FOREST RESEARCH DEVELOPMENTS IN SWEDEN¹

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A FREE TRANSLATION FROM SWEDISH

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BIOGRAPHY

Axel Brandstrom was born in Umea, Sweden, June 9, 1898. He attended public schools and gymnasium in Sweden in 1905-1915, entered the College of Forestry, University of Washington in September 1915 and graduated with a B.S.F. degree in June 1919. He was employed as logging engineer, time-keeper and Asst. Logging Superintendent in Western Washington 1919-1922; on road and bridge construction contracting in Western Washington and Oregon 1923-1927; as Asst. Professor, College of Forestry, University of Washington (Logging Engineering) 1928-1930; as Senior Forest Economist, U.S. Forest Service 1931-1940 (in charge Logging Economics Research Pacific Northwest Forest Experiment Station); as Chief Forester, Crown Zellerbach Corporation, Portland, Oregon, 1940-1946; and has been a Consulting Forester from 1946 to date.

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ABSTRACT

Up to the beginning of this century, forest research in Sweden was mostly of the trial and error type from which came some step by step improvements in forestry practices but no really sustained progress as they know it today. Modern forest research in Sweden had its modest beginning about 50 years ago. Solidly based on the natural sciences and more recently pushing ahead toward modern machine age developments, Sweden's forest research program is now moving ahead on a broad front and with the strong and eager backing of the forest industries and their organizations, as well as of the Government and the public. Professor Streyffert traces and describes these developments, not only in the more well known fields of silviculture, stand management, forest regeneration, utilization, soil science, etc., but also in the new and fascinating field of forest genetics and forest tree improvement work. Through it all runs a thread of practical reasoning and sound grass roots economics working toward maximum rewards from management of their forest lands.

The inception of forest research in Sweden cannot be tied down to any definite year or to any specific event. Its development in our days has been intimately tied in with the advance of the natural sciences which are the foundation of our knowledge and understanding of the life requirements of trees and forests—and of associations of trees in the forest. Con-

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tinuing development of our knowledge of these requirements is one of the principal pre-requisites for continuing advancement of forest research.

The Early Days

Long before the natural sciences had advanced to the point where they could serve as a foundation and guide for research in the applied sciences, such as in forestry and agriculture, the practitioners in these fields, in their quest for a better living from the land and better management of their resources, had to find their way in the main through practical experience,—in other words, the hard way. In agriculture such experience could be gained quite easily and rapidly; as a result a good deal of progress had been made, limited, of course, by inadequate knowledge of some of the fundamentals. In forestry, corresponding experience, as far as the establishment, growth and management of new timber crops was concerned, was incomparably less, because in those days our predecessors were engaged primarily in the harvesting of overmature virgin stands. When the time came for serious attention to re-forestation and better forestry practices, they had little or no experience of their own to look back on, and so had to look for guidance to foreign lands and principally then to Germany. Along with this came the start of our higher forestry education in 1828; in connection with this some experimental work was carried on which in the absence of a solid footing in the natural sciences, was mostly of the "trial and error" type. This was about as far as our forestry research developments had advanced at the close of the last century.

The Present Period

With this we move up to the present century and the time when the natural sciences had advanced far enough to furnish some basic guidance for systematic forest research. Sweden's first move in this direction occurred in 1902, through establishment of what later became known as our National Forest Research Institute (Statens Skogsforsoksanstalt). For a good many years this organization had to carry on with very meagre funds, but nevertheless it managed to do a great deal of basic work of inestimable value for the solution of vitally important problems that came to the fore at a later date. As our forests grew in value, and as their tremendous importance to our national economy became more fully recognized, more funds were made available; this in turn has made it possible for forest research to take its rightful place as the path-finder, guide and stimulant to constantly improving forestry practices throughout our land.

The Basic Difficulties in Forest Research

These developments have now given us a modern and, by our standards, well-financed forest research organization. However, even with ample funds and competent personnel, forest research, as we all know, is naturally beset with some inherent difficulties to slow its pace and confound its findings and conclusions. This can be grasped most readily by comparing forest research with agricultural research.

One of the principal difficulties here is that it takes a very long time to follow through the life cycle of a forest—a century or so from seed to harvest—and this means that it generally takes a long time to get the answers from studies and experiments having to do with the growth and development of the stand and its response to various methods of treatment. Where agricultural research can arrive at the answers in a matter of months, forest research often has to wait for years and sometimes for decades. This disadvantage is being felt very keenly today in work now under way in the new and very promising field of forest genetics, tree breeding and forest tree improvement research.

