The Growing Tree *

By Prof. J. H. PRIESTLEY

RECENT studies of the growth of the tree, helped by some new methods, have shown that each season this growth begins in the bud, whence it spreads downwards over the rest of the tree. The discovery of this fact may influence, in quite a surprising way, our understanding of the tree—its form, its structure, and its vital functions.

LONGITUDINAL AND RADIAL GROWTH

The plants we call trees clearly have certain characteristics in common, though the botanist does not group them together in one class. They produce new crops of leaves periodically, but usually they do not flower for a number of years. Green leaves add to the substance of a plant, whilst flower and fruit exhaust it, so that the tree continues to gain in size and weight for many years. Much of this added weight is wood and bast, of which new increments are added each year, on the outer surface of the wood and the inner surface of the bast, by the activities of a growing tissue lying between wood and bast, called the cambium.

Each new crop of leaves is not borne directly upon the old wood but on new shoots which emerge from the buds. These new shoots grow in length, whilst the old branch system thickens but grows no more in length. The two growth processes do not seem connected at first sight, but the tree will only be understood when we realise that they depend very closely upon one another. During this year a new method of studying radial growth

has been developed by which it has been possible to show how closely extension growth and radial growth are connected.

When the cambium recommences growth, its cells become very liquid, and the bark together with the bast easily peels from the wood, or, as we say, the bark 'slips'. The new soft plastic tissues

FIG. 1.—Photomicrograph of a strip of new tissue scraped from the surface of the old wood in ash. These cells have been formed by division of the cambial cells. $\times 100$.

can then be scraped off the hard old wood surface with a sharp tool, and long strips of tissues, newly

formed from the cambium, can be obtained with the utmost ease. It has thus been possible to show that these tissues are first formed beneath the buds as they commence to grow, and that the cambial activity spreads thence always downwards—down the branches and down the trunk. These strips of tissue, as shown in Figs. 1, 2, and 3, exhibit beautifully under the microscope the structure of the new

FIG. 2.—Photomicrograph of strip similar to that in Fig. 1, taken from spruce. Note the great length of the cells. $\times 133$.

cells just formed from the cambium, and their study should reveal many new and interesting facts as to the changes these tissues undergo as they are transformed into wood.

This new method has revealed most clearly the dependence of radial growth upon the buds. Cambial activity only begins after the buds commence growth, and cambium growth always spreads downwards from the base of the buds. We now know why, when pruning, the knife should cut across the stem just above a bud. Thus no piece of stem is left projecting above the topmost living bud. When such a piece of stem is left, the cambium in it never grows again, and this piece of stem withers to an unsightly snag.

The growth of buds depends very much upon light. The forester therefore plants his trees close together, so that the lower, side branches are shaded and their buds soon cease to grow. These branches then grow no more in thickness, lose their water, and become dry. On such withered branches the bark does not 'slip' but clings close, whilst on the main stem around their bases it is being pushed outwards by the growth of the cambium. The bark is thus thrust into sharp folds around the base of each withered branch, and the strain increases with continued growth until the dry branch is snapped off. Thus the lower dead branches are swept off, new wood still forms each year, and the stumps of these branches are gradually buried in the wood of the growing trunk, not to be seen again until they appear as knots in planks cut from the trunk. On the surface of the tree, the folds of bark may

* Substance of the presidential address to Section K (Botany) of the British Association at York on Sept. 5.

persist for many years, indicating the presence of these branch stumps, as the ripples on the pond tell of the stone sunk in its depths. The folds may be studied and recorded very simply, by placing paper over the bark and rubbing it with cobbler's heel-ball.

SOFTWOOD AND HARDWOOD TREES

Branch systems, and the knots they leave in the timber, are rather different in two different tree types, the broad-leaved hardwood and the needle-leaved softwood. The former belong to the class

of Dicotyledons, whilst the softwood belongs to the conifers.

