A case study of feral olive (*Olea europaea*) dispersal in northern Victoria. Part I: plant age and growth habit characteristics

S.D. Hamilton[A], **T. Minotti**[B], **C. O'Dwyer**[B] and **G. Brodie**[B,C]
[A] Hamilton Environmental Services, 2345 Benalla-Tatong Road, Tatong, Victoria 3673, Australia.
[B] Dookie College Campus, The University of Melbourne, Nalinga Road, Dookie, Victoria 3647, Australia.
[C] Corresponding author.

Abstract

European olive (*Olea europaea* L.) has successfully invaded several regions in Australia including the district surrounding Dookie College in northern Victoria. Feral populations of olives have spread from abandoned groves established in the late 1870s but due to a revitalization of the olive industry in the 1990s there is concern about increase in feral olives from this new source. Feral olives do not produce fruit until they are 10 years old so using techniques that can accurately age feral olive trees such as stem diameters or plant height will enable land managers to prioritize the control of reproductive individuals.

This study evaluated ring counting of the stems on European olive trees and it proved to be a successful means of estimating the age of stems, with the estimated age of the widest stem the best estimator of plant age. Significant relationships between estimated stem ages, stem diameter, plant height and width were also established. The relationship between the diameter of the widest stem and estimated age will prove invaluable in developing a broad age structure profile of the feral European olive plants of the district.

Introduction

Olea europaea L. (European olive) belongs to the Family Oleaceae, and originated from the Mediterranean region. They were first planted in Australia in 1805 at Elizabeth Farm in Parramatta (Parsons and Cuthbertson 2001) as ornamentals but it was not until the mid to late 1800s that commercial groves were established in South Australia (Spennemann and Allen 2000). The first Victorian plantings were at Dookie College, 35 years later in the late 1870s (MacDonald 1915). Due to the high production costs and low demands, many of these groves were considered unprofitable and were abandoned providing fruit for fruit-eating birds and foxes (Spennemann and Allen 1998). It was not long before olives became naturalized, establishing feral populations throughout parts of Australia, particularly along roadsides and within remnant woodlands within the 400–600 mm annual rainfall range (Spennemann and Allen 2000). Olives are invasive, shading out native species and research has shown that they can reduce native plant diversity by at least 50% (Crossman 2002, Bass *et al.* 2006). The European olive is now considered a serious threat for the indigenous woodland floras of southern Australia and is identified as a proclaimed weed in areas of South Australia, a declared weed in some areas of New South Wales (Spennemann and Allen 2000, Parsons and Cuthbertson 2001) and an environmental weed in Victoria (Carr *et al.* 1992).

The European olive is an evergreen multi-stemmed tree that grows to heights of between 2–15 m, with a dense rounded canopy. Its bark differs in colour depending on the age of the stem, with juvenile plants having a silver-grey to green bark, becoming grey and roughening with age (Muyt 2001). Its leaves are opposite, 3–8 cm long, 1–4 cm wide, glossy dark grey-green above, silvery scaly below. The small creamy-white flowers of European olive arise in spring with purple-black drupe fruit containing a hard brown seed maturing in summer (Spennemann and Allen 2000, Parsons and Cuthbertson 2001). The cultivated European olive tree begins to bear fruit between 10–12 years of age if unirrigated (in areas with 500 mm of rain) and 4–5 years in irrigated areas (Spennemann and Allen 2000).

Since the early 1990s, there has been a revitalization of the European olive industry due to small boutique hobby farmers and commercial orchards, which has lead to an expansion of the area under olives (Hobman 1995). Spenneman and Allen (2000) indicated that in 1998, the number of olive trees in Victoria totalled 350 000, an increase of 200% from the previous year. While there are no accurate figures on Australian production of olive oil, it was estimated at about 1500 t in 2003, a figure that is likely to grow rapidly as the estimated 8 million trees that have been planted in Australia in the last decade come into full production (Australian Olive Association 2009).