Another major handicap is that forest research, as carried on in the field, usually runs up against so many variables that it often becomes extremely difficult, not to say impossible, to isolate and control various factors that may affect the results of any given experiment or series of experiments. Forest conditions, with regard to soil, moisture, aspect, topography and local climate, etc., and the history of the stand as to origin, past cuttings or other treatment, etc., are altogether too variable to permit the degree of controlled experimentation and validity of results that we would like to have. Fortunately, higher mathematics in the form of regression analysis has here come to our aid and thereby made an important contribution to progress in this difficult field. However, this modern research tool, too, has its limitations; for example, it has not yet given us the final answer to the highly complicated problem of determining for any given forest type the best form of stand management as affected by various forms of thinnings and their influence on the development and regeneration of the stand. This is one of the important questions forest research is trying to answer, and there are many more.

Some New Developments in Forest Research

Forest research as already implied has a good deal in common with agricultural research. In both cases the basic aim is to obtain from the soil greater crops of better quality and at the lowest cost; in other words, the goal is to get the most, of the best, for the least.

In working toward this goal, agricultural research in our country as well as elsewhere has during the last decades led the way to a rather amazing step-up of crop production on the farms. This has been accomplished in the main by pushing ahead along two different lines, namely:

- (1) the use of artificial fertilizers, and
 - (2) the development of new and improved races and varieties of plants.
- By analogy, we naturally infer that production from our forests can also be stepped up by proceeding along the same lines.

In this respect, forest research is now pushing ahead aggressively on the development of new and improved races and varieties of forest trees. To this subject we shall return later.

With regard to the use of artificial fertilizers, this is a development that has not as yet come into practical use in our forests, although we do go in for it in our forest nurseries. This does not at all imply that the established forests do not respond to such treatment; on the contrary, experiments along this line show very clearly that they respond very well by decisive increase of growth even with a comparatively modest use of fertilizers. However, under present conditions this does not appear to be a paying proposition. The stumpage realization value of a ton of wood is generally less than the corresponding value of a ton of farm produce, and this fact alone puts the timber grower at the bottom of the list for the competitive use of fertilizer. Then, too, the cost of spreading the fertilizer in the woods is higher than on the farmer's open fields. Nevertheless, the eventual use of fertilizers for specific purposes should not be swept aside as a visionary pipe dream. Thus, the thought is being passed around that artificial fertilizers may find profitable use in specially favored locations, or in the final stage of production at the end of the rotation when selected high-quality crop trees are putting on their final layers of high-priced wood. There is also the thought that fertilizers may come into the picture with the introduction of new improved tree races which are now in the process of development; in fact, taking a leaf from the book of agricultural experience, we may indeed seriously question the practicability of introducing these high producing strains on our typical low quality forest lands unless we find it practical at the same time to go in for some artificial fertilizing. And so we have here some justification for our research people to do some advance exploring.

Soil Science and Research

In this connection, it may be of interest to note that investigations are under way to determine whether the presence or absence of certain mineral "trace elements" in our forest soils has any important effect on the rate of growth—a possibility which would be analagous with agriculture's experience along this line. However, unlike agriculture, the situation on a large proportion of our forest lands is that the soil is constantly being enriched with a comparatively heavy deposit of natural fertilizer—the duff layer formed by leaves, needles, twigs, branches and decaying stumps and roots—which is rich in mineral elements, and which, as it gradually decomposes and joins with the mineral soil, creates a very favorable soil condition. However, this soil condition in turn, as revealed by research, may be altered to a considerable extent by our cutting and regeneration methods. As a further complication, we have in our country—principally in the northern parts—very large areas of forests where climate and site conditions inhibit the natural decomposition of the duff, creating instead an incompletely decomposed mat of organic materials. This is the very troublesome "raw humus" which to us is an unfailing sign of a very unfavorable soil condition and a warning signal to which we must pay strict attention in our stand management and regeneration methods.

And so it will be clear why forestry in our country is so closely tied in with soil science and why we are actively engaged in forest soil research which indeed is a matter of fundamental importance to us.

A special branch of this line of investigation is our peat soil and peat bog research from which has come the scientific foundation and impetus for innumerable drainage or ditching projects whereby a very large area of previously useless land has been transformed into very productive and valuable forest land.

