The Aims and Methods of Swedish Forest Research

Den svenska skogsforskningens mål och medel

by

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CONTENTS

The Aims and Methods of Swedish Forest Research.[1]

The general purpose of forest research is to give guidance on the most rational methods of silviculture, i.e. establishment, tending and harvest of forest trees under various conditions.

Due to economic, social and other considerations it is not within the realm of research to determine management aims. However, it is incumbent upon research workers to investigate the consequences that will ensure from different goal-setting under various conditions, and to study how the desired purpose can best be achieved.

The general definition of forest research covers far reaching and manifold objectives with numerous intermediate steps towards the goal that looms in a distance: rational forestry. The definition of the purpose of forest research will always be kept dynamic by the development within fields of various human activities, not least within the field of forestry.

This paper will briefly review the most important fields of forest research and current research tasks as well as present the means and methods used to deal with problems of research.

The *central objective* of forest research is to investigate the development and the yield that various methods of stand establishment and treatment may give under different biological conditions (sites, species and race). The biological conditions here pertain to all the factors that excert influence on the life of trees, directly or indirectly. Problems of growth and yield in a wide sense are of that reason the centre around which associated research tasks may be easily grouped.

The problems of growth and yield in forest research have been approached along two avenues, basic research and yield research. The first approach is primarily concerned with the causal relationships concealed behind external phenomena and deals with the basic factors that promote or inhibit the growth. The studies provide key points of discussion for the practical solution of forestry problems. The second approach is by way of analyses of the development and the yield under various conditions on the basis of data from descriptions of external phenomena.

[1] Paper presented at the festival meeting of the Royal Academy of Agriculture on January 28th, 1955.

The yield research in forestry is to a great extent depending on the results and the progress of basic research related to forestry. In the long run basic research findings are necessary accessories for a successful solution of the problems in yield research. Simultaneously the results of yield research are indispensable when converting the results of basic research into practical programs of action. It is not a question of either-or, but rather of both.

1. The fundamental conditions for forest yield.

In Sweden basic research associated with forestry started rather recently; actually it was first initiated in the 19th century. It is based to a great extent upon developments made in the sciences of biology and has had the advantage of receiving many stimulating impulses from agricultural research. The work has been concentrated particularly on investigations of the extremely complex processes that take place in the soil and in the trees.

The growth of a tree is determined on one hand by the amount of water and plant nutrients the tree can absorb from the soil and the carbondioxide in the air, on the other hand by the light and temperature conditions of the site. All these factors form together the ecological environment of a tree. In the forest, however, the environment is never dependent solely upon the primary qualities of the site. On the contrary, it is also determined to a great extent by competition and interactions between the trees and between the trees and all the individual organisms above and in the soil which constitute a forest plant community. Thus, it is of the greatest importance to investigate not only the life requirements of various species and the primary properties of different sites but also the life of various forest communities and the general conditions for plant co-existence and occurrence.

A detailed description of the work included in the extensive field of research does not fall within the scope of this paper, which must be confined to a few examples.

Studies of the *primary site conditions* of the forest have always occupied a prominent place and deal with questions that fall within the provinces of climatology, geology, hydrology and soil science. We realize immediately the obvious dependence of forest growth upon the manifold properties of the site.

Comprehensive investigations have been devoted to *forest plant communities*—the forest type—as a biological co-existence. In forestry the forest type is frequently employed as a simple means of classifying the site and its significant properties with respect to the silvicultural treatment. In research it is necessary to test the utility of the forest type for this purpose and to define it as closely as possible. The results of studies on the forest types and their ecology have shown the importance of plant nutrients for forest growth far more clearly than hitherto and provided a better understanding of the effect of various silvicultural measures on the supply of available nutrients.

In the beginning of the century studies on the importance of plant *nutrients as factors of growth* were concentrated on the supply of nitrogen, and HENRIK HESSELMAN was able to show by his classical soil investigations that in many instances the presence of nitrogen in the soil is very important for the development of young growth. He also proved that an insufficient supply of nitrogen is an obviously limiting factor to the forest yield. More recent investigations on the role of nitrogen have both confirmed and extended HESSELMAN's results.

During the past ten years the forest nutrition has been the subject of far more comprehensive studies than formerly, both with regard to the occurrence of nutrients in the soil and to their significance for forest growth. Many different lines of research have been followed, including analytical fertilization investigations in the field and physiological research in the laboratory. Attempts have also been made to determine by leaf analysis the quantities of the different nutrients normally present in various tree species. The purpose has been to ascertain, on the basis of normal values, whether there is a lack of nutrients in the soil of a forest stand or in a nursery. When judging the possibilities of increasing the yield of a forest by fertilization we must know what substances are lacking.

