QUANTIFYING OUR ARBORICULTURAL LEGACY – ANALYSIS OF AGE CLASS DISTRIBUTIONS.

Dave Williams
Principal Consultant – ArbEcology Pty Ltd

Introduction

The majority of street trees that provide an impact in the landscape result from decision making processes conducted many years in the past. It is important to identify whether current decision making processes will leave a similar legacy for future generations.

Many large land managers today maintain an inventory of their street tree assets. It would appear that the primary drivers for conducting a tree inventory, in most cases, relate to risk management and works scheduling (Keller and Konijnendijk 2012). While these are arguably essential to the management of large populations of trees there is much more that can be determined from the information collected. To date most of the published analysis of inventory data concerns the species diversity (e.g. Frank et al. 2006, Ningal et al. 2010, Thaiutsa et al. 2008) or the dimensions of the trees (e.g. Ningal et al. 2010, Thaiutsa et al. 2008). This paper aims to investigate one potential methodology for analysing inventory data to evaluate the overall sustainability of the tree population.

In the context of an urban environment there are many reasons why trees may require removal including risk mitigation, infrastructure works, aesthetics, vandalism, etc. It is rare that any removal of trees are conducted prior to there being a necessity to do so, a common goal of street tree management is an increase in the size of trees (Ordóñez and Duniker 2013) which is not consistent with proactive tree removals. While an admirable ideal, if the retention of large/old trees is a tree management driver it is possible that a situation is created where a large proportion of the tree asset will require removal in a short space of time. If we are to provide an equivalent benefit from our street trees to all future generations then appropriate proactive tree removals may be justified.

There have been attempts to promote a variety of age classes within a tree population to prevent large scale removals based on mortality, such as Kirnbauer et al. 2009, however (in particular the cited paper) this relates to establishing a planting program to promote this variety rather than an analysis of the existing population.

In bushfire planning and management one approach to ensuring ecologically sustainable fire regimes in a landscape unit is based around the concept of theoretical age class distributions. The fundamental principle is that in order to achieve older age classes of vegetation there must be proportionally more younger age classes to account for an increasing probability of disturbance as the vegetation community ages. It is not intended in this paper to assess this method in relation to its appropriateness in the context of bushfire planning and management.

It is expected that with some modifications this method can be used to analyse existing tree populations and provide guidance on tree removal and planting management.

Method

The likelihood of a tree requiring removal at a certain age may be represented by a notional "Hazard Function" where the probability of removal varies with the age of the tree. In the example (Figure One) the assumption is that when a street tree is in the first few years of life there is an increased probability of removal due to factors such as transplant shock, followed by a period of lower probability of removal while the tree remains vigorous and the final stages where the tree is more likely to require removal due to mortality. The area under this curve will equal a probability of 1.0, i.e. after a period of time (in this example 100 years) all of the trees in this or greater age classes will have been removed. If the removal of trees follows the function in Figure One then the age class distribution is likely to look something like that in Figure Two. It should be noted that it is assumed that removed trees are replaced almost immediately.