The Gain in Production through Thinnings

Until two or three decades ago we foresters were taught, or took it for granted—or in any case we claimed—that by systematic thinnings of second growth stands we could substantially increase the total volume of wood produced in the course of a rotation. This claim, like the premature announcement of Mark Twain's death, seems to have been somewhat exaggerated. According to the findings of the Forest Research Institute, based on some 50 years of thinning experiments on permanent sample plots, thinnings in well stocked stands do not bring on any significant increase in the total amount of wood produced over the rotation. In other words, a well stocked stand, which retains satisfactory stocking throughout the rotation, will produce just so many cubic feet of wood, regardless of whether we thin it or not, and regardless of how frequently we thin it. Obviously, however, in the unmanaged stand a good deal of wood is lost through natural thinnings—i.e., through mortality losses which occur throughout the life of the stand—and failure or inability to utilize this material means of course the loss of that much wood volume. Furthermore, in the unmanaged stand as contrasted to the well managed stand, a good deal of the wood on hand at the time of harvest (i.e., at the end of the rotation) will be of inferior quality and will include a higher percentage of material below utilizable size and grade, all of which is due to the fact that trees of inferior type, quality or form were not taken out of the stand at an earlier stage whereby their subsequent growth increment could have been transferred to the better trees. Thus we arrive at the conclusion that, although a good thinning practice does not add to total wood production, it does add considerably to the production of utilizable wood; and it does add to the quality and value of this utilizable wood. Furthermore, the stumpage returns from the thinnings (i.e., in cases where thinnings are profitable) constitute a reduction of the capital tied up in production, thus giving us as the end result a higher return on a smaller average investment. In short, the rentability of the forest investment is enhanced by giving us "the most, of the best, for the least".

The Quality Question

The quality of the timber harvest is particularly important to a country like Sweden, whose principal outlet is the world market where it enters

into competition with forest products from other wood exporting countries. These competing forest products come from countries which in their turn export the best of their products, much of which is still being obtained from high quality virgin forests.

Investigations are now being carried on by the Forest Research Institute in co-operation with two other research organizations, the Forest Products Research Institute and the Central Laboratories of the Cellulose Industries, to determine whether site conditions and methods of stand management have any important effect on the suitability and conversion values of timber for lumber and for pulp.

The quality of the timber is also affected by the density of the newly established regeneration on restocking lands. Here we strive for dense stocking so as to bring on the early closing of the stand with ensuing crowding and competition which makes for finer branch formation (i.e., smaller knots), early natural pruning and minimum taper of the stems—all conducive to production of good quality timber.

The Small-Wood and Cull-Wood Utilization Problem

The desirable thing for proper development of the well stocked stands is to undertake "cleanings" and initial thinnings at a very early stage. However, this costs a great deal of money which frequently cannot be recovered in full from the thinnings; in fact, in most cases there is no market at all for this under-sized material. This has now become a very serious problem in our current forestry situation. We have on our hands very large areas of young second growth stands which have sprung up subsequent to the compulsory Reforestation Law of 1903. A large proportion of these stands are now badly in need of initial thinnings which cannot be carried out except at a heavy loss due to lack of market outlets. During World War II, when Sweden's imports of coal and oil were completely shut off, millions and millions of cords of this type of wood were cut for fuel. This was a happy time for the foresters who wanted their young stands thinned; however, with the end of the war the fuel wood demand dropped off very abruptly and so it is that the thinning problem is with us again—and this time more or less on a nationwide scale. Even in the old mining districts of Central Sweden, where charcoal making used to take care of the small wood problem, the situation has changed very much for the worse due to the drastic decline of this form of wood utilization.

This is a difficult and serious problem now pressing very hard for a solution. It is being tackled from several angles. The vital problem is to find suitable outlets for thinnings which because of small size or other disabilities fall below the utilization standards so far adhered to by the pulp mills and other wood using industries. The nearest way out for the present might be to try for a revival of the fuelwood demand through aggressive promotion, "national interest propaganda" and other means.

However, logging and transportation costs for this small stuff are high, and rise very rapidly with declining dimensions. Scarcity of man power is a further obstacle, in fact, so much so that the only solution, if there is a solution, would appear to be through successful mechanization of the logging and transportation. This is one of the specific problems assigned to forest research as a part of a broad, nationwide attack on the whole problem of mechanization and rationalization of logging and transportation. To this subject we shall return again.

While a revived fuelwood outlet might give some relief for the present, the permanent solution would seem to lie in its eventual and profitable use for industrial purposes. This is the solution now being sought, not only for the undersized thinnings, but also for a whole array of logging left-overs normally left behind in our saw timber and pulp timber operations. These consist of small top logs and logs culled because of excessive decay or deformities of various types, and including also fairly large quantities of low grade hardwoods, of which we have in the past utilized only the high quality logs suitable for veneer and furniture stock.

With regard to the recovery of defective logs, the Forest Research Institute in co-operation with the cellulose industry undertook some time ago a study involving the identification and classification of the various types of rots that attack our trees and logs, both before and after logging. The purpose of this study was to find out what types and degrees of rot the pulp industry can profitably utilize or silently tolerate, and what types it has to definitely reject because of seriously adverse effects on the quality of the pulp, — in short, to draw the line between what to take and what to leave. The results of this study led to the lowering of quality specifications pertaining to defective pulp logs, and from this new source the pulp industry is now getting very appreciable quantities of wood. This has been of particularly great importance to the pulp mills in Northern Sweden, where it has served to alleviate to an appreciable extent the very grim wood shortage that has been confronting them.

