion, and climate regulation. The cultural services include the intangible benefits that people obtain from ES through recreation, social relation, cognitive development, and aesthetic experience. Finally, supporting refers to those services necessary for producing all other ecosystem services, such as providing habitat for species and maintaining genetic diversity (Millenium Ecosystem Assessment, 2005).

A large body of literature has investigated the regulating role of ES in supporting biodiversity, pollinators, carbon sequestration, flood protection, and mitigation of heat waves in cities (see, for example, the reviews of Amorim et al., 2021, and Wang et al., 2014). Along with the biophysical quantification of ES provided by UGI, estimations of the economic benefits provided by ES have also been extensively analyzed (Herath and Bai, 2024), focusing on the role of trees and urban forests (Elmqvist et al., 2015; Kim et al., 2021; Majumdar et al., 2011).

Despite a strong interest in UGI analysis, few works have focused on the benefit provided by urban hedgerows from an economic viewpoint. In a context characterized by an increasing urbanization, hedges can represent a viable solution for cities to achieve goals related to mitigating urban pollution, establishing functional biodiversity networks, and enhancing human well-being (Blanusa et al., 2019; Montgomery et al., 2020). Compared to the other UGI, hedges have a relative compact nature, and their growth can be easily controlled through regular pruning, which can also create different shapes thanks to topiary art (Blanusa et al., 2019). If in public spaces hedges are used as perimeters for parks or to delimit roads and paths, they are also highly appreciated in private spaces, where they beautify gardens, provide privacy, and prevent intrusions. These considerations suggest that the aesthetic appreciation of UGI is important also from economic viewpoint. User-friendly tools and techniques available for practitioners and decision-makers can be, in fact, crucial for the economic appraisal of hedges, such as in cost-benefit analysis promoted by public administrations or damage evaluation on public or private green spaces. The increase in biotic and abiotic diseases in hedge species (Biondi et al., 2022; Hansford et al., 2017; Gullino et al., 2021; Kodati et al., 2023) can further justify this interest. However, expeditious economic method based on expert judgments – such as parametric equations – have not been developed for urban hedges. Within these premises, the aim of this paper is to introduce a new parametric technique for the economic appraisal of the aesthetic value for urban hedgerows. A combination of web-based, field-based, and GIS-based application was used to develop and test a new methodology that appraises UGI combining aesthetic and economic valuation.

After a literature review, the methodological section presents a summary of parametric formulae currently applied for trees appraisal. Next, the equation to adapt parametric analysis to hedges is explained and tested in a case study in an urban park in Italy. Finally, the results are reported and discussed, highlighting the strengths, weaknesses, and potential improvements of the proposed method.

2. LITERATURE REVIEW

2.1. Biophysical appraisal of Urban Green Infrastructure

Focusing on regulating services, several studies have examined the importance of UGI from both carbon sequestration (McKinley et al., 2011) and pollution removal (Escobedo et al., 2011) viewpoints. Life Cycle Assessment (LCA) was applied to evaluate carbon dioxide equivalent emissions and removal by afforested areas, tree rows, social allotments, lawns, and hedges in an urban park in the metropolitan area of Milan (Italy) (Nicese et al., 2021). Santiago et al. (2022) employed Computational fluid dynamics (CFD) simulations of UGI scenarios to provide recommendations on the selection of locations and characteristics of trees and hedgerows based on deposition effects and pollution removal. The mitigation effect of vegetation barriers for pedestrians' exposure to airborne particles from traffic was investigated in a study of Tran et al. (2022) focused on Singapore city.

Other research topics related to UGI include biodiversity enhancement and heat mitigation in cities (Endreni, 2018; Francoeur et al., 2021; Roeland et al., 2019). Among several worldwide examples, butterfly species richness in relation to urban park characteristics was analysed by Sing et al. (2016) in the Federal Territory of Kuala Lumpur; Yenneti et al. (2020) depicted mitigation strategies to contrast urban overheating through green spaces and infrastructure in Australian cities.

Most studies investigating UGI focus on the assessment of parks and gardens and their effect on cultural ES (Pinto et al., 2022; Salmond, 2016), with aesthetic appreciation being a major concern (Roy et al., 2012). Among others, Aboufazeli et al. (2022) developed an artificial neural network to predict landscape aesthetic quality in natural ecosystems of urban areas to assist in the planning and management of UGI. With the same objective, multicriteria analysis was used by Ghafari et al. (2020) to provide a ranking of ornamental species in Rasht City (Iran).

Investigations into specific components of UGI mainly focus on trees; however, domestic gardens (Loram et al., 2008) and flowers in street vegetation (Todorova et al., 2004) have also been evaluated.

A few research focus on hedges in urban contexts and their specific ability to provide ES. The benefits of maximizing the capture and retention of airborne pollutant particles have been investigated, considering species, leaf morphology, and canopy density of hedgerows (Varshney and Mitra, 1993). A scenario involving the planting of 100 km of the best-performing species for pollution removal was estimated to quantify avoided damage and costs from health, environmental, and economic viewpoints (Qadir et al., 2021). The effect of reducing urban noise was examined for hedges of Prunus laurocerasus and Laurus nobilis, stressing significant attenuation correlated to the porosity of hedges (Bioacca et al., 2019). Höpfl et al. (2021) explored whether and how traditional rural hedging techniques, hedge types, and hedgerow networks could be adapted to urban green areas. The aesthetic value of hedges in the Bukovynian Carpathian region of Ukraine was defined by Myronchuk et al. (2021); the authors modified a scale for assessing the ornamental characteristics of shrubs to score the value of hedges based on indicators such as crown density, shoot colour, leaf shape and colour, time and duration of flowering, size, colour, and aroma of fruit. ES, as well as ecosystem disservices of hedgerows in urban contexts, were investigated in a literature review developed by Blanusa et al. (2019).

2.2. Economic appraisal of Urban Green Infrastructure and motivation of the study

Despite the biophysical quantification of ES provided by UGI being well-represented in scientific literature, economic appraisal has also been widely analyzed in recent decades, mainly focusing on trees evaluation. Xu et al. (2021) assessed the combination of externalities with the quantification of the total economic value of ES provided in Beijing, including climate regulation, carbon sequestration and oxygen production, water control and conservation, air pollution reduction, noise reduction, and cultural services. This evaluation was conducted using various methods such as the combination of replacement cost, carbon tax, shadow project, afforestation cost, and market price methods. An extensive literature review on the monetary benefits related to the restoration of ecosystem in urban area was implemented by Elmqvist et al. (2015). The authors also stressed how many non-monetary benefits have been empirically defined, mapped, or measured in cities, especially those related to physical and psychological health.

