EXPLORING AND COMMUNICATING KNOWLEDGE OF TREES IN THE EARLY ROYAL SOCIETY

by

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For nearly 150 years after its foundation, Fellows of the Royal Society collected information on trees, investigated their anatomy and physiology, promoted planting and improved planting practices, and introduced, naturalized and classified foreign species. Their discoveries and advice were widely disseminated and used. Historians have generally neglected this interest, although the Society’s first publication was an influential work on trees. They have also overlooked the significance of Stephen Hales’s remark in *Vegetable Staticks*—that he hoped his enquiries into the nature of plants would improve skills in agriculture and gardening—and his linking of sap movement to tree pruning. Fellows’ experiments and field trials not only advanced knowledge of the structure, nutrition and growth of trees but also provided empirical evidence supporting instructions for cultivating them.

Keywords: early Royal Society; John Evelyn; Stephen Hales; natural history; experiments and field trials; communicating knowledge of trees

TREE PLANTING: PATRIOTISM AND PROFIT

The first publication to receive the Royal Society’s imprimatur was John Evelyn’s *Sylva, or a Discourse of Forest-Trees and the Propagation of Timber*, published in 1664 in response to an appeal from the Navy for the Society to encourage the preservation and planting of oaks, urgently needed for shipbuilding after great losses and damage to timber trees during the Civil War and interregnum. The appeal, in the form of ‘Quaeries’ (see appendix 1), was presented to the Society on 17 September 1662 by Sir Robert Moray (FRS 1660). Composed by Commissioner of the Navy, Peter Pett, it concerned replanting the royal forests, chases and parks—‘almost wholly cut down and decayed’—with oaks and other ship-timber and assumed that Charles II could be persuaded that this would benefit both the royal purse and the Navy. Pett also proposed that the King should have first refusal of all suitable timber on private land, at a price agreed between Commissioners and landowners; that using oak for house-building in and around London should be forbidden

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(imported fir being substituted); and that all landowners in England and Wales should plant one acre in every hundred with oaks or elms. Pett would have discussed this document with Samuel Pepys, then Clerk of the Acts, whose *Diary* mentions their meetings, including two in June and August 1662 with Sir John Winter, colliery manager in the Forest of Dean, when they read his previous contract with the King and ‘talked of... the timber there’ (on another occasion Pepys and Winter discussed a new contract and studied a map of the Forest). Gaps in Royal Society records concerning its deliberations on the forests are partly filled by Pett’s letter to Evelyn of 4th November 1662, on ‘ye great business of ye Forest of Deane which is now on foot’. Pett wrote that the Society, having answered the ‘Quaeries’ he gave to Lord Brouncker (FRS 1660) and Moray, had ‘much enlarged upon that subject’; he begged Evelyn to bring the relevant passages to the meeting next day at Gresham College, where he might see them.

A significant result of the Navy’s request, which accorded with the early Society’s Baconian aspiration for its work to be useful, was that it provoked a long passage in *Sylva* on improving the Forest of Dean and the other royal forests (including enclosing land for planting) in which Evelyn—presumably with the Society’s support—urged the King to ‘assert his power’ over those in charge who were neglecting their duties. He urged landowners to plant and preserve forest trees, especially on barren land, citing examples already finding this financially rewarding; he suggested removing some iron mills and advocated an Act to preserve standard trees, unless in decay. Evelyn recommended to the King, Parliament and Commissioners that county deputies—accountable to ‘the Lord Treasurer and to the principal Officers of His Majesties Navy’—be appointed to monitor woods, ensuring swift prosecution of improvements and reform of defects; and that ‘such proportions of Timber etc. were planted and set out upon every hundred or more of Acres as the Honorable Commissioners have suggested...’. Evelyn concluded, provocatively:

> the care of so publick and honourable an Enterprize as is this of Planting and Improving of Wood, is a right noble and royal undertaking... more worthy of a Prince who truly consults his glory in the highest Interest of his Subjects than that of gaining Battels, or subduing a Province.

*Sylva* received royal approval, and more than a thousand copies were sold, resulting, Evelyn declared, in more than two million timber trees being planted. Its success may be attributed to the fact that, while encouraging landowners to enhance their estates with ornamental and fruit trees, Evelyn also presented powerful economic arguments in favour of planting timber trees—a further incentive for them to obey their patriotic duty.

Until fairly recently Evelyn was universally accepted as *Sylva*’s author, which is hardly surprising because in Godfrey Kneller’s 1689 portrait he is depicted proudly holding a copy (figure 1), his name appeared alone on the title page, and he always referred to ‘my *Sylva*’; moreover, the Society’s proceedings and imprimatur attribute the treatise to him. Scholars, however, have now shown that although Evelyn’s role was central, *Sylva* originated as a collective endeavour undertaken within the early Society’s Baconian ethos. Evelyn, John Goddard (FRS 1660), Christopher Merret (FRS 1660) and John Winthrop (FRS 1662), who had previously shown an interest in trees, were asked to respond to the Navy’s request, but Evelyn—already an acclaimed author and experienced planter and gardener—combined their papers. This *ad hoc* committee was one of several concerned with agricultural improvements—‘a model for the collective
inquiry the Society wished to promote’. As a Baconian, Evelyn would no doubt have collaborated willingly and he acknowledged the assistance of ‘divers Worthy Persons’; their contributions add weight to his discourse.

**Towards a natural history of trees**

Evelyn’s title was evidently intended to link *Sylva* to Bacon’s *Sylva Sylvarum*, the eighth edition of which also appeared in 1664, subtitled ‘a Natural History’. Fellows probably
envisaged Sylva as contributing to a cumulative natural history of trees.\textsuperscript{15} It contained a fund of empirical evidence about trees and advice on their cultivation and use—based on personal observation and experiment where possible, as Bacon had advocated\textsuperscript{16}—mingled with anecdotes, myth, folklore and remarks on extraordinary trees, on forests, woods and planting barren land.