The Dookie College (formerly Cashel Experimental Farm) olive grove was established in 1879 (Burr 1997), and has become a point source for the naturalization of European olive across bushland and roadsides within the district. Other plantings of European olive have also been identified within the Dookie region, and it is likely that they too have contributed to the dispersal of olives. In recent decades, it has been observed that European olive abundance and distribution in the district has expanded dramatically (Borthwick personal communication, 2003).

Control of feral olives is expensive and labour intensive often requiring multiple chemical applications and mechanical removal. Costs of herbicides alone can range between \$750 and \$3000 ha^{-1} (Virtue *et al.* 2008). In addition many local landowners do not perceive olives to be a threat. Therefore a strategic control program needs to be implemented to assist with targeting and prioritizing individual trees for control.

Dendrochronology

Dendrochronology or tree-ring dating is the method of scientific dating based on the analysis of tree-ring patterns. The technique was developed to establish tree age by counting of growth rings. It can be used in more complex growth and stand studies and analysis of past environmental conditions or events (Stokes and Smiley 1968, Ogden 1978, Schweingruber 1988, Banks 1997, Wimmer and Vetter 1999). Simply stated, trees in temperate zones grow one growth-ring each year, and develop annual rings of different thickness depending on weather, rain, temperature, etc. in different years (Schweingruber 1988). For the entire period of a tree's life, a year-by-year record or ring pattern is formed that in some way reflects the climatic conditions in which the tree grew. For example, adequate moisture and a long growing season results in a wide ring, while a drought year may result in a very narrow one.

All trees have growth cycles in response to environmental conditions and these cycles generally occur on a regular seasonal basis with cambial activity influenced by different external conditions depending on tree species and growing site (Schweingruber 1993, Banks 2000). However, some trees apparently lack regular periodic growth cycles due to the climate in which they occur, and such trees may grow at a constant rate, in response to aseasonal patterns or rely on episodic events for growth to occur (Schweingruber 1993, Banks 2000, Parsons and Cuthbertson 2001).

Trees from the same region will tend to develop ring patterns of the same width for a given period. These patterns can be compared and matched ring for ring with trees growing in the same geographical zone and under similar climatic conditions (Schweingruber 1988, Schweingruber 1993). If rings can be counted reliably, then for a species in a specific region, it is possible to develop a graphical relationship between stem diameter and age based on tree-ring dating (Schweingruber 1993, Banks 1997), however, other methods, such as carbon-dating could be used to confirm the reliability of determined age wherever possible (Cherubini *et al.* 2003).

European olive is a typical 'double stop' Mediterranean evergreen sclerophyllous plant species, where plants come to a growth stop in both winter and summer (i.e. the lack of activity in the cambium coincides with periods of climatic stress) (Cherubini *et al.* 2003). Whilst many Mediterranean trees have annual growth rings (Enright and Goldblum 1998) this is yet to be clarified for olives. Mediterranean trees are also likely to have false rings which can cause errors in tree-ring dating. False rings occur due to the production of small thick-walled latewood cells commonly triggered by drought which is more evident in younger faster growing trees (Copenheaver *et al.* 2006). Droughts are a common occurrence in northern Victoria. The presence of false rings in a sample can be reduced by avoiding sections of the stem near actively growing branches (Copenheaver *et al.* 2006) and by evaluating whole stem disks rather than core samples or slices of stems because they are easier to identify (Cherubini *et al.* 2003).

The aims of this research were two-fold. Firstly to determine whether growth rings are indeed laid down annually in olives, and secondly to develop predictive models that can be used within the district to determine the age of olive trees based on readily measurable characteristics. These models can then be used by land managers to identify reproductive individuals, and hence prioritize management.

Methods

District background

The study site is adjacent to the Dookie College campus of the University of Melbourne, which is found 35 km east of Shepparton in Victoria, Australia (38°18'S, 142°42'E), and 220 km north of Melbourne and the Victorian coast. The climate of Dookie College is typically Mediterranean, with an average annual rainfall of 556 mm and 99 rain days, mostly in the winter months. Approximately 330 mm of this rainfall falls in the period May to October, and there are on average 22 frosts annually, usually between April and September. Evaporation exceeds rainfall from September to April, and direct sunlight hours vary from 12 in the summer, to less than seven in the winter. The maximum mean monthly temperature is 21.6°C in February, and the minimum mean monthly temperature is 3.7°C in July. Summer temperatures can exceed 41°C (University of Melbourne 2003).