As reported by Price (2003), all the usual methods for valuing non-market benefits and costs may be applied to the aesthetic values of urban trees. Expert judgment, as well as direct methods (e.g. contingent valuation method - CVM) and indirect methods (e.g. travel cost method – TCM and hedonic pricing – HP), have been extensively applied (Chintantya and Maryono, 2018; Tan and Zhao, 2007). For examples, Notaro and De Salvo (2010) evaluated the social benefits due to the presence of cypress landscape in Lake Garda area (northern Italy) through CVM, stressing how the present value of trees' landscape exceeds 100 million €. Majumdar et al. (2011) quantified the willingness to pay for the maintenance of UGS in Savannah (Georgia, USA) in the range of 81-167 M$. Innovative applications of TCM for the monetary evaluation of cultural ES have been developed by different authors (Cetin et al., 2021; Kim et al., 2021; Lamhamedi et al., 2021; Zhang et al., 2020; Zhang et al., 2022). HP has been used to quantify the economic value of UGI, often in combination with Geographic Information System (GIS) techniques (Kong et al., 2007; Zhang and Dong, 2018).

The literature review confirms and strengthens the motivation of the current study outlined in the introduction, namely the implementation of a parametric approach for the economic appraisal of hedgerows. This approach aims to integrate scientific techniques useful for the financial analysis of UGI.

3. METHODOLOGY

3.1. Parametric approaches

Parametric approaches are widely used from scientific, professional, and practitioner viewpoints for the appraisal of UGI and, particularly, urban trees. The development of parametric methods for determining the value of ornamental plants has been prompted by various factors, including the difficulty of identifying some basic elements, i.e. *i*) the interest rate, in the case of application of financial methods, and *ii*) the market price of the area where the tree is located, in the case of applying direct or complementary methods (procedures that quantify the value of the tree by the difference between the value of the asset – land, garden – with the tree and the value of the asset without the tree) (Polelli, 2008). In addition, parametric approaches facilitate the adoption of a sufficiently standardized procedure, allowing use by personnel who may not be particularly specialized in appraisal of compensation, such as for damages inflicted on publicly owned plants in urban areas. The essence of these procedures is outlined by the following steps (Polelli, 2008):

– identification of a certain number of indices, each independent of the other, which are expressive of the elements contributing to the plant's appreciation;
– specification of an assessment scale appropriate to each index;
– linking the indices together through arithmetic operations;
– multiplying the score by the monetary value assigned to the point, generally corresponding to the purchase price of the plant species at a given size.

Different parametric techniques are described in the literature, with a brief overview of some of them provided below (Tugnoli, 2012). The *English method*, or *Helliwell Method*, returns the economic value of a tree by multiplying a base monetary amount by seven factors: size of the tree, life expectancy of the plant, its importance from a landscape perspective, its insertion into the context, the presence of other plants (social condition), health, and a particular factor called Special Factor. This parameter was introduced to account for valuable elements not covered by the other factors (Helliwell, 2008). The *American method*, or *C.T.L.A. method*, attributes a basic monetary value to the tree by multiplying the size of stem (diameter) by a hypothetical Unit Tree Cost. This value is subsequently adjusted based on species, health and location. The basic monetary value can only decrease; it can remain unchanged only for trees of extraordinary and recognized value (Council of Tree and Landscape Appraisers, 2018). The *Australian method*, or *Burnley Method Revised*, is conceptually identical to the C.T.L.A. method but adjusts the value based on the plant's life expectancy, overall appearance, location, and health (Moore and Arthur, 1992).

The *S.T.E.M method*, or *New Zealander method*, uses a points system to assign an economic value to the tree. It considers twenty attributes, with each attribute receiving points from 3 to 27, which are then multiplied by a unitary cost (Flook, 1996). The *Danish method*, or *VAT03 Method*, was implemented to create a model suited to Denmark's specific needs. Parameters used for economic evaluation include the cost of the young plant in the nursery, age, health status, and its integration in the landscape context (Randrup, 2005). In the *Spanish method*, or *Norma Granada*, the tree's generic baseline value is determined by specific factors such as growth rate, longevity, size, health status, and placement in the landscape context (Asociacion Espanola de Parques y Jardines Publicos, 1999). The *Swiss modified method* starts from a base value (the price of the tree in the nursery) and increases it based on vegetative vigour, health, social condition (whether the tree is in a group, row, or isolated), location, and size of the single plant (Ponce-Donoso et al., 2017). This method was later adapted for Italian cities (Pirani and Fabbri, 1988). The *German method* is similar to the Swiss one but introduces an environmental insertion index, which evaluates how well the plant fits into the landscape context, its distance from other trees, and a depreciation factor if the specimen is seriously damaged (Bernatzky, 1978). Finally, the *C.A.V.A.T.* (Capital Asset Value for Amenity Trees) *method* has two versions: Full and Quick. In both versions, the basic value – calculated from the stem diameter – is multiplied by the so-called Unit Value Factor. Life expectancy, location, and other dendrometric variables are then considered. The Full method is widely applied in several contexts worldwide and often includes additional commentary and specifications (Heuch, 2020). It is mainly used to determine the financial value of individual or groups of trees or their replacement value (e.g., in case of damages). The Quick Method is often used to estimate the value of a population of trees for management purposes and is designed for speed in appraisal (Doick et al., 2018). The Full Method comprises seven steps (determining the basic value plus six steps for basic value adjustment), while the Quick Method involves four steps (determining the basic value plus three adjustments) (Doick et al. 2018).

Comparison among methods have been developed in different research studies (García-Ventura et al., 2020; Ponce-Donoso et al., 2017; Watson, 2002). The effect of root pruning on tree value was quantified by comparing C.T.L.A., Burnley Method, Helliwell Method, and S.T.E.M. (Benson et al., 2019). Some works introduced the iTree application in the comparison (Ma et al., 2011). The iTree software (USDA, 2022) is also often applied to quantify ES delivery in UGI in both urban e peri-urban areas (Zanzi et al., 2021). Finally, innovative parametric techniques have been tested, such as introducing Discrete Choice Experiments (Rakotonarivo et al., 2016; Train, 2003) to appraise the utility that the community derives from the enjoyment of aesthetic, architectural, historical, and cultural externalities of trees (Sardaro et al., 2017) or employing Adaptive neuro fuzzy inference system (Jang, 1993) to value solitary trees using vague (fuzzy) evaluation of input parameters based on expert knowledge (Peták et al., 2022).

3.2. Adaptation of parametric approach to urban hedges

The proposed technique to appraise hedgerows in urban area is based on parametric approach. The main differences between the presented method and existing parametric analysis developed for trees (and sometimes shrubs) consists in the possibility of substituting a hedge plant (e.g., if damaged) with another at "prompt effect". Therefore, in the analysis of hedges, no coefficients are needed to adjust the economic value of plant available in nursery to match its (near) mature dimension. Aesthetic appreciation and value are thus based on the utility that people and society attribute to the hedge (Turner et al., 1993). The economic value of the single trait of hedgerow is therefore adapted to its location and health status.

