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Flexible, open-source programmes and estimating projections of urban tree benefits: A case study in Amherst, MA

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Inventories of urban tree populations and affiliated analysis software are valuable, contemporary tools in use by municipalities across the globe. While software that allows users to explore the values and benefits of discrete urban tree populations may be readily available, capacity to model and project tree growth is limited. Using existing urban street tree inventory data from Amherst, MA (USA), a generic platform for tree growth modelling was developed to be implemented by the user at the source code level, called "Xylem". Agile programmes like this provide a fast-working, extensible platform to generate tree growth projection data that can be delivered efficiently to the end user. The Amherst case study offers an example of how programmes written in Python 2.7 have application and can be readily customisable, to add value to existing tree inventory data.

Keywords: agile; diameter at breast height; DBH; growth; inventory; programme; projection; Python 2.7; silviculture; Xylem

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Introduction

There is ongoing effort to better understand growth behaviour of trees in urban forests worldwide (Leibowitz, 2012). Since the early 1990s, non-linear regression models have been used in an attempt to better predict urban tree growth behaviour (Frelich, 1992). While more information exists about trees growing in traditional forests, the diversity of the urban ecosystem makes much of this knowledge inapplicable (Rogers, Lawrence, & Hutchings, 2012). Cities themselves are, after all, dynamic (Cadenasso & Pickett, 2008). They feature vegetation succession, widespread site disturbance and intensive management practices that make urban tree growth less predictable than trees growing in plantations or traditional forests.

Urban tree growth modelling is not a mature science (Rogers et al., 2012), and accepted methodologies risk becoming obsolete with emerging research. Popular tree growth projection techniques use well-researched strategies at the cost of being unable to evolve as new prediction models emerge. In this manuscript, tree "projection" is used in reference to the estimation of future tree diameter (i.e. diameter at breast height or DBH) growth increase based on urban tree growth rates estimated by tree-specific inventory information.

With burgeoning urban populations and increasing interest in urban greening initiatives (McHale & Lefsky, 2009), urban tree inventory maintenance is recognised as a necessary part of effective urban planning (Bond, 2013). With a current tree inventory,

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programmes like i-Tree Streets offer understanding into air quality, heating/cooling and aesthetic benefits of tree populations (i-Tree Streets Manual Version 5, 2015). i-Tree Streets, and similar analysis programmes, quantify complex interactions between urban trees and man-made structures that provide benefits to the community (i-Tree Streets Manual Version 5, 2015). Curating inventories and using analysis tools like i-Tree Streets is accepted practice for appraising forests, but tree growth projection remains a critical – and often missing – component of effective long-term urban forest management.

Computer-based technologies, and the affiliated need for programming, are becoming increasingly integrated into every workforce sector (Griffiths, Mackey, & Adamson, 2007) including the urban forestry profession. For decades, computer programmes have been used by conventional foresters to maintain data pertaining to tree inventories (Belcher, Holdaway, & Brand, 1982). With the progression of technology, automated tree projection and analysis has evolved. The profession has observed the development and application of empirical growth models in programmes like i-Tree, Lindenmayer-Systems, L-PEACH and STEMS (Belcher et al., 1982; McPherson & Peper, 2012). These programmes vary widely in utility, application and efficacy.

STEMS was developed when the theory of growth projection and tree benefit analysis for forest stands was in its infancy. In the late 1970s, inventory procedures and growth/yield models for select tree species groups were established, but a programme to analyse and simulate dynamic and varied forest stands was needed (Belcher et al., 1982). STEMS' purpose, as with subsequent programmes, was to improve management practices relative to long-term planning and resource evaluation (Belcher et al., 1982). Using an empirical model, one module of STEMS projected current forest resource levels (from an inventory) by simulating planting, growth, harvest and death of single trees within the stand. A second programme printed a plot-specific summary of the inventory both before and after projection (Belcher et al., 1982).

i-Tree is a suite of several programmes relative to urban forest inventory, projection and analysis. Like STEMS, it uses empirical models of growth behaviour; field measurements are collected and data are analysed to simulate urban tree growth (McPherson & Peper, 2012). i-Tree Eco and i-Tree Design both make use of a tree growth projection model. The data for this "tree growth projector" are largely derived from Kansas, MS and Minneapolis, MN, but incorporates information from other regions of the United States also (McPherson & Peper, 2012).

