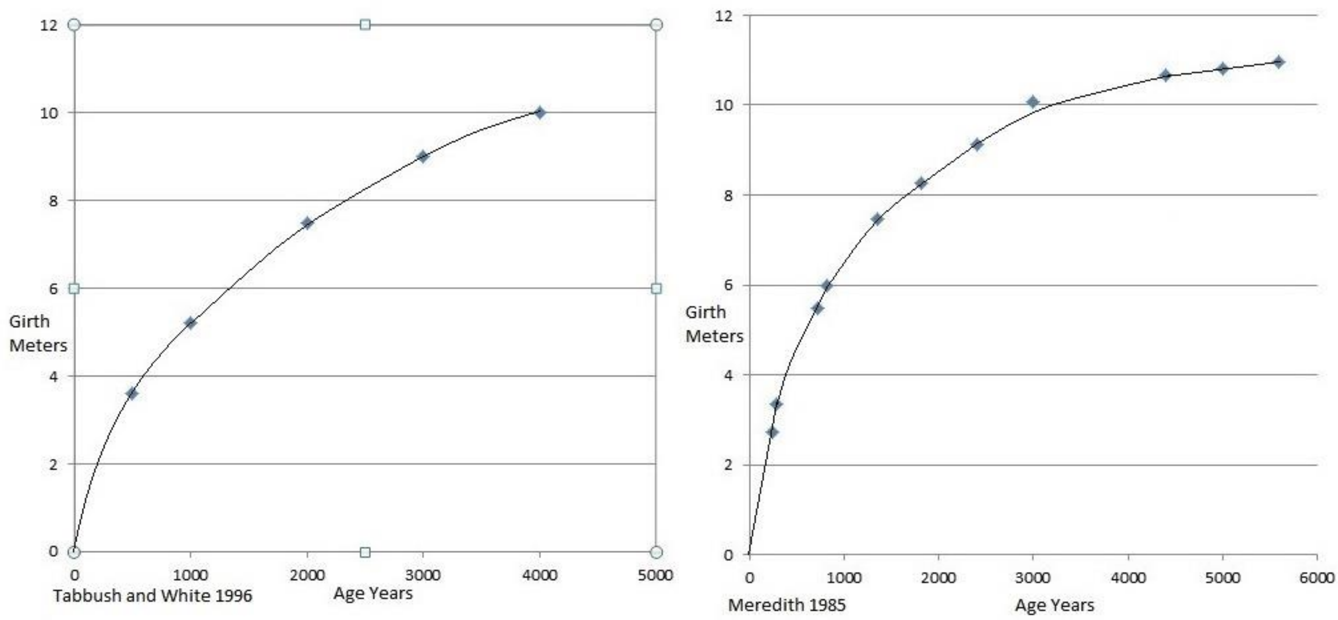
Finding ages for large specimens of Taxus baccata

The need for a modular approach in cracking a 200 year old conundrum

As a gardener I have long been used to yew as a hedging material or piece of topiary, and even the occasional specimen tree, but in a very few gardens there are yews which are really huge, giving rise to the question "how old are they?", and it was a very old yew in a Hampshire garden where I worked in the 1980s that first made me curious. Exposure to the yews at Newlands Corner near Guildford a decade later set the seal on my fascination with the subject and began my exploration of woodland and churchyard specimens.

A review of previous work and opinion showed that yew age had been a knotty problem in science for almost two centuries, ever since the botanist Augustine de Candolle had a credible go at ageing the vast yew in the churchyard at Fortingall in Perthshire. Ages have risen and fallen throughout history ever since, and estimates for yews of 10 meters in circumference or more have fluctuated between 200 and 5000 years during the interim up to the present day; but it is during the last three decades or so that we have seen the quoting of ever higher and more questionable age estimates. These estimates were justified by the introduction of parabolic and exponential age/girth curves as a basis for theorising about yew ages.

Figure 1. Examples: parabolic (Tabbush and White 1996 A curve) and exponential (Meredith 1985) curves used in the past for making estimates of yew ages. Note the way that (according to the exponential curve particularly) a yew cannot reach 12 meters in girth in a realistic time frame, if (practically speaking) ever. This "theoretical terminal girth" is a serious problem for all such curves, as yews have sometimes substantially exceeded the measure. It is assumed from the exponential curve that a yew, once it reaches 10 meters in girth will typically take well over 3,000 years to increase its circumference by a further meter. That idea is not remotely borne out by the longitudinal girth measuring and stump evidence in Figure 2.