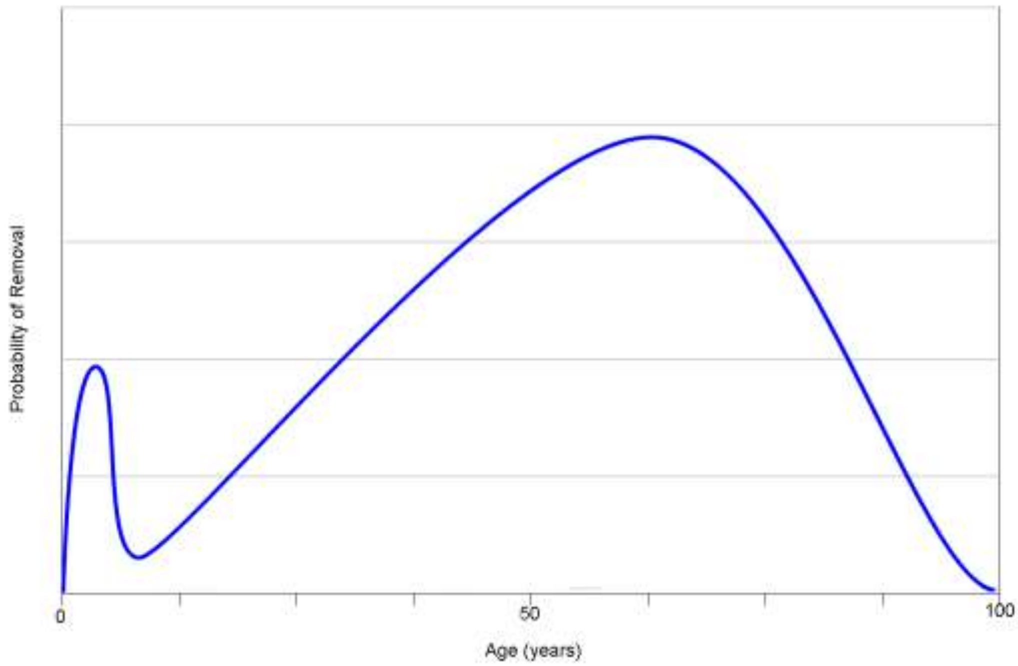


Figure 1. Theoretical Hazard Function

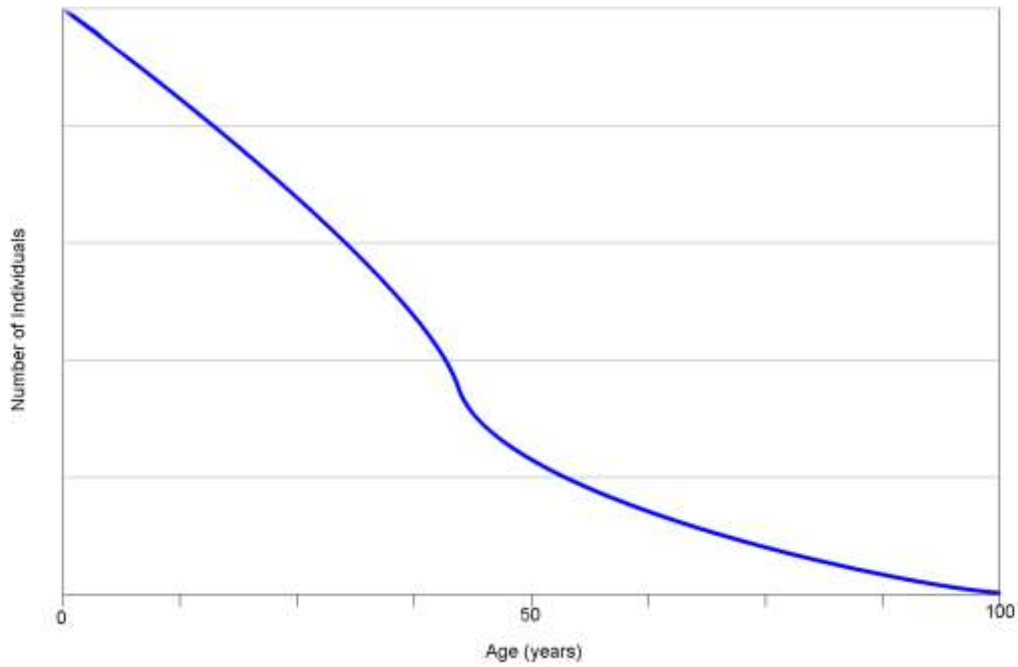


Figure 2. Variable Hazard Function Age Class Distribution

It may be possible to conduct further investigation to make this notional hazard function more accurate, however this would involve a much higher level of data capture that may not be justified by an increase in 'usefulness' of this model.

The simplest form of hazard function is one where there is an equal probability of a tree requiring removal at any age. Using this function the age class distribution in a tree population will be represented by a negative exponential curve (see Figure Three). Figure Four shows that for practical purposes using either hazard function the result is similar and as the mathematics of a constant hazard function is much easier it is the one used as the starting point for this analysis.

