The Impact of Different Tree Planting Strategies in the Piazzas of a Northern Italian City

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Abstract

Achieving urban sustainability goals, and improving the quality of life in cities, are aided by the careful selection of tree species for public green spaces. Numerous trade-offs and synergies are necessary to consider when selecting tree species for successful public green spaces. In this transdisciplinary research we consider the impacts of nine different tree planting scenarios, as modelled with i-Trees, in three piazzas of Bolzano, North Italy. The scenarios consider the opinions of the general public gathered from focused workshops and data collected via a purposefully created smartphone application. Shade provision and aesthetics were the primary factors that influenced citizen tree preferences. Scenarios which included larger tree species generally performed the best due to the greater provision of ecosystem services that arises with larger tree dimensions. Ecosystem disservices also increase with larger trees but can be minimised by careful species selection. Public participation in the planning of urban green spaces can be a beneficial activity which ensures new planning outputs will be well-received whilst providing opportunities for education of citizens about the multiple ecosystem services and disservices in urban contexts.

Introduction

Urbanisation is associated with many adverse environmental impacts which can form the basis of public health issues in cities (WHO, 2010). There is currently a burgeoning body of research demonstrating how increasing the proportional cover of greenspace (trees, green roofs, green walls) can ameliorate these problems. The benefits which greenspace provides for humans are known as ecosystem services (ES), or nature-based solutions (Lafortezza et al., 2018). These ES include removal of air pollution via passive filtration (Beckett et al., 1998), providing local cooling through shading and evapotranspiration (Speak et al., 2020), and interception of rainfall runoff (Livesley et al., 2014). Increasing the quantity and quality of urban greenspace brings with it a multitude of benefits which work to improve the livability of cities and enhance urban resilience to threats such as climate change (Kim and Lim, 2016).

The widespread implementation of successful urban greening initiatives has several obstacles to overcome. Most importantly, there is a lack of cheap, available land in cities and trees often require maintenance in order to survive in an environment which presents challenges (Salmond et al., 2016). Next, different urban tree species do not provide the same ES at the same magnitude, and the ES do not benefit all urban residents equally. There are often trade-offs to consider when selecting tree species, for example a species such as *Gleditsia triacanthos* has a pleasing aesthetic due to its attractive foliage and flowers, however it does not provide much shade (McPherson, 1984). Trees also have a number of ecosystem disservices (EDiss) to factor in, which are controversial negative aspects arising from the complexity of ecosystems in an urban setting (Lyytimäki, 2015; Von Döhren and Haase, 2015). These include allergy-inducing pollen production, and the emission of Biological Volatile Organic Compounds (BVOC) which can be the precursor to ground level ozone pollution in cities with consequent negative respiratory effects (Calfapietra et al., 2013).

There is thus a need for highly thought-out public green spaces which consider the trade-offs, disservices, and co-benefits with planning issues (Salmond et al., 2016). It follows that there is a need for research which considers the impacts of different species choices and demonstrates how a little experimentation in tree planting strategies can reap diverse benefits. Single issue modelling studies need to be incorporated into work that considers the bigger picture, and investment in green infrastructure needs to assimilate evidence-based research on the multiple biophysical and social processes whilst remaining relevant to human decision making.

A further issue to consider is the current low level of involvement of the public and stakeholders in urban tree planning and management processes (Alam and Lovett, 2019). As the main users and beneficiaries of these spaces, they are the actors who have vested interests in the design, use and protection of public green spaces. Scientific lists and planning frameworks should not be the only sources consulted during the planning phase, and the voices and perspectives of communities should be integrated into the process (Salmond et al., 2016). This is especially important in the light of concerns around environmental justice and inequalities in access to urban green space, which raise questions around for whom urban greening is carried out (Sister et al., 2019).

Participatory urban green planning as well as transdisciplinary research for sustainable cities has gained momentum in the past decades (Pauleit et al. 2019, Pogačar et al. 2019). These approaches comprise an integration of urban residents into the identification of current research questions, involving them in the research process, and deriving recommendations for the practice of urban planning together with actors and stakeholders. Participatory and transdisciplinary tools and methodologies have been developed for these particular purposes by the social sciences (e.g., Parker et al. 2020).The governance of urban green spaces can be improved by participatory approaches (Alam and Lovett, 2019), and this can be a two-way process which educates citizens and encourages the participation of actors who previously felt excluded from the process. The public are generally unaware of the full range of benefits that greenspace provide, with education being key to the acknowledgement of tree services (Fernandes et al., 2019). Citizens frequently cite shade and cooling as a benefit but neglect to mention spiritual or biodiversity aspects (Lohr et al., 2004; Ordóñez et al., 2016). Opening people to the full range of benefits through education will increase participation and protection of green space (Pauleit et al., 2019).

At the municipal level, data are often not available to practitioners, and all indicators of ES and EDiss are rarely covered in city greening programs. Cities tend to make pragmatic decisions based on limited indicator sets (Carmen et al., 2020) with feasibility of planting schemes related to costs and local contexts being key. Maintenance costs of urban trees rather out prioritise their value for the urban ecosystem and human wellbeing (Kronenberg, 2015). Methods are needed therefore to demonstrate the multiple benefits of different combinations of species, in real-world settings whilst also considering the EDiss which may be linked to certain decisions. Traditional urban forestry tends to follow conservative guidelines, with little room for experimentation, resulting in for example, monospecific plantings of low maintenance tree species.