The softwoods have usually a very regular 'Christmas tree' habit of branching, a new whorl of branches appearing usually each year, and each spring as the buds begin to grow, radial growth begins and spreads downwards from the buds, but the

FIG. 3.—Photomicrograph of the new tissues, derived from the cambium in sycamore. Through the new tissues, are developing vessels (a) which are in communication with the leafy shoot above. $\times 100$.

lower and more shaded the branch, the slower the radial growth activity spreads down it. As a result, the cambium is growing actively on the main trunk, around the bases of the lower branches, before growth has begun on the branch bases themselves. The old wood of the branch is thus gripped in the new wood of the trunk which forms around it but is not in actual union with it. Only later, as the cambium on the branch also begins to grow, do branch and main axis join in forming one common sheet of wood. In a thin softwood plank, therefore, the wood of the branch may lie loose in the wood of the trunk and, if the wood of the main stem rots away, the tapering ends of the whorl of branches may often be seen projecting inwards into the hollow trunk (Fig. 4).

In the hardwood, branches do not arise in so regular a manner, or so many at one level, but when growth begins, the branch base and the main axis at the same level commence growth at almost the same time. Main stems and branch therefore join in forming a common layer of wood from the outset, and thus the knot, even in a thin plank, will be firm. This continuity of wood from the branch to the main axis is clearly shown in Fig. 4.

In both poplar and oak in Great Britain, branches that do not make good growth tend to be cut off

before they wither, by a natural process of abscission (see Fig. 5). This happens especially with flowering branches of the Canadian black poplar, and each summer the ground beneath trees that have commenced to flower is carpeted with branches with smooth expanded bases which have fallen from the trees, while saucer-shaped scars are left on the branches from which they have fallen.

In the softwood, the living cells of the cambium are like very long, thin threads. Each thread grows in size and then cuts itself lengthwise into two equally thin threads, of which the inner one will in time become a new wood element, as seen in Fig. 2. In the process it will absorb much water, its wall will thicken and lignify, its living contents will disappear, and it will thus become a fibre or tracheid. All these fibres are of much the same size, a few millimetres long, and they all expand about the same amount during development, more in the early part of the season, when they form the thin-walled spring wood, less later on when they form the summer wood, so that each year's ring of wood is thus recognisable as an annual ring. As all the developing tracheids, cut off from the cambium at the same time, do the same thing, to the same extent, in about the same period of time, the wood is very regular and composed entirely of similar fibres. When these developing tissues were scraped off the old wood in June, a fine spray shot into the air to a height of more than a foot, so that the liquid in these minute developing tracheids must have been held under great pressure. It is this pressure, squeezing the soft cambium cells out against the inside of the bark, which probably

FIG. 4.—On left, a branch union in a hardwood (Large-leaf maple), showing clearly the continuity of wood from branch to main axis. In the centre (Grand fir) and on the right (Douglas fir) are cross sections of softwoods, in which the inner wood of the main stem has rotted away, leaving the tapering ends of the wood of branches projecting into the hollow cavity. The branch of the Grand fir, in the centre, was growing horizontally and has formed more wood on the lower side. (Photograph by Mr. Pemberton, British Columbia.)

accounts for their curious shape. The more vigorous the growth of the tree, the longer these thin flattened threads of cambium cells become.

In the hardwood, on the other hand, the cambium cells are much shorter, smaller cells, and cut off cells like themselves towards the wood, which later may take in water and expand. But these short cells have transverse walls at the top and the bottom, which collapse under the strain, so that the contents of the cells coalesce. This happens to certain vertical series of cells over long distances

in a very short time, so that a long row of such tiny cells expand very considerably in width and coalesce end to end to form a vessel which may be many feet in length and more than a tenth of a millimetre in diameter, as shown in Fig. 3. The formation of this vessel, like cambial activity, begins beneath the bud and spreads thence very rapidly downwards. It follows that, at lower

FIG. 5.—Twigs of oak, fallen whilst still living by a process of natural abscission. The swollen scars are shown clearly. About $\frac{1}{2}$ natural size.

levels, the cell which lies just in the line of such a vessel is expanding with water before its neighbours which were formed at the same time, and its expansion takes place at their expense. The vessel segment expands relatively greatly, whilst the other cells are squeezed and elongated. These longer cells, when later their walls thicken, become the fibres. Thus the hardwood, in contrast to the softwood, has a diversified wood structure, with vessels interspersed amongst elongated narrow fibres, whilst the swelling of the vessels is not accompanied by a great pressure against the cambium, the cells of which remain relatively short.