The formula for the negative exponential curve representing the age classes takes the form:

$$a_t = b\ \mathrm{e}^{kt}$$

Where:

a	= the number of individuals present at time *t*
t	= the age class in years
b and *k*	= constants

In order to make practical use of the above some values must be known:

Total Tree Population (a_{total})	- the total number of individuals in the tree population
Annual Tree Removals (*r*)	- the number of trees removed from the population annually
Tree Removal Cycle (*c*)	- is the number of years taken to remove a number of trees equivalent to that of the total tree population
Maximum Life Span (*m*)	- is the maximum amount of time a tree is likely to exist in a street

The average number of individuals in the first age class period (assuming a 1 year age class period) will be equal to the average number of trees removed each year. The average number of individuals in the last age class period will equal ${}^{c}/_{m} \times {}^{a_{\text{total}}}/_{m}$. By using the number of individuals in the first age class (a_{first}) and the number of individuals in the final age class (a_{last}) the above formula can be resolved.

Once the formula has been resolved the theoretical number of individuals can be calculated and compared to field data or planting records to identify where certain age classes are appropriately, under or over represented within the population.

Case Study

To illustrate this concept data from the Shire of Macedon Ranges were analysed. The data were collected as part of a risk mitigation and works scheduling inventory conducted in 2011. The age of each tree were captured into estimated ranges.