Lindenmayer-Systems or "L-Systems" provide a mathematical visualisation of tree growth and branching (McPherson & Peper, 2012). Applicable to nine deciduous tree species in California, L-Systems can accurately model decades of growth and produce an animation of what that tree may look like (McPherson & Peper, 2012). L-PEACH is another related programme that utilises 3D working models of trees to simulate growth in different environments. L-PEACH simulates interactions with a network of trees and their individual resource usage, and has generated successful predictions of growth based on water and nutrient uptake (McPherson & Peper, 2012). While the scope may be limited by tree species and geographic location, the success of these programmes that simulate such complex processes may have widespread application in the future.

Tree growth projection in Amherst, MA

Our research in Amherst, MA, involves the structured development of new tree projection programmes. The programming is performed in Python 2.7., a well-known,

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easily understandable programming language that is readily compatible with the MS Excel tree inventory data spreadsheets. Documentation, existing research and empty Xylem projects can be found in the open-source code base. The Python programming language, relative to tree projection, lends itself to small, simple programmes that can be developed to meet the requirements of the end user (i.e. urban forester). To ensure quality and speed of development, choosing the right software engineering strategy is critically important. Agile software design is a modern development strategy; paramount in Agile development are interactions between individuals, customer collaboration and response to change to create a software product that produces satisfactory results for the end user. Another feature of this type of development is small, incremental releases that are approximately 2–4 weeks apart (Begel & Nagappan, 2007; Williams, 2007).

The creators of STEMS remarked decades ago, "most of these models have been restricted to one or a few (tree) species groups in a relatively narrow geographical region" (Belcher et al., 1982). Contemporary urban ecologists are demanding "evaluation programmes that go beyond narrowly focused assessment … to encompass a variety of regional climates, growing conditions, and management regimes" (McPherson & Peper, 2012). The utility and application of research on urban tree growth modelling are widespread. This research is becoming more important as urbanisation expands, and regulations and policies demand a holistic planning process that encompasses a broad number of concerns, including those that are environmental (McPherson & Peper, 2012). A greater understanding of urban tree growth is necessary for successful urban planning in the twenty-first century, and an essential component related to performing an automated tree projection. Better understanding of urban tree growth yields insight into how different management scenarios can affect urban tree health, and the affiliated environmental and economic services provided by urban tree populations (McPherson & Peper, 2012). By modelling and projecting growth trends, urban forest investments may be made with more certainty in a manner that minimises tree maintenance costs and maximises urban tree-related benefits (Rogers et al., 2012).

The purpose of this research was to (1) create a programme to estimate future urban tree growth using tree inventory data from several sources in Amherst, MA; (2) gain a greater understanding related to the affiliated ecosystem services accrued as trees age and increase in size; and (3) explore the feasibility of making this application widely available, using Agile, open-source programming.

Methods

The open-source Xylem urban tree projection programme executes an urban inventory tree growth projection using street tree inventory files and a growth rate table. It has the capacity to forecast inventories for a given number of years into the future, as trees increase in size. The idea for Xylem (i.e. Xylem Amherst) originated when the Tree Warden for Amherst, MA, requested an urban forest status report using current tree inventory data. Growth rates were synthesised from i-Tree Design and data from analysing tree growth projections with i-Tree Streets were incorporated into a municipal urban forest technical report. i-Tree Design features peer-reviewed growth modelling strategies but would be arduous to use on a large number of trees. A second version of Xylem (i.e. Xylem_UMass) was developed utilising the urban forest inventory data from the University of Massachusetts campus (Amherst, MA). In this instance, a more sophisticated growth projection was fabricated which related % DBH increase to DBH and growth classification (Coder, 1996). A third iteration of Xylem (i.e. Xylem_AOP) was