Good reasons also exist for experimenting with fertilizers in connection with numerous regeneration problems. Regeneration is often difficult to obtain on sites that have been non-productive for a long period of time. In such cases it is worth while to investigate whether fertilization is likely to be effective. A phenomenon in silviculture, such as the frequently occurring stagnation period of young spruce—retarded growth during the first 10—15 years—may possibly be overcome by fertilization. There is reason to believe that this is the case of stagnating spruce planted on heather moor. In northern Sweden the primary cause of stagnation in spruce may be due to unsatisfactory root development accompanied by an acute nitrogen deficiency. When applying the shelterwood system problems are also encountered which may be alleviated by application of nutrients.

Many of the studies on ecological and physiological problems in forest nutrition have yielded very interesting results and it is probable that fertilization of forest soil may, under special conditions, become a rational measure in forestry practice. At the present time forest fertilization represents an important field of research in many respects.

Forest ecology research has clearly shown that thinning also has a fertilizing effect since fresh nutrient material is produced by, amongst other things, decaying roots of felled trees. Furthermore, the competition for nutrients and moisture is decreased, and the conditions that promote the release of nutrients in the soil and in the litter are improved. The importance of the increase of light for a favourable growth reaction, observed in individual trees, appears to have been considerably overrated.

It is also, in the long run, important to determine the rate at which the nutrients in the soil can be replenished. The answer to this question will decide whether a satisfactory growth of the forest trees can be maintained in the future without continuously depleting the soil with respect to nutrients. We possess very little knowledge on this point.

A wider knowledge of the site requirements of the various species as well as of their general and special nutritional demands would throw considerable light on a very important forestry question: *the right species on the right site.* Our knowledge on these subjects is very limited. The productive capacity of a site will be only partially utilized for hundreds of years if a species that is unsuited to the site is selected for artificial regeneration. To explain such efficiency losses and to indicate means of eliminating them should be one of the most urgent tasks of research. The choice of species is made quite summarily in current forestry practice, particularly in northern Sweden. This is associated in part with certain regeneration problems, however, to which will be referred later.

The research worker seeks to utilize not only the immediate yield capacity of the forest by adopting suitable silvicultural measures, but he also attempts to increase this yield. We have just referred to one line of research with this end in view, fertilization. Another line is *genetic research and forest tree breeding*. The first and most important purpose of tree breeding is to produce better races and to find ways to maintain them by genetical and practical means. Of course, we can not yet tell what gains may be obtained in the future by these means, but the possibility of securing valuable results justifies every effort in this direction. Recently numerous investigations and research activities have been undertaken by various agencies in this extensive field of work. Valuable contributions by NILS SYLVÉN should be mentioned in this connection.

Forest tree breeding is carried out along different lines. The methods to be considered are: selection, crossing and polyploidy. The selection of individual trees is characteristic for silviculture, right from the seedling stage to the final cutting. In other words, tree breeding by selection and silviculture are intimately associated with each other.

An essential task is concentrated on the solution of the very complex problem concerning the importance of the genetic structure of forest trees for the yield. The properties of trees are always determined by heredity and by environment. The mutual relationship of these factors may be studied in various ways. The genotype of the individual tree is studied by vegetative propagation by means of cuttings or grafts which are planted out in different environments, e.g. various spacings. The progeny is tested in various ways, such as by sowing seed from open pollination, from controlled pollination or from self pollination. Only the two last methods of pollination are entirely satisfactory from genetic point of view. The problem may be accentuated in the following manner: a good looking tree is not always a good genotype and a tree with a good genotype does not always produce a satisfactory progeny. Our knowledge regarding the interactions between heredity and environment is inadequate. Intensified studies of these complex problems in collaboration between geneticists and forest yield research workers are necessary.

Currently the breeding of conifers is carried out mainly by selection and crossing. The work of selection and crossing also makes use of what the geneticists call *hybrid vigour.* The method is based upon the observation that crossings between different species or races frequently exhibit an increase in growth. The results obtained in the breeding of other plants justify a close investigation of the employment of hybrid vigour for the improvement of conifers. An example of this form of breeding may be mentioned.