Within these premises, the proposed formula is expressed as follows:

$$V = P_{s,h} \times L \times R \times E \times G \times T \times A \times C \times SF \quad (1)$$

where V is the value of hedgerow (€). $P_{s,h}$ is the price of a single plant of the same species (*s*) and height (*h*) available at the nursery. The choice of the price should be based on local nurseries or, in other terms, on a similar area and period of appraisal; L and R represent the length (m) and the number of rows of the examined hedge, respectively. E is the plant density expressed as plants per meter (pl/m). G is the hedge vigour expressed as a percentage, ranging from 0 (indicating dieback, leaf loss, etc.) to 1 (indicating a vigorous plant without phytosanitary or health problems). The G factor also takes into account the presence of gaps in the hedge: for example, a vigorous and healthy hedge with one half dead or removed should have a G value of 0.5. The choice of the G parameter can be determined in different ways. From the practitioner's viewpoint, the estimate could be performed through field evaluation, directly attributing a value based on expertise. Alternatively, a Likert scale, linguistic evaluator, or fuzzy scale that can be transformed into numerical judgements could be introduced.

The basic value of the hedge, depending on price, size, and health, will be corrected as a percentage with additional parameters. T represents the probability of attendance at the specific location of the hedge. This value is quantified by merging the population density of the municipality with the degree of rurality. The C.A.V.A.T. method introduces population density divided into classes. In the present work, the same approach is recalibrated for the Italian conditions and its population distribution. Eleven classes are depicted as follows: 1 (<21 inhabitants/km²), 2 (21÷40 inh./km²), 3 (41÷60 inh./km²), 4 (61÷80 inh./km²), 5 (81÷100 inh./km²), 6 (101÷150 inh./km²), 7 (151÷200 inh./km²), 8 (201÷250 inh./km²), 9 (251÷300 inh./km²), 10 (301÷350 inh./km²), 11 (>350 inh./km²). The class of rurality is a qualitative index defined in five categories: rural, near rural, periphery, near centre, and centre (Pirani and Fabbri 1998, modified). The two indexes are combined by a cross-tabulation (Table 1) to define a corrective parameter of V ranging from 0% to 50%. This correction range is based on maximum correction values reported in the literature for Italian conditions (Pirani and Fabbri, 1998).

Table 1. Index of attendance probability (T).

Class of population density	Class of rurality/urbanisation				
	Rural	Near rural	Periphery	Near centre	Centre
1	1.000	1.025	1.050	1.075	1.100
2	1.010	1.043	1.075	1.108	1.140
3	1.020	1.060	1.100	1.140	1.180
4	1.030	1.078	1.125	1.173	1.220
5	1.040	1.095	1.150	1.205	1.260
6	1.050	1.113	1.175	1.238	1.300
7	1.060	1.130	1.200	1.270	1.340
8	1.070	1.148	1.225	1.303	1.380
9	1.080	1.165	1.250	1.335	1.420
10	1.090	1.183	1.275	1.368	1.460
11	1.100	1.200	1.300	1.400	1.500

The fruition potentiality as well as aesthetic value also depend on accessibility (A). In urban areas, hedgerows are usually located close to roads and path; thus, accessibility can be defined based on the type of property in the area. The parameter applied in the formula for accessibility is 1 for public areas and 0.6 for private ones. The visual appreciation of a specific (urban) green infrastructure is influenced by the presence of other UGI, such as urban forests, tree rows, shrubs, grasses, etc. The scenic effect of UGI under tree cover decreases its positive impact compared to hedges in open areas. Although there may be positive correlations between hedges and variables related to tree cover that cannot be evaluated in a parametric approach due to their complexity (e.g., habitat connections, ecological corridors, etc.), the parameter C introduces a negative influence on the scenic aspect and adjusts the value V as follows: hedge not covered by trees: $C = 1$; hedge under tree rows: $C = 0.7$; hedge under the canopy of tree groups or urban forests: $C = 0.5$.

According to Helliwell and C.A.V.A.T. methods, additional parameters (special factors – SF) can be introduced in the evaluation. Potential SF can be either positive or negative. Positive SF include: *i*) being an integral part of a designed landscape, including avenues or designed parks or gardens; *ii*) contributing to the arrangement of an important place or building; *iii*) being located in a school or at its entrance; *iv*) being in a particularly relevant position, such as at the entrance to a public building; *v*) being part of a larger grouping that gives character to the area, such as a long-groomed road; *vi*) serving as a commemorative or memorial hedge; *vii*) being known to have been planted by a notable person. Negative SFs include: *i*) incorrect localization, such as spreading across a narrow path; *ii*) obstruction, such as vigorous thorns on a sidewalk or path; *iii*) shallow roots that damage the sidewalk; *iv*) fruits or seeds that cause discomfort. Each *SF* contributes for +/-10%, with no more than four *SF* allowed in each evaluation (Doick et al., 2018).

3.3. Case study

The parametric method was tested in a case study located in Cascine Park in the city of Florence (Italy) through a combination of web-based, field-based, and GIS-based application. The park spans an area of 130 hectares and features a mix of urban forest and other urban green infrastructure, making it the largest green space in the urban and metropolitan area of Florence and one of the most extensive urban forests in Italy. This selection was made due to its representativeness of national UGI (Sacchelli and Favaro, 2019).

Main roads, cycle roads, footpaths, and squares within the park were thoroughly covered using the Google StreetView application, with images spanning different years between 2015 and 2022. This tool, in combination with photointerpretation on Google Maps application, was used in a preliminary desk phase to accurately locate the hedges. Subsequently, the hedges were georeferenced using QGIS software to create a linear vectorial file (shapefile) of the hedgerows. An attribute table was then associated with the shapefile, and for each feature (single trait), the real presence of the hedge, species, density, depth, height, as well as G and C parameters, were verified and quantified through field sampling conducted in August 2023. The analysis was based on a stratified sample of points defined using the "Random points along line" module in QGIS. The G factor was estimated using a Likert scale with 11 values (ranging from 0 to 10) and then transformed to a 0-1 range.

The probability of attendance for Cascine Park was quantified by cross-tabulating the population density of the Florence municipality (3,534 inhabitants/km^2 as of 2023 – ISTAT, https://www.istat.it/en/– corresponding to class 11 in Table 1) with the class of rurality/urbanisation (near centre, according to Table 1), resulting in a T value of 1.4. Cascine Park is owned and managed by the Municipality of Florence, and all considered hedge lines are public and accessible. Consequently, the accessibility parameter (A) is equal to 1. Positive SF were identified based on proximity to Points of Interest (POI). POI – identified in the list described in section 3.2 – were georeferenced in QGIS. A buffer of 20 meters on POI was created to select point intersected in the buffer. Each selected point was assigned a SF of +10%. Potential negative SF were verified in the field by checking for of presence or absence of impactful characteristics.

For the case study, a statistical analysis using multiple regression was carried out to test correlation among the economic value of UGI and the individual attributes applied in Eq. 1.