There are a number of tools available to researchers and urban forestry practitioners which facilitate the quantification of ES, often translating these benefits into a financial metric useful to greenspace practitioners restricted by budgets. In particular, the i-Tree suite of applications (www.itreetools.org), developed by the USDA forest service are well known (Nowak and Crane, 2000). They use tree inventory data to quantify an array of ES and EDiss and the statistical models are based on peer-reviewed literature and empirical data from reference cities in different climate zones across the United States, with support added recently for worldwide regions. i-Tree has been used for a variety of research outputs such as assessing the benefits of vacant land (Kim, 2016), modelling air pollution reduction in different planting scenarios (Jayasooriya et al., 2017), and estimating the carbon sequestration potential of urban forests (Boukili et al., 2017; Russo et al., 2014). It is particularly suited for modelling the projected future impacts of tree-planting schemes and quantifying how the ES increase as the trees approach their mature size (Nyelele et al., 2019; Parsa et al., 2019). It has been used by municipalities worldwide to communicate the benefits of existing urban forests such as in Campbelltown, Australia (Seed Consulting Services, 2018), and London, United Kingdom (Rogers et al., 2015). In fact, the very process of using i-Tree has the added benefit of educating urban forest managers about the multiple benefits they provide (Raum et al., 2019).

In the present study, part of the greenCITIES project, we consider a large number of different tree planting scenarios in three piazzas of the City of Bolzano in Northern Italy. The scenarios are designed as realistically as possible and also include input from public consultations and stakeholder workshops. By means of a smartphone application, the opinions and preferences of city residents are also incorporated into the research methodology. The aim of this inter- and transdisciplinary research is to test how simple models and consideration of different approaches to tree planting can aid in the coordinated implementation of urban greening programs which target certain ES while simultaneously considering the EDiss.

Methodology

Study site

The study was conducted in the City of Bolzano in the Autonomous Province of South Tyrol in northern Italy. The city has a population of 107,000 inhabitants (Ufficio Statistica e Tempi della Città, 2018) and green areas cover around 3.9 % of the city's extent, which provides about 20 m^2 of greenspace per inhabitant (Chiesura and Mirabile, 2012). Bolzano has a moist, continental climate (Köppen classification 'Cfb') characterised by hot summers.

Three piazzas were chosen as the focal point of the study (Fig. 1). These spaces represent the local range of urban greening from very low to relatively high greening percentage. Piazza Domenicani has few trees which are mostly of a small size. Piazza Mazzini is a public space in two halves, divided by a busy road, with a grassy park area and a paved area with a row of small trees. Piazza Vittoria has a large park area with many tall trees and a paved car-park area. At the time of writing, Piazza Vittoria was the subject of discussion in the city because the car-park area was due to undergo conversion into an underground car-park. The future use of the surface area was debated as local interest groups wanted the area to become a green area with reduced traffic and more opportunities for social activities.

Smartphone data collection

A smartphone application was created specifically for this study with the aim of gathering voluntary data from citizens and tourists in Bolzano using the MIT (Massachusetts Institute of Technology) App Inventor (MIT, 2020). The MIT App Inventor is a free to use visual programming environment for creating applications for Android smartphones and tablets. The app, which was named 'BZcomfort', was available to download for Android devices only, from summer 2018. An advertisement campaign using social media, radio and printed flyers was undertaken to maximize the number of participants downloading the app and generating data for the study. The app consisted of a series of questions related to the urban trees of Bolzano, available in the three common spoken languages of the region – Italian, German and English. The questions were:

- What is your favourite urban tree species?
- Do you feel thermally comfortable outdoors in Bolzano in the summer?
- What is it that is appealing about a location in Bolzano that you like to visit on hot, sunny days?
- Is there anything negative about the urban trees in Bolzano?
- Do you have any suggestions for improving the urban forest in Bolzano?

In addition, there were questions to ask the user how well-informed they feel about climate change, urban heat islands, and how important they feel trees are in cities. No demographic data was collected.

Scenario models

The piazzas were visited in summer 2018 and the trees were measured according to the i-Trees methodology (Nowak et al., 2008; i-Tree Eco, 2017), thus creating a base scenario. The measurements included diameter at breast height (DBH), tree height, crown width, height to crown base, percentage canopy missing and crown condition, and light exposure. Species information was available from the online public tree inventory maintained by Bolzano municipal gardens department (Comune di Bolzano, 2020).

In addition to the base scenario (scenario 1), nine theoretical tree planting scenarios were constructed for each of the three piazzas, thus resulting in 30 separate scenarios for modeling. Scenario 2 was a random selection of the popular species as declared by the users of the app. Scenario 3 used tree species with the provisioning ES of food production (fruit and nuts) as there is a growing trend of using urban spaces for growing food (Park et al., 2019). The trees in scenario 4 were chosen for their high Leaf Area Index (LAI), and thus high shade provision, based on measurements made on over 70 species in Bolzano (Speak et al., 2020). Scenario 5 used species which were found to simultaneously provide relatively high ecosystem services and low ecosystem disservices in a study in the nearby town of Meran (Speak et al., 2018). Trees often planted in Bolzano for their high ornamental value (tree crown shape, spring flowers, leaf shape, autumn leaf colour) formed the basis of scenario 6.

Native species growing in the local natural environment chosen from a forestry report (Comune di Bolzano, 2019) constituted scenario 7, because people often perceive native species to be superior to non-native trees in cities (Goodenough, 2010). Scenario 8 replaces the piazzas with parks, using common species from the existing parks in the city, as determined from the municipal tree inventory.

Scenarios 9 and 10 come from participatory research undertaken with schoolchildren, local residents and other stakeholders, respectively. Students from two schools were invited to visit the piazzas and then undertake a mapping exercise in which they developed and presented their ideas for how the piazzas should look in the future. In addition, a public event was undertaken in April 2019 by a citizen-focused activist group called *Lab:BZ* (www.labbz.it), comprised mainly of architects, planners and designers, who wished to influence the transformation of the city in a direction which addresses the concerns and desires of citizens of Bolzano. The event was attended by local residents and business owners in addition to the greenCITIES project researchers and the aforementioned professionals. Participants were encouraged to draw plans for their ideal use of the space, indicating suggestions of which tree species they would use. Informal interviews with participants, discussing their experiences with public consultations regarding urban planning in Bolzano, were also recorded.

A major limitation for the species chosen for scenario 10 was the fact that the proposed space for planting is above an underground carpark and therefore species were constricted to those with shallow root systems of 2 m. A summary of the planting scenarios is presented in Table 1 and the lists of trees and diagrams of the planting patterns used in the scenarios can be found in the supplementary material.