WATER SUPPLY TO OPENING BUDS

These characteristic growth processes in the tree have a direct bearing upon such a problem as the movement of water in the tree. The water enters at the roots, and great forces are needed to carry it to the tops of trees which may be more than 300 feet high. It moves in the wood, in the tracheids of the softwood or the vessels of the hardwood, and it is usually assumed to-day that it is driven upwards by forces in the root and pulled by forces at work in the leaves from which water is evaporating. But we have seen that if a bud does not grow, both the bud and the twig beneath it lose water, so that the growth of the bud seems to attract water into it. Water is necessary for the growth of the bud, and an old experiment seems to throw light upon the entry of water into the bud in spring. If a cut branch is warmed in spring, water can be seen to well from the wood at both cut ends. In the uncut branch on the tree, the same movement of water will take place as the

temperature rises, but now, from the way the wood has been formed, all this water will find its way into the buds, where the ends of the most recently formed wood elements are to be found. Then the bud begins to grow, and growth spreads downwards through the cambium beneath the bud.

It can be shown that both these growth processes attract water out of the old wood by osmotic forces developed in these growing tissues. Water movement in wood can be shown to take place under the operation of such forces, and the conditions to develop such forces can be demonstrated in the developing tissues. When new wood develops beneath an expanding bud, down over the surface of the old wood, water is moved from the old wood, which thus acts as a reservoir, into a new system of pipes the terminus of which is to be found in the elongating shoot with its new leaves. It is evident that this is the way in which the new shoot obtains its water, and that this is the explanation why a branch that does not grow loses its water to the growing parts of the tree. This gives us quite a new picture of water movement in the tree, which is no longer seen as a movement along one set of pipes, either pushed from below or pulled from above in direct continuity with the new shoots.

WATER SUPPLY TO THE EXPANDED FOLIAGE

During the winter, when water still enters the roots and the shoot system is not growing, the supply of water in the old wood is increased; but immediately growth begins in spring, water is drawn from the old wood into the new tissues, and a simple type of experiment shows that it is withdrawn more quickly than it is replaced. When the wood is cut open under a coloured liquid such as Indian ink, no ink enters the newly developing vessels, which are obviously full of liquid, but it rushes into some of the old wood lying just beneath these new tissues, thus showing that their contents are in a condition of tension. In early summer, when the leaves are expanded, the ink will also enter the first formed of the new wood elements, the contents of which must also now be under tension. This experiment is most striking if carried out in June with the ash, when the long vessels lie just below the surface of the cambium and are visible to the naked eye. When they are cut open under Indian ink, the ink shoots both upwards and downwards at a rate which often exceeds 20 ft. a minute, and thus travels to a distance of many feet from the place of injection. The ink will not pass the cross walls which close the vessels at intervals, but lead nitrate will do so, and can be shown to travel in a few minutes down into the roots and up into the leafy shoots. The experiment has a very practical side, because it shows how soluble poisons may be successfully used to kill a tree. This is sometimes a real need, as in tropical Africa at present, where control of the movement of the tsetse fly is being attempted by completely clearing belts of country of vegetation.

It is usually assumed to-day that when the contents of the wood are in a tensile condition, the wood contains liquid sap at relatively high ten-

sions. This view is difficult to reconcile with the rapid entry of the injecting fluids, and the result of further injection experiments is to suggest that many wood elements in tension contain water vapour. Such elements, when water is available, will readily fill with water again. These observations do not solve the problem of the ascent of sap in tall trees, but they do suggest it is ripe for reconsideration. They also remind us that the buds and branches at a great height always obtain their water by a machinery that is only set in motion by their own growth.