The location of the study area, including hedges and POI, is reported in Figure 1.

4. RESULTS

The total length of hedges in the Cascine Park is 31,554 m. For sampling purposes, at least one random point was selected for each vectorial trait, which was depicted by roads intersection and/or variation in hedge characteristics, resulting in a total of 75 traits. For traits with sufficient length, a maximum of three points, spaced out by 80 meters, were randomly selected for each segment. Each random point was investigated along a transect of 20m. In total, 153 sample points were created and implemented. After field analysis, one sample point and its corresponding hedge were excluded due to the presence of flowerbed. Therefore, the total length of transects is thus equal to 3,040 m, which represents 10% of total hedge length.

The hedges in Cascine Park consist of ten species: Berberis julianae, Buxus sempervirens, Laurus nobilis, Ligustrum sinense, Myrtus communis, Prunus laurocerasus, Quercus ilex, Spiraea japonica, Spiraea x vanhouttei, Viburnum tinus. The main characteristics of the hedges, classified by species, are reported in Table 2.

The hedges are mainly composed of single rows (R) (95%): approximately 1,500m are made up of two rows (with Spiraea x vanhouttei, Spiraea japonica, Quercus ilex, Viburnum tinus and Laurus nobilis) and 80m consist of three rows (Quercus ilex).

The most represented specie is Viburnum tinus (6,467m, 20.5%), followed by Spiraea japonica (5,489m, 17.4%), Quercus ilex (5,250m, 16.6%), Prunus laurocerasus (4,196m, 13.3%) and Laurus nobilis (4,130m, 13.1%). Other species each constitute less than 10% of the total

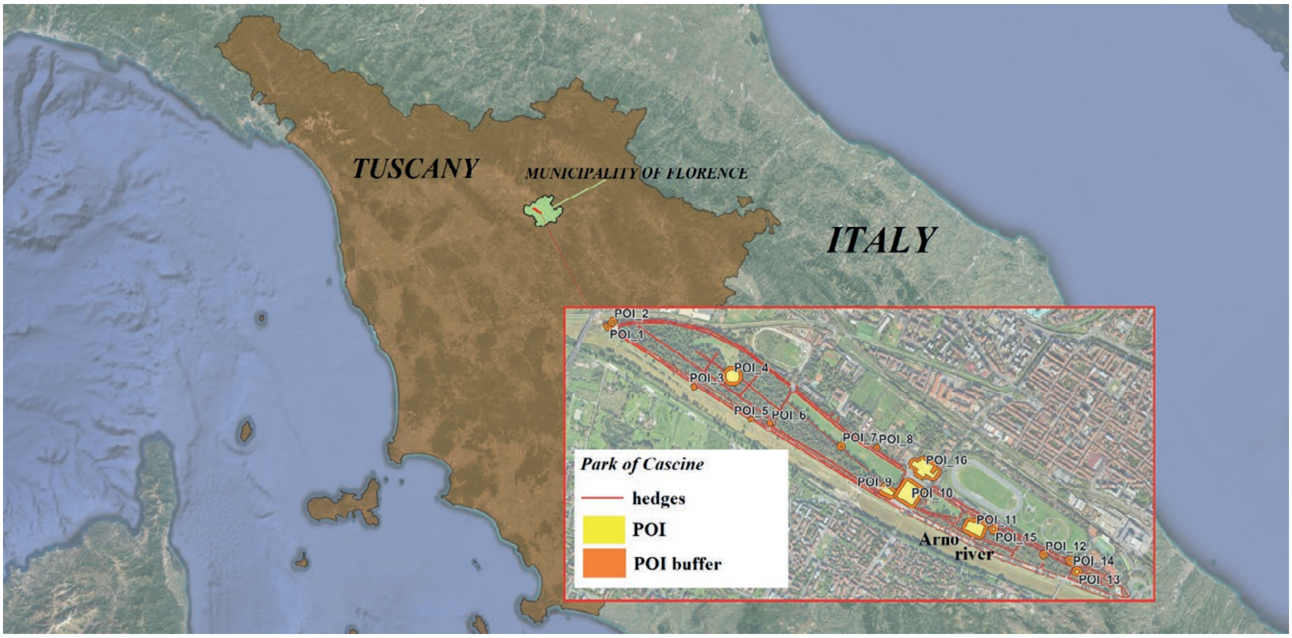

Figure 1. Study area.

Table 2. Characteristics of hedges per species.

Specie	Average height (m)	Average depth (m)	Average density (pl/m)	Average G	Average C	Average SF	Total lenght (m)	Lenght on total (%)
Berberis julianae	0.56	0.44	3.17	0.55	1.00	1.00	2,593	8%
Buxus sempervirens	0.60	0.33	4.27	0.24	0.50	1.00	781	2%
Laurus nobilis	1.07	0.57	2.94	0.73	0.62	1.02	4,130	13%
Ligustrum sinense	1.17	0.35	2.22	0.47	0.51	1.00	2,367	8%
Myrtus communis	0.80	1.00	3.33	0.70	0.70	1.10	27	0%
Prunus laurocerasus	0.71	0.37	1.95	0.38	0.76	1.00	4,196	13%
Quercus ilex	1.68	0.92	2.32	0.78	0.70	1.01	5,250	17%
Spiraea japonica	1.22	0.77	2.77	0.59	0.69	1.01	5,489	17%
Spiraea x vanhouttei	0.80	1.60	3.33	0.65	0.70	1.10	255	1%
Viburnum tinus	0.94	0.56	2.80	0.72	0.65	1.02	6,467	20%
Total values (weighted on lenght)	*1.07*	*0.61*	*2.65*	*0.62*	*0.69*	*1.01*	*31,554*	*100%*

length. Analysis of species characteristics highlights that the greatest average height is associated with Quercus ilex (about 1.70m), followed by Spiraea japonica, Ligustrum sinense, and Laurus nobilis. However, the greatest depths are linked to Spiraea x vanhouttei and Myrtus communis (1.60m and 1.00m, respectively). Buxus sempervirens shows the highest density in the rows (more than 4 plant per linear meter).

Hedge vigour (G) exhibits good values for Quercus ilex (0.78), Laurus nobilis (0.73) and Viburnum tinus (0.72), while lower values are reported for Buxus sempervirens (0.24), Prunus laurocerasus (0.38) and Ligustrum sinense (0.47). Berberis julianae results always located out of coverage (C=1), whereas Buxus sempervirens is placed under the canopy (mainly in the urban forest of the park: C=0.5). Other species have intermediate values, ranging from C=0.76 for Prunus laurocerasus to 0.51 for Ligustrum sinense.

All traits with Myrtus communis and Spiraea x vanhouttei are located within a buffer of 20m from POI (average SF=1.1). No traits with Berberis julianae, Ligustrum sinense, Prunus laurocerasus or Buxus sempervirens present an increase in V due to special factors (SF=1). Negative SF are not observed.