Collecting material for such a history was in tune with the Society’s ‘Baconian-inspired programme of information-gathering’, considered crucial to effecting improvements.\textsuperscript{17} Strangely, considering the need to encourage planting, the first questionnaire, circulated by the Georgical Committee and printed in Philosophical Transactions in 1665—‘Enquiries concerning Agriculture’—omitted timber trees.\textsuperscript{18} In the following year, however, when Robert Boyle (FRS 1660) published ‘General Heads for a Natural History of a Countrey, Great or Small’,\textsuperscript{19} his list of ‘external productions of the Earth’ to be recorded included timber trees of ‘great bulk’ and ‘what coppices, groves, woods and forests the Country has or wants…what soyles they most like or dislike; and with what Culture they thrive best.’ Boyle probably knew Arnold Boate’s Natural History of Ireland, which recorded timber in its survey of natural resources.\textsuperscript{20} Robert Plot (FRS 1677) successfully used questionnaires to obtain information on trees and other matters and Natural History of Oxfordshire (1677) and Natural History of Staffordshire (1686) contained details of woods, a practice emulated in subsequent county surveys.\textsuperscript{21} For later editions of Sylva, Evelyn drew on Plot’s Histories and works by John Ray (FRS 1667) for further information about extraordinary trees,\textsuperscript{22} which were not only wonders of nature but also often attained an immense size, indicating that mature trees, if not felled prematurely—a practice that Evelyn deplored\textsuperscript{23}—could supply much valuable timber.\textsuperscript{24}

**IMPROVING PLANTING PRACTICES**

Sylva’s publication was also connected to the Society’s plan for a complete system of agriculture linked to a collaborative Baconian History of Trades intended to reform practical knowledge.\textsuperscript{25} Evelyn, Boyle, Henry Oldenburg (FRS 1663) and John Beale (FRS 1663) were among those connected to Samuel Hartlib’s circle of puritan reformers with aspirations to improve agriculture, including the cultivation of fruit and timber trees.\textsuperscript{26} They took their Baconian ideals and projects with them to the Royal Society, of which they were all founding or early Fellows,\textsuperscript{27} and attempted ‘to inculcate a more scientific attitude to husbandry’, seeking improvements that could be verified by experiment.\textsuperscript{28} Such attitudes and aims are apparent throughout Sylva—and Pomona, the discourse on fruit trees and cider production published with it, mainly the work of Beale, author of Herefordshire Orchards, a Pattern for All England (1657). He was indefatigable in promoting and publicizing agricultural advances, especially through Philosophical Transactions; his many letters to Evelyn and Oldenburg indicate his contributions to Evelyn’s works.\textsuperscript{29}

Evelyn derived Sylva’s practical advice—also expressed as Baconian aphorisms—\textsuperscript{30} from the ancients, from earlier English works, and from personal experience. He concentrated on raising seeds, establishing tree nurseries, transplanting young oaks, coppicing, and valuing and felling timber; he stressed the importance of skilful pruning but deferred to the experience of ‘our Country-man, honest Lawson’, quoting his instructions at length.\textsuperscript{31} Evelyn raised many trees planted at Sayes Court in his own nurseries\textsuperscript{32} and he evaluated
his field trials, encouraging readers to do likewise: ‘Try all sort of seeds,’ he urged, ‘and by their thriving you shall best discern what are the most proper kinds for Grounds . . . .’ In 1706 Sylva included a ‘Table of Soils and Situations’ for trees, based on trials, to which later writers referred. Promoting a comparative method reflected the experimental ethos of Sylva—an important legacy of the work.

Evelyn’s early advice would have assisted inexperienced planters. John Houghton (FRS 1680), who edited A Collection for the Improvement of Husbandry and Trade (1692–1703), summarized some of it, as well as Evelyn’s remarks on tree species. It is clear, however, that maintaining Sylva’s utility was important: ‘Many more useful Observations are to be collected . . . from the diligent experience of Planters’, Evelyn stated, and an advertisement in Philosophical Transactions requested readers to send additions or improvements to Oldenburg. Contributions from many sources appeared in later editions; Evelyn also drew on the detailed instructions in an acclaimed work by another practical man, Moses Cook, head gardener to the Earl of Essex.

**Later innovations**

Evelyn said little on managing timber plantations—essential to the Society’s original purpose—but the subject was addressed by later writers, including Richard Bradley (FRS 1712) and Philip Miller (FRS 1730). Bradley, first Professor of Botany at Cambridge, was a prolific writer on husbandry: A Philosophical Account of the Works of Nature (1721), containing a chapter on propagating timber trees and improving barren lands by planting, attracted more than 500 subscribers, including Isaac Newton, Hans Sloane and Christopher Wren, as well as French naturalists Étienne-François Geoffroy and Bernard de Jussieu. Important new advice on managing forest trees appeared in New Improvements of Planting and Gardening (1717), The Gentleman’s and Gardener’s Kalendar (1718) and his other works. Bradley also performed a useful service by appending Beale’s Herefordshire Orchards to the former from 1724 and by publishing a revised edition of Houghton’s Collections, containing Evelyn’s ‘Table of Soil and Situations’, Plot’s Enquiries and much additional information on trees.

Philip Miller was Superintendent of the Chelsea Physic Garden (1722–70) and author of the universally esteemed Gardener’s Dictionary, which ran to eight editions (1731–68) and six abridgements (1735–71); although not confined to trees, in terms of botanical knowledge of tree species and planting advice it represented a great advance on Sylva. Miller’s detailed instructions for raising oaks—still considered the most important timber tree—decreed that extensive plantations be sown ‘where they are to remain’. Miller always emphasized his considerable planting experience, claiming to have planted large numbers of Scotch firs; his instructions on raising evergreens were especially valuable, little then being known about them. He was reported to have advised many landowners including the fourth Duke of Bedford (FRS 1742), who probably consulted him regarding the famous ‘Evergreens’ plantation at Woburn.