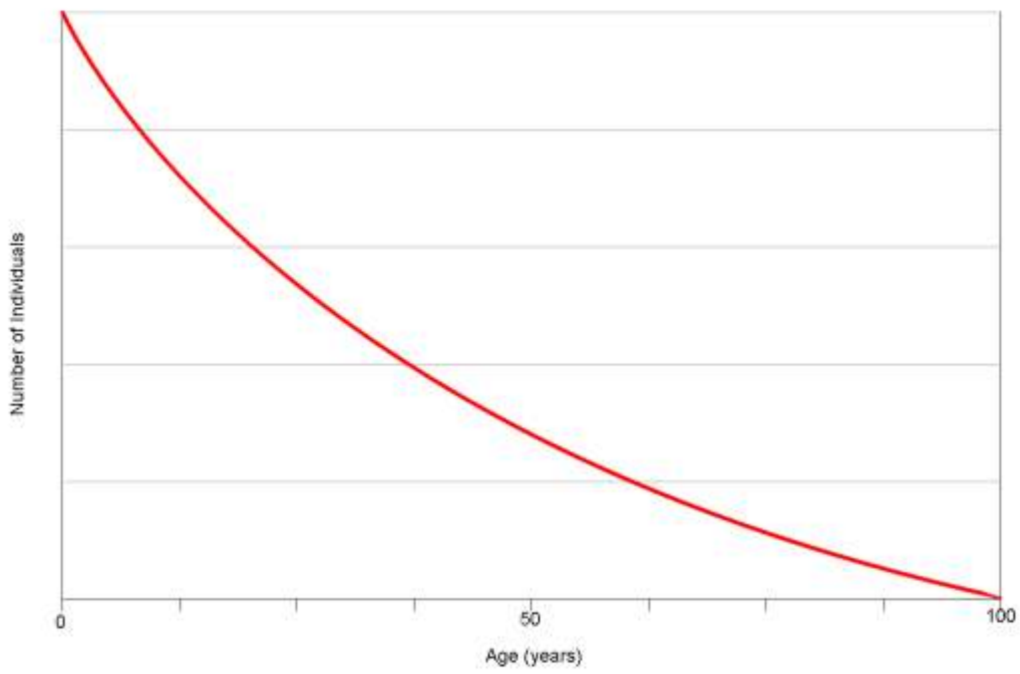


Figure 3. Constant Hazard Function Age Class Distribution

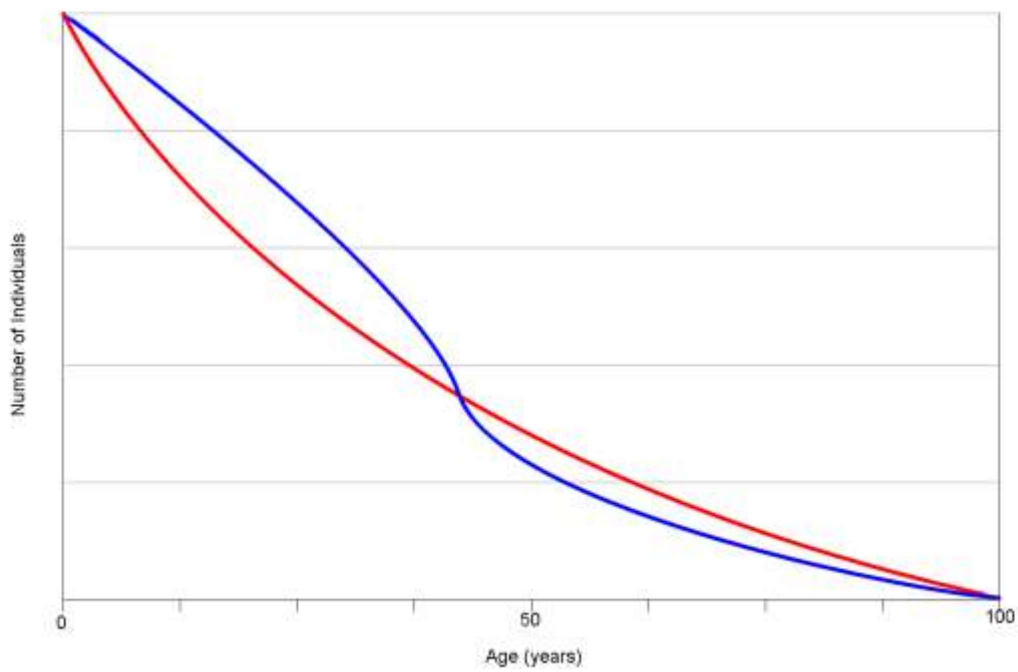


Figure 4. Variable & Constant Hazard Function Age Class Distribution

The following is known about the tree population:

Total Tree Population (a_{total})	= 27,485
Annual Tree Removals (r)	= 500
Tree Removal Cycle (c)	= 55
Maximum Life Span (m)	= 100

From this we can see that:

$$a_{\mathrm{first}} = 500$$

and

$$a_{\mathrm{last}} = \frac{55}{100} \times \frac{27485}{100} = 151$$

To resolve the original formula we use the fact that:

$$500 = b\mathrm{e}^{k\times 1}$$

(from a_{first})

$$b = \frac{500}{\mathrm{e}^{k}}$$

And

$$151 = b\mathrm{e}^{k\times 100}$$

(from a_{last})

Therefore

$$151 = \frac{500}{\mathrm{e}^{k}} \times \mathrm{e}^{100k}$$

$$151 = 500\mathrm{e}^{99k}$$

$$\ln(151) = \ln(500\mathrm{e}^{99k})$$

$$\ln(151) = \ln(500) + \ln(\mathrm{e}^{99k})$$

$$99k = \ln(151) - \ln(500)$$

$$k = \frac{5.01728 - 6.21461}{99}$$

$$k = -0.0121$$

Then

$$b = \frac{500}{\mathrm{e}^{-0.0121}}$$

$$b = 506.088$$

The formula to calculate the theoretical number of individuals (*a*) at a given time (*t*) in the Shire of Macedon Ranges is:

$$a_t = 506.088e^{-0.0121t}$$

We can then use a spreadsheet to calculate the theoretical numbers of individuals within a given age class to compare it to the field data. Figure Five shows the comparison from the data collected during the inventory and the calculation of the theoretical numbers of individuals.

The analysis of the data suggests that the Shire of Macedon Ranges is over represented in the Less than 10 years and 10-20 years age classes and underrepresented in the 20-50 years, 50-80 years and 80+ years age classes.

While there is very little that can be done to rectify these figures in the short term as it is not possible to establish 20+ year old trees on a large scale, there may be an issue with tree survival after 20 years that has caused this imbalance and would be worth investigating. For example, a large proportion of the trees in the Less than 10 years age class are natural regeneration in rural roadsides and it may be that after 20 years competition between individuals results in a significantly higher mortality rate.