All scenarios consider the feasible tree density allowed by the spaces with respect to current infrastructure, apart from scenario 8 for Domenicani which imagines the whole piazza as a park, and scenario 9 for Mazzini which removes the road and unites the two halves into one park.

Table 1

– Details of the nine theoretical tree planting scenarios for the modeling of the three piazzas

Scenario	Name	Description
2	Popular	Favourite tree species as indicated by the app data collection
3	Edible	Tree species which produce fruit or nuts
4	Shade	Tree species with high leaf area index (LAI) for high shade
5	Max Ecosystem Service	Tree species which simultaneously have high ecosystem service and low ecosystem disservice, based on Speak et al. (2018)
6	Ornamental	Tree species with a high ornamental/aesthetic value
7	Local	Tree species which grow in the local area of South Tyrol (N Italy)
8	Park	Species and planting which mimics a local park
9	Children’s plan	Domenicani – 3 *Fagus sylvatica*, 2 *Prunus avium*
		Mazzini – Remove the road and create a large park with broad mix of species including *Ginkgo* and *Cedrus*
		Vittoria – Mix of species mostly chosen for aesthetic value
10	Stakeholder’s plan	Domenicani – broad mix of species chosen for size
		Mazzini – broad mix of species chosen for size
		Vittoria – *Tilia* for shade and an avenue/pergola of *Wisteria*

The trees for all the scenarios were chosen at random from pre-defined lists (Supplementary material), apart from scenarios 8 and 9 which followed specific planting schemes culminating from discussions within the workshops, and scenario 1, the current situation. Piazza Domenicani represents a space where the existing trees are replaced. Piazza Mazzini represents a space where the existing trees on the paved half are replaced and the trees on the park half are kept. The scenarios for Piazza Vittoria do not replace any base scenario trees but just replace the paved area next to the small but dense park area.

All scenarios were modelled as full inventories using the i-Trees ECO software (version 6). Average heights, DBH, crown width and height to crown base for each species were estimated from a database of 6,371 trees measured in the nearby City of Meran (Speak et al., 2018). Therefore, the scenarios are recreating spaces with mature trees and not simulating a real-world scenario of planting young trees. All trees were assumed to be in 100 % condition and have a crown light exposure value of 5 (the maximum used in i-Trees). Weather and pollution data from 2015 were used in the i-Trees models.

The i-Trees outputs used to compare scenarios were carbon storage and sequestration, air pollution capture, rainfall runoff retention, and BVOC production over the course of a year. Tree crown volumes were calculated by initially imagining each crown to be a cylinder with crown width as the diameter and tree height minus the height to crown base for the crown height. This volume was multiplied by 0.33 for trees in the pinales order which are treated as a cone shape with a third the volume of the cylinder. Deciduous crown volumes were treated as an ovoid with 2/3 the volume of the cylinder. These volumes were used to calculate leaf area density (LAD) by dividing the leaf area (an i-Tree output) by the volume, as used by Scholz et al. (2018). This tree trait was used as a proxy for shade cooling as the LAD is strongly related to ground surface cooling under the tree (Speak et al., 2020). A second estimate for the cooling potential was taken using the two-dimensional canopy cover, calculated from the crown widths and treating each tree as a circle. This was represented as a percentage of the total area of the Piazza and can be considered a measure of the quantity of shade, whereas the LAD is a measure of the quality of the shade. The crown volumes were also used to estimate fruit production, for fruit-producing species, by using the crown volume as a proxy for fruit quantity and giving non-fruit-producing trees a value of 0.

Finally, the ecosystem disservice of pollen production was quantified by using the 1–10 Ogren Plant Allergy Scale (OPALS) which considers the allergenicity of the pollen alongside the amount produced, length of the pollen season, and specific gravity of pollen grains (Ogren, 2015).

As the ES and EDiss are measured on different scales, a re-scaling step was included using the following formula:

$$I = \frac{\mathrm{x} - \min\left(\mathrm{X}\right)}{\max\left(\mathrm{X}\right) - \min\left(\mathrm{X}\right)}$$

where *I* is the rescaled indicator value, x is the tree variable value and X is the entire range of x. The rescaled indicators have values between 0 and 1 and this method is beneficial for dealing with variables with extreme values, however it can increase the range of variables with low variation (Freudenberg, 2003). The ES and EDiss variables in this study tend to be highly skewed, as they are strongly linked to the tree crown size, so this rescaling approach is appropriate.

Code was written using R version 4.0.2 (R core team, 2020) which selected fixed numbers of trees randomly from the scenario lists and summed and averaged (sum divided by the number of trees) the ES and EDiss scores. This was repeated 10,000 times and the average of all the runs and the best-performing combination of species for each scenario and study site were extracted. The random simulations were not required for scenarios 1, 9 and 10 as these represent the baseline and the two citizen-designed spaces which are invariable. For Piazzas Mazzini and Vittoria, the trees in the existing park areas were added to the simulations. Finally, to compare the scenarios with the base situation, the ratio of the summed scores of the scenarios to those of the baseline was calculated. ES and EDiss were treated separately. A value greater than one indicates an improvement in the average per-tree provision of ES, and a value less than one for EDiss indicates the species combination has less negative impact than the baseline situation.

Results

Public survey

A total of 57 people took part in the tree survey using the smartphone app. The proportions of response categories can be seen in Fig. 2. Half the respondents reported Bolzano as a hot city in the summer. The main preferred outdoor space by far (74 % of responses) was the Talvera park, a large park next to the city centre. Shade was the most reported characteristic of a preferred outdoor space with fresh air and breezes coming next. Shade was also an important factor determining the favourite urban tree species of respondents; however, aesthetics was the most common. Many respondents declined to list any negative perceptions of the urban forest, however, those that did reported a broad range of EDiss with small trees and trees with little shade being recognized as less desirable. Planting more trees, choosing appropriate species, leaving old trees, and planting taller trees and fruit trees were offered as suggestions for improving the urban forest of Bolzano.