The Dookie College olive grove

The first olive grove in Victoria was planted along the main drive to Dookie College between 1879 and 1884 (Thompson 1880, National Trust of Australia n.d.).

The olives in the grove were utilized for oil production up until around 1946 (J. Borthwick and S. Provan personal communication, 2003). The fruit was collected using sticks to knock the olives from the trees onto sheets lying on the ground. This removal method no doubt left fruit remaining on the trees for bird collection and dispersal. Today, the remainder of the olive trees in the grove are still undergoing patchy harvesting seasons, but in most years the fruits are left. Due to the age of the olive grove and the reason for planting them, 120 of the 213 remaining trees have been listed with the National Trust of Australia and are therefore protected (National Trust of Australia n.d.). A major pruning and shaping of all the remaining individuals was undertaken in 2001 by the University of Melbourne to enhance their longevity based on their heritage value.

Plant sampling

A total of thirty feral olive plants (single and multi-stem) varying in diameter and height classes on the western side of the road reserve on the Dookie-Nalinga Road, 200 m south of the main drive entrance to Dookie College, were selected. In addition, four trees of known age were sampled from the abandoned olive grove on campus. The sampled trees were all within an area of 1 ha, on an area with the same relief, and with the same mapped soil type (Downes 1949). These were used to validate ring counts.

All plants were photographed, and their height and width measured. Heights were measured using a tape where appropriate or estimated using a clinometer. The projected width of the canopy was measured using a tape. European olive is generally a multi-stemmed plant, with a significant buttress at ground level, particularly if the plants have been disturbed (e.g. either by being formally pruned or grazed). This presented a significant problem in terms of sampling the 'stems' from each plant. Discs (whole diameter) were cut from the buttresses of 10 plants, with varying diameter at ground level, and evaluated for the presence of growth rings: no growth rings were definable in any of the samples collected because buttress material tends to be largely undifferentiated tissue. On this basis, it was decided to avoid material from the buttress, and to take samples from each stem of the plant as close to the buttress as was practicable. To this end, each stem of each individual selected plant was cut near the base (n = 268). A whole stem disc for each stem was taken. All of the stems on plants were sampled to allow for evaluation of any differences between stem ring counts growing on the one plant. The oldest ring count from all stems on the plant was used to date the plant.

Growth rings

Discs were air-dried for two months. To enhance the wood grain each disc was sanded using a fine graded sandpaper and buffed with a lamb's wool buffer attached to an electric drill (after Looby 2007). Growth rings in cross-sectional samples were identified based on anatomical characteristics. Upon initial macroscopic inspection concentric bands of light and dark coloured wood were very obvious, and it was assumed these bands reflected cambial activity under varying growing conditions (after Looby 2007).

It was assumed that one complete set of early and late wood growth (rings) equalled one year's growth, and no false rings were observed, however, there was considerable variation in the width of rings and the patterns of these variations assumed to be due to the prevailing rainfall conditions of that period of growth, i.e. the widest rings were consistently evident in stems dated in 1974 and 1993, years in which major flood events occurred in the district, and indeed when all sampled plants were temporarily inundated.

Using the outcomes of growth ring identification and annual ring validation, growth ring analysis and counting was undertaken on stem samples in order to build a diameter-age relationship. Two counting radii were established on each sample and ring counting was performed with the assistance of a magnifying dissecting microscope, and a hand lens. Radii were located subjectively to maximize ring clarity, and to avoid any areas of wood malformation within each sample, and rings were marked with a pencil. There were no significant issues of heartwood decay, and there was no need to estimate missing growth rings.