Testing age estimates

The idea of these curves, particularly in terms of the parabolic curve (which alone of the two graphs in Figure 1 has a formal scientific basis; no scientific or mathematical rationale for use of the exponential curve in ageing yews has ever been produced) is reasonable enough in theory- the tree gets bigger, yet once mature the canopy doesn't change much. Therefore the ring width must diminish as the tree grows; the broadly stable annual product of wood being spread thinner over its surface each year. This is a potted version of John White's theory of "Constant Annual Increment" or CAI, and all of the graphs which yield ages of multiple thousands of years rely on that basic concept.

It is right and inevitable that extraordinary age claims of 3000, 4000 and 5000 years should be tested, even when they are based on the sound general theorising of a Forestry Commission expert like John White. The question is not whether White produced a useful theory, but whether it is appropriate to use it in this way. Some theorising is necessary; direct measurement of age is not viable. In contrast to the age estimates recently made on bald cyprus (Stahle et.al. 2019) where annual ring analysis was carried out on very old wood, effective old wood ring analysis is not possible on yews of large size because they are invariably hollow. The radio carbon dating technique that Stahle has also used for this ageing effort is of no use for much the same reason; in our wet climate yew wood usually lasts perhaps 500 years and often less, even when contained at the centre of a tree. The wood needed no longer exists to carbon date. Very old planting records or historical references are sometimes claimed as evidence, but have a way of vanishing or becoming otherwise untenable when actually looked up, and DNA tests and partial ring width evidence (the latter often incorrectly labelled "dendrochronological" evidence) are frequently misused and misunderstood, even in apparently credible and science based articles on yew. Often, claimed causal links from evidence to age estimate are of suspect validity. Any reader wishing to know what a valid estimate of very high tree age using dendrochronology and carbon dating looks like need look no further than that work done by Stahle et. al. on bald cyprus.

What has become clear is that (until now) there has been absolutely no unequivocal evidence that could separate a claim of 1,000 years from a claim of 5,000 years for an old yew, although many balanced and conservative estimates have been made in the past by writers such as Robert Bevan-Jones, observant professional conservationists and ecologists (and also the arborist Stephen Dennis in 1998) often citing real ring width or girth increase data that they have gathered. The extremely high ages that some researchers and enthusiasts have given, however, are at best incautiously based on theory that is untested for this particular use, and at worst on nothing of scientific value. Confusingly, some including Meredith have labelled certain yews with very high ages while at the same time claiming that the true age of any large yew can never be known. The true ages can in fact be known, not in exact years, but in the same way that an antiques expert can label a piece of furniture Georgian we can (with due care) give a general era of planting or seeding, and for instance distinguish between (in the UK) probable Elizabethan, late Saxon and potentially Dark Age specimens.

In order to test the appropriateness of the exponential and parabolic curves to yew ageing I ran a study starting in 1996 which looked at the annual circumference increase of many yews of varied girths, and also carried out a study on various sites of almost 200 stumps of yews which were still complete from the bark to the centre. My studies were designed to see whether the typical annual ring widths that Tabbush and White projected, and which Meredith implied by his age estimates in *The Sacred Yew* (and his general estimates that the exponential graph in Figure 1 is constructed from) matched the ring widths that I could thus calculate for real yews. The results would advance the debate by tending to confirm or deny the high age estimates. To my surprise and regret the evidence showed that there was a clear problem with the exponential and parabolic curves, and that the 5,000 year old yews …weren't. The problem remained that new ages couldn't be calculated with any degree of certainty or accuracy because an acceptable scientific mechanism for doing so was still lacking. A graph constructed from my data appears in figure 2.

Figure 2. This graph was constructed from measured girth increase of real yews over time, and stump ring counts with girth data from 240 yews in total, and it shows the typical girth of yews of particular ages based on the evidence gathered. Despite later adjustment (seen in figs 4 and 5 and also explained in the text below) it still represents strong evidence that UK yews of c10 meters girth are more likely to be under 2,000 years old than up to or over 5,000.