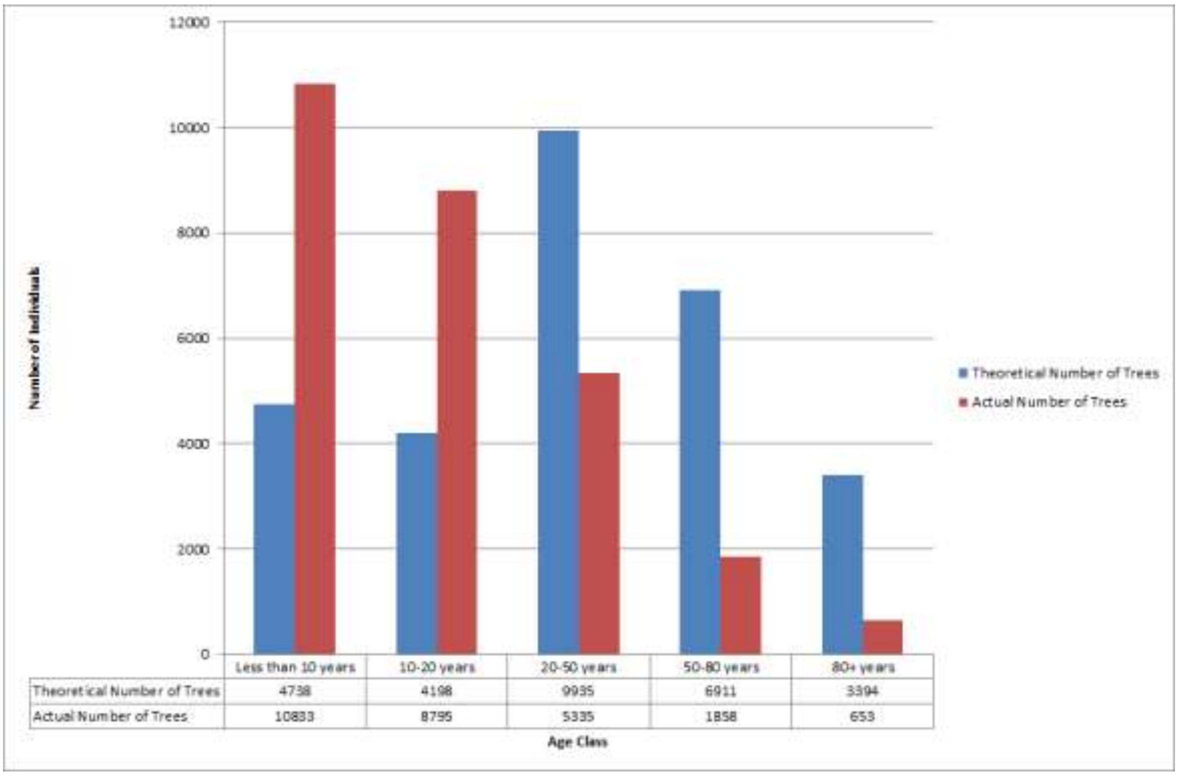
Discussion

The aim of this paper was not to provide a detailed analysis of a particular municipal tree population but rather to explain and demonstrate a particular type of analysis. To that end there are several assumptions that we must be mindful of while interpreting the results of the analysis. These include:

- The analysis is based on the assumption that all available planting spaces are filled. In most municipal areas this is unlikely to be true, however if the vacant spaces are excluded from the analysis the results are still valid.
- It is difficult to estimate the age of a tree. This can be overcome by using wide age class ranges that decrease the likelihood of miscategorisation. It also highlights the usefulness of recording planting year for all future plantings.

This type of analysis is not intended to drive wholesale tree removals from within age classes to try and even up the theoretical balance, but following the normal routine tree removals in a municipality there may be an opportunity for the removal of an appropriate number of the worst specimens from an over represented age class. In conjunction with other available information this could be a tool that contributes to the sustainability of the tree population.

Provided the assumptions and limitations of any input data are acknowledged and accounted for in the analysis, simple models such as this one can provide great insights into the current state of the tree population and likely future scenarios.