Statistical analysis

The relationship between measured and estimated features of olive plants and stems, such as plant height and width, stem diameter and stem age, was evaluated using correlation and regression analysis. Linear or polynomial equations were fitted to each relevant pairing, and Spearman's rank correlation coefficients (R^2 values) calculated for each relationship. Correlation coefficients were tested for significance using a Student's t distribution with degrees of freedom n = 2 (Sokal and Rohlf 1995).

Results

Validation of ring counting to estimate age in olive

The effectiveness and accuracy of ring counting as a means for estimating age of Olives was validated using two approaches. Firstly, there was significant variation in the width of recent growth rings and the patterns of these variations, due to the prevailing climatic conditions of the period of growth: wider ring dating correlated consistently with two recent flooding events (1974 and 1993), while narrow rings (more of a compacting of rings) were consistently dated during years of recent major drought events (e.g. 1972/73, 1982/1983, Banks 2000). For more than 95% of samples examined, these wider and narrower growth rings were readily observed in the expected position in the ring structure, suggesting that there was a high level of certainty that the expected and actual age of a growth ring were similar, especially those rings produced in the last 30–40 years. The compression of rings older than 1960 made it difficult to use this technique to correlate wider or narrower ring width to years of known climatic extremes (e.g. the drought years of the early 1930s).

Secondly, the four widest stems on plants of known age (planted in 1880) were evaluated, and variability amongst radii and overall mean ring counts was evaluated against the expected number of annual growth rings (Schweingruber 1988, 1993). This analysis showed a general trend of few missing or false rings, despite the age of the plants. All except one of the eight radii showed good agreement between expected and actual rings counts (<3.3 % difference between expected and actual ring counts over the 122 years of growth), and with annual ring formation to known-age growth rings discussed above.

Relationship of stem diameter and estimated stem age

There was a highly significant relationship between the age of olive stems (by ring counting) and stem diameter (Figure 1, P <0.001, n = 268). This was best explained by the linear regression equation Age = 0.4584 × D; where D is the diameter of the stem in mm.

Relationships with widest stem diameter

Plants had up to 38 stems of different diameters arising from the buttress, and, based on this analysis, different estimated ages. The widest stem, which was often the most central and upright on the plant, was invariably the oldest (Figure 1). This stem was considered to provide the best estimate of plant age. The widest stem was then evaluated for relationships with measured plant parameters.

There were highly significant relationships between the diameter of the widest stem and tree height (Figure 2, P <0.001, n = 30) and tree width (Figures 3, P <0.001, n = 30).

There was also a highly significant relationship between the diameter of the widest stem and the estimated age of the plant (Figure 4, P <0.001, n = 30). This highly significant relationship indicates that the use of the widest stem from a plant, rather than all stems on a plant, is an appropriate indicator of plant age.

Discussion

This study has shown that growth rings can be used as an accurate determinant of age for European olives and that growth rings in olives are laid down annually. The accuracy of counts was validated by comparison with ring growth patterns in trees of known age, and by evaluation of ring widths with significant recent flooding events. It would appear that the accuracy of such estimation is over 95%.

There was a clear significant relationship between stem diameters of all stems, and the estimated age by ring counting, of European olive trees around Dookie College (Figure 1). In particular, a significant