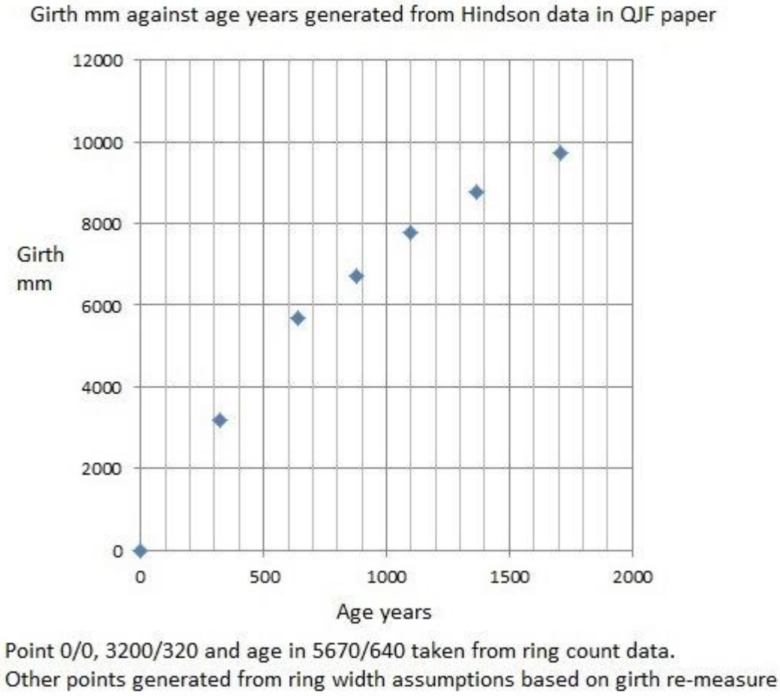
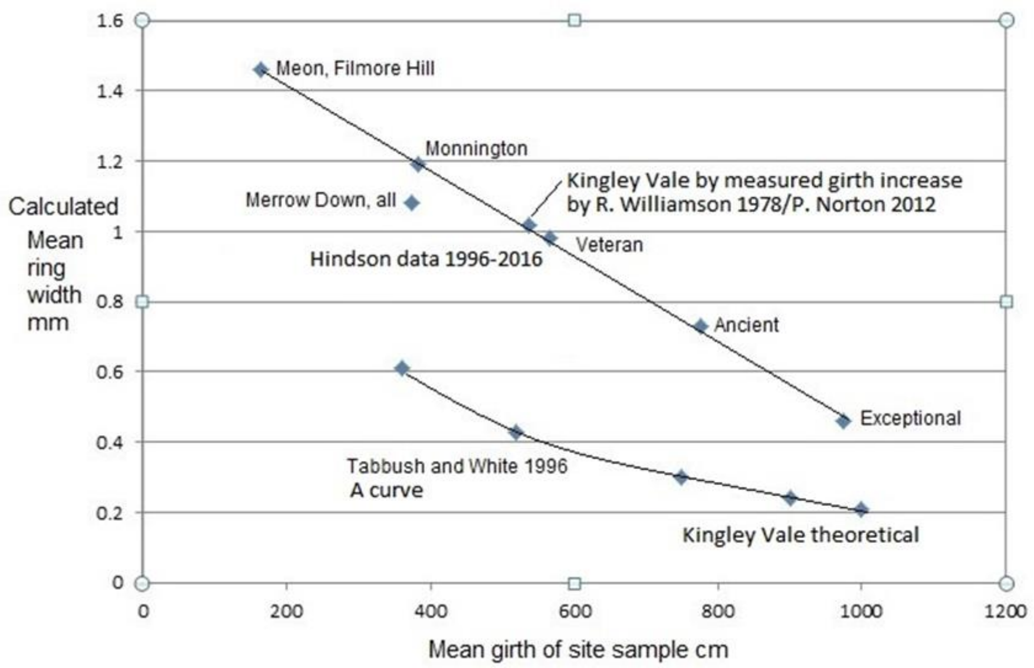