Bradley and Miller cited Evelyn but challenged his advice on the basis of their own experience. Nevertheless, Sylva’s influence persisted into the nineteenth century thanks to Dr Alexander Hunter (FRS 1775), founder of the York Agricultural Society and editor of the well-known Georgical Essays (1769), who in 1776 published the first of five editions of Silva. It incorporated Linnaeus’s taxonomic system and binomial nomenclature, brought Evelyn’s advice up to date, and drew on the work of Bradley,
Miller and others. The Royal Society was not involved in this venture, but the 650 subscribers, mainly landowners and gardeners, also included the naturalist-Fellows Joseph Banks, Peter Collinson, Thomas Pennant, John Lightfoot, Daniel Solander and Richard Kaye. Hunter attributed its success to the recommendation of his ‘patron’, almost certainly Joseph Banks (FRS 1766)—a friend, also interested in agricultural improvement and planting. Banks no doubt actively encouraged Hunter’s project, perhaps by paying for the botanical plates (figure 2) and tables, which he checked for accuracy; certainly, as a botanist, he would have welcomed a Linnaean edition of *Silva* incorporating the latest planting practices. The third Duke of Portland (FRS 1766) also assisted Hunter by paying for *Silva’s* portraits of his famous oaks by the well-known artist S. H. Grimm, and allowed his head gardener, William Speechley, to contribute valuable instructions on raising oak plantations.

The Society of Arts’ planting awards

Although individual Fellows remained dedicated to effecting agricultural reform, the Royal Society withdrew from technological improvement; however, the Society of Arts, established in 1754 to promote such matters, awarded premiums for timber production from 1757. Of the four founding members who were Fellows of the Royal Society—Henry Baker, Stephen Hales, James Short and Gustavus Brander—Baker, a botanist (FRS 1740), did most to foster planting. He presented a pamphlet by Edward Wade advocating planting timber trees on common land and waste ground (which cited Evelyn on potential profits), and his proposal to award medals rather than monetary premiums to landowners encouraged many important participants. Peter Collinson (FRS 1728), John Ellis (FRS 1754) and Miller—arguably the most eminent botanist-gardeners with the greatest knowledge of tree species at that time—were invited to discuss the first advertisement offering premiums; although no record of any contribution survives, the published version shows expert knowledge of timber trees. Over the years, millions of trees were planted and improvements were effected to land and planting procedures. Among Fellows of the senior Society who received medals and became celebrated planters were the fourth Duke of Bedford (FRS 1742) and Richard Watson, Bishop of Llandaff (FRS 1769).

Hales’s connection to the Society of Arts may have prompted his suggestion that *Philosophical Transactions* should publish ‘Observations on the Growth of Trees’ by the Norfolk landowner Robert Marsham, containing tables of measurements and cubic content of oaks and other trees on his estate, collected over specific periods. Hales’s comment, that it might be ‘the means of encouraging the planting of Timber Trees, especially the Oak, which grows scarce and yet is of the greatest importance to us’ was astute, because Marsham’s method was widely recommended.

Introducing, naturalizing and naming foreign trees

During the eighteenth century more than 500 tree species were introduced into Britain, mainly from North America. Miller and Collinson were prominent among Fellows importing and distributing seeds and young trees, and undertaking trials to propagate and naturalize them. They sent their American collector shipping instructions, and Miller also addressed the subject in *The Naturalist’s and Traveller’s Companion*. The loss of valuable seeds in transit or storage also stimulated experiments. John Ellis, for instance, informed Linnaeus of his many trials to preserve acorns; he also sent some, stored in
beeswax, to William Aiton, who sowed them successfully at Kew—an experiment that Ellis presented to the Society, with Aiton’s report. Miller described his experiments demonstrating that seeds ‘need air or they will not grow’. During his time at Chelsea, and until 1799, 50 dried specimens, including exotic trees, were delivered annually to the Royal Society, where they were displayed and the lists were read at meetings (and published in Philosophical Transactions). Tree specimens included acer, cedar, juniper, larch, lime, plane, thuja and tulip.

Among the first to plant exotic trees on a grand scale were the eighth Earl of Pembroke (FRS 1685) and the second Duke of Richmond (proposed for election in 1724 by Sloane). Contemporary reports record their passion for collecting trees and their pride in their plantations; their generosity in sharing seeds, plants and information on culture; and their encouragement of practical trials. Miller hailed Pembroke’s collection at Wilton as ‘the best in any one Garden in this Kingdom’, and ‘the fame and variety’ of Richmond’s...
Goodwood plantations were recorded in 1754 by Richard Pococke (FRS 1742). Such accounts stimulated visitors and encouraged further planting.

The influx of new species put pressure on botanists to classify and name them. From 1730 Miller strove to standardize nomenclature and correct ‘egregious Mistakes’ causing problems for gardeners and planters, as well as botanists, although he did not adopt Linnaean binomials until 1768. Although he had earlier acknowledged the benefits of the sexual system, he thought Linnaeus insufficiently experienced in cultivating plants to distinguish between species and varieties—because different ‘soils, situations and culture greatly alter the appearance’. Miller is credited with several generic names, including Abies (fir), Acacia, Castanea (chestnut) and Larix (larch), and with the names of some trees unknown to Linnaeus. In 1807 the Cambridge botanist, Thomas Martyn (FRS 1786) published The Gardener’s and Botanist’s Dictionary, a revised and enlarged version of Miller’s work, containing many new tree species. Changes to the classification and nomenclature of trees, as botanists defined and redefined genera, species and varieties, can be traced through the various editions of these two works.