Figure 3 reveals that the majority of respondents believe themselves to be at least a bit well-informed about climate change issues, whereas the topic of UHIs appears to be less well-known. The majority of respondents agree that trees are important elements in cities.

Scenario models

Looking at the averaged results in Fig. 4, and the ratios in Fig. 5, some differences between the scenarios and piazzas are evident. The scenarios in Vittoria score relatively higher than the other two piazzas because of the presence of the park area with many large trees. The poorest performing scenario was the edible tree one, however, this scenario also produced the lowest EDiss, especially BVOC production. The stakeholder plan for Piazza Vittoria also scored very low in ES due to the sparse planting pattern and inclusion of *Wisteria sinensis* which does not score well in various ES categories, despite being a very attractive tree due to its growth form and flowers.

The scenarios with the highest average scores for Domenicani and Mazzini are the popular tree, park tree and stakeholder plans. The popular tree and park scenarios also produced the highest scoring combinations of trees (Fig. 4b), and also high scores in EDiss. The ratios reveal that most scenarios outperform the base scenario in these two piazzas, while only the popular and park scenarios were able to outperform the base scenario for Vittoria, and only using the best-performing combination of species. The EDiss of the new scenarios in Piazza Domenicani are generally higher than the baseline scenario as the baseline situation consists of *Aesculus x carnea* and *Magnolia obovata* which are low pollen and low BVOC producers.

In terms of actual changes in the ES and EDiss we can compare the best performing scenario (Scenario 2 – popular species) with the baseline scenario (Table 2). The improvements, as represented by growth factors, are considerable, especially for Piazza Domenicani where carbon storage, pollution removal and canopy cover all increase by at least one order of magnitude (alongside increases in average pollen score and total BVOC production).

Table 2
– Comparison of annual ecosystem service and disservice provision between the baseline scenario and the popular species scenario. Rainfall runoff expressed as a financial equivalent calculated by i-Trees

	Domenicani			**Mazzini**			**Vittoria**		
	Baseline	Scenario 2	Factor	Baseline	Scenario 2	Factor	Baseline	Scenario 2	Factor
Ecosystem services									
Carbon storage kg	437.1	18800.6	43	7736.90	25096.9	3.2	27432.70	48532.4	1.8
Carbon storage kg m^{-2}	0.11	4.59		1.45	4.70		3.91	6.91	
Carbon sequestration kg $year^{-1}$	70.2	314.8	4.5	214.5	484.2	2.3	570.7	869.9	1.5
Avoided rainfall runoff €	0.07	0.56	8	0.42	0.89	2.1	1.23	1.92	1.6
Pollution removal g $year^{-1}$	483.9	6377.6	13.2	3576.9	9500.4	2.7	10359.60	17651.2	1.7
Canopy cover m^2	117.8	1400.54	11.9	660.5	1291.2	1.9	1471.9	3066.6	2.1
Canopy cover %	2.8	34.2		12.4	24.2		20.9	43.7	
Average Leaf area density m^2 m^{-3}	1.97	0.63	0.3	1.81	1.16	0.6	1.19	0.99	0.8
Fruit production m^3	0	0		0	0		0	0	
Ecosystem disservices									
Pollen Ogren scale	4.8	6.1	1.3	7.1	6.2	0.8	5.8	5.5	0.9
BVOC g $year^{-1}$	10.5	8105.26	771.9	1707.8	9869.7	5.8	6162.10	16129.9	2.6

Discussion

The use of a smartphone app to collect data on citizen attitudes to urban forestry generated some interesting results despite the relatively low number of respondents. It is a cheap and rapid way to get both an overview of the level of knowledge of citizens regarding tree services and disservices, and an indication of the importance attached to them by considering the response frequencies. For example, as in other studies, tree shade was revealed to be the most reported reason for visiting public green spaces (Lohr et al., 2004), and shade was second in importance in determining a favourite species. Unsurprisingly, when asked to name a favourite species, aesthetics was the most reported, as visual interaction is the primary method of engagement with nature and defines initial relational experiences (Ordóñez et al., 2016). The more abstract, less visible, services, such as rainfall retention and air pollution reduction, would not factor into a person's choice of favourite tree. People frequently named one tree in particular as their favourite, such as a large, monumental *Platanus acerifolia* which is the first thing one sees upon leaving Bolzano train station, and had connotations of 'home' for some respondents. This exemplifies the strong personal bond which people can feel for trees.

Tree disservices mentioned were mostly related to the lack of provision of shade by small trees, and physical impacts such as damage to infrastructure, branch-fall and the removal or over-pruning of damaged or overgrown trees. With regards the last point, some respondents specifically lamented the lack of communication from the municipality with regards to removal of older trees, which citizens often feel emotionally attached to. Suggestions for improvement of the urban forest mostly included a call to plant more trees, and to leave older trees. Some specific suggestions were made about species choices, such as avoid planting female *Ginkgo biloba* trees to prevent the foul-smelling fruit, and plant more tall conifers in parks.

The app responses also revealed that urban heat islands are a less well-known phenomenon than climate change. This reinforces the idea that education of the general public is advisable on the specific benefits of urban trees such as cooling urban microclimates. Most respondents recognized the importance of trees in cities but the results hint at the possibility that knowledge of the multiple reasons why may be limited. These knowledge gaps can be addressed by environmental education in cities. Besides school and university education for sustainability, community-based stewardship (Tidball and Krasny, 2010) or civic ecology practices, such as focal practice of urban ecosystem restoration (Higgs 2003) and community gardening can add to a better understanding of environmental patterns and processes by the public.