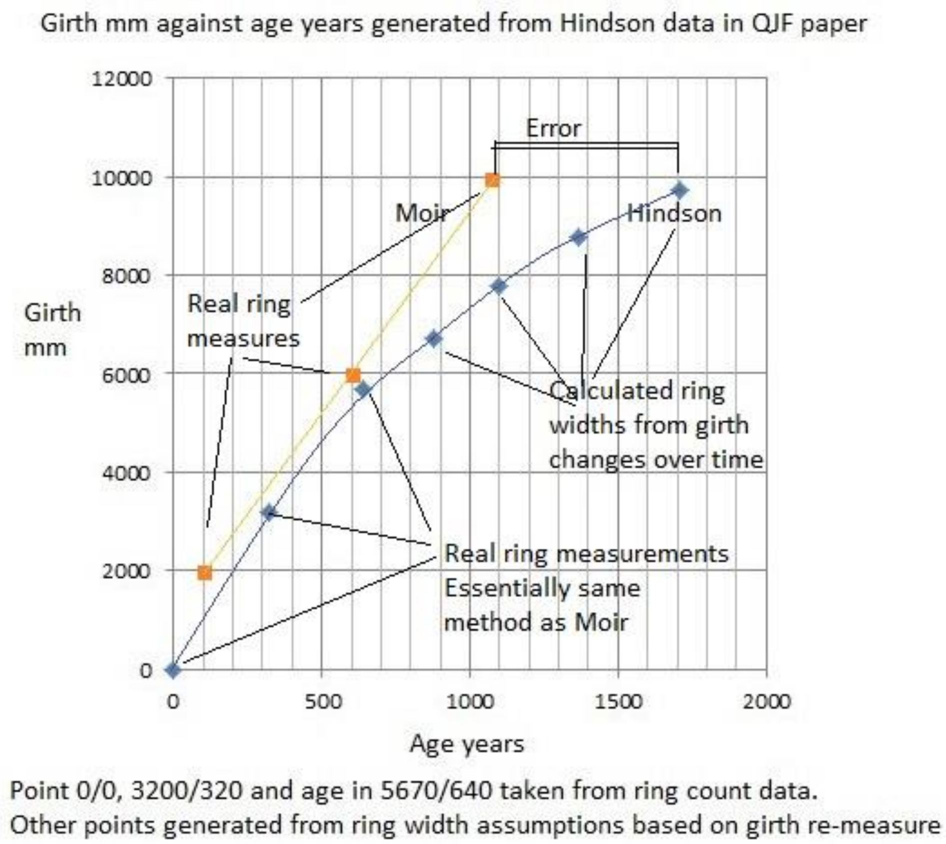
Figure 3. The ring width graph calculated by Hindson from girth change/time *field data compared with the theoretical ring widths in curve A produced by Tabbush and White for yews at Kingley Vale. Hindson's ring widths projected from real measurements are much higher than CAI theory would allow, so yews are found to be younger for a given girth.*



Conflicting evidence

The next stage in the development of this work to find good age estimates for large specimens of Taxus baccata involved the dendrochronologist Dr. Andy Moir of the Institute for the Environment at Brunel. He kindly sent me some of his work, and it included an age/girth graph based on his Pressler core samples of many yews of all ages. The graph was also included by Fred Hageneder in his 2007 book *Yew - a History*. This graph was not curved. It was linear. What Moir had found was that ring widths on the growing parts of a yew are typically about the same; the vertical lobes of the bole tend to grow outwards at a standard rate whatever the size of the yew. This was a stunning finding; it was direct physical evidence that yew ages couldn't be calculated from John White's CAI theory or Meredith's curve which both predict uniform and extremely high ring densities on the outer parts of large yews. The trouble was that it didn't agree with the age/girth graph (Figure 2) that I'd produced from measures of real yews either. I'd ended up with three conflicting theories, two of them based on direct physical evidence. I'd hit a brick wall.

Figure 4. This graph demonstrates the unexpected difference between the radial Pressler core data produced by Dr. Moir and the combined circumference increase data found by Hindson in Figure 2. Both graphs are representations of real measures.