This acute wood shortage has also compelled the northern mills to direct their brains and efforts toward closer utilization of small thinnings—and also, as a wholly new development, to go in for the use of hardwoods for pulp.

With regard to their use of small thinnings, one of the principal obstacles in the past—aside from the high logging costs—was the barking problem. The difficulty here is that this type of small wood could not be barked effectively in their drum barkers or attrition barkers, nor could it be done economically by hand. With the new barking devices now developed, this problem has apparently been solved by some of the mills. In other cases, the way out has been to convert this type of wood, bark and all, into fibre board.

With regard to the use of hardwoods for pulp, the major success is birch, which after a good deal of research and experimentation was found to be suitable for making a very high grade pulp. Even aspen is now being used for pulp.

One of the long standing problems with birch has been the heavy sinkage losses in the long transport down the rivers. This problem was tackled by research many years ago, principally by various methods of seasoning and end sealing, etc., prior to the floating operations, but no satisfactory over-all solution was found. Today's answer to this problem is to keep the birch out of the waterways entirely, by using motor trucks for transport all the way to the mills.

The Spacing Questions in Plantations

Despite these encouraging developments, we must still recognize that our small-wood utilization problem is far from being solved, and particularly so with regard to the very small material that comes, or could come, from early thinnings in our second growth stands. This is indeed a problem that might defy all attempts to get a fully satisfactory solution along the lines we are now working. However, this, in turn, has brought up the thought that the easier way out might be to reduce our production of this size class of trees by cutting down on the density of stocking in the initial establishment of our second growth stands. This, of course, cannot be controlled to any fine degree where we rely on natural regeneration, but it can be controlled by going in for wider spacing where we regenerate by planting or seeding. In this respect, wider spacing would result in more rapid growth of the young trees and at the same time, perhaps, permit a long enough deferment of the initial thinning operations to bring the trees to sufficient size for profitable utilization for pulp wood. As an incidental result, it would also reduce the cost of planting or seeding which in itself is of great importance nowadays in view of the high costs involved. On the debit side, however, it would give us lower quality stands. This would be of particular importance with respect to our saw timber production, but could perhaps be remedied by going a bit stronger on artificial pruning. Here again, we are opening up some important questions which need to be cleared up by some painstaking thinking and research.

The Regeneration Problem

It is a well known fact, as disclosed by our National Forest Inventories as well as by general observation, that we have large acreages of forest lands which are not growing as much timber as they should. Among the offending classifications in this respect are the non-stocked lands which have failed to restock after the mature timber was removed—and this despite the fact that we have had a compulsory Reforestation Law in effect since 1903. Another delinquent classification consists of

poorly stocked second growth lands which do not carry enough growing stock to produce a normal crop. And a third delinquent consists of mature residual stands thinned out by improperly conducted selective cuttings to the point where comparatively little growth is obtained from the remaining trees and yet the stand is not opened up sufficiently for new reproduction to come in.

We can generalize as to the reason for this deplorable situation by saying that we have some difficult regeneration problems to contend with. But we should also say that in the past we often relied too blindly on natural regeneration in situations where it had little or no chance; we should also say that a large proportion of these difficult situations was created by applying the wrong system of cutting.

The fact is that we have in our country some very large areas, and a great many areas of lesser extent, where it is very difficult to get natural regeneration. This is particularly true of Northern Sweden and more specifically at elevations above 1,000 feet. Here the principal obstacle is the raw-humus layer which is a great hindrance to germination of the seeds and a great hindrance to further development of the seedlings. Contributing to these difficulties is the fact that in those same localities seed production is very uncertain, and usually very sparse, with fair seed years occurring only at long intervals. For these and various other reasons the regeneration problem is extremely difficult in the North, and similar difficulties occur in more limited areas through the rest of our country.

It is only natural then that in this raw-humus territory, forest research found a very large and important field to explore. One of its principal problems was to determine how the cutting operations should be conducted to obtain satisfactory natural regeneration. In this respect the basically most important part of the research job was the investigation of the raw-humus, formations carried out by Professor Hesselman. These investigations disclosed that the trouble with the raw-humus was that its nitrogen content was not available for the growing plants; they also disclosed that by giving the sun and the rain unhindered access to the ground, this nitrogen was released for formation of ammonia and salt-peter, both conducive to normal germination of the seed and healthy development of the seedlings. On the basis of these findings, supplemented by further findings with regard to the need for elimination of root competition in the regenerating areas, the answer to the natural regeneration problem in the raw-humus areas was definite and clear: Clear cut by large enough blocks to permit the sun and the rain to get unhindered access to the ground thereby transforming the raw-humus to a condition favorable for regeneration and growth.