The base price of sample points for the year 2023 was established by consulting detailed catalogues and price lists of nurseries in Pistoia district (Tuscany), located 30km from the study area. This district is one of the most developed and productive nursery regions at the national level. The base price, defined by specie and height, is reported for all sample points in Appendix A.

From an economic viewpoint, the total value of the hedges in the park is about 1,973,000 € (Table 3). The highest performances are achieved by Viburnum tinus and Quercus ilex, each with a total value exceeding 500,000 €. Spiraea japonica (375,394 €), Laurus nobilis (200,902 €), and Berberis julianae (115,850 €) also demonstrate significant economic relevance. Myrtus communis and Buxus sempervirens have the lowest total values. The average (unitary) value for species shows significant relative importance for Spiraea x vanhouttei (135.80 €/m), followed by Quercus ilex (112.90 €/m) and Viburnum tinus (106.07 €/m). Conversely, poor unitary values are obtained by Buxus sempervirens (13.71 €/m) and Ligustrum sinense (20.76 €/m).

Results can also be reported at a spatial level. Figure 2 shows the percentage of each species within every hedge trait.

Buxus sempervirens (Figg. 1 and 2b) and Ligustrum sinense (Figg. 1 and 2d) are mainly or exclusively located under the canopy in urban forest (as confirmed by the C index in Table 2). Myrtus communis has a very limited distribution (25 m) in the northwestern corner of the park (Fig. 2e). Berberis julianae is sited in the hedge along the Arno river (southwestern orientation) (Fig. 2a), while Spiraea japonica mainly occupies the northern hedges along the main roads (Fig. 2h). Spiraea x vanhouttei is used as an ornamental hedge in the main square of the study area (POI_10; Figg. 1 and 2i). Other species such as Laurus nobilis (Fig. 2c), Prunus laurocerasus, (Fig. 2f), Quercus ilex (Fig. 2g), Viburnum tinus (Fig. 2j) are widely distributed throughout the Park.

Figure 3 presents the main characteristics of hedge traits.

The highest hedges (Fig. 3a) are represented by Quercus ilex in the southwestern trait along the river, as well as by Laurus nobilis and Spiraea x vanhouttei close to POI_10. In this latter area, greater depths are highlighted (Fig. 3b). The geographic representation of trait vigour is shown in Fig. 3c: in confirmation of Table 2, Buxus sempervirens exhibits the lowest G factor. Values below average are also reported for Prunus laurocerasus,

Table 3. Economic value of hedges per specie.

Specie	Total value - V (€)	Average V value (€/m)
Berberis julianae	115,850	44.69
Buxus sempervirens	6,007	13.71
Laurus nobilis	200,902	42.55
Ligustrum sinense	51,906	20.76
Prunus laurocerasus	72,511	32.31
Myrtus communis	2,349	85.52
Quercus ilex	538,549	112.90
Spiraea japonica	375,394	74.71
Spiraea x vanhouttei	34,060	135.80
Viburnum tinus	575,856	106.07
Cascine Park	*1,973,385*	*72.20*

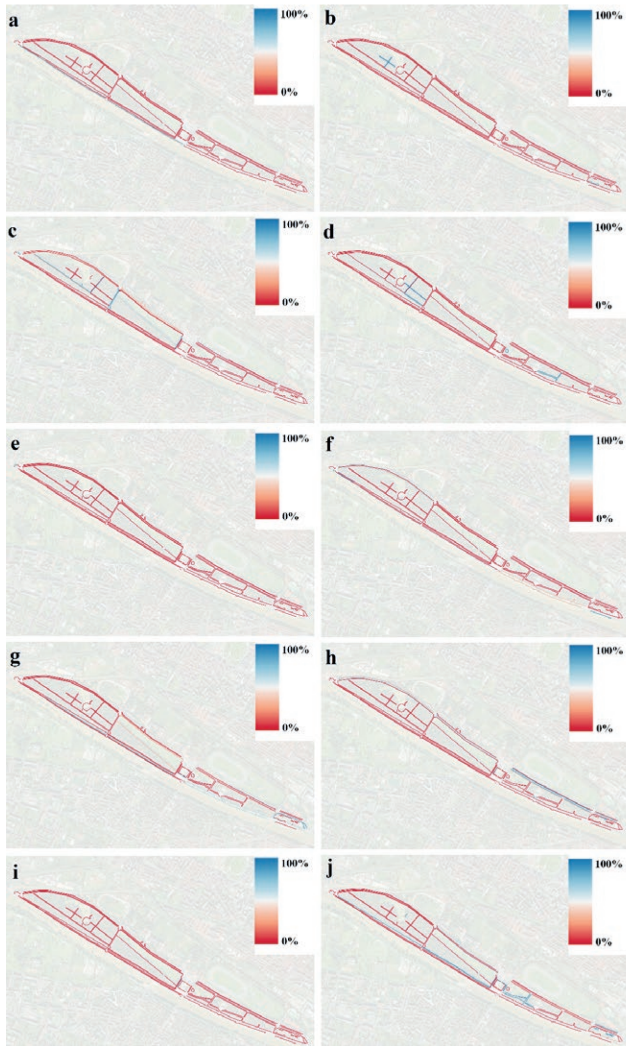

Figure 2. Percentage of species per hedge trait: a) Berberis julianae, b) Buxus sempervirens, c) Laurus nobilis, d) Ligustrum sinense, e) Myrtus communis, f) Prunus laurocerasus, g) Quercus ilex, h) Spiraea japonica, i) Spiraea x vanhouttei, j) Viburnum tinus.