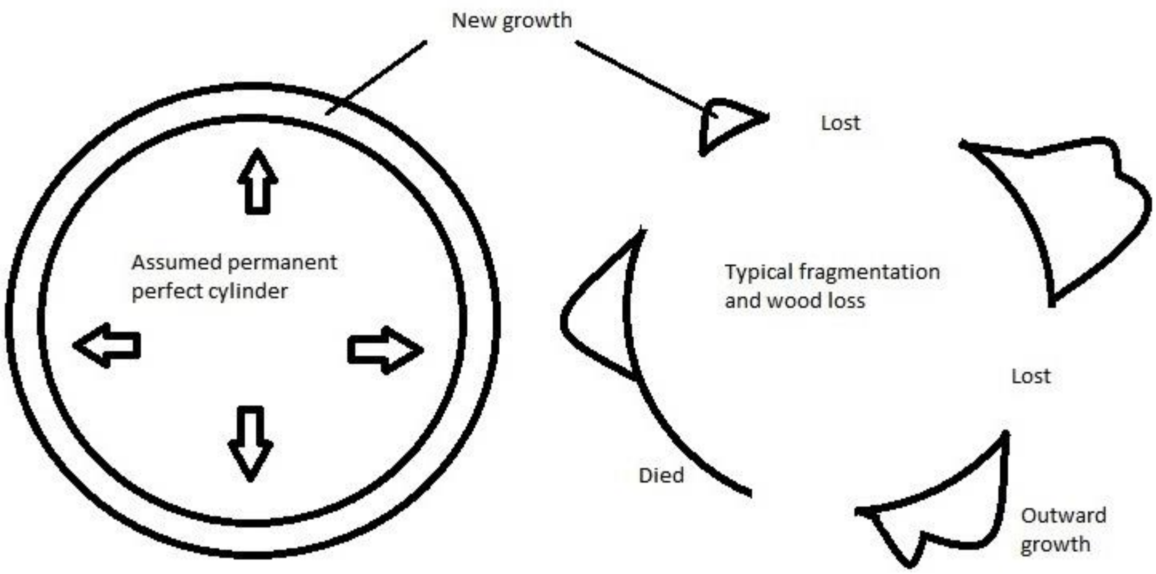
Synthesis

After carefully considering these and other graphs and the physical form of various yews, a fusion of the following ideas came to me: (1) The idea of CAI had to be right because a yew can only make so much wood in a year, (2) the idea that the yew grows its lobes out at an even rate had been demonstrated by Dr. Moir, and (3) I had a measured average circumference increase that was different from the graph which Dr. Moir projected from his Pressler cores. His graph and my graph were supposed to represent the same thing in different ways but our results on circumference increase didn't match, even though both sets of data were directly measured on real yews, and measured on the same parts as well, i.e. the fastest growing areas which naturally tend to protrude from the trunk and form the measured circumference. I was also interested to note the difference that my graph in Figure 4 was still subject to the terminal girth issue, whereas Moir's was not.

Occam tells us that we shouldn't needlessly multiply entities, but here was a necessary entity if ever I saw one: there must be an unaccounted-for variable.

The possible existence of a powerful variable that was confusing the data was checked for, and it was found to be an assumption that both Moir and I were using in different aspects of the calculation to create graph data- that the yew trunks we were measuring were perfect cylinders. In fact when putting a tape measure around a yew, what is actually measured is the horizontal geometry of the trunk. The tape usually runs from one fastest outward growing point to the next taking in bigger and bigger areas of fresh air the larger, more uneven and fragmented the yew is.

Figure 5.Cross sectional bole diagrams explaining how one particular assumption of CAI theory deviates from observed yew growth. Certain things about this simple and unscaled representation need clarification: (1) the fragmented yew does not in reality start from a perfect circle when producing the new wood shown, (2) the cross-sectional area of wood produced is what is important between diagrams rather than any comparison of new surface area because the ring width densities are very unevenly distributed in the new wood of the fragmented yew.



The same amount of wood- the "Constant Annual Increment"- is laid down in each case, but because of the growth being heavily concentrated in certain parts of the trunk the girth increases faster than expected in CAI theory. The lack of wood availible to effectively cover the whole bole is probably the driver for partial trunk death and fragmentation. Hindson 2019.

It is now understood that the puzzle of yew age can only be resolved if the habit of these trees to fragment and to grow more on some areas of the trunk than others is effectively and realistically taken into account. This previously difficult and confounding reality, once understood, has yielded a unifying principle. Most of the wood that followers of CAI theory had assumed to be laid evenly over the whole trunk is actually concentrated in these vertical runs that grow out quickly and at a steady rate. That makes the tree increase its girth (but more particularly its diameter) faster than one would expect for the amount of wood available, particularly when the yew is large enough to fragment. No great age adjustment is indicated for yews where the evenness or integrity of the circumference is not substantially compromised. The deviation due to mismatch of circumference and diameter can be seen in Figure 4 coming into play at about the 6 meter mark.