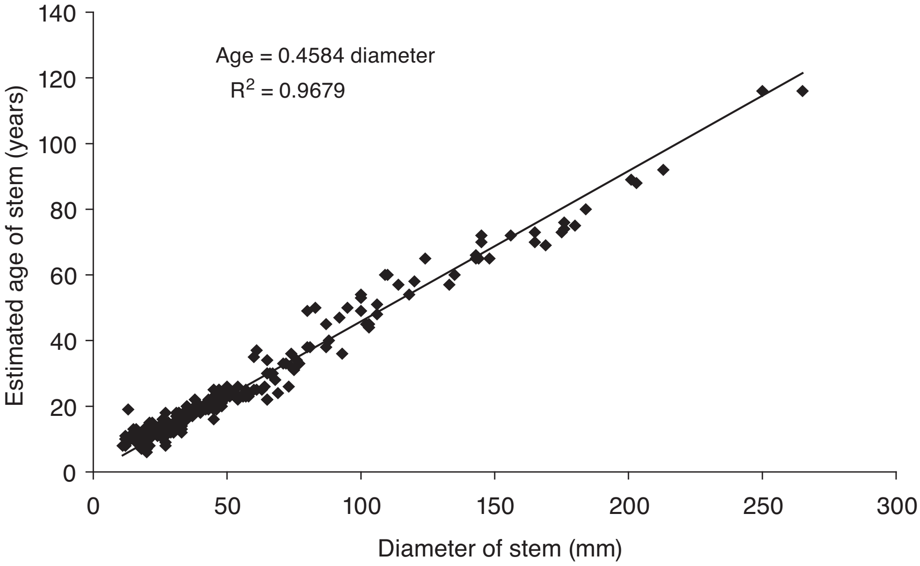

Figure 1. Relationship between stem diameter and estimated stem age, as determined by dendrochronological analysis. Significant to P <0.001.

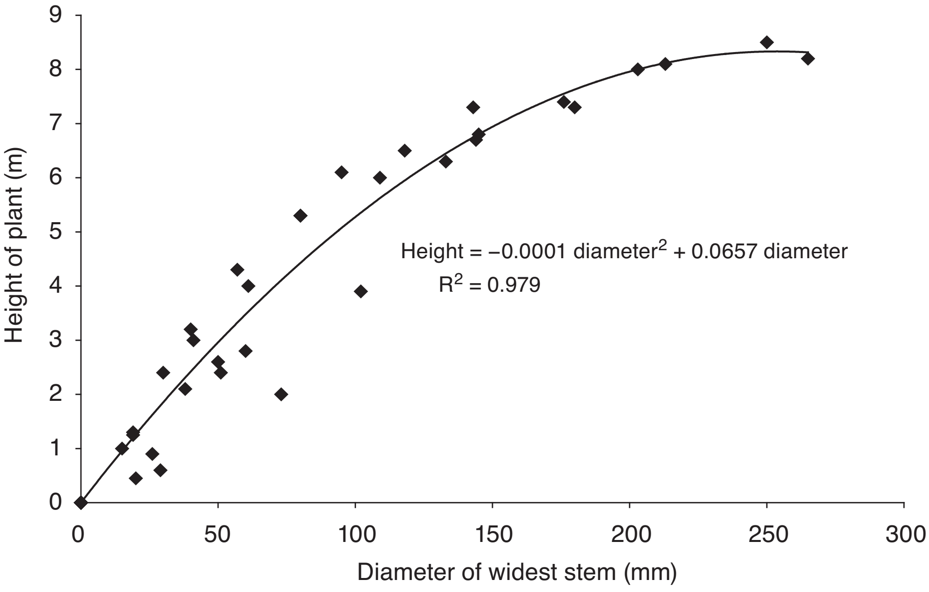

Figure 2. Relationship between the diameter of widest stem and tree height. Significant to P <0.001.