Recent investigations have confirmed the experiences that the employment of material of southern spruce provenances is frequently accompanied by an increase in yield, particularly in the early stages. The great increase in growth appears to continue till maturity on suitable sites and in climatically satisfactory locations. The investigations seem to show that the use of a seed material of southern provenance may prove useful to a greater extent—even from a geographical point of view—than was previously considered possible. East European spruce seed in particular has been found to give excellent results even in "frost pockets" as far north as the city of Umeå.

A new "spruce race" possessing desired qualities may be obtained after bringing together material of various origins and by artificially crossing the best trees in special *seed orchards.* Seed orchards of this kind have already been established for Central European spruce. The intention is to utilize its rapid growth and the hybrid vigour which readily occurs when crossing different materials. The question of provenance is also being studied exhaustively for other tree species.

In addition a number of complex questions in which problems of genetic and ecological nature are inter-related should be mentioned: May one given population utilize the nutrients available in the soil more effectively than another? What do we know about the nutrient absorption and the nutrient requirements of the various types of trees? Here, we are faced with theoretical problems of fundamental importance to all forms of plant breeding.

By the employment of tagged atoms, known as *isotopes,* we can now trace the course of the nutrients through parts and organs of a plant in a far more accurate manner than was formerly possible. Certain pilot experiments show that genetically dissimilar materials *may* exhibit differences in nutrient absorption. The preliminary investigations appear to present effective means for penetrating more deeply into these questions, but it is too soon to draw any definite conclusions at the present time.

The contributions and problems of genetics and other sciences related to questions of practical regeneration will be dealt with in a later section. This applies also to the protection of the forest and the timber against the attack of parasitic fungi and insect pests.

The study of the natural conditions for forest growth presents the sciences with a vast task with innumerable detail problems, only a few examples of which can be mentioned here. As the problems are gradually solved our knowledge of the life of a forest will be extended and deepened. The forestry expert will thus acquire a sound biological foundation for the steps he takes. His eye will perceive more sharply and clearly what is actually occurring in nature as the result of different treatments. He can more rapidly draw the correct conclusions from his observations. A study of the separate biological processes taking place in the forest can not alone give the quantitative and qualitative development of stands growing under varying conditions, which is necessary to know to form a practical opinion on the principal questions in silviculture. The supplementary details of the life of a forest is studied by yield research, a description of which follows.

2. Forest yield research.

When a mature stand has been cut a new generation is established by regeneration.

A forest stand can be established in a number of different ways. The chief methods are natural regeneration obtained by seeding from seed trees or from surrounding stands and artificial regeneration obtained by sowing or planting. The development of the stand will differ to some extent depending upon method of establishment. Consequently, the choice of method of regeneration will influence the entire development of the stand.

After suitable tending during the seedling and sapling stages a forest stand has developed to the stage when the first thinning may be considered desirable. The forester must choose the suitable time and decide how the thinning should be carried out. Due consideration must also be given to the interval which should elapse before the next thinning. After repeated thinnings during the long growth period of a stand a point will be reached when it is necessary to decide when the final cut should take place.

Since every thinning produces after-effects during the whole life of a stand it is difficult to obtain a clear view on these points. The decision should depend upon the total yield, but in view of the long period of growth nobody is in a position to estimate the future yield on the basis of personal experience. Here, yield research must show the way.

As already mentioned, *the purpose of yield research is to determine the development that can be achieved by different methods of establishment and by various treatments of a forest stand under different biological conditions.* No basis is available for deciding on the measures to be adopted in silviculture without a knowledge of the numerous biologically possible alternatives for the development of a stand. Neither can a planned schedule of biological or economic nature be drawn up for carrying them out.

Since the period of growth in the forest is long and because the sites and the forest stands vary widely, considerable difficulties had to be overcome by research workers to devise and apply suitable methods of yield research. Nevertheless HENRIK PETTERSON, by his pioneering work has laid a sound foundation for modern research in this field. A significant clarification of the chief problems of stand treatment and of other yield problems of current interest, is now available for practical purposes and numerous important results have already been obtained. A brief outline of the *new method* will be presented.

The Forest Research Institute of Sweden has a considerable number of thinning experiments that have been laid out progressively during the course of a few decades in stands of various ages. They have subsequently been thinned and recorded approximately every fifth year. The short fragments of development observed so far are spread over practically all the ages that occur. Thus, to form a conception of the entire course of development of a stand it is necessary to combine these evolutionary fragments—comprising the interval between two thinnings—in some way or other.