Similarly it may be pointed out that the downward movement of food in the tree—a movement that is usually associated with the bast—seems to

be linked with the growth of the bast. This tissue is also formed from the cambium, its formation beginning in the leaf, whence the process spreads gradually down the branches to the trunk and the roots; and the spread of this process of growth synchronises with the time at which a gain of dry weight takes place in the lower regions of the tree. If an attempt is made to estimate the amount of transfer of substance involved in the formation of the new tissues from the cambium, this downward-progressing growth process evidently largely accounts for the movement of substance that takes place. It is clearly impossible to dissociate the problem of transport in the tree from the processes of growth.

Measurements of Solar Radiation *

THE work of the Smithsonian Institution's Astrophysical Observatory during the decade 1920–30 is described in vol. 5 of its *Annals*, recently published after an interval of ten years since the appearance of the preceding volume. To assist the reader in forming a proper perspective view of the work, the volume is prefaced by a brief description of the long research on solar radiation undertaken by the Observatory, first under Langley, and later under Dr. C. G. Abbot. It forms an impressive account of a great investigation, of fundamental importance to meteorology, in which the Smithsonian Institution has been the pioneer and practically the sole worker. The latter is to be regretted, since it is desirable to have independent determinations of so important a quantity as the sun's radiation. There is fortunately no doubt, however, as to the substantial accuracy of the mean Smithsonian value of the 'solar constant'.

One decisive result has emerged from the work of the Observatory, as a consequence of gradual improvements both in the instruments and methods of observation, and in the understanding and reduction of the measurements. It is that the sun's radiation, as it reaches the outside of the earth's atmosphere, and after correction to the mean distance of the earth from the sun, is constant within very narrow limits. At earlier stages of the work the Smithsonian view was contrary to this; it was contended that the observations showed variability over a range often exceeding five per cent; the supposed variations ranged over several per cent in the course of years, and showed correlation with the sunspot period; there were also variations over short periods of a few days, which were believed to be confirmed by independent observations for more than fifty days at Bassour in Algeria and Mount Wilson in California. Important consequences for terrestrial weather and weather forecasting were inferred from these results.

In the present volume an account is given of the establishment and progress of several solar radiation observatories, located on mountain tops in

desert lands, at which a daily record of the sun's radiation is attempted, both as received at ground level, and as inferred after allowing for atmospheric absorption. The conclusion is reached that "the earlier impression [of considerable solar variations] is not supported". "We incline to think that the earlier impressions of a larger solar variability were founded on measurements too much affected by terrestrial atmospheric influences. A residuum of apparent solar variation remains, nevertheless, after making all possible improvements. Comparison of results of remote stations; correlations with other measurements independently made by other observers; and especially correlations with weather changes at remote stations, all incline us to consider present indications of solar variation as largely real" (p. 5). The average deviation of the solar constant as measured at a single station on a single day is given (p. 244) as 0.29 per cent, the probable error being 0.24 per cent, as derived by comparing the measurements of the best station (Montezuma, Chile) with those made at Table Mountain (1926–30).

These changes are very small, and in view of the great difficulties involved in correcting accurately for atmospheric absorption, a proof of real solar variability must, as is stated, be very difficult. Comparison of the variations recorded at Montezuma and Table Mountain, in cases where satisfactory daily observations occurred consecutively at both stations simultaneously over intervals of ten days or longer, is thought, on the whole, to show a great similarity in the march of the curves, though there are instances of great dissimilarity. But it is pointed out that in these intervals solar changes exceeding 1.5 per cent are rarely indicated.

My own impression, after reflecting on the observational difficulties, the possibility of accidental agreements between the changes at different stations, and the past history of the research, is that the reality of these small variations is not proved. To establish them, much better evidence is required in the form of long-continued observations at different stations, and also independent determinations by different methods at the same station. The correlations with other measurements, and especially with weather changes, which

* *Annals of the Astrophysical Observatory of the Smithsonian Institution*. Vol. 5 (Pub. No. 3121). By C. G. Abbot, L. B. Aldrich, and F. E. Towle. Pp. ix+295+11 plates. (Washington: Government Printing Office.)