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developed using a blank “Archetype” file, which captured useful elements of the structure of Xylem_UMass. Xylem_AOP operated on an inventory of 48 research oak (*Quercus bicolor*; *Q. rubra*) street trees located in Amherst, MA (Amherst Oak Project or “AOP”). To demonstrate how easily changes could be made within the structure of Xylem, growth rate data from the original Xylem programme were reused to carry out the projection on the oak species inventory.

The objectives of Xylem are to: (1) use existing urban tree inventory data to perform tree growth projections; (2) offer flexible ways to create a projection instead of utilising a static projection method; (3) use Agile development practices to release quality software quickly; and (4) progress alongside, and aid in the interpretation of, the expanding pool of knowledge concerning urban forestry and urban ecology.

In keeping with the pillars of Agile development, a feedback loop between all involved parties was prioritised. The original Python projection programme centred on the requirements of the Tree Warden, the software design of the developer and the synthesis of growth rates by the researcher. When the third Xylem programme was developed, the gap between client request and initial software release was only a few days, compared to the initial time period of 4 weeks. By collaborating with other entities in acquiring and utilising the most up-to-date inventory and growth data, the programmer must use each inventory entry as an input, apply tree growth and write the resulting entry with the projected DBH to the new, projected inventory. These inventories are analysed using i-Tree Streets, so interested parties may learn about the projected future benefits of their urban forest.

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Analysis

The Xylem programmes developed in the Amherst case study (Xylem_Amherst, Xylem_UMass, Xylem_AOP) are comparable to one another by the ratio of usable inventory entries to total entries, their programme efficiency and based on what specific inventory data are consulted in order to modify tree growth projection. Xylem_Umass made improvements to most of these metrics and introduced new features and structure beyond what was found in the prototype, Xylem_Amherst. This structure was cohesive enough so that when the UMass-specific rates table and projection routine were stripped away, the Xylem_Archetype (Python) file remained, so future Xylem programmes could be easily developed. Xylem_Archetype was integral in the creation of its successor, Xylem_AOP.

The Town of Amherst street tree inventory featured 37,320 entries stored on an MS Excel (.xls) document. The necessary information to perform an urban tree growth projection existed in only 6303 entries (<6%). The remaining (unusable) entries simply consisted of a Tree ID, date of most recent update and a status update indicating if the tree was new, existing or if a planting was planned for the future. A necessary artefact needed to carry out a tree growth projection analysis for the usable entries was tree growth rate data. Growth rates that generalised growth behaviour in cm/year for the 118 tree species in the Amherst urban forest were retrieved from i-Tree Design. The Python 2.7 tree projection programme then iterated through each entry in the inventory, determining the amount of projected growth from the generalised growth rates and modifying (i.e. scaling back) that growth based on deadwood and trunk condition. The desired growth rate (cm/year), was achieved by sampling each species and projecting 10 years of growth in i-Tree Design. The measureable growth was divided to get a generalised value of growth/year, as per Nowak and Bodine (2013).

The University of Massachusetts Amherst (i.e. UMass) tree inventory featured 5395 entries, of which 92% were usable (Table 1). A growth table was employed which related annual % growth to DBH and growth increments per cm (Coder, 1996). Xylem_Umass introduced several enhancements compared to the Xylem_Amherst prototype. Xylem_Amherst considered only years of growth, but Xylem_UMass afforded users the option to set the name of the working inventory file, as well as which columns the information required for projection (e.g. ">Which column is the LOCATION RATING? AA..."). Additionally, to ascertain the rate of growth, Xylem_Amherst consults data from solid-state memory (the hard disk) while Xylem_UMass maintains this data table in main memory (RAM). The table is loaded once, from an Excel file and used until the user terminates the programme; this accounts for significant gains in efficiency as RAM is more quickly accessed than information on disk (Dahlin & Anderson, 2012).