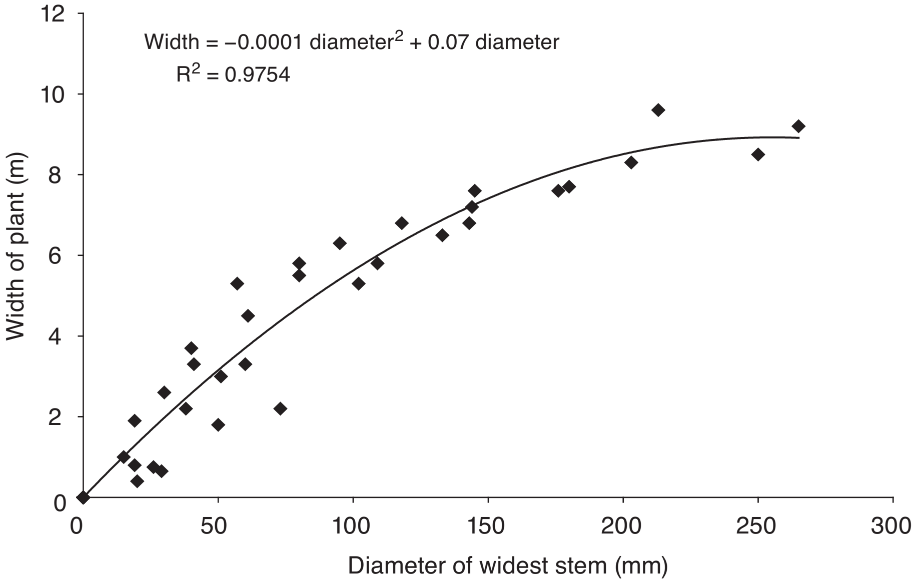

Figure 3. Relationship between the diameter of the widest stem and tree canopy width. Significant to P <0.001.

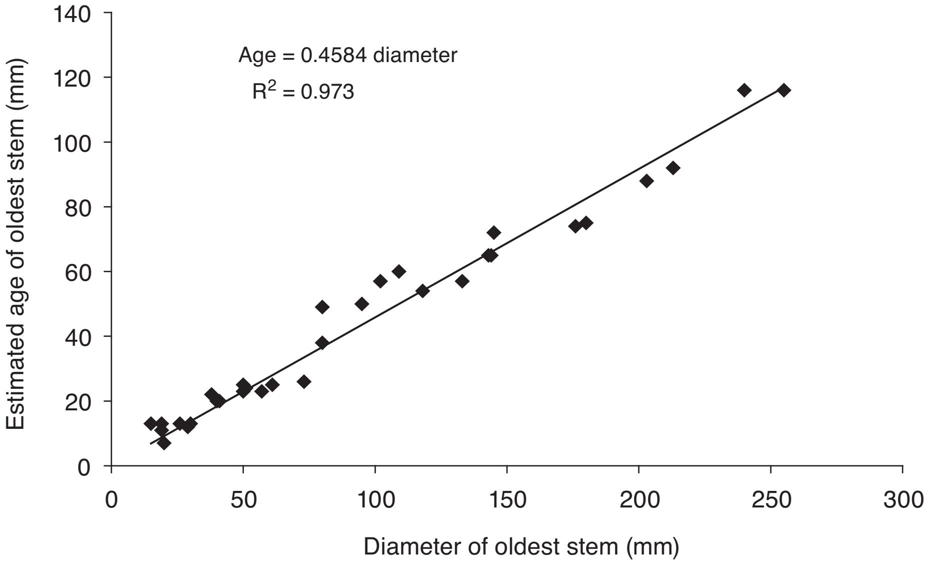

Figure 4. Relationship between the diameter of the widest stem and the estimated age of oldest stem, as determined by dendrochronological analysis. Significant to P <0.001.

relationship existed between the diameter of the widest stem and the estimated age of the oldest (largest diameter) stem (Figure 4). This means that diameter can be used as an index of plant age, and in particular, only the diameter of the widest stem needs to be measured in the field. Mekuria *et al*. (2002) also found that circumference of the tree was a good estimation of tree age. However, their study did not include multi-stemmed trees due to the possible errors associated with trunk size measurements. Excluding multi-stemmed trees from this current study would reduce possible sampling by 83%.

There is also a clear relationship between the diameter of the widest stem, and the height (Figure 2) and canopy width (Figure 3) of these trees. Because estimated age and the diameter of the widest stem are also highly significantly related (Figure 4), the diameter of the widest stem could also be used as an index to model the canopy width and plant height of these trees as well. Indeed, height or width could be use as a rapid estimator of age of the plant on this basis, which could save time during assessment surveys.

Conclusions

The management of feral olives is costly and difficult usually requiring multiple applications of chemical control followed by removal. Nevertheless there is a need for land managers to prioritize their management targeting those trees that are most likely to have immediate impacts, i.e. those trees which are reproductive. Feral olives take between 10–12 years to produce seeds so older trees are considered a priority for management action. Measuring height and diameter of largest stem is a quick and accurate assessment of tree age, however, the findings of this paper would need to be validated, and re-calibrated accordingly, in areas other than the Dookie district.

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