The growth during an interval of thinning is influenced by many measurable factors which relate in principle to the site, species, the race, the condition of the stand at the beginning of the period, its preceeding history, the form of thinning and the climatic conditions during the period. The way in which these different factors may be suitably described to enable us to make as accurate an assessment as possible of the growth during the interval is not clear in advance. It is evident, however, that an estimate can actually be made by such simple means as a repeated division of the material into groups and a calculation of the mean values in all the subgroups. A conception of the manner in which the different factors influence the growth can be obtained. There are also many unknown or obscure factors, of course, which affect the growth. Their effect cannot be described but manifests itself in the form of a variation of the mean values in different groups. We cannot reduce this variation until research has provided possibilities for a more precise group definition. The point is that the variation should be reduced to such an extent that the mean values can be used as a basis for our activities.

In practice, it is found necessary to consider many detail factors during the computation of growth. Readily it will be appreciated, however, that a division of the material into groups cannot be carried very far in reality. The groups increase numerically with enormous rapidity on each new subdivision until a practically impassable limit is reached. Consequently, it is of vital importance in yield research, as in many other branches of research, that mathematical statistics can provide a method of evading these difficulties. This method is known as *regression analysis*.

Regression analysis operates in the same manner as a manifold classification of data and it computes in principle the mean values as is desirable when a division into groups is possible. It adjusts also these group mean values in relation to one another. The regression analysis may be regarded as an approximation, and a division into groups as an unattainable ideal. The method leads to mathematical functions which indicate the relation between the most probable value of the quantity sought for—in this case the increment —and the observed values for a number of the factors influencing the quantity.

Regression analysis aims at providing a quantitative expression for the influence of different factors on a course of events. It corresponds in this respect to the experiment in biological sciences. In the experiment, however, the influence of a single, or a small number of factors, is studied, whereas other relevant factors are maintained at a constant level as far as possible. The scope of the problem is thus restricted and an endeavour is made to elucidate a limited section at a time. Yield research, on the other hand, can make no progress by limiting its problems. Simultaneous consideration must be given to as many details of the complicated reality as possible, which calls for the checking of a large number of factors. For reasons that will be readily appreciated, it is furthermore hardly possible to maintain any factors constant on the sample plots out in the forest. Yield research has no choice therefore; it cannot solve its most important problems in any other way than by regression analysis or by other closely related mathematical-statistical methods.

The form of yield research outlined here results in tables which indicate the probable stand development and the yield when applying different silvicultural programs, under various biological conditions e.g. different geographical districts and site classes, species and races, etc.

Silviculture is a means to an end. This end may differ in individual cases but, generally speaking, it should have an economic purpose. *When the biological possibilities for inducing different developments are known, it only remains to select the one that offers the greatest economic advantages.* The purpose of forestry is to produce economic values. As far as research is concerned, this necessarily involves the ability to estimate the timber yield during the whole rotation period and to express the yield in terms of value. To achieve this end yield research must rely also upon the results of work in the fields of wood technology, work technology and forest economics.

After studying the observation material derived from the permanent thinning experiments of the Forest Research Institute along the new lines, we have obtained useful guidance on the chief problems related to the tending of a stand and to the yield. It has been possible to draw conclusions of fundamental importance concerning the yield of conifers on different sites and the dependence of the yield upon the silvicultural measures adopted, such as planting, sowing, cleaning, thinning and the length of the rotation period. With regard to thinning, comprehensive studies have been devoted to the choice of time for the first thinning and the interval of thinning as well as the form and severity of thinning. In this way the necessary data have been provided for a *discussion on the economy of silviculture*. Rational thinning is of vital importance to the value of the yield and to profitable forestry.

The material available for these investigations, however, has been incomplete and limited, particularly in the case of northern Sweden. Consequently, we are able to form only a very approximate opinion on many problems of significance for the work of regeneration e.g. the yield from planting in comparison with that of naturally regenerated stands, the importance of early cleaning in seedlings stands, the influence of spacing on the quantity and the quality of the yield, the yield of mixed coniferous forests, the yield of birch and aspen on different sites, etc. We know, however, *that considerable future values are at stake*. The review must be confined to a description of only a couple of the points concerned: the question of early cleaning of saplings and the influence of various spacings in planting and in seeding.