Due to the progress and cohesion of Xylem_UMass, a "blank slate" version was created for application by other urban foresters with their own tree inventory and growth rate data who would wish to create their own Xylem programme. Use of the Xylem_Archetype aligns with the goals of Xylem, offering a platform for future tree growth projection programmes that can utilise previous growth data, as well as current data. The final programme produced for the Amherst case study originated as the Xylem_Archetype. The inventory for the Amherst Oak Project was the smallest of all three, consisting of only 48 oak trees. The programme was given a hardcoded rates table with growth rate data from Xylem_Amherst (instead of being housed in an external file and read from disk/memory). Changes to validity checks and growth table accesses were made to accommodate the old projection method. Following these programming steps, all other modifications to runtime behaviour could be made through the *setup* command accessible from the command line.

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Table 1. Characteristics of runtime behaviour of two Xylem programmes.

	Xylem_Amherst	Xylem_UMass
Growth table metric (g)	Growth rate (cm)/year (by species)	Growth %/year
Access pattern	Species	*X*-axis: Growth rating by plot type, condition and location rating *Y*-axis: DBH
Modifiers($o_{1...}o_n$)	• Deadwood • Trunk condition	None
Usable entries	16.9%	92%
Running time	414 entries/s*	900 entries/s*
Runtime options	• Years	• Years • Species column • Name column • DBH column • Condition column • Location column • Growspace column • Spreadsheet file name

*Notes: Measured on an Intel i7 quad-core 2.9 GHz processor, 8 GB RAM.

Essential to performing a tree growth projection is the Python 2.7 programming language. The Python programme opens and reads the Amherst street tree inventory, runs through each entry performing a number of tasks, saving the projection data to a new spreadsheet after outputting the number of usable entries. At each inventory entry, one of two subroutines is executed. If the entry is deemed valid by having a populated DBH value in the cell, a projection is carried out in four steps: (1) A growth rate for the species of that row is determined by consulting an external file with all growth rate data; (2) A deadwood modifier for projected growth is determined based on the "DEADWOOD" column for that entry; (3) A similar modifier is determined for "Trunk Condition" (Table 2 for more information on steps 1–3); and (4) The growth rate (cm/year) is multiplied by the number of years entered by the user, giving generalised projected growth, which is then multiplied by the two modifiers (the aforementioned steps 2 and 3) to yield the final adjusted amount to be added to DBH. The projected DBH is printed to the new inventory and all other fields are reprinted as they were in the original tree inventory. If the row is deemed invalid, it is simply reprinted without executing the projection routine.

At their core, the execution steps of Xylem_UMass mirror the read-project-write loop of Xylem_Amherst but noteworthy changes to the projection and write routines were made to achieve a more efficient design. Since invalid entries used for Xylem_Amherst were numerous, a strict set of conditions was instituted to test

Table 2. Inventory data used in Xylem_Amherst DBH projections.

Component	Information	Use in Programme
Table (rates.txt)	A map of tree species featuring rates of growth. A list of tree species names was generated by finding all unique names in the "Common Name" column − 118 total. Tree species growth rates were identified using i-Tree Design. Rates appeared as a value (centimetres per year) and were the average 10 years of growth in i-Tree Design	The programme identifies values in rates.txt for each entry, locating a match for the name. The corresponding rate is fed back into the programme to be processed further
Deadwood	Tree experts were consulted during the development of the tree growth projector, to see which fields may be most pragmatic to modify growth and refine projections. Growth was scaled back based on amount of deadwood present	The inventory maintains deadwood as one of four percentage ranges which are mapped to a modifier for projected DBH • "<25%" DBH not modified • "25–50%" 10% of predicted growth is removed • "50–75%" 15% removed • ">75%" 25% removed
Trunk Condition	If a tree's stem has been compromised, the programme anticipates slower growth. In consultation with experts, the developer decided to only deduct from growth for the worst conditions of trunk condition	Trunk condition is kept as a single word identifier. Twenty-five per cent of projected growth is deducted if condition is "Poor"