The mapping exercise with schoolchildren and the workshop with stakeholders and citizens revealed that the inclusion of trees as a means of improving the public spaces was very important. It was felt that the piazzas should become meeting places, with facilities such as cafes, benches and playgrounds to facilitate the use of the spaces by as many different groups of people. The planting of trees and increasing green space was integral to making the piazzas lived spaces and revitalizing local businesses. The feedback from the workshop and stakeholder interviews revealed criticism of the past behaviour of the City Council's Buildings Commission because they rejected any proposals made by the public. The piazzas Vittoria and Domenicani, in their current forms, were seen as suffering from neglect and degradation. Stakeholders were often playful and provocative with their proposals for the spaces, which reflects a frustration with the inability of the city to break free from its past and incorporate the views of citizens. (Solly, in press)

Dissemination of the results of the modelling work presented in this study might be one way to demonstrate the multiplicity of ES and EDiss associated with public green space. The models experimented with a wide range of scenarios with different themes and species mixes and showed how this can produce variability in the provision of ES and EDiss. It can be used to show urban forestry practitioners the potential impacts of changing or augmenting existing public spaces. Existing dense park areas with large trees (Piazza Vittoria) proved hard to beat in terms of ES provision. This underlines the importance of protecting the valuable resource of old trees in cities (Lindenmayer et al., 2014). When the trees in the baseline scenario are small, such as with the *Magnolia* trees in Piazza Domenicani and the *Gymnocladus dioicus* in Piazza Mazzini, improvements in ES provision are easily achieved in the model scenarios with huge increases in carbon storage, and tree canopy cover (Table 2) for example. It is worth noting that in Piazza Domenicani, for scenarios 4 (shade) and 6 (ornamental), the new planting scenario only improved on the baseline scenario when the optimal mix of species was modelled. This shows that if a goal of tree planting is to maximize ES provision, then careful consideration should be given to the species and quantities. On the flipside of this, the EDiss also increased greatly in Piazza Domenicani with respect to the baseline situation, reaffirming the need for judgements regarding trade-offs. BVOCs become an issue when combined with hot, summer weather and car exhaust fumes, so perhaps planting high BVOC emitters in pedestrian zones would lower the potential impact locally, notwithstanding the fact that BVOCs can be transported by winds. The selection of trees that maximize ES and minimize EDiss (scenario 5) generally worked in all three piazzas to improve on the baseline situation relatively.

It is fortuitous that the popular species mix of scenario 2 was generally the best scenario, therefore, maximizing ES provision whilst increasing the frequency of the favourite trees of citizens. This is mostly because the popular trees tended to be the potentially larger species (*Pinus, Platanus, Quercus, Tilia*) and the provision of ES (and EDiss) is tightly bound to high leaf biomass (pollution capture, rainfall retention, shade) and tall trunks (carbon storage). We are not advocating handing over the control of urban tree planting programs to the general public, and basing tree inventories on favourite species, but more suggesting a system in which the public are free to become more involved in the process after receiving state-of-the-art information on the pros and cons of available species.

The challenge now is how to incorporate environmental decision-making tools such as i-Trees into urban tree management practices. i-Tree outputs are often mentioned in internal reports and external forums but rarely influence funding increases or changing tree policies (Raum et al., 2019). However, there is a strong practitioner desire for prescriptive templates in decision making, that consider financial aspects (Salmond et al., 2016) as municipal budgets are often limited so maximising ES and minimising costs is the current model.

Improvements and suggestions for future research

The use of smartphone apps for gathering data is a quick, economic and creative method of gathering data, however it limits the pool of respondents not only to those with smartphones but to those that are inclined to take part in volunteered research, which tend to be young and female, and most likely to have an extravert personality type (Stachl et al., 2017).

i-Trees is a good tool, allowing the multiple ES and EDiss to be modelled, but it can ignore the subtleties of influencing factors such as sensitivity to light exposure and species classification (Pace et al., 2018). For this reason, it is not advised to use it for research which relies on a high level of precision and accuracy of outputs. As a tool for a holistic appraisal of the benefits of urban forests it is unsurpassed and future research could elaborate on its and its use as an educational tool for practitioners. In the present study, we modelled the piazzas with mature trees based on average empirical dimensions. An improvement on this would be to gather information on the size of nursery trees which are used for new plantings and model the increase in ES and EDiss over time until the trees reach maturity.

Conclusion

In this paper, we have tested a number of tree planting scenarios informed by real world considerations such as food provision or the opinions of city residents. Differences in the potential provision of ES and EDiss between the scenarios reveal that a little experimentation on the part of municipalities can produce considerable beneficial impacts down the line, that help to achieve urban sustainability goals. The general public often feel strongly about the green space in the places that they live and there need to be systems in place which allow the participation of well-informed citizens in the process of selecting trees for the successful planning of urban green spaces.

Declarations

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Conflicts of Interest

There are no conflicts of interest to declare

Availability of data

The data will be available as supplementary material and any further data requests will be answered personally

Code availability

Not applicable

Authors contributions

Andrew Speak – concept development, fieldwork, data analysis, writing

Leonardo Montagnani – concept development, manuscript checking

Hillary Solly – fieldwork, writing

Camilla Wellstein– concept development, manuscript checking

Stefan Zerbe – funding application, concept development, manuscript checking

Ethics approval

The research was approved by the University of Bolzano faculty council in a letter dated 26.01.2017

Consent to participate

All users of the smartphone app agreed for their data to be used for the purposes of research. The smartphone app was anonymous and no personal data were recorded.