With this irrevocable answer, the old cutting methods which left varying amounts of growing stock on the land (in the form of seed

trees or sloppy residual stands from selective cuttings) through the regeneration period were completely ruled out.

It should be emphasized, however, that this is a rule applicable only to a specific set of conditions. When we step out of our raw-humus areas, we are dealing with forest conditions which are so variable with regard to climate, soil and stand conditions that no broad generalizations can be applied. In this respect our forest research has had a whole series of problems to work on, involving studies of our various forest types as management types, with particular attention to the regeneration problems. By and large the answers to the regeneration problems are now pretty well in hand.

Despite the fact that we know pretty well how best to get natural regeneration, there are many cases where, for one reason or another, natural regeneration fails to come, or is too long delayed to justify waiting. In these cases we must meet the situation by planting or seeding.

This might appear to be an easy matter. Actually, however, this, too, often runs into difficulties and particularly so on the very same area where natural regeneration runs into difficulties. This was the situation so frequently met with in earlier days in connection with seeding and planting projects in the raw-humus areas of Northern Sweden. These almost invariably turned out very poorly or failed completely and in large part for the same basic reasons that caused natural regeneration to fail. Now that we know how to overcome the difficulties of the raw-humus problem, we can proceed with planting and seeding with reasonable assurance of success. Planting and seeding on a large scale will have to be done in these northern areas as a part of a very large forest restoration project which is now ready to start.

The Provenance Question

In going into planting and seeding projects, it is extremely important that we know about the source of the seed, commonly referred to as the provenance question.

A good many years ago, foresters began to notice that some of the planted pine stands in Southern Sweden were of extremely poor quality. The trunks were crooked, in many cases forked, and invariably rough limbed and large knotted; growth stagnated at an early age. These stands all had to be cut before they reached saw timber size, yielding for the most part only a low fuel wood value. Further investigation disclosed that the seed from which these stands had been grown had been imported from Germany.

Similar worthless pine stands, all in the form of plantations established in the second half of the last century were later discovered in a good many places, mostly on large country estates in Southern and

Central Sweden. In these cases, too, it was found that the seed had been imported from Germany.

This was Sweden's first, and very costly experience with the provenance problem; one of the first jobs tackled by the Forest Research Institute was to get better acquainted with the nature of this problem. From their investigations came the discovery that certain tree species among others Scotch Pine (*Pinus silvestris*) are particularly sensitive to transfer to a new environment where climatic conditions deviate from that of the place of origin. Seed or transplants from such species therefore cannot safely be shifted too far in a north and south direction, nor to drastically different altitudes. For this same reason too many of the earlier pine plantations in Northern Sweden originating from seed collected in Southern Sweden turned out very poorly, resulting in stands of definitely inferior type. Since we now know with a fair degree of certainty what the provenance limitations are, this troublesome risk factor has been removed.

The Exotics Question

Closely associated with the provenance problem is the question of bringing in foreign species which are rated as superior to our own with respect to rate of growth or quality. This thought naturally comes to us when we compare North America's tremendous variety of commercial tree species with the relatively few species native to our country, or Northern Europe as a whole. This is particularly striking with respect to the conifers, where our whole forest economy is based on only two species, Scotch Pine (*Pinus Silvestris*) and Norway Spruce (*Picea Exelsa*). In view of this situation, we naturally would like to know what some of these superior species growing in the same latitudes and altitudes as ours might do for us if brought to our shores.

This idea has been so tempting that a good many trials have been made in the past, mostly by private individuals who have established experimental plantations from seed brought in from various parts of the world, principally North America. As a result, we already have a good deal of experience to look back on, although final judgment should, of course, be held back pending further study and observation.

On the basis of our experiences so far, it appears that these foreign species, when grown in our country, rarely retain the superior growth rates they show in their native habitat. The inference is that we cannot offer them as good growing conditions as they have in their place of origin. As a rule, they do better on our better sites, but so do our own species. Furthermore, where we do have the very best growing conditions, these imported species are as a rule more susceptible to insect and fungi attacks than are our own species.

These are, by and large, rather discouraging answers to some of the high hopes entertained in our country some twenty or thirty years

ago; for this reason, popular interest in the foreign species has declined. However, studies and experiments are still being carried on, mainly by the Forest Research Institute, and with the thought that we may still have something substantial to gain along this line. For example, one of our difficulties with our high-producing spruce on our best sites is its susceptibility to root rot, which seriously cuts down its value production, and this would seem to justify the introduction of some closely related foreign species resistant to root rot. Likewise on our high elevation sites in Northern Sweden, some suitable foreign species might indeed show definite superiority to our own. These are among the principal questions now being explored.