The competition between the seedlings on seeded areas and in dense natural regeneration is particularly heavy and the development is retarded just at a time when the growth curve should climb most steeply. Cleaning, i.e. early release in young stands, is therefore of the same fundamental importance as in corresponding cases of agriculture and horticulture. The calculations obtained from yield research provide convincing reasons to believe that the total yield during the rotation period may be increased this way by 15 to 20 per cent and that the capitalized value of the future annual revenues may be raised by 50 to 100 per cent. The problem is closely associated with the question of suitable spacing in artificial regeneration. Much work is necessary, however, for a more detailed investigation of these important questions.

In view of the fundamental interest which these questions of yield possess the Forest Research Institute has initiated an extensive yield investigation along modern lines.

The new yield investigation comprising our most important species and types of stand has a wider purpose than that of merely facilitating yield predictions. A large number of sample plots which have been carefully described as to the increment and classified with regard to the site and the quality of the trees, provide a deeper insight into the conditions of the growth. For this purpose samples of soil and humus are also collected for an investigation of the soil and its properties. Needle samples from the crowns of the conifers have been collected and investigated for micro nutrients that may throw further light on the qualities of the site. Botanical features and other characteristics of the trees that are considered to be specific for different genotypes, are determined from sample trees. A simultaneous observation of the environment and heredity may show that their respective effects can be distinguished during the statistical analysis of the data.

To render the desired assistance to practical silviculture yield research must also be combined with investigations on *the quality of the timber*. For this purpose representative wood samples are taken from trees, the technical properties of which are examined in collaboration with the Swedish Forest Products Research Laboratory.

In the cellulose industry, for example, it is very important to know to what extent different sites and different methods of silviculture affect the yield of pulp and the quality of paper. Thus, very valuable results have been obtained from a recently concluded examination of the material from the yield study. The investigation was restricted to an enquiry concerning the influence of the site and the tree quality on the yield and quality of sulphite pulp from spruce.

The extensive field work in connection with the new yield investigations has now advanced to a stage where the observation material from northern Sweden can be subject to a comprehensive analysis. This entails team work on a large scale. The goal towards which we strive in the interest of silviculture will eventually be reached with the co-operation of experts in various branches of research. On this account, the new yield investigations have been discussed in detail. They present two main problems.

The primary task consists in an investigation of the possible development of stands growing under various biological conditions. For this purpose close co-operation is necessary between forest yield research, biological research and mathematical-statistical research. When a choice has to be made at a later opportunity between the biologically possible alternatives of the factors that are economically favourable under different conditions, further links must be added to the chain of co-operation: studies in wood technology and wood chemistry on the technical properties and the utilization of wood, work technology studies to analyze costs of cutting, transport and other phases of work, and forest economics research to study distribution of costs, price developments, rates of interest, etc.

To ensure successful team work the various research branches must have made sufficient progress in their own fields to be competent to participate in the common task. In view of the advances made in recent years in the branches concerned, the time appears to be ripe for a fruitful collaboration in forest yield research work.

The new yield investigations will not, of course, solve all the problems of forest management. The objective is less ambitious, but extremely important. To make decisions in regeneration and tending—the fields most important to the yield and to the economic planning, we need to establish a far more solid basis for practical work than is available at present.

Although it is difficult to predict future developments we can not fail to note that the science of genetics is endeavouring in various ways to impart new properties to our species and combinations of new properties. We have seen that in certain cases exotics grow better than do our own species. Soil scientists try, by different means, to improve the supply of nutrients in the soil. The climatic conditions appear to change slowly. The industries can manufacture a constantly increasing variety of products. All these facts may lead to consequences we can not tell. They may also involve changes in the conditions for forest growth in our country that create new and important tasks for yield research.

3. Forest regeneration research.

Yield and regeneration are parts of one and the same problem. Regeneration research may be considered from the same viewpoints as those previously associated with yield research. First we must investigate the biological possibilities for bringing about regeneration. Afterwards an economic choice must be made between them. The future yield resulting from different methods of regeneration plays a prominent part in making the choice. The aim here is to combine a high yield with low regeneration costs.

The young growth should be of a quality that makes an increase of the future timber yield possible. The problem of establishing young growth on an economically satisfactory basis is of utmost importance in forestry.

Biological research which has been discussed above is also of fundamental importance to the solution of regeneration problems. Special biological problems as well as closely interrelated silvicultural and technical questions must be added, however. Such matters are of that reason dealt with when discussing different methods of regeneration. In recent years work in regeneration research has been concentrated mainly to northern Sweden where the need for prompt guidance in problems of reproduction has been most urgent in connection with the rehabilitation of forest land.