Interactions between British and French naturalists

In the 1730s declining forests and shortages of quality timber alarmed the Académie royale des sciences, as they had the early Royal Society. The agronomist Henri-Louis Duhamel du Monceau (FRS 1735) and the Comte de Buffon (FRS 1740) were asked to suggest remedies. Their advice, based on extensive trials and observations (conducted by Duhamel in the royal forests and by Buffon on his own estates) helped to improve planting procedures—in Britain as well as in France. They were elected to the Royal Society as ‘foreign members’ before this research: Duhamel had undertaken investigations on wood for the Académie, and Buffon’s translation of Vegetable Staticks appeared in 1735. Duhamel’s 14 proposers included Hans Sloane (FRS 1685), Stephen Hales (FRS 1718) and the second Duke of Richmond (FRS 1724), a renowned planter; Buffon was also endorsed by Sloane, and by Martin Folkes (FRS 1714). Buffon became known as an authority on trees: he included some in l’Histoire Naturelle and was cited on several species in the Encyclopédie in the 1750s, but Duhamel was recognized as the era’s foremost forestry expert—a reputation fully justified by the extent and rigour of his trials and by the advice he derived from them, which covered every aspect of raising trees and managing plantations.

Buffon’s most important research followed routes indicated by Evelyn. His trials stripping trees of their bark some time before felling, for instance, were prompted by Evelyn’s remark that some people advised this; Buffon found—as did his English friend Nathaniel Hickman (FRS 1725)—that the procedure improved the timber’s strength and solidity. These trials were summarized in the Dublin Literary Journal in 1744 and 1745. Duhamel later endorsed Buffon’s conclusions, and Miller, noting the procedure’s success in France, advocated changing the law to allow it in England. Alexander Hunter also drew attention to it, quoting Buffon’s explanation for its success: ‘the sappy part ... becomes as hard as the heart.’ Duhamel did not cite Sylva directly but its influence is apparent, especially in Des Semis et Plantations des Arbres et de leur Culture (1760) and De l’Exploitation des Bois (1764). Duhamel’s works were popular in England, which he visited in 1750 to compare agricultural practices. Traité de la culture des Terres (1750–61), based on Jethro Tull’s ideas, appeared as A Practical Treatise of Husbandry (1759), and the translation of Éléments d’Agriculture (1763) announced it was
Buffon’s instructions for planters appeared in two valuable memoirs describing and evaluating his planting trials: Sur la conservation et le rétablissement des forêts (1741) and Sur la culture et l’exploitation des forêts (1742). These were available at the Royal Society from 1750 and also appeared, translated and unabridged, in the 1761 edition of the Earl of Haddington’s influential Treatise on The Manner of Raising Forest Trees. Discussing restoring woods in the earlier memoir, Buffon pronounced Evelyn and Miller knowledgeable and experienced, but because their experiments were on a smaller scale, he devised his own. However, he followed Evelyn in addressing such matters as when to fell trees and frost protection, and in championing tree nurseries, coppicing, planting barren land and planting for posterity. He also adopted a comparative approach, undertaking numerous trials sowing acorns or using young trees, in different soils and situations, weighing and measuring the produce of particular areas ‘to compare the annual increase’, and recording failures and successes. In 1742 Buffon commended the utility of his enquiries and observations on methods of protecting sowings of acorns, on ways of preparing land (no preparation at all produced the best results), and on dealing with failing trees (cutting them to the ground encouraged new growth because ‘all the strength of the sap is carried to the roots’ enabling them to ‘shoot out with vigour’). Forming large plantations by using nursery-raised trees he found too costly (which confirmed Miller’s advice to sow on the spot).

EXPERIMENTAL PHILOSOPHY: INVESTIGATING STRUCTURE, NUTRITION AND GROWTH

Sylva’s genesis within the Society demonstrates the significance to Fellows of the acquisition and dissemination of knowledge of all aspects of trees and their role in nature, and explains why many investigated them in addition to encouraging planting. As Michael Hunter has pointed out, for early Fellows utility was not confined to practical matters but also meant improving knowledge of nature. Trees’ anatomy and growth were examined from the Society’s earliest years, notably by John Goddard (FRS 1660), Robert Hooke (FRS 1663) and Nehemiah Grew (FRS 1671). When listing Fellows’ achievements in his history of the Society, Thomas Sprat included the presentation of observations on ‘the Pores and Valies in wood: the Anatomy of Trees’, indicating this as a subject worthy of enquiry within the Society’s programme of experimental philosophy. Microscopy and comparative anatomy revealed mysteries of the inner structure and growth of trees and facilitated insights into the causes of some puzzling phenomena. Investigations were recorded in Philosophical Transactions and in early works published by the Society: Hooke’s Micrographia 1665 and three works by Grew—The Anatomy of Vegetables Begun (1672), to which Hooke contributed microscopic observations on the pith and pores, The Comparative Anatomy of Trunks (1673) and The Anatomy of Plants (1682).

Although many Fellows could have seen these works, Evelyn also drew attention to them in Sylva, with other relevant items: experiments undertaken by the Society in 1663 and 1664 to test the ‘strength and fortitude’ of wood, Merret’s names for tree parts, Hooke’s microscopical study of petrified wood, and taxonomic information on tree species taken from Ray’s works. In 1664 Evelyn summarized Goddard’s
anatomical studies of trees. Using transverse sections of trunks, Goddard confirmed that, as was commonly supposed, their size increased by the addition of annual rings that were larger and more distinct in quicker-growing trees such as fir and ash; a great oak might have several hundred. He found that rings were broader on the south-facing side and that firs produced one less ring above each annual row of boughs than below it; that buds connected through all the rings to the centre, causing knots whose hardness probably resulted from the fact that their growth was restricted; and that a grafted bud appeared to root itself into the stock. He investigated the bark (formed of much thinner rings) and pith, discovering that growth occurred as nourishment reached through ‘all the Pores and substance’ of the tree, although mostly between bark and body, which suggested that a tree would die if the bark were cut around. In 1706 Evelyn repeated this but directed readers to the microscopical studies of trees by Grew, Malpighi (FRS 1669) and Leeuwenhoek. The plates in their works were significant in furthering knowledge of trees by facilitating comparison, which revealed differences between species in pith, wood and bark, as well as in the sap and air vessels (figure 3). Grew also considered the effect on the sap of air, which enters, he said, through ‘leaves, trunk and roots’, insertions in the trunk conveying it from the air vessels into the sap and back again. Goddard seems to have been first to stress the importance of air to growth, and Hales later found the air in plants ‘very serviceable in carrying on the work of vegetation . . .’.
The motion of the sap

The motion of the sap, and especially its apparent ability to defy gravity in ascending to the tops of trees, exercised many Fellows, stimulating experiment and discussion. This was facilitated by Philosophical Transactions, whose regular appearance encouraged a reasonably swift exchange of views, demonstrating Oldenburg’s conviction that communicating ‘the progress of the Studies, Labours, and attempts of the Curious and learned’ was essential for promoting and improving philosophical matters, advancing learning and encouraging profitable discoveries. A vivid impression emerges of a dynamic discourse in progress as Fellows responded to each other’s work—on trees as on other matters.