	Less than 10 years	10-20 years	20-50 years	50-80 years	80+ years
Theoretical Number of Trees	4738	4198	9935	6911	3394
Actual Number of Trees	10833	8795	5335	1858	653

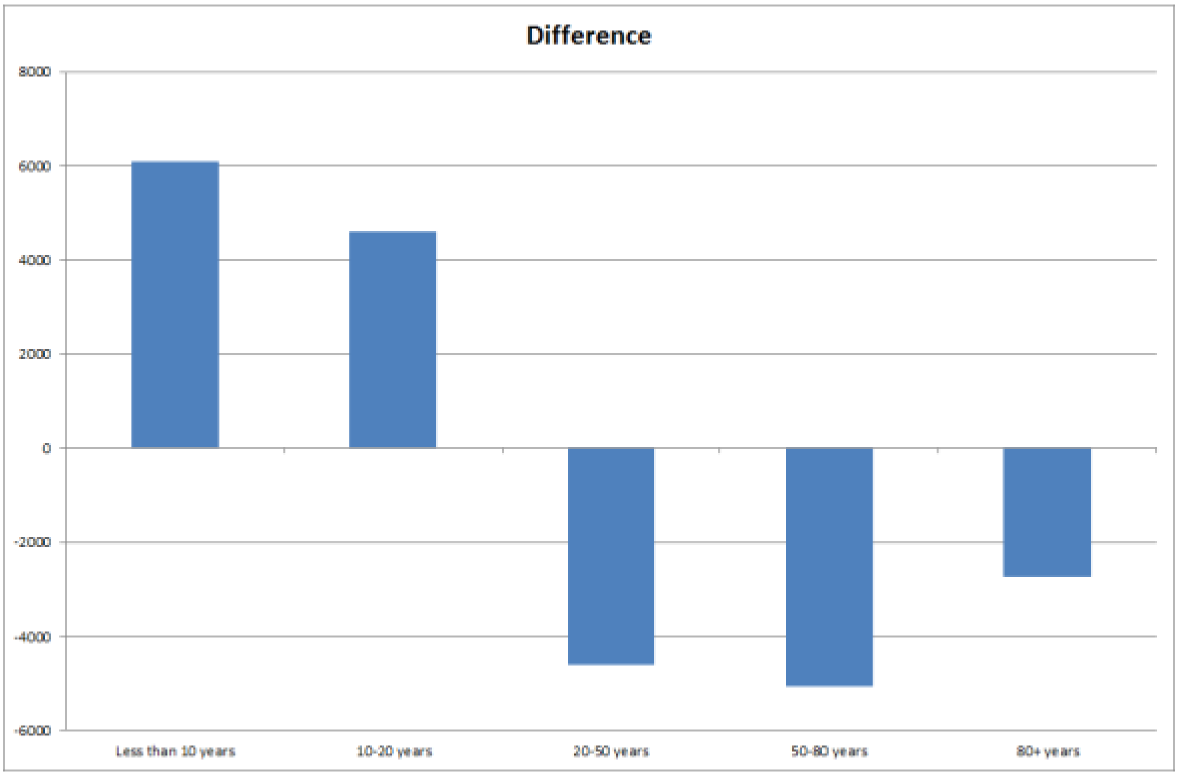


Figure 5. Shire of Macedon Ranges- Theoretical vs. Actual Tree Numbers

References

Frank, S., Waters, G., Beer, R. and May, P., 2006. An analysis of the street tree population of greater Melbourne at the beginning of the 21st century. *Journal of arboriculture,* **32**(4), pp. 155-163.

Keller, J. and Konijnendijk, C., 2012. Short communication: A comparative analysis of municipal urban tree inventories of selected major cities in North America and Europe. *Journal of arboriculture,* **38**(1), pp. 24-30.

Kirnbauer, M., Kenney, W., Churchill, C. and BAETZ, B., 2009. A prototype decision support system for sustainable urban tree planting programs. *Urban forestry & urban greening,* **8**(1), pp. 3-19.

Ningal, T., Mills, G. and Smithwick, P., 2010. An inventory of trees in Dublin city centre. *Irish geography,* **43**(2), pp. 161-176.

Ordóñez, C. and Duniker, P., 2013. An analysis of urban forest management plans in Canada: Implications for urban forest management. *Landscape and Urban Planning,* **116**, pp. 36-47.

Thaiutsa, B., Puangchit, L., Kjelgren, R. and Arunpraparut, W., 2008. Urban green space, street tree and heritage large tree assessment in Bangkok, Thailand. *Urban forestry & urban greening,* **7**(3), pp. 219-229.