The investigation of conditions under which satisfactory regeneration in accordance with present day requirements can be obtained by natural means and the manner in which one should proceed to achieve this end is the foremost task of regeneration research.

Natural regeneration presents problems that concern suitable methods of regeneration cutting as well as clearing of cut-over areas and other measures for promoting regeneration e.g. mechanical and chemical treatment of the ground, controlled burning, etc. To clarify these matters it is necessary to obtain a deep insight into the biological conditions for natural regeneration. This is achieved by observations on the structure of the regeneration, the forest type, the parent stand, the soil, the climate, the occurrence of parasitic fungi, insect pests, etc. The regression-analytical methods described earlier will frequently be found of great assistance when studying the observation material.

In the beginning of the 1940s the possibilities for natural regeneration were investigated especially for spruce sites in northern Sweden. The investigation showed that the difficulties of regeneration were considerable, particularly at elevations exceeding 200 meters above sea level. It appeared necessary to resort to subsidiary measures to ensure satisfactory regeneration.

There are extensive regions in other parts of Sweden where natural regeneration is rendered difficult by herbaceous vegetation, drought, etc. The need for a better knowledge regarding the possibilities and means for ensuring satisfactory natural regeneration under varying conditions is urgent.

Artificial regeneration by sowing and planting cut-over land and residual stands is a means of rapid reproduction. Investigations carried out under the application of modern field research methods have demonstrated that—contrary to the general belief formerly held—the prospects of obtaining satisfactotry results by artificial regeneration are considerable even in the upper and interior districts of northern Sweden. Many biological and technical problems must still be solved, however, before artificial regeneration can be made successfully in its practical application.

The need for forest ecology research is becoming increasingly urgent concerning the growth and vigour of seedlings oftentimes growing in severe environments and under unfavourable climatic conditions. The problem of stagnating spruce which has been mentioned comes under this heading. Technically there are also a multitude of unsolved problems. Intensive work must be devoted to the elimination of the current losses which are far too common. We must also understand how to benefit of the gains that lie within reach.

A reduction of the current labour costs for artificial regeneration by at least 25 per cent should be possible by the adoption of improved manual methods and organization of the work and by increased application of the piece-work system. For an annual reproduction area of approximately 100,000 hectares this would correspond to a saving of 5 to 6 million Kr.Sw. The *annual* demand for forest regeneration during the next 20-year period is currently estimated at 100,000 hectares for the whole country. Increased biological knowledge would most probably prevent future losses of corresponding magnitude.

To reduce the costs of regeneration further attempts have been made to mechanize heavy work by employing *tractor-pulled equipment for scarification*. The experiments have been successful and the method is now widely applied. The costs for tractor operation are reduced to less than half of those for well organized manual work. The method has been applied as a preparation for sowing as well as planting, and in both cases with satisfactory results from a biological point of view.

The upland forests present special difficulties with respect to regeneration, and efforts are being made to overcome them in various ways. A thorough preparation of the soil by means of tractors is one of the methods that is being tried for natural and artificial regeneration. In artificial regeneration special experimental areas are being established with Siberian and American species.

Due to differences in the growth rhythm and in the requirements of pine and spruce as regards the site, the establishment of mixed coniferous stands by artificial means is complicated by difficult problems. The attention of research workers has been directed to this important task which is of special interest for forestry in northern Sweden.

A regeneration problem of importance may be alleviated by *the use of herbicides*. Without these chemicals it would be virtually impossible to rehabilitate extensive areas in northern Sweden that by negligence are overgrown with birch of inferior quality. The chemical progress made in this field should be followed and the application of brush control methods should be studied and developed. Special attention should be devoted to the effect of the chemicals on the microflora of the soil.

Other problems closely associated with artificial reforestation are related to the *seed*, its treatment and storage, as well as *nursery practices* including the measures against insect pest and fungi, problems concerning transplanting, sorting, etc.

Interesting results have been obtained from investigations in this field. For instance, it may be mentioned that the importance of careful de-winging methods have been demonstrated and methods have been devised for examination of the quality and the constitution of seed by X-ray photography. Unsuitable de-winging methods probably represent a contributary cause for the failure of old forest regenerations and the X-ray techniques widen the perspectives for seed analysis in the future.

The *idea of using seed orchards* is based on selection and propagation by the grafting and crossing of fine phenotypes, called plus-trees. Seed orchards are now established on an extensive scale in different zones of the country. The seed orchards serve the purpose of producing large quantities of genetically good, well developed and fully