In Micrographia (1665) Hooke investigated the possibility of valves in wood but, despite diligent endeavours, could not be certain whether the ‘Microscopical pores of Wood or Piths’ contained anything like the ‘Valves in the heart, veins and other passages of Animals . . . .’ His experiments to determine the height to which liquid would rise in a small glass pipe—or ‘artificial pore’—and his speculations on ‘channels or pipes through which the . . . natural juices of Vegetables are convey’d’, were referred to by Boyle when publishing his own related experiments, conducted in 1668. Boyle thought it possible that ‘Nature, or . . . the most wise Author of it, may have made such Contrivances in Plants, as to make Liquors ascend in them to the Tops of the tallest Trees’; he considered the likelihood of something equivalent to valves and discussed the probable effects of heat.

Christopher Wren (FRS 1660) had also pondered the question of valves, although his deliberations were not published until 1750. Anatomists agreed, he said, that some pores present in all wood ‘rise perpendicularly, but with straps’, whereas others run horizontally from pith to bark. On repeating ‘a known experiment’ to raise water in pipes, he asserted that ‘Vicissitudes of heat and cold in ye Aire’ were alone sufficient to raise the sap to the tops of tall Trees, which ‘a Skillfull Engineer’ cannot effect with water ‘without great force and a Complicated Engine’; but he was certain that valves operated to ‘keep the sap from falling down’, and that the Sun’s heat caused water drawn in by the root to rise ‘from valve to valve’ to the top. To demonstrate this, he described an experiment using an apparatus composed of a glass pipe filled with water, with smaller pipes (part filled) inserted at intervals, each just below a valve (figure 4); the air in these pipes being heated, the water is pressed upwards opening the next valve above it; and when the cold contracts the Aire in the heads . . . the water [in the long pipe] is sucked up to supply it and opens constantly from valve to valve, let the height be what it will . . . This is what such an Engine will performe; it remains we should shew that the fabrick of Trees is naturally such a kind of pneumaticall Engine.

Wren believed this to overturn the idea of ‘a Secret motion in Nature, contrary to that of Gravity, by which plants aspire upwards’ but added that it ‘may require a great collection of Phaenomena with a large history of plants to shew how they Expand the leaves and produce the Seeds and Fruit from the same raine water . . . ’. In 1673 Grew discounted the valve theory, arguing that a branch cut at both ends, ‘. . . always bleeds . . . upwards and downwards alike freely . . . ’ Later he emphasized the sap’s energy and the pressure forcing it from the roots up into the pith and bark causing ‘the dilation of the Trunk . . . and the shooting out of the Branches . . . ’ and creating ‘a most ready and copious ascent of the sap . . . from the bottom to the top of the highest Tree’. Hales’s experiments would eventually confirm ‘the great force of the ascending sap’.
Fellows’ interest in these subjects probably inspired the ‘Queries concerning Vegetation, especially the Motion of the Juyces...’, inserted in *Philosophical Transactions* in 1668. Beale and Dr Ezerel Tonge, a Herefordshire rector, responded quickly; although not a Fellow, Tonge’s thorough research provoked further trials, as Oldenburg no doubt expected. Beale declared that the juice ascends ‘by the inward Bark’ and ‘after ’tis concocted to partake of the nature of the plant...’. Tonge found the annual rings ‘full of Circular Pores’, or ‘Pricks’. To discover whether the sap ascended more in these, or between the body and the bark, he suggested an experiment, adding that sap taken from a hole bored into the heart of the tree should indicate differences between the heartwood and the timber. Ray and Francis Willughby (FRS 1663) confirmed Tonge’s ‘prick’t circles’ and found that sap ascended, not only in these circles and between the body and the bark, but also ‘through the very Body of the Wood’; it also descended. They discovered that old trees bled sooner and faster than young ones; that trees bled more if pierced on the north side than on the south; that a wound made before the sap rises ‘will bleed when it doth rise’; and that cold weather stopped the flow of sap. Their investigations of bleeding in sycamores appeared in *Philosophical Transactions* between 1669 and 1671, with some by Martin Lister (FRS 1671). In 1673 Grew verified the sap’s ascent through wood, bark and pith.

**EIGHTEENTH-CENTURY INVESTIGATIONS OF SAP MOVEMENT: PRACTICAL IMPLICATIONS**

The early experimenters focused on improving knowledge of plant structure and the mechanisms of nutrition and growth without considering practicalities. Even Evelyn, who quoted William Lawson’s instructions on pruning, did not immediately recognize the significance of Lawson’s assertion that wasteful boughs and suckers draw sap from the
bole, whereas, if cut close, ‘the strength of all the sap would have gone to the bulk’.107 In 1706, however, Evelyn declared that nothing was ‘more necessary, in order to Pruning, than the knowledge of the Course and Nature of the Sap’.108

When Bradley, Miller and Hales conducted their investigations into the sap, they immediately drew attention to the practical implications of their discoveries, with the clear intention of establishing principles for pruning practices based on solid scientific evidence. In the preface to Vegetable Staticks Hales wrote:

...doubtless a farther insight into the vegetable oeconomy must needs proportionably improve our skill in Agriculture and Gardening, which gives me reason to hope that inquiries of this kind will be acceptable to many who are intent upon improving those Arts: Since they cannot be insensible that the most rational ground for Success in this laudable pursuit must arise from a greater insight into the nature of Plants.109

Hales’s work is usually analysed in terms of his endorsement of Newtonian ideas—and his approach to plant physiology was quantitative, with an emphasis on weighing and measuring—but historians have tended to neglect his significant role in improving tree cultivation.110

Bradley, whose publications preceded Hales’s, had read Grew and recognized that the cultivation of trees could be improved by a knowledge of their anatomy and physiology. He showed the role of the sap in growth and why it must be considered when pruning trees. His first experiments, published in Philosophical Transactions in 1716, included a microscopical drawing of a branch’s ‘Capillary Vessels’ and an explanation of how its diameter increases.111 Bradley also clarified the Sun’s role in starting and maintaining the sap in motion until, in winter, it condenses ‘into the consistency of gum’. He argued against its all returning to the root in winter (as most people thought)—otherwise, he asked, ‘How comes it that Trees cut in November and December will put forth Branches and Leaves the following Spring, though they have no Root or Earth to feed them? This plainly shews that the Sap is condensed or checked in the Tree’.112 Further experiments convinced him that the sap vessels must be preserved ‘entire’ and that

At the Time of Transplanting a Tree it was by no means proper to cut off any of the Branches or wound any of the Vessels, if possible, that the Sap might circulate more freely and the Tree might remain in better Spirit, till it had renewed its Roots which of Necessity must be wounded at Transplanting.113

Later Bradley asserted that making great amputations ‘when the Sap is in full Vigour ... will weaken and endanger the Tree’.114

Whether Bradley’s research inspired Hales is not known.115 Hales’s plant physiology considerably advanced understanding of the role of the leaves in promoting growth—of great consequence to those cultivating trees. He found that the capillary sap vessels in the trunk imbibe moisture plentifully but require the perspiring leaves to promote its progress, demonstrating this by showing that a cut branch imbibes water from either end but if the leaves are removed this ‘soon subsides for want of [their] plentiful perspiration’ (figure 5).116 Although the leaves contain the plant’s ‘main excretory ducts’, designed to remove redundant fluid, they also draw nourishment up to the young shoots and fruit, nature taking care to arrange them to ‘render them most serviceable to this purpose’.117 He verified the influence of the Sun’s warmth in expanding the sap in all parts and found that with its assistance, ‘the force of dilating sap and air’ was sufficient to extend shoots and expand leaves (figure 6).118
Because Hales intended his enquiries to improve skills in agriculture and gardening, he would surely have consulted Miller, England’s foremost gardener, whose tables prepared from experiments measuring leaf perspiration, featured in *Vegetable Staticks*, ‘as he communicated them to me’. Hales also described their (separate) experiments with evergreens, showing that they perspired little and that their ‘thick, viscid, oily sap
protected them from cold and prevented their leaves from falling’, leading Miller to advise pruning resinous trees only sparingly.\(^{120}\) In 1730 Hales proposed Miller as a Fellow.

Hales concluded that as trees increase in height, ‘lateral branches shoot out, each lower order being longer than those immediately above them . . .,’ while if crowded together—as in woods and groves—the lower branches, perspiring little, die from insufficient nourishment but the trees grow taller, since the upper branches, exposed to the air, perspire plentifully, drawing sap to the top.\(^{121}\) Miller and later writers would urge early thinning of woods to avoid the ill-effects of overcrowding.\(^{122}\) Hales also found that, in trees growing in the open, ‘the perspiration and attraction’ of the lateral and top branches were nearly equal, checking upward growth; as the leaves continued to expand, the supply of sap increased to meet the demand for it.\(^{123}\) He surmised that leaves support vegetable life as the lungs support animal life, and thought that plants probably drew some nourishment from the air through their leaves.\(^{124}\) He declared:

\begin{quote}
The serviceableness of the leaves in drawing up the sap, and the care we see nature takes, in furnishing the twigs with plenty of them may instruct us . . . not to be too lavish in pruning them off . . .[and] to be as careful to cut off all superfluous shoots, which we are assured do draw off in waste great quantities of nourishment. . . .
\end{quote}

Comprehending this might offer ‘some useful hints to the Gardiner, in the pruning and shaping of his trees . . .’.\(^{125}\)
Miller quoted Hales at length in *Gardener's Dictionary*, applauding him for ‘setting the Operations of Nature in the Business of Vegetation in a much clearer Light than was ever before done’ and for clearing up ‘mistaken Notions concerning the Motion of Sap in plants...of great service to promote the more skilful Management of the various Sorts of Trees’. He urged gardeners to study *Vegetable Staticks* carefully and to undertake pruning ‘upon the Principles therein laid down’. It is very likely that the utility of Hales’s discoveries might have been limited without Miller’s making them known to a wide audience of improving landowners and practical men. Lesley Hanks says that Buffon applied Hales’s insights on sap movement directly to his forestry research. This is apparent in his early investigations with Duhamel on the annual rings and frost damage to plantations, but his memoirs on preserving and cultivating forests, based on his planting trials, contain nothing on pruning or the role of leaves in promoting growth. Duhamel, however, cited Hales frequently in all his works, and *La Physique des Arbres* (1758), devoted to the anatomy and physiology of trees, contains many of Hales’s experiments on sap movement, as well as simplified reproductions of his figures.

**Experiments on air: further benefits of tree planting**

In 1659 Beale wrote to Oldenburg, quoting Hartlib:

> Trees doe breathe, draw and give breath...some plants doth cherish life in some others and fit ye place for their habitat... Tis time for London to think of this and to accept of a sweete and easy remedy against ye corrosive Smoake and the Sea coale.

Evelyn addressed this theme in *Fumifugium: or the Inconvenience of the Aer and Smoake of London Dissipated* (1661), advising planting sweet-smelling shrubs and trees to combat London’s ‘infernal Smoake’ and improve the air.