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Town of Amherst	*University of Mass*
GROWTH_Table[species] => growth rate(in/yr)	GROWTH_Table[DBH][growth rating] => annual percentage growth

for inconsistencies in the UMass tree inventory. Checking for the availability and proper formatting of species name, common name, DBH, condition and location fields help to safeguard from reprinting entries unusable for analysis, or from a programme crash.

Valid entries enter a loop that for n years applies annual percentage growth n times. Determining annual percentage growth means accessing a two-dimensional array of values where the x-axis = DBH, and the y-axis = growth rating. Similar to the way Deadwood and Trunk Condition modifiers for the town of Amherst reduced generalised growth by species, Xylem_UMass used inventory fields to give each tree a low growth rating (higher annual growth) or a high growth rating (less annual growth). Plot type, specific tree condition and location appraisal are processed to approximate the growth rating, representing tree vigour (Coder, 1996).

There are 13 distinct ratings (ranging from 0 to 12) that an entry can be assigned (Table 3). To give each of the 13 growth rate categories an even chance of being picked for a random tree, each characteristic can increase the index by a number from 0 to 4. Thus, the minimum index for an urban tree growing in "ideal" conditions is 0 (0+0+0) and a tree growing in very adverse urban growing conditions might receive an index of 12 (4+4+4). To ease the process of formatting projected inventories for use with i-Tree Streets, the write routine was changed so that invalid entries were ignored, and no longer reprinted (examples and documentation available at https://github.com/gmarkv10/Xylem).

Table 3. Inventory data used in Xylem_UMass DBH projections.

	Information	Use in Programme
Growspace	According to tree experts, available growing space for trees is an important limiting factor. Thirteen unique designations for growspace were identified with each being assigned a value or a range of values between 0 and 4	Example growing space descriptions: 0 = "unrestricted" no obvious trees growth restrictions 4 = "street tree" restricted growing space and compaction present 2 or 3 = "landscape island" where space limitations may vary widely
Condition	Condition is maintained numerically in a range from 0 to 100 to quantify the overall well-being of a tree. Five ranges of conditions were assigned to values between 0 and 4	A high median was found in the set of Condition data so "0" was reserved only for trees with a condition higher than 90. Cut-offs for ratings occur at 70, 50, 25 and 0
Location	Location assesses the immediate surroundings of the urban tree. Location is handled in a similar manner to Condition	A high median was found for Location ratings also, thus the cut-offs started at 89 for a 0 and so on for 74, 49 and 0. A value of 3 is not possible since there was so little below 50 that if an entry did not meet the last cut-off, it was simply assigned a 4

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Results and discussion

The original programme written for the Town of Amherst was an exercise in using Python 2.7 as a means to project tree growth. Input from a research consultant was instrumental throughout the development process, relative to understanding and synthesising urban tree species growth rates from i-Tree Design. Similarly, consultations from a silvicultural consultant in the development of the Xylem_UMass programme were crucial in determining how tree growth vigour may be quantified and analysed based on inventory data.

Xylem_Amherst had the most entries, the lowest usable entries ratio and the worst runtime statistics. Only approximately one in six entries was usable since many trees from the Town of Amherst inventory had missing elements (i.e. species, DBH). Beneficial information was still gleaned from the usable entries and conclusions were reached relative to how Amherst's urban forest ecosystem services might appreciate. Using growth rates from i-Tree Design, inventory data and input from collaborators, the analysis regarding projections for Amherst's urban forest showed an increase in overall urban forest benefits of 30.6% (Figure 1) over 20 years (a value of $119,596). Over that time, storm water abatement would increase the most at 50.6% (a value of $21,388). The two biggest contributors, energy savings and aesthetic benefits, were also projected to appreciate growing by 36% ($62,399) and 14% ($20,281), respectively. The unusually high number of incomplete entries had no noticeable effect on the usability of Xylem_Amherst. They were, however, a contributing factor precluding the reprinting of invalid entries in subsequent versions of Xylem, since warnings and error messages occurred more frequently when formatting and analysing the data with i-Tree Streets. Initial delivery of Xylem_Amherst, however, did stymie usability as installing the necessary libraries (xlrd and xlwt) to work with the MS Excel spreadsheets was challenging for end users with limited computer knowledge. As a result, detailed instructions for initial setup were included in the documentation.