Forest Genetics Research

At the same time that our interest in the direct introduction of foreign species has declined, our interest in the possibility of increased volume and value production through improvement of our own species, or through the development of new varieties by crossing our species with foreign species, has been strongly on the up-grade. Here again, our thinking and hoping has been spurred on by the magnificent results in plant improvement which have been obtained in the agricultural field. But here again, forestry is up against some inherent disadvantages to slow its pace.

The most obvious difficulty here, as already noted, is in the long life span of the forest, which places our experimental approach in a sort of slow-motion straight-jacket. A further complication is that in forestry we depend very largely on natural regeneration of the stands. However, artificial reforestation by planting and seeding is going ahead on a large enough scale to create the strong interest now shown.

The start of this movement was made in 1936, when the Association for Forest Tree Improvement was formed on the initiative of Professor H. Nilsson-Ehle, whose work on plant heredity and plant improvement in agriculture had attracted wide attention. This association has successfully undertaken this important and promising job. Its central organization, together with laboratories, greenhouses and nurseries, is located at Ekebo in Southern Sweden, and affiliated branch establishments have been set up in various parts of our country. The costs connected with this have come from private donations, as well as through a supporting organization formed by the forest industry organizations and the Forest Service. As a further step, it should be noted that the Division of Forest Genetics at the Forest Research Institute has now been greatly expanded. Thus, it is seen that interest in this subject is strong, and well supported both by the forest industries and the government.

Most of the forest tree improvement work now under way is based on the same principle as the improvement of our agricultural plants, namely, on the variations occurring between individual plants of a given species. By careful selection of the best individuals and by letting these selected plants

take care of the perpetuation of the species, we develop a superior race within the species. This is in principle one line of approach which is being followed, both in the improvement of agricultural crop plants and farm animals. This is also the line which, at this stage, is being pursued most strongly in our forest tree improvement work.

This same principle of selection of superior individuals has, as a matter of fact, long been applied in our normal forestry practice where we leave the best available individuals for seed trees. Where the perpetuation of the forest relies on natural regeneration, this is, of course, as far as we can go. Our normal practice in this respect is thus based on the right principle in that we are moving in the right direction. However, the trouble is that this movement is so exceedingly slow. Furthermore, this method of selection has some very serious shortcomings which become particularly striking in their application to forestry. The reasons for this are:

1. The superior characteristics, on the basis of which we select seed trees, are in part of an hereditary origin, and in part caused by environmental factors. For example, a straight clear trunk on a fine-looking saw-timber tree may in part be due to heredity and in part to the fact that the tree happened to grow in a very dense stand which brought on early natural pruning and a straight stem.

2. To the extent that the superior characteristics are governed by heredity, there will be wide variations in the progeny, all in accord with known laws of heredity. The unknown father in free pollination when the pollen comes to the seed tree from long distances contributes to a further widening of variations in the progeny.

If we want to take another step—and this is necessary for real progress—we must further determine to what extent the superior characteristics of the selected individual are caused by heredity and to what extent they are caused by environment. This is done through study of the progeny where both parents are known, all in accord with established scientific procedure, (such as by crossing, self-pollination, etc.). Such controlled crossings between different "plus variants", combined with progeny tests, are the basic core of our forest tree improvement work.

Now, this takes us into a field which requires a lot of work and a lot of time. However, even on the basis of the outward appearance of the progeny it is possible to draw certain preliminary conclusions and to proceed further on that foundation.

When it comes to translation of this selection principle into practice by supplying seed or seedlings superior to those available to us in the past, a great deal of important work has already been done through close co-operation between forest industry organizations, the Forest Service and the local forestry boards. Furthermore, a group of the most deeply interested forest industry companies, and others, have formed an organization called "The Association

for Practical Forest Tree Improvement", for the purpose of getting the earliest possible application on their own domains of the findings and discoveries of the research organizations.

In order to make quick initial progress on a broad front, we have as a first step made a nationwide survey to define the locations of those forest areas (the plus areas) which are deemed to have the best local race of trees and which, therefore, are most suitable for seed collection to supply our needs. At the same time we have also mapped out the "minus areas"—which, by the same token, are designated as unsuitable for our seed requirements.

We have outlined within the "plus areas" specific "plus stands", which are usually small areas of a hectare or two and which are deemed to be of distinctly superior type within their local race—a superiority based on exceptionally fast growth rates, good form and good quality. The seed collected from these "plus stands" is as yet of limited quantity and is set aside for the use of the forest nurseries.

As the final step in this initial nationwide seed tree survey, we have spotted and carefully described and catalogued a number of individual trees—so-called "elite trees"—which are trees that deviate very strikingly from their environment as indicated by extraordinary height, extraordinary size, and extraordinary form and quality. It is on these elite trees—of which we now have a total of about 3,000 catalogued in our country as a whole—that our forest tree improvement development really depends. This means that they are used for the progeny tests after controlled crossing.