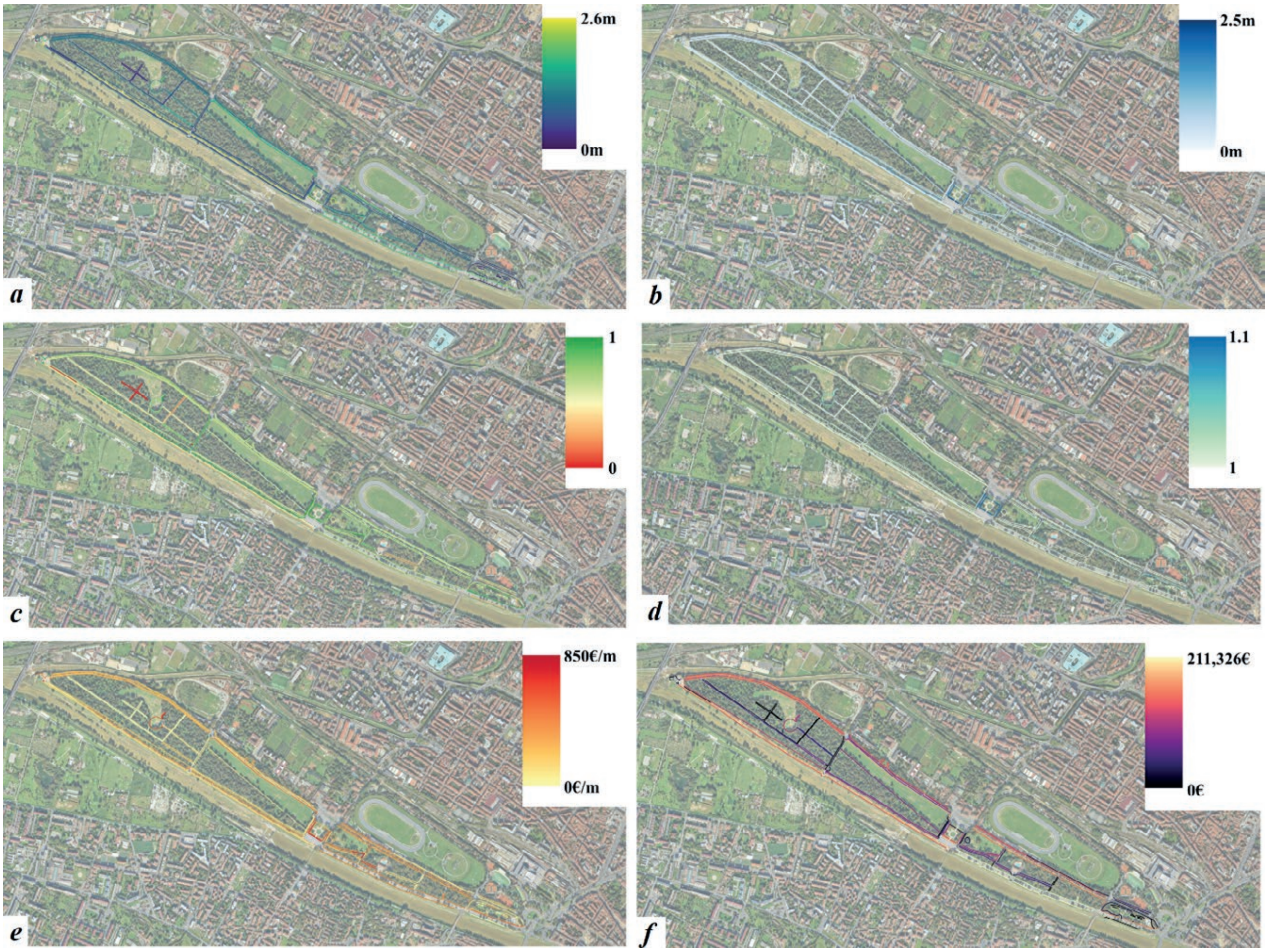

Figure 3. Spatial representation of hedge characteristics: a) height, b) depth, c) G factor, d) Special Factor, e) unitary value, f) total trait value.

Ligustrum sinense and Berberis julianae. Field analysis reveals, however, that low G scores for Ligustrum sinense and Berberis julianae are mainly due to gaps in the hedges resulting from phytosanitary problems. On the other hand, Buxus sempervirens and Prunus laurocerasus demonstrate widespread drying and insect attacks.

The main influence of SF (Fig. 3d) is concentrated in specific traits close to POI_1, POI_2, POI_10 and POI_14.

The combination of all these factors leads to the economic value of the hedge. The unitary value (Fig. 3e) seems to be particularly affected by the presence of POI, as well as the height of the hedge, which directly determines the base price. In addition to these indices, the total value of traits is obviously influenced by the length (Fig. 3f).

To confirm the above considerations carried out with image analysis, a multiple regression was conducted. This analysis examined the statistical correlation between the economic value (both unitary and total) and hedge variables. The constant value of Equation 1, namely accessibility (A) and probability of attendance (T), as well as the base price (which is obviously correlated with economic value), were excluded from the evaluation. Depth was introduced to assess its potential link with the results, despite not being part of Equation 1. The statistical outputs are presented in Table 4.

The statistical analysis confirms the importance of length for total value quantification, as indicated by the very low adjusted R^2 in column "Total value – b", as well as p-value<0.05 and 0.01 in the "Unitary value – a" and "Total value – a" columns. In cases of potential significative correlation (see the adjusted R^2 values in columns "Unitary value – a", "Unitary value – b" and "Total value – a"), plant height emerges as the most important variable for determining both unitary and total value (p-value<0.01). The number of rows seems to be signifi-

Table 4. Statistical correlation among economic value and hedge characteristics.

Variable (symbol in brackets)	Unitary value - a[1]	Unitary value - b[2]	Total value - a[3]	Total value - b[4]
Lenght (L)	-2.17**	Not considered	10.05***	Not considered
Height (h)	3.74***	3.55***	2.73***	2.02**
Depth (not present in Eq. 1)	-0.78	-0.69	0.21	-0.08
Rows (R)	3.60***	3.42***	0.63	0.64
Density (E)	0.51	0.56	0.64	0.21
Vigour (G)	0.73	1.35*	1.82**	-0.65
Coverage correction (C)	1.65*	0.80	1.87**	1.62*
Special Factors (SF)	0.12	0.66	0.85	-1.06
Adjusted R^2	*0.59*	*0.57*	*0.67*	*0.17*

Note: [1]unitary value (€/m), "lenght" variable included; [2]unitary value (€/m), "lenght" variable excluded; [3]total value (€), "lenght" variable included; [4]total value (€), "lenght" variable excluded; *p-value<0.1; **p-value<0.05; ***p-value<0.01.

cant only for unitary value. Other correlations, such as those with the coverage correction factor and vigour, are medium or low. Depth is not relevant for the economic analysis. Statistics in Table 4 also reveal, contrary to visual evaluation, that Special Factors seem to be not significant for economic output, as well as density.

The sign correlation clearly confirms intuitive trends, also for the C index. Coverage negatively affects both unitary and total values (note that C=1 indicates the hedge is out of coverage).

5. DISCUSSIONS

The results of the study provide a total value of the hedges in the Cascine Park of 1,973,000 €. The findings highlight the significance of height in determining the economic value of hedges, particularly in terms of unitary value. Length, intuitively, influences total value positively. Its negative influence on unitary value may be due to the purchase cost of species and varieties (more expensive species could be planted in limited spaces, but this aspect should be investigated in future analysis). The number of rows also significatively influences the value. Depth was introduced in the analysis to test its influence in parametric approach; depth seems not to be correlated with V, allowing the focus to remain on height in field sampling and avoiding the inclusion of additional dendrometric variables. The absence of correlation between depth and V is probably due to low relation between depth and length. Depth depends in fact on the planting scheme and does not significantly vary during the lifespan. Other indexes, such as hedge vigour (G), seem to have a reduced impact on V, stressing the complexity of variables that can influence the importance of hedges. The G factor impacts the results through both phytosanitary diseases and gaps in plant coverage within a single trait. While this streamlined approach simplifies field sampling for operators, future adjustment to the approach may warrant splitting the terms to separately control both variables. In the case study area – in fact – two species with G values below the average score are mainly affected by unclear gap (Ligustrum sinense and Berberis julianae); other species are strongly influenced by pathogens. Buxus sempervirens presents extensive damage from box tree moth (*Cydalima perspectalis* Walker), one of the major factors causing injuries to the specie in Italy (Badano et al., 2019; Bella, 2013; Ferracini et al., 2022). Prunus laurocerasus has also been affected by health diseases in recent years (Marchi et al., 2011; Quaglia et al., 2014; Vettraino et al., 2016). Recent extensive damages occurring to species in urban greenery in the Florence-Pistoia metropolitan area puts the use of the species as hedge plants at risk (Biondi et al., 2022). A certain statistical significance for V quantification is also related to coverage (C).