Consent for publication

All authors give full consent for publication

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Figures

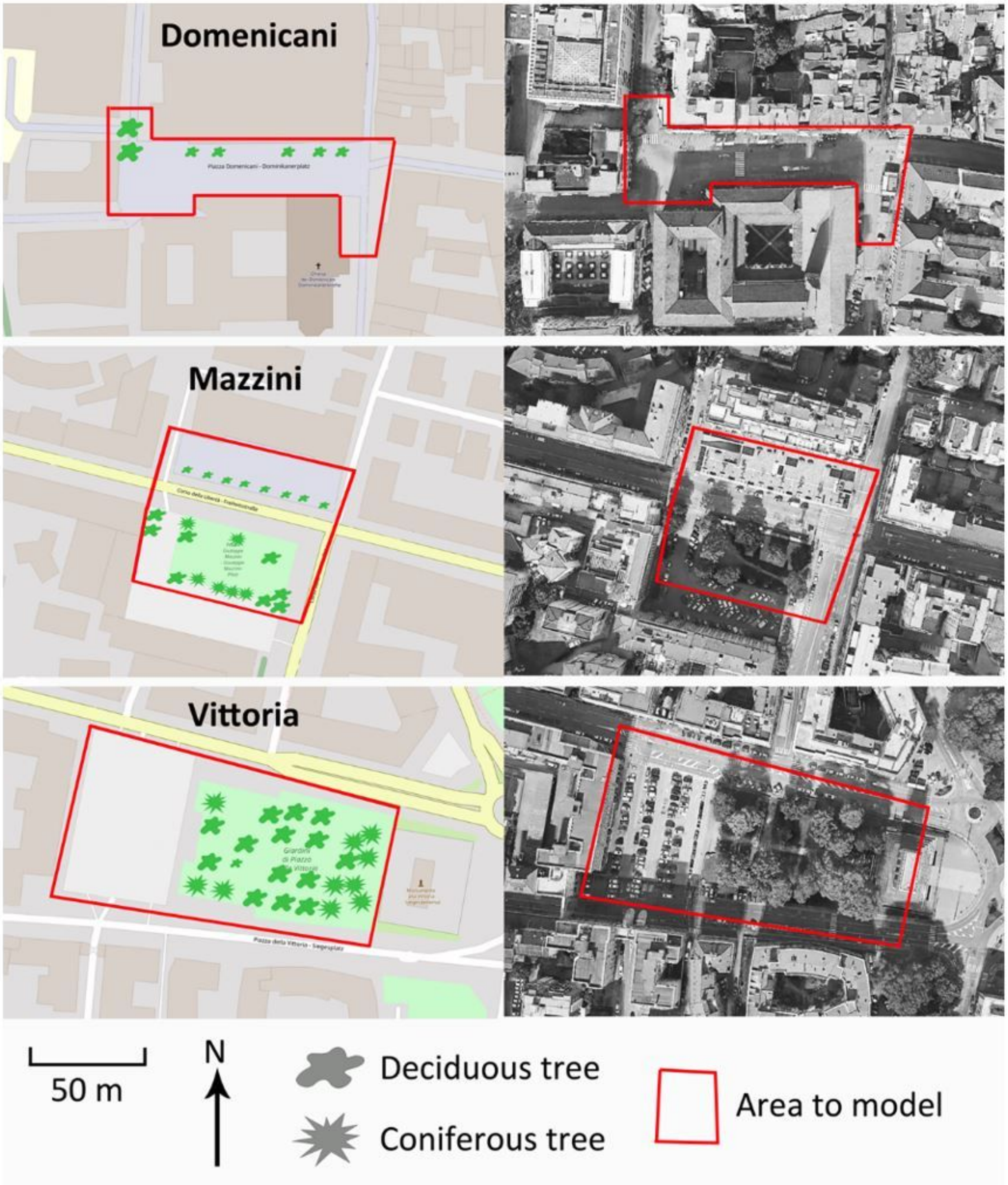

Figure 1

schematic diagrams (using openstreetmap as a base) and aerial views (GoogleEarth) of the three study sites in the City of Bolzano