At the start of this development, our research people had to go right back to the elite trees for the seed and the pollen, but today they are getting it from established "seed orchards", where the work can be carried on much more conveniently and efficiently.

The establishment of these "seed orchards" (or seed plantations) was accomplished by grafting slips from the elite trees on low-cut trunks of young trees previously raised in the orchard. These grafts produce a tree with identically the same hereditary characteristics as the mother tree from which the slip was taken. In this manner we can reproduce the mother tree characteristics in sufficient numbers so that enough seed can be produced to supply practical needs. Blooming and cone setting of the grafts is hastened through the use of fertilizer and by strangulation and other measures.

These seed trees are usually kept down to a height of about 10 feet, which makes it easy to collect the cones. Through controlled crossing, which can easily be done under this stream-lined set-up, and by subsequent progeny tests, we are thus in the process of developing new permanent local races of distinctly superior characteristics, and from these we shall successively build up permanent seed tree plantations, from which the seed requirements of our country can be supplied.

It is figured that the normal requirement of pine and spruce seed for our country as a whole amounts to about sixteen tons per year, of which approxi-

mately one-half should consist of seed from the seed tree plantations. The required total area of such plantations is figured at about 500 hectares. Establishment of such seed plantations has been started in several locations, and these in turn will be combined with forest nurseries where mechanized handling can be expected to result in reasonably low-cost production of seedlings.

Other Tree Improvement Methods

The foregoing covers the principle line of approach which is now being followed in our forest tree improvement work. There are, however, two other lines of approach which are also being worked on. One of these is by chromosome improvement (polyploidization). The other is by crossing between different species.

The chromosome improvement approach attracted a lot of attention a few years ago, when Professor Nilsson-Ehle discovered the so-called "giant aspen" in Southern Sweden. It was found that this larged-leaved and fast-growing aspen had twice as many chromosomes as the ordinary aspen. The high hopes which were then entertained in some quarters to thereby step into a rapid increase of our wood production have not materialized. However, by continuing with patient work along this line, some important progress is likely to come.

Crossing between different species leads to the development of hybrids which, to a very appreciable extent are superior to both parents with regard to rate of growth. This method of tree improvement is therefore creating a great deal of interest too. The hybrid developed from Swedish and Canadian aspen (*Populus tremula* and *Populus tremuloides*) has attracted attention because of its rapid growth.

All this work on forest tree improvement is still a very young branch of our forest research. Nevertheless, a great deal has already been accomplished and we have substantial hopes that more will be accomplished as time goes on.

The Mechanization and Rationalization of Forestry Operations

There remains to be discussed another line of research which is of comparatively recent origin, and which falls entirely outside the scope of the Forest Research program originally outlined at the beginning of this century. This new line of research has to do with the mechanization and rationalization of all phases of our forestry operations.

The principal reason for moving into this field is that our forestry operations have been suffering very badly from an everincreasing shortage of manpower. This, as we well know, is a problem which all our industries have had to contend with during the post-war period. The general source of this nation-wide problem is in the levelling off of our population increase, during a period when our over-all national production has been increasing at a very

rapid rate. As far as forestry operations are concerned, the situation has become the more acute because of the shift of our population from country to city—a movement which has been going on for many years, but which has become particularly rapid during the last decade. In this respect, agriculture is in the same position as forestry. Because of this critical situation, both agriculture and forestry have been pushed into the problem of mechanization and rationalization of their operations. For agriculture, the problems involved in this change-over have been comparatively simple, and for this reason they have been able to go into it quite rapidly and effectively. In the forestry field the problem is much more complex, and will take a longer time to solve. Among the principal difficulties here are the vast expanses of area, difficulties of terrain, lack of roads and isolated locations. Furthermore, the volume per acre of the material to be harvested is comparatively small; our trees and logs are extremely small, which, of course, poses an additional problem for mechanization. Despite these handicaps, the general feeling in the industry has been, right from the start, that by tackling the problem aggressively and persistently, it will be solved. To accomplish this we were in need of well-organized and well-financed research organizations, and this we feel has been attained.

The initial start on this research work dates back to 1937, when the larger forest industry companies of Northern Sweden, in collaboration with the Forest Service, formed a joint organization for studies and investigations of this type. In the same year, the larger forest industry companies of Central Sweden formed a similar organization. A few years later the forest industry companies of Southern Sweden followed suit. In 1950 our Forest Research Institute set up a special division for the same general purpose, though with emphasis on long range objectives and over-all co-ordination.