The method used in this study can be applied to plan potential interventions for hedges management. The parametric application allows to define current and potential economic values of hedges, focusing on traits that could be managed to increase aesthetic appreciation. For example, Table 5 reports V quantified with current data and modified by setting the value of G at its maximum (1), indicating a hypothetical condition of optimal vigour.

The species most affected by pathogens, such as Buxus sempervirens and Prunus laurocerasus, reveal the highest gaps in economic value potential. However, in absolute terms, Viburnum tinus and Spirea japonica exhibit a greater delta from current to hypothetical values due to a combination of their G factor (0.72 and 0.59, respectively) and widespread diffusion. The good G score obtained by Quercus ilex (0.78) leads to a V differ-

Table 5. Comparison between current and potential value based on G factor.

Specie	V with current G (€)	V with potential G (€)	V difference (€)	V gap (%)
Berberis julianae	115,850	199,108	-83,257	42%
Buxus sempervirens	6,007	47,324	-41,317	87%
Laurus nobilis	200,902	251,253	-50351	20%
Ligustrum sinense	51,906	89,233	-37,327	42%
Myrtus communis	2,349	3,356	-1,007	30%
Prunus laurocerasus	72,511	196,756	-124,245	63%
Quercus ilex	538,549	63,1268	-92,719	15%
Spiraea japonica	375,394	593,444	-218,049	37%
Spiraea x vanhouttei	34,060	53,293	-19,232	36%
Viburnum tinus	575,856	797,836	-221,980	28%
Total	*1,973,385*	*2,862,870*	*-889,485*	*31%*

ence that is half that of to the previous species, despite accounting for 17% of the total hedge length.

The parametric method can also be applied for damage quantification. Following the appraisal state of the art, damage quantification in UGI is typically developed using a complementary approach. Total damage (D, expressed in €) is computed as:

$$D = (V - V^{*}) + X \quad (2)$$

where V is the value of hedgerow without damage, V^{*} is the value of damaged hedgerow, and X comprises extra costs (e.g., costs of felling and eliminating the old plant(s), expenses for the supply and planting of new subject(s), expenses for the work of arranging and preparing the land, expenses for the restoration of urbanization works and artefacts, and street furniture).

6. CONCLUSION

The presented study, to the best of the authors' knowledge, stands as the first parametric method available in international scientific literature for appraising the economic value of hedges in urban green areas. The model allows for the adjustment of financial index with dendrometric and additional factors, thereby incorporating aesthetic relevance into the economic evaluation. The parametric approach facilitates the sampling of hedgerows, allowing for expeditious economic evaluation, quantification of damage, and analysis of the potential convenience of management. In particular, the improvement of vigour and health conditions of individual traits, as well as the substitution or replacement of individual plants, can be assessed through the quantification of current and potential values, laying the foundation for cost-benefit analysis in urban green spaces.

In the case study area, the parametric approach was applied in combination with a desk phase based on web applications such as Street View and satellite imageries. These apps can favourite large-scale investigations (e.g., for an entire city or administrative area); however, the model can also be fully and easily applied through direct field sampling in individual public or private parks and gardens, allowing for a multiscale approach.

In large-scale analysis (e.g., evaluation of hedge for an entire city), some parameters could be quantified semi-automatically or through desk analysis and GIS. The class of rurality/urbanisation could be computed by classifying the real distance from the city centre or rural areas. The localisation of hedgerows on plein air or under the canopy cover of street trees/urban forest could be defined by merging the kernel density of trees and the distance from roads/paths.

For future evaluations, improvements, and modifications to the method, several enhancements can be considered. The proposed formula for calculating the value of hedges currently assigns equal weight to all parameters. Future refinements could involve adjusting these weights based on the subjective opinions of practitioners, stakeholders, or specific local conditions. Weighting of parameters could be developed through different techniques; among these, the Analytic Hierarchy Process (AHP) can be proposed and evaluated due to its wide application for scoring variables in decision-making problems (Saaty, 1990).

Another weakness of the approach, common to several parametric techniques, is the potential subjectivity in choosing the value of each parameter. However, among the variables proposed in Eq. 1, price (P), length (L), number of rows (R), density (E) and accessibility (A, based on private/public property of hedge) are clearly measurable and definable in an objective way. The parameter C considers trees coverage (hedge out of coverage, hedge under tree rows, or hedge under the canopy of tree groups); thus, through the analysis of the canopy projection onto the ground and the spatial distribution of trees, C can also be objectively defined. The probability of attendance of a specific place (T) combines population density and class of rurality, with the latter categorised based on its distance from the city centre. Special factors (SF) can be evaluated by the distance (or if included in a defined buffer) from relevant and important landscape, avenues, parks, places, buildings, commemorative or memorial hedges etc. (positive SF); negative SF can be assessed based on the presence or absence of impactful characteristics, as demonstrated in the case study.

In the case of updated image coverage (e.g. for Street View application), future lines of research should be directed to G factor quantification to decrease subjectivity in evaluation. The G variable could be extracted from screenshot of images, cut along hedge margins, and post-processed in image-editing software to compute the vitality of plants. One possibility is to quantify red, green, and blue waves length to compute greenness indexes (Grilli et al., 2022).

Seasonal variability in economic value, such as that observed in deciduous species for both hedges and trees, is not considered in this study, as it is assumed the potential irregularities in aesthetic value are already considered in the base price. Future research should address this aspect.

Moreover, applying the model in further areas and cities is recommended to analyse results under different geographical conditions and species. Even with suggested improvements, the model represents a valuable tool for policymakers, decision-makers, researchers, and practitioners in hedge analysis.

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Appendix A. Price list of sample points.