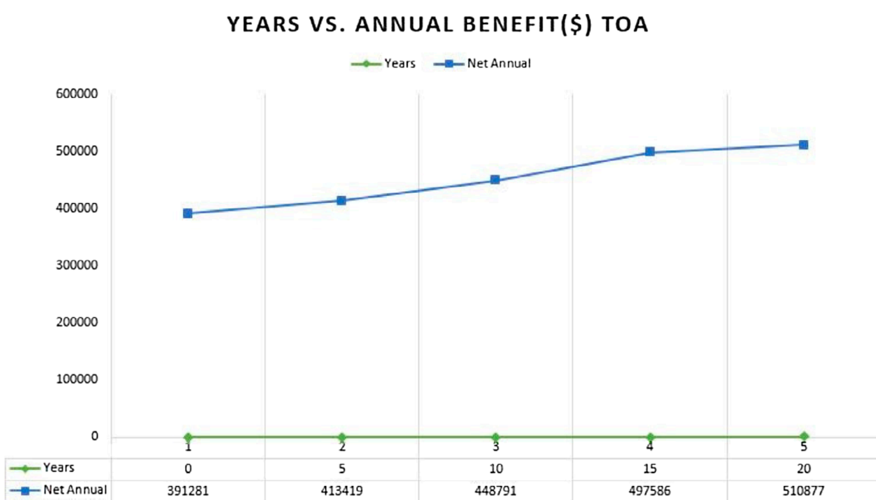

Figure 1. Analysis on Town of Amherst projections with Xylem_Amherst (0–20 years) showing an upward trend of 30.37% over the course of 20 years.

When Xylem_UMass was drafted, we desired a new projection method to prove the concept of adaptable design. By configuring Xylem_UMass to access a table on annual percentage growth (Coder, 1996), we learned that a radically different set of data on growth behaviour could be utilised to make projections. A silvicultural consultant helped determine a suitable method that accounted for a tree's growing location (e.g. sidewalk planter, landscape island, etc.). Projection analysis performed on the UMass campus tree inventory depicted that storm water run-off reduction would increase by 21.6% (a value of $10,186) over the next decade. Improvements to air quality (i.e. pollution abatement, emissions reduction from energy savings) (i-Tree Streets Manual Version 5, 2015) were projected to increase by 20% (a value of $7028) and while aesthetic benefits are a large contributor to the urban forest's value (34.2% or $17,000), they were only projected to improve by 1.7% (a value of $2857). UMass inventory entries were more complete than the Amherst entries and 92% were usable. After learning about accessibility issues for inexperienced users in Xylem_Amherst, the prompt was made more usable by adding a file, which stored a configuration for Xylem_UMass. The *setup* command allows end users, without programming experience, the ability to reconfigure a Xylem programme without viewing or altering the code. Ultimately, the more well thought out structure of the Xylem_Amherst prototype led to the idea of the Archetype programme.