Thus, we now have four separate organizations working in this field. This may seem to be more than should be required for a country as small as Sweden. However, the problems to be solved are in many respects basically different in the three major geographical divisions of our country, and for this reason, plus the fact that closer field contacts can thus be maintained with the supporting industry, the present set-up has proven both desirable and effective. Useless duplication of studies or projects is avoided through close collaboration, including exchange of ideas, working plans and experiences. A friendly regional rivalry to accomplish things spurs them on.

The mechanization of our forestry operations is of particular importance, of course, with respect to the heavy manual work involved in the logging operations. This represents the last large category of really hard manual labour in Sweden's otherwise fairly well-mechanized industrial life. This old-fashioned back-breaking labor has no doubt been the principal reason why so many of the young country-born workers have rejected the woods work and turned their affection instead to the lighter work available in the towns and cities. If the toughest parts of this work can be shifted over to machinery, it will no doubt be easier to again attract this kind of men to the woods.

Furthermore, in the long view, mechanization may be the only way in which those engaged in forestry work can be paid wages high enough to meet the competition for labor from the manufacturing industries.

The heaviest work in the woods is falling and bucking. The principal obstacle to mechanization here is that our timber is extremely small and the cuttings are scattered. Nevertheless, through persistent work in recent years, we have now developed one-man power saws light enough and effective enough for our particular conditions; further improvements of these machines are still under way. This gives us some hope that a more or less complete and nation-wide mechanization of falling and bucking will soon be attained.

Similarly, the construction of portable barking machines, suitable for use at landings or roadsides in the woods, has now progressed far enough to suggest that the days of hand barking of logs in the woods are fading out fast. Hand barking, like falling and bucking, is one of the really hard jobs in the woods, and has drawn very heavily on our limited manpower.

With regard to transportation from stump to mill or from stump to driveable river, the widespread use of motor trucks represents the major advance. This form of transportation is particularly important in Southern Sweden, where driveable or towable waterways are lacking, but it has also made an important place for itself in Central and Northern Sweden, mainly as an adjunct to river driving. A good deal of fruitful work was done in working out the successful use of motor trucks for our type of timber and operating conditions, including the associated problem of loading, etc., and further work along this line is still going on.

With regard to skidding or other forms of initial transport from stump to truck road, we have as we well know some very special problems arising from the extremely small size of our timber and small volumes per acre. This has favored horse logging in the past, and may continue to do so in the future. Meanwhile, the mechanization possibilities are being worked on by the research organizations.

Hand in hand with mechanization of the logging operations will naturally come the concentration of production into larger working units. This need not interfere with good forest management; on the contrary, by forming larger production units, the auxiliary forestry operations, such as planting and forest improvement work of various types, can also be similarly concentrated with some hope for reduction of costs and simplification of work supervision and administration. However, for the time being, the administrative work load connected with re-planning of operations and disruption of the old set-up will naturally be very heavy.

This discussion of various phases of the mechanization studies does not by any means cover all the projects now under way. Cost studies and work performance studies, for example, are being conducted to determine variations in costs or work performance as affected by forest conditions, timber size, climatic conditions, depth of snow, etc., partly to give a basis for setting up

fair piece-rate pay schedules, and partly as a basis for cost analysis as a preliminary to rationalization of the various steps involved in the work. An inventory classification of existing types of hand tools, (saws, axes, etc.) as well as studies of their relative effectiveness has also been made, and from this has come new ideas on tool design and construction, which, according to actual tests are definitely superior. Well-designed hand tools and good care and proper use of these tools are essential for maximum work performance. This in itself appears to be a fairly fertile field for further study and development.

Summary

Our present forest research program is moving ahead along many different lines. It has been built up step by step to seek the solution of the various practical problems met with in our forestry work. Its organization and its work program, in the future, as it has in the past, will be set to serve this goal.

We need have no hesitation in saying that for Sweden the work already done and now under way by our forest research organizations is of tremendous importance. The enormous value which our national forestry enterprise represents demands a well organized and aggressive research effort in order that forestry and its dependent industries shall be able to keep up with the world-wide progress now under way in all lines of industry and production.

The present organization of our forest research effort is fairly well designed, we believe, to meet its present problems, and to handle future problems and developments as they come. It represents in principle what we believe to be a sound structural design in that the research effort is handled by several independent organizations and supported by different groups of interests, rather than to have all of it concentrated in the hands of the government, with all the disadvantages, handicaps and short-comings that might follow under such a monopolistic set-up. Sparked by private initiative, some of the most important phases of forestry and forestry operations have been subjected to systematic research of a high type. A fruitful collaboration has been established between this privately sponsored research and the government sponsored research carried on at the Forest Research Institute. The Institute's generally long-range and rather tightly controlled research is supplemented in turn by the somewhat heterogeneous research work carried on by staff members at the Royal Forestry School. In addition to this, we are fortunate to have appreciable funds available for support or subsidization of research work carried on both by organizations and by individuals.