Scientific support for such views took time to emerge. While Hales found the air ‘full of acid and sulphureous particles...’ which were ‘imbibed by the leaves...’, he did not directly infer any improvement to the atmosphere. However, Joseph Priestley (FRS 1766)—for whom ‘the discovery of the provision in nature for restoring air...injured by the respiration of animals [was] one of the most important problems in natural philosophy’—concluded that plants ‘reverse the effects of breathing and tend to keep the atmosphere sweet and wholesome’. Attempting to discover which trees would best fulfil this purpose, John Ingenhousz (FRS 1769) found those with larger leaves, especially elm, most effective. In 1776 Alexander Hunter’s *Silva* drew the attention of planters to Priestley’s remarks. Seventeenth-century and eighteenth-century Fellows collected and disseminated information about trees, encouraged planting and improved their cultivation; their investigations greatly advanced knowledge of trees’ structure, nutrition and growth. Professional foresters, who from the 1790s provided instructions for planting and managing trees, rarely acknowledged their sources but there is no doubt that they reaped the benefit of the ‘Studies, Labours, and attempts of the Curious and learned’ who preceded them.
APPENDIX 1

The following is the full text of the document presented to the Society on 17 September 1662 by Sir Robert Moray (Royal Society Classified Papers 10 (iii) Agriculture 1660–1740 fol. 20). Michael Hunter kindly assisted me with its transcription.

Queries touching the Preserving of Tymber now growing And planting more in His Majesty’s Dominions of England & Wales

1st. Whether it were not adviseable that his most sacred Majesty might be moved, now there is so great a scarcity of Tymber for the Supply of his Navie, that all such of his Forests, Chases & Parks, that ly within 20 Miles of the Sea or any Navigable River, and whose soyles shall be found fitt for propagating of Tymber for the service of the Navie, May be planted with Oke, Elme, Ash and Beechen Tymber, in such manner & proportion as may still consist with His Majesty’s benefit & pleasure in his Gaine, And whether the planting of them may be not a far greater emprovement of those Lands then is now made.

2. What Proportion of these Forrests Chases and Parks shalbe planted, and whether Hills or Dales or promiscuously if his most excellent Majesty shall give way thereunto, And whether that quantity of ground, that shalbe thought fitt to Plant, ought not to be plowed & sett with Acornes, Ash Keys, Beech Mast, and what the charges of each Acre may come to per Est[ate] to plant, and from tyme to tyme to fence off. And if any part of those grounds, shalbe found fitt for planting of Elme—Whether the Transplanting of young Elmes, be not the most probable way of propagating that sort of Tymber.

3. Whether His Majesty for supply of his Royal Navie, now his owne Tymber in all his Forests, Chases and Parks being almost wholly cut downe & decayd, might not to have the refusall of all Oken, Elme, Ash and Beechen Tymber growing upon any Man’s private Grounds, that is or shalbe offered to sale, before any part of it be butted or sold to any Private person: Provided the King give such a valluable consideration & such security for it as it may be worth, to be agreed for, between the Officers and Commissioners of His Majesty’s Navy for the tyme being, and the party that owns the Tymber. And in case they cannot agree in ____ daies after the tymber is felled, & thus offered to sale, to the Officers and the Commissioners of the Navie, that then the Owners have Libertie to sell, to whom he please.

4th. Whether it may not be prudence to forbid the building of Houses, in or about the City of London, the Liberties of the same or within 10 Miles of the said Cittie, with Oken Tymber, unless for Ground Plates, For that the want of Oke may be supplyed with Firr, which at the distance before mentioned may be bought at reasonable rates. And the Transport of Firr will not only begett an encrease of seamen, but be also an Advantage to His Majesty in poynt of Customes.

5th. Whether provision might not be made by Planting Especially of Oaken Tymber, throughout all his Majesty’s dominions of England & Wales, so as that every owner of Land may Plow up, Sow or sett with Acornes, One Acre of land, out of each Hundred Acres. Or so many Oken, or Elm Trees, in Hedgerowes as shalbe equivalent to one Acre, Sowne or Sett.

ACKNOWLEDGEMENTS

I am grateful to Patrica Fara and Richard Yeo for advice on early and late drafts; to Michael Hunter for checking my transcription of the document attached as an appendix; and to two anonymous referees for their helpful suggestions.
NOTES


3 Pett is identified by his handwriting (see note 5).

4 Entries 18 June, 14 August and 20 June 1662.

5 Letter, Pett to Evelyn, British Library Add. 78317 fol. 23. Evelyn’s *Diary* (op. cit., note 1) confirms that he attended Gresham College on 5 November.

6 Evelyn, *Sylva* 1664, pp. 111–120.


8 Evelyn, *op. cit.* (note 1), 16 and 26 February, 27 October 1664; Birch, *op. cit.* (note 2), vol. 1, pp. 212 and 347; *Sylva* 1664 (imprimatur).


10 Birch, *op. cit.* (note 2), vol. 1, p. 111. (Volume 1 contains all references to *Sylva*.)


13 See Sprat on Fellows ‘mutually assisting each other’, *op. cit.* (note 12), p. 76.


15 Five editions appeared: 1664, 1670, 1679, 1706 and 1729 (the last posthumously).


18 *Phil. Trans.* 1, 91–96 (1665). The committee was founded in 1664 at John Beale’s suggestion (Birch, *op. cit.* (note 2), vol. 1, pp. 402 and 407).

19 *Phil. Trans.* 1, 186–189 (1665–66).


21 Robert Plot, *Enquiries propounded to the most Ingenious of each County in my travels through England and Wales* (Bodleian Ash 1820), fos 222–225, trees on p. 222. Forests and woods are marked on Plot’s maps. See also William Marshall’s County Surveys from 1787; Thomas Martyn, *The Gardener’s and Botanist’s Dictionary*, vol. 1 (Woods) (1807).