To carry out a comparative tree projection analysis between Xylem_Amherst and Xylem_UMass, a 1000 tree sub-sample from the Town of Amherst tree inventory was analysed. Slight modifications were required: a *setup* command was run to reconfigure the programme to examine the appropriate columns, and the subroutine that determines growth class was altered to compare location, condition and plot type with values that appear in the Amherst inventory (instead of UMass). An i-Tree Streets analysis of the tree population sub-sample demonstrated that 10-year projections by Xylem_Amherst and Xylem_UMass were within a close margin (about 4%) of one another, relative to $/tree values (Figure 2) with small variations. Xylem_Amherst predicted a 20.3% increase in CO_2 sequestration, but Xylem_UMass projected only a 14.4% increase, a difference of 5.9% (mean diff. = 3.6%). The programmes, projected inventories and

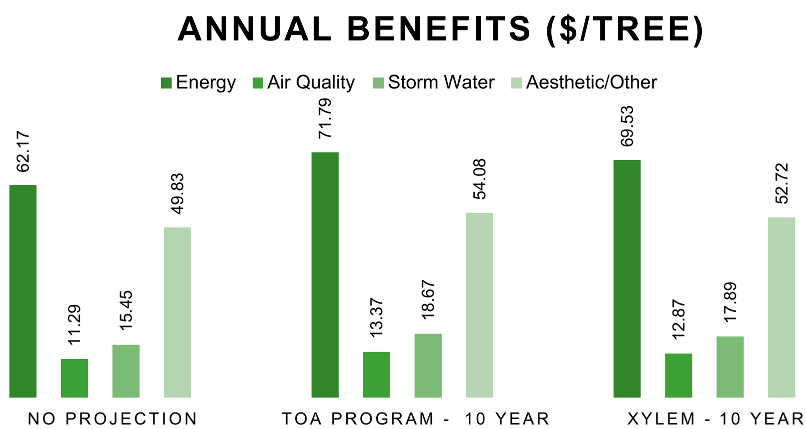

Figure 2. Benefits given on an analysis of a set of 1000 urban trees with no projection, a projection with Xylem_Amherst and a projection with Xylem_Umass.

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relevant i-Tree Streets files can be found in the ToA Comparison folder in the online Xylem repository.

The Xylem_Archetype was created to ensure the useful elements gleaned from the first two programmes were accessible when carrying out future tree projections. We learned that by removing the chain of method calls from the main projection loop, UMass-specific inventory variables and the growth table, we could make a blank Xylem programme on which to base future projects. We discovered in its initial use with Xylem_AOP that a "bare-bones" Xylem programme, urban tree inventory and growth rate data could be developed into a legitimate tree growth projector in less time than simply starting over. The Amherst Oak Project programme also provided insight into the ease of introducing previously used projection methods to a new application. Since the newly planted research specimen trees comprising the Amherst Oak Project inventory were so young, improvements for carbon sequestration were shown to be as high as 733% over 10 years (an increase in value from $3 to $22). For that reason, Xylem_AOP was the only programme where projected CO_2 sequestration benefits showed the most improvement. The Xylem_AOP forecast of the Amherst Oak Project research trees projected a 40.9% improvement in aesthetic benefit, which is still relatively high compared to Xylem_Amherst's 14.4% and Xylem_Umass' 1.7% increase. Reasons may vary, but aesthetic benefits may be consistently lowest when compared to other benefit increases because tree species has a greater influence on increased property value than tree growth. The reprinting routine was reworked for a final time in Xylem_AOP. After learning that unusable entries posed an obstacle in processing inventories for i-Tree Streets, Xylem_UMass stopped printing unusable rows. Xylem_AOP took this a step further and stopped reprinting unusable columns; thus spreadsheets produced by Xylem_AOP only included condition, species and DBH. Apparently, the closer the projected inventories can be to the accepted formatting standard found in the i-Tree Streets documentation, the higher the quality of analysis.

With each new programme in the Xylem suite, the concept of a flexible urban tree growth projector was further refined. Lessons learned from the original Xylem_Amherst programme led to the more efficient, more usable, but deliberately different Xylem_UMass. The introduction of a different tree growth projection method, with input from experts, achieved meaningful projections for UMass' inventory data. The final projection programme, Xylem_AOP, honed the idea of an initial Xylem programme structure, into which growth behaviour data and inventory data can be infused. With the Xylem_Archetype structure, Xylem_AOP was released in the shortest time of all three programmes (7 days), with factors like reusing growth rates and the relative simplicity of the AOP inventory contributing to the expedited release. Of importance was the Archetype that made Xylem more distributable – an area worthy of further research.