The really good part is that we actually have a mean growth rate for the faster growing parts of all yews courtesy of Dr. Moir and so we are, when ageing a yew, able to measure the diameter of the tree directly -cutting out the confounding problems of fragmentation and unevenness around the circumference- and can simply apply his mean ring width findings to get a baseline age. The beauty of that method is that (according to the logic of all the older theories) using diameter instead of circumference and real ring width samples as a guide to growth should make no difference at all mathematically speaking when compared with the previous methods.

In reality however the differences are very significant, and are partly represented by the gap between Dr. Moir's graph and mine, as in figure 4. The reasons for the various differences between all the graphs shown are multi factorial, but they revolve around the assumptions which create mistakes in projecting an accurate average ring width to directly or indirectly populate each graph; specifically the reasons include fragmentation which causes changes to two factors: the whole surface area of the tree and also the measured circumference; and another clear issue is uneven ring distribution in lobes which causes higher bole outgrowth than expected. These variables are hard to unpick from one another or quantify. Anyone wishing to delve deeper into the various flawed assumptions and assess them will need to begin with copies of Tabbush and White's (1996) paper in the Quarterly Journal of Forestry, as well as Hindson, Moir and Thomas (2019) in the same journal. The subject is large however, and it is sufficient here to point out that all of the graphs represented above are very different as a result of errors in basic assumptions, especially the use of the "perfect cylinder" idea rather than consideration of the uneven and fragmented trunk that occurs on large yews in reality; and that "terminal girth" which always seems to be calculated at about 12 meters is quite possibly a mathematical artifact of this perfect cylinder fallacy.

Simply, the circumference increase of large yews that are measured through time sometimes seems to stall or sometimes accelerate as the tree gets larger and fragments, generating a chaotic pattern most famously noted by Alan Mitchell as "a random scatter of points" (in Evans 1988) that can only be partly resolved by averaging together the growth measurements of many individuals. The diameter increase is less chaotic, and in this respect the tree is more likely to persistently grow outwards at a broadly even rate on the retained parts of the bole throughout its maturity and senescence as indicated by Moir's findings. It is therefore the diameter which is the more reliable measure for ageing yews and unlike previous circumference based models allows for the existence of "modules", the more or less separated and discrete vertical sections of wood which are usually found in very large yews, an idea related to the "functional units" described by Lonsdale (2013).

Concluding discussion

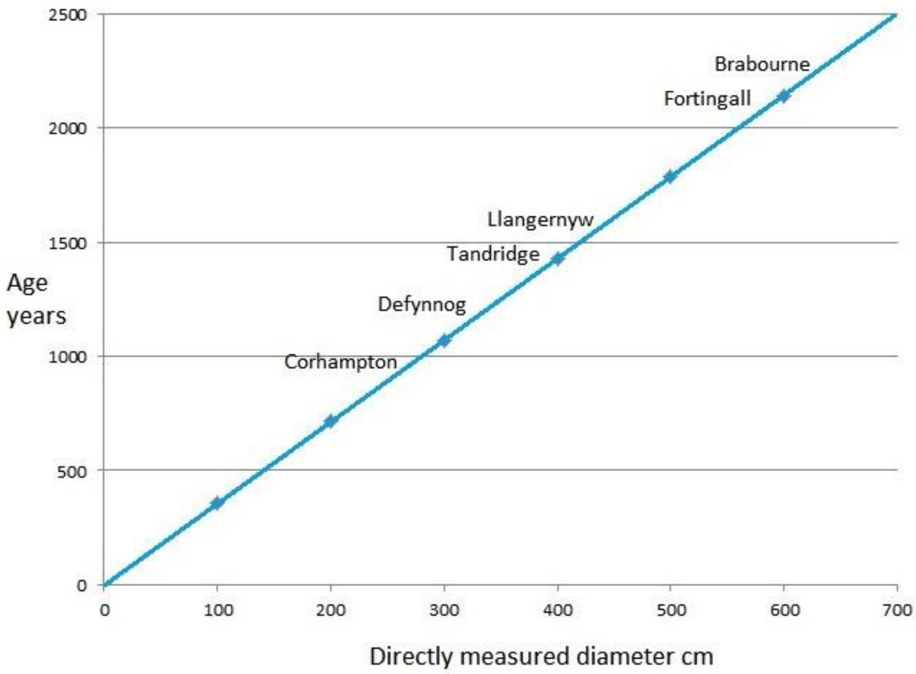
It must be understood that all of the graph lines in Figures 1-4 above are calculated using the circumference in one way or another, and so <u>all of these graphs are actually wrong</u> to a greater or lesser extent, and are only shown here to illustrate the way in which the methods compare with one another.