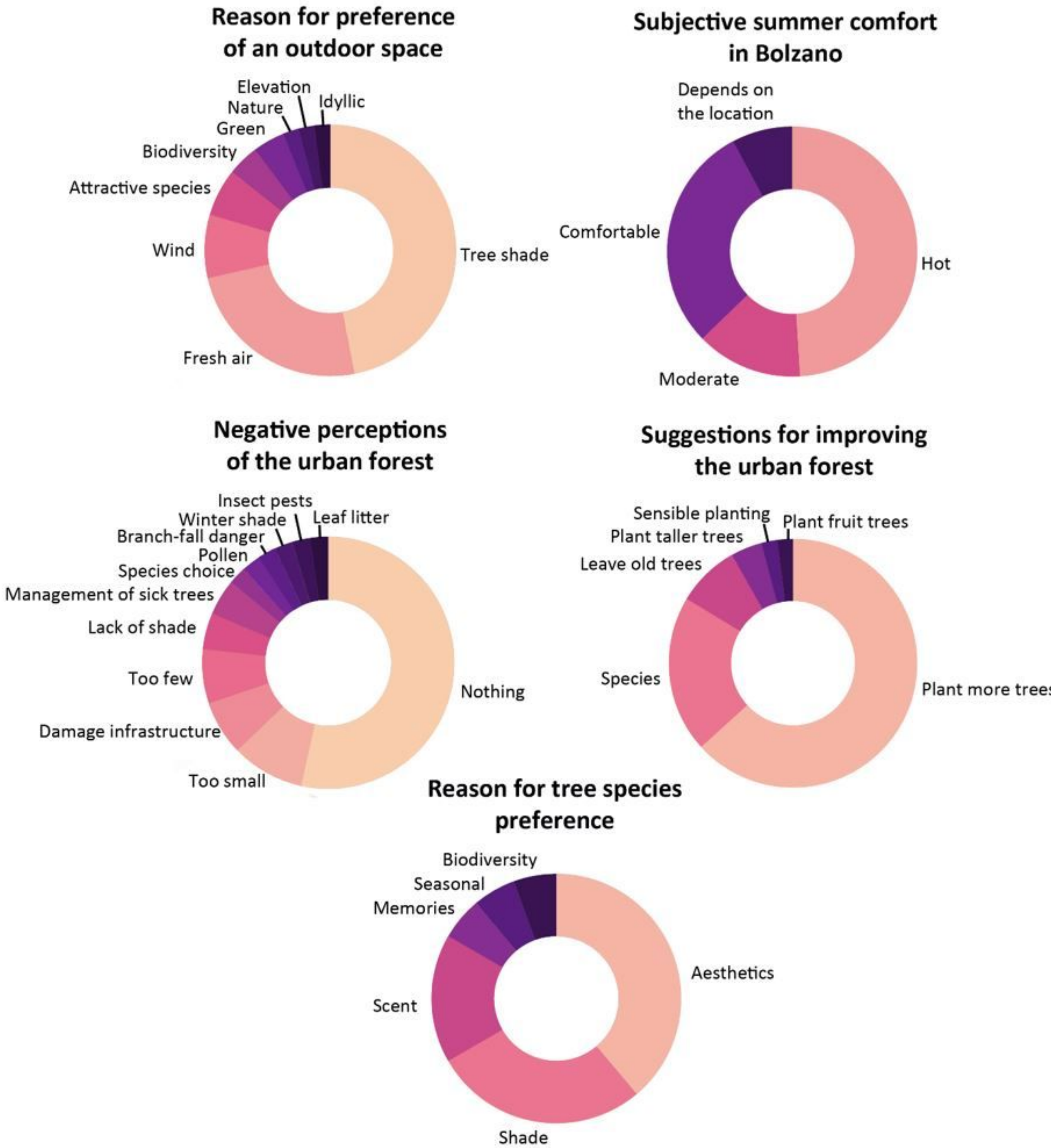

Figure 2

Response frequencies of the categorized questionnaire responses.

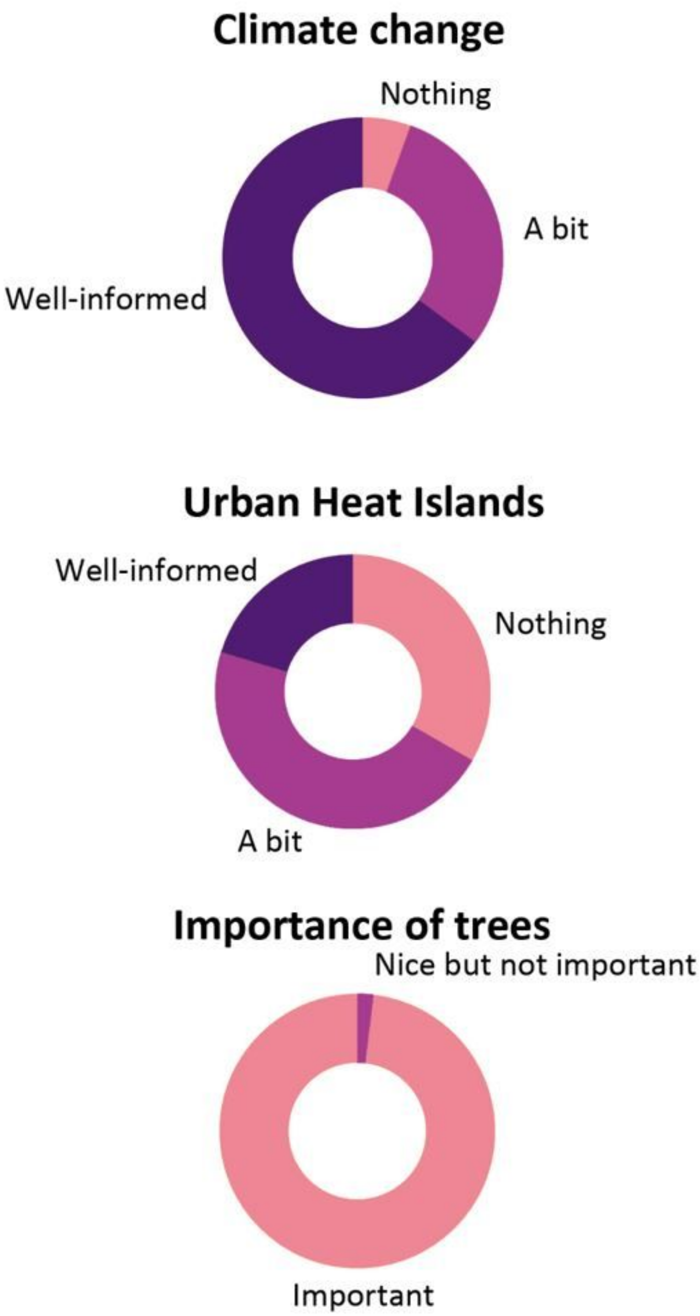

Figure 3

Response proportions for self-reported knowledge level of climate change, urban heat islands and the importance of trees in cities.