It is worth noting that the methods employed by the Xylem programmes are complementary. Because of differences in the way tree growth behaviour is encapsulated, a faster growing tree species will be ascribed a higher growth rate with Xylem_Amherst, whereas with Xylem_UMass, a younger, more vigorous tree will be projected to grow more rapidly. As an improvement to both designs, and a demonstration of the power and flexibility of Xylem, a programme that utilises a weighted or unweighted average of two projection strategies, one for species growth and one for age/diameter growth, could be designed. Additionally, a mortality modifier could be added to remove trees at random or account for other desired criteria from the inventory (e.g. Trunk Condition <10 and Location Rating <50). The urban forester may also wish to include inventory

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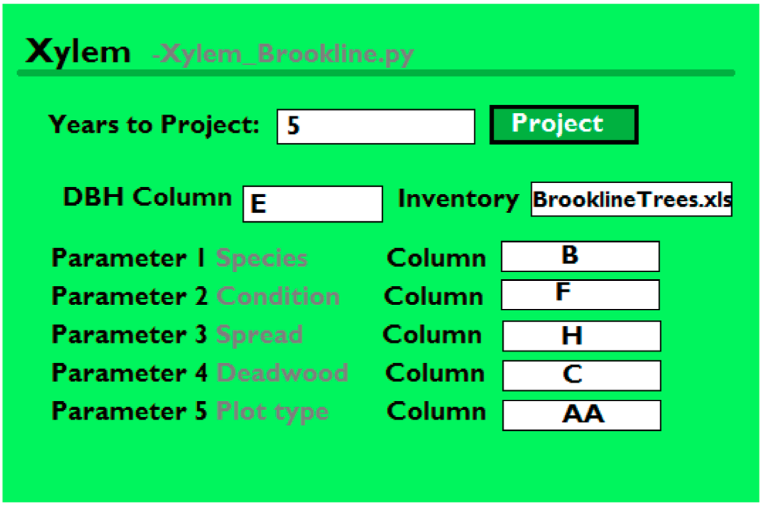

Figure 3. UI (User Interface) prototype for a future Xylem programme where a user can set the characteristics of an analysis they would like to perform by manipulating fields on the screen.

information on the rate of new trees that are being planted; Xylem may then have a subroutine that injects new entries to represent the planting of new trees.

Commands that a user can type into the Xylem interface like *setup* may add value for users with a non-technical background. A repeated prompt from command line like this is called a REPL (Read-Eval-Print-Loop). Xylem's REPL provides the necessary queues and information a user might need to carry out a new projection. For developers, this narrows the gap between testing and running a Xylem programme, but makes using a production version of Xylem pedantic. With the non-technical user base in mind, Xylem may benefit from a more conventional Graphical User Interface (see prototype, Figure 3).

Conclusions

The Amherst case study represents a successful proof-of-concept regarding the application of novel urban tree projection programmes. A software developer using Agile practices, collaborating with experts in the urban forestry field, should use the entire gamut of research available pertaining to urban tree growth, and refine projections with condition data from the inventory. Further research on the efficacy and accuracy of using the Xylem structure may help to minimise the gap between an expanding pool of knowledge on urban tree growth, and methods employed by projection programmes. As urbanisation expands and the practice of urban forestry continues to mature, more insight may be gained into how management scenarios can affect the long-term well-being of urban trees and the services that they provide. Industry experts are calling for greater collaboration between tree researchers, managers and scientists (Leibowitz, 2012). Xylem and Agile computer programming practices are well positioned to address this challenge by stressing cooperative input from these parties to improve the legitimacy of tree inventory projections and add value to existing tree inventories.

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Disclosure statement

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