Sample point ID	Height (m)	Specie	Price (€/plant)
0	0.9	Viburnum tinus	34.00
1	0.9	Ligustrum sinense	16.00
2	1.7	Ligustrum sinense	30.22
3	0.9	Ligustrum sinense	16.00
4	0.7	Ligustrum sinense	12.44
5	1.95	Viburnum tinus	144.00
6	0.8	Laurus nobilis	7.00
7	1.75	Viburnum tinus	120.00
8	0.9	Ligustrum sinense	16.00
9	1.1	Ligustrum sinense	19.56
10	0.65	Laurus nobilis	5.06
11	0.7	Laurus nobilis	5.44
12	0.65	Laurus nobilis	5.06
13	0.6	Laurus nobilis	4.67
14	0.7	Viburnum tinus	16.50
15	1.5	Spiraea japonica	49.50
16	1	Spiraea japonica	33.00
17	0.4	Prunus laurocerasus	7.11
18	1.5	Spiraea japonica	49.50
19	1.5	Spiraea japonica	49.50
20	0.8	Laurus nobilis	7.00
21	0.8	Spiraea x vanhouttei	29.07
22	1.75	Laurus nobilis	30.00
23	2.5	Quercus ilex	92.00
24	0.8	Spiraea x vanhouttei	29.07
25	1.85	Spiraea japonica	51.05
26	0.8	Viburnum tinus	34.00
27	0.8	Viburnum tinus	34.00
28	0.5	Viburnum tinus	10.50
29	1	Viburnum tinus	51.00
30	0.7	Viburnum tinus	16.50
31	0.65	Viburnum tinus	16.50
32	0.8	Quercus ilex	10.00
33	0.75	Quercus ilex	6.80
34	1.85	Laurus nobilis	30.00
35	0.65	Laurus nobilis	5.06
36	0.65	Laurus nobilis	5.06
37	1	Laurus nobilis	12.50
38	0.55	Berberis julianae	16.92
39	0.6	Prunus laurocerasus	10.67
40	1.7	Prunus laurocerasus	50.00
41	0.5	Prunus laurocerasus	8.89
42	2.5	Quercus ilex	92.00
43	2.3	Quercus ilex	66.00
44	2.5	Quercus ilex	92.00
45	2.5	Quercus ilex	92.00
46	2.5	Quercus ilex	92.00
47	0.65	Berberis julianae	20.00
48	0.55	Berberis julianae	16.92
49	0.5	Berberis julianae	15.38
50	0	Prunus laurocerasus	0.00

Sample point ID	Height (m)	Specie	Price (€/plant)
51	0	Prunus laurocerasus	0.00
52	1.6	Laurus nobilis	20.00
53	0.65	Viburnum tinus	16.50
54	2.6	Quercus ilex	92.00
55	2.6	Quercus ilex	92.00
56	2.6	Quercus ilex	92.00
57	*0*	*flowerbed*	*0.00*
58	0.4	Prunus laurocerasus	7.11
59	0.6	Prunus laurocerasus	10.67
60	0.4	Prunus laurocerasus	7.11
61	2.5	Prunus laurocerasus	100.00
62	0.8	Myrtus communis	34.00
63	0.7	Spiraea japonica	23.10
64	0.65	Spiraea japonica	21.45
65	0.9	Spiraea japonica	29.70
66	0.8	Viburnum tinus	34.00
67	0.9	Viburnum tinus	34.00
68	0.6	Viburnum tinus	16.50
69	2.3	Quercus ilex	66.00
70	0.9	Viburnum tinus	34.00
71	2.4	Quercus ilex	66.00
72	0.8	Quercus ilex	10.00
73	0.55	Quercus ilex	5.34
74	0.7	Buxus sempervirens	24.95
75	0.4	Viburnum tinus	6.20
76	0.45	Viburnum tinus	6.20
77	0.45	Viburnum tinus	6.20
78	0.85	Quercus ilex	10.00
79	1.7	Viburnum tinus	120.00
80	1.5	Viburnum tinus	120.00
81	1.3	Quercus ilex	24.00
82	1.85	Spiraea japonica	51.05
83	1.75	Spiraea japonica	57.75
84	0.9	Prunus laurocerasus	16.00
85	0.8	Prunus laurocerasus	16.00
86	1	Spiraea japonica	33.00
87	0.5	Prunus laurocerasus	8.89
88	2.3	Laurus nobilis	50.00
89	0.65	Prunus laurocerasus	11.56
90	1	Spiraea japonica	33.00
91	0.8	Spiraea japonica	26.40
92	0.65	Laurus nobilis	5.06
93	0.8	Viburnum tinus	34.00
94	1.5	Laurus nobilis	20.00
95	0.85	Viburnum tinus	34.00
96	1.9	Ligustrum sinense	33.78
97	1	Ligustrum sinense	17.78
98	0.5	Buxus sempervirens	17.82
99	0.5	Buxus sempervirens	17.82
100	0.5	Buxus sempervirens	17.82
101	0.7	Laurus nobilis	5.44

Sample point ID	Height (m)	Specie	Price (€/plant)
102	0.5	Laurus nobilis	3.89
103	0.9	Laurus nobilis	7.00
104	1.7	Ligustrum sinense	30.22
105	0.9	Ligustrum sinense	16.00
106	0.7	Laurus nobilis	5.44
107	0.65	Viburnum tinus	16.50
108	1.6	Viburnum tinus	120.00
109	0.7	Viburnum tinus	16.50
110	0.8	Buxus sempervirens	28.51
111	1.1	Spiraea japonica	36.30
112	0.55	Quercus ilex	5.34
113	0.7	Viburnum tinus	16.50
114	0.6	Viburnum tinus	16.50
115	0.8	Quercus ilex	10.00
116	0.95	Spiraea japonica	31.35
117	1.1	Viburnum tinus	51.00
118	0.5	Viburnum tinus	10.50
119	0.65	Quercus ilex	6.80
120	0.7	Quercus ilex	6.80
121	1.2	Spiraea japonica	39.60
122	1.1	Spiraea japonica	36.30
123	1.1	Spiraea japonica	36.30
124	0.75	Spiraea japonica	24.75
125	1.1	Spiraea japonica	36.30
126	0.8	Spiraea japonica	26.40
127	1.7	Ligustrum sinense	30.22
128	0.4	Ligustrum sinense	7.11
129	2	Spiraea japonica	66.00
130	1.85	Quercus ilex	66.00
131	1.85	Laurus nobilis	30.00
132	2.5	Laurus nobilis	85.00
133	0.9	Ligustrum sinense	16.00
134	0.6	Ligustrum sinense	10.67
135	0.95	Viburnum tinus	34.00
136	0.9	Viburnum tinus	34.00
137	1	Viburnum tinus	51.00
138	0.6	Viburnum tinus	16.50
139	1.8	Viburnum tinus	132.92
140	1	Viburnum tinus	51.00
141	1.8	Viburnum tinus	132.92
142	0.7	Viburnum tinus	16.50
143	0.95	Viburnum tinus	34.00
144	0.75	Viburnum tinus	16.50
145	1.85	Spiraea japonica	51.05
146	0.95	Viburnum tinus	34.00
147	1.8	Viburnum tinus	132.92
148	0.65	Viburnum tinus	16.50
149	0.8	Laurus nobilis	7.00
150	0.9	Laurus nobilis	7.00
151	0.65	Laurus nobilis	5.06
152	2.3	Ligustrum sinense	40.89