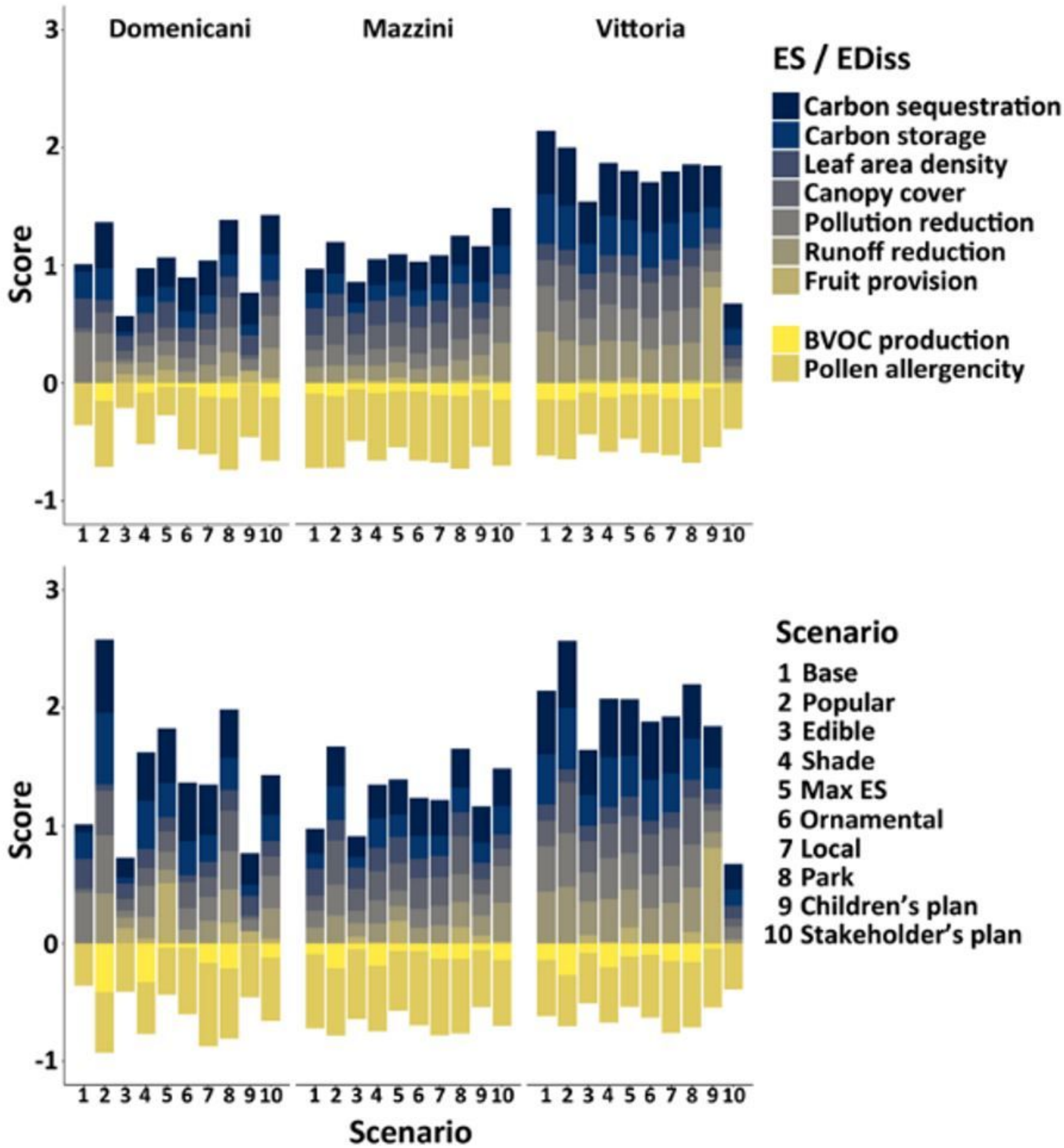

Figure 4

a) Average and b) best-performing scores for each scenario modelled in the three piazzas.

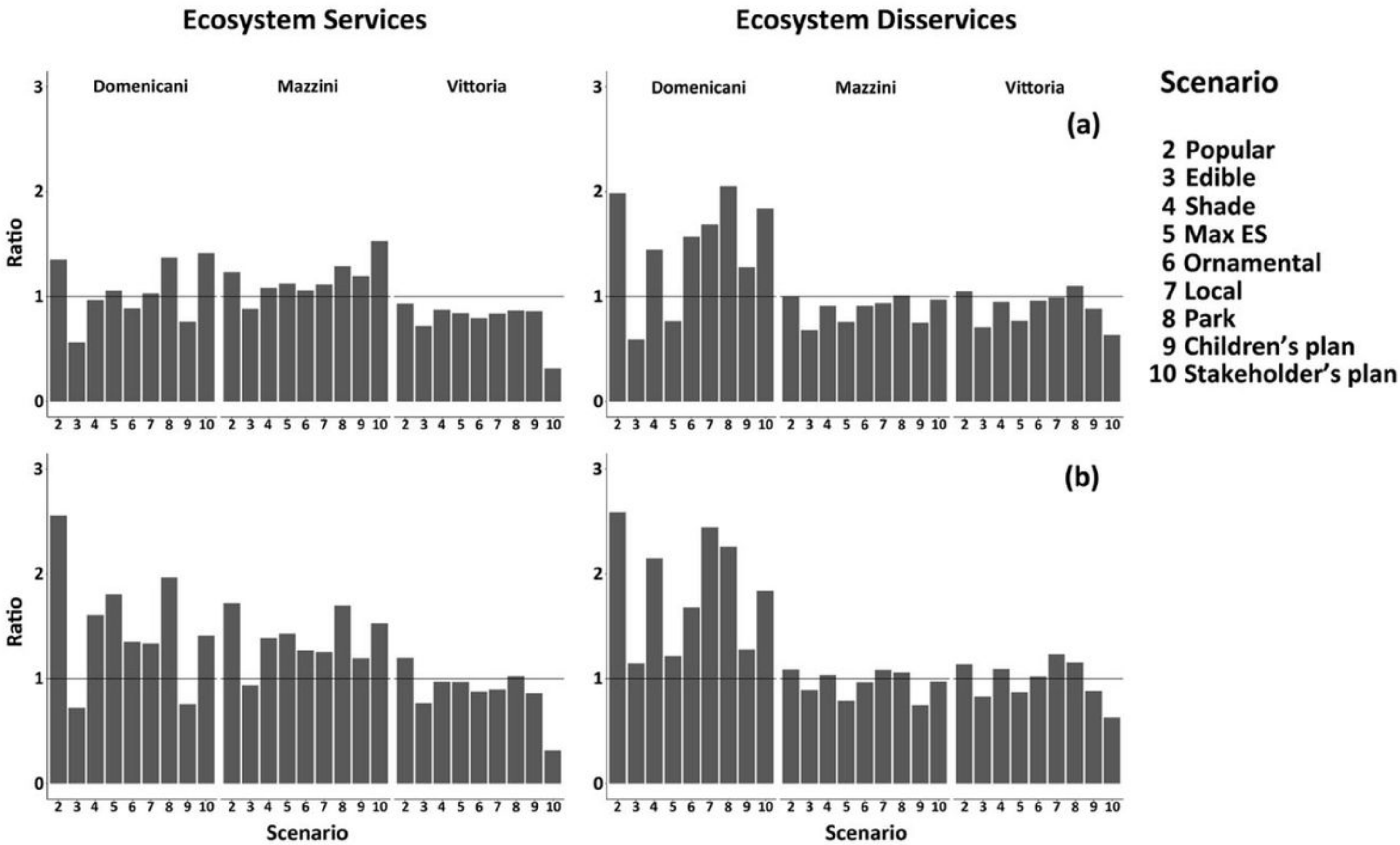

Figure 5

Ratios of each scenario to the base scenario for a) average and b) best performing model outputs

Supplementary Files

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