Moir uses a perfect circumference assumption to calculate his graph line from real radial ring widths, and Hindson generates ring widths from measured circumference changes over time using the same perfect cylinder assumption. The truth is close to these two graphs in Figure 4 because the measures used are from statistically acceptable samples of physical field data, and they can be repeated and checked by other researchers. A "correct" graph would be a fusion of Hindson and Moir's, with a slightly higher growth rate than Moir shows because of the difference created by his perfect circumference assumption, but linear like Moir's graph because vigorous radial outgrowth on a yew produces a standard typical ring width, a fact which was missed in Hindson's curve in figures 2 and 4. Such a graph would represent maximum diameter/age (Figure 6).

These ideas were polished for peer-reviewed publication with Dr. Peter Thomas, without whom the whole lot would probably have remained less comprehensible than it is now. Thanks in this respect are also due to the anonymous peer reviewer at the Royal Forestry Society whose work as devil's advocate was invaluable. The result was the 2019 publication of *Estimating the Ages of Yews- Challenging Constant Annual Increment.*

It is interesting that the age results we have found broadly verify ageing work done by a number of previous academic authors, including Robert Bevan-Jones, and in fact almost everyone who has made a genuinely scientific enquiry into the subject. The right answer has, at least in part, been out there all the time. Those who want big ages for the old yews really don't always seem to want to listen to relevant science. There is a natural drive in the human psyche for sensation, fables. That is valid to a point, but does not mean that those engaged in scientific investigation should automatically cave in to that hunger. Science produces answers; it does not begin with the answer wanted then gather evidence for it, which is a kind of pseudoscience. Much pseudoscience has been produced (and not even published but publicised anyway) on the subject of yew ages and it is as well to be alert to the phenomenon when studying the whole field of research. That said, the age of up to 2,000 years we feel we can confirm for living UK yew specimens at present is an enormous and exciting figure, and can only seem disappointing in comparison with the inflated claims of the very recent past. And the yew's potential for immortality remains unchanged by this new "modular theory"; indeed, the modular concept tends to support immortality in the face of the difficult terminal girth problem described in Figure 1 as no theoretical maximum diameter is necessary to the new mathematics.

Figure 6. Graph: a*pproximate projected age by directly measured diameter. Some yews which have already been physically assessed by diameter are included. Fortingall requires further assessment. Brabourne (Kent) is a lost yew assessed for diameter by Evelyn in the 1600s, and was the largest yew ever properly recorded.*



There are all sorts of factors which affect yews and the progress of their growth. The next stage of investigation is to take into account the many environmental and morphological variables which affect yew growth in the UK; from the extremes of tiny cliff yews to the opposite case of the open-grown hulks which feed in a self-cycling cascade on their own rot and increase in girth at a vast rate reaching perhaps 6 meters in girth in only 400 years. Most yews do not approach these extremes however, and the new theory represents a stable baseline for further method to be built upon and more specific age investigations to be carried out. The various environmental factors are usually transitory in the context of the whole age of any particular old yew, for instance shading by another tree may hold the yew back, but only for as long as the shading tree lives, and moribund yews growing at imperceptible rates tend eventually to begin to produce very vigorous growth again if they survive. Pilot studies and other work not yet published suggest that investigation into the various environmental variables will not show any vast increases in projected age that would return us to the idea of the largest UK yews now in existence being up to 5,000 or even 3,000 years old. Work also needs to be done outside the UK to see how yews respond to substantial altitude with dry conditions, and other variables found in many locations outside the UK which have not been investigated at all.

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