22 Plot describes such trees in chapter 6 in both works: John Ray, *Catalogus Plantarum* and *Historia Plantarum*.


24 The timber content of great trees—fallen or felled—was regularly recorded.


John Houghton, *op. cit.* (note 34), 15 no. 409; 16 no. 483.

Evelyn, *Sylva* 1664, p. 107; advertisement, *Phil. Trans.* 2, 398 (1666) [no author].


Bradley, revised edition of Houghton’s *Collection* (note 34), vol. 3; and Plot’s *Enquiries* (note 21), vol. 4, pp. 292–298.


Philip Miller, *Gardener’s Dictionary* 1759 (Quercus; Planting).

Miller, *Gardener’s Dictionary* 1731, 1768 (Preface); 1759 (title page).

Miller, *Gardener’s Dictionary* 1759 *op. cit.* (Pinus, Planting, Lopping).


Evelyn adopted the spelling *Silva* in 1706.

Alexander Hunter, *Silva* (Preface). Martyn recorded that Banks’s woods had been ‘very carefully managed since 1727’ *op. cit.* (note 21) I (Woods).

Banks–Hunter letters (Kew, BA 1, fos 47 and 55–56). Hunter later thanked Banks for ‘favours’ (*Silva* 1812, p. viii). By engraving the plates himself, the artist, John Miller, also ensured their accuracy.


Collinson refused (Linnean Society, Collinson correspondence, letter 23 March 1757); Ellis had joined in 1755 and Miller’s occasional attendance in an advisory capacity is recorded.


56 Phil. Trans. 51, 7–12 (1759).

57 Hales to Ellis, 18 December 1758 (British Museum, Birch papers Add. 4309, fo. 45). Marsham quoted by Nathaniel Kent, Hints to Gentlemen of Landed Property, p. 203 (1775) and Martyn, op. cit. (note 21), vol. 1 (Woods).


60 Philip Miller, The Naturalist's and Traveller’s Companion, p. 20 (1772).


62 Philip Miller, Gardener’s Dictionary 1768 (Planting).


65 See, for instance, Miller’s preface to Catalogus Plantarum, pp. vii–ix (Society of Gardeners, 1730); Miller is identified as the author by Pulteney, op. cit. (note 40), vol. 2, p. 244.


68 Miller, op. cit. (note 65), p. ix.

69 Philip Miller, A Short Introduction to the Science of Botany, pp. 5–11 (1760).


72 Ibid., p. 146.

73 Ibid., pp. 189–190 (Buffon) and 140–149 (Duhamel du Monceau).

74 Ibid., p. 167.

75 Buffon, ‘Moyen facile d’augmenter la solidité, la force at la duree du bois’ (1740) (cited by Hanks, op. cit. (note 71), p. 167); Evelyn, Sylva 1664, p. 93. Plot also described this practice (Natural History of Oxfordshire (1677), p. 166; Natural History of Staffordshire (1686), p. 384; and ‘A Discourse concerning the most seasonable Time of Felling of Timber’, Phil. Trans. 16, pp. 455–461 (1686–92)). For more on Plot see Turner, op. cit. (note 7), pp. 628–630.


78 Philip Miller, Gardener's Dictionary, Preface (1752); Quercus (1759).


80 Duhamel du Monceau, Elements of Agriculture (1764) (title page).


82 In 1750 the Académie sent its Mémoires to the Society (via Buffon), in exchange receiving Philosophical Transactions (Hanks, op. cit. (note 71), p. 266 and note 46); abstracts of Buffon’s memoirs also appeared in Journal des Scavans in December 1743 and March 1746.

Buffon in Haddington, ibid., pp. 92–94. For Buffon on stripping trees see p. 91.


Duhamel disagreed with this practice (Des Semis et Plantations des Arbres et de leur Culture (1760), p. lvii).

Hunter, op. cit. (note 9), p. 89.


Sylva 1664, pp. 88–90.

Sylva 1706, p. 236.


Stephen Hales, Vegetable Staticks, pp. 319–320 (1727).

After Harvey’s discoveries it was common to liken sap vessels to arteries and veins, and several Fellows, including Hooke, Beale, Bradley, Grew and Hales, discussed circulation.

Phil. Trans. 1, 1–2 (1664/5).


This undated experiment, although recorded in another hand, is presumed to have been by Wren. It is tipped in between pp. 242–243 of the Royal Institute of British Architects’ ‘Heirloom’ copy of Wren’s son’s Parentalia: Memoirs of the Family of the Wrens (1750); ‘Of the rising of the Sap in Trees’ is item XXXVI on a list of Wren’s manuscript and printed tracts (p. 243). I am grateful to Jim Bennett for informing me of this experiment.


Hales, op. cit. (note 93), p. 359.

‘Queries concerning Vegetation, especially the Motion of the Juyces . . .’, Phil. Trans. 3, 797–801 (1668).


John Beale and Ezerel Tonge on sap movement, Phil. Trans. 4, 853–862; 877–881; 913–923 (1668/9).

John Ray and Francis Willughby on sap movement, Phil. Trans. 4, 963–965 (1668/9).

Grew, op. cit. (note 92), pp. 41–43.

William Lawson, quoted Evelyn, Sylva 1664, pp. 73–76.

Sylva 1706, pp. 206–207.

Hales, op. cit. (note 93), pp. iii–iv.

For instance, D. G. C. Allan and R. E. Schofield, who discuss Hales’s work in depth, ignore his remarks on pruning and only mention in passing that he recommended his conclusions to gardeners and farmers (Stephen Hales, Scientist and Philanthropist, p. 47 (Scholar Press, London, 1980)).


Richard Bradley, New Improvements of Planting and Gardening, pp. 1–8 (1717).

Richard Bradley, Monthly Register of Experiments and Observations (May 1722), p. 68.


See Allan and Schofield, op. cit. (note 110), p. 31.
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121 Hales, *op. cit.* (note 93), Experiment 124, pp. 348–353.
122 *Gardener’s Dictionary* 1768 (Woods).
126 *Gardener’s Dictionary* 1759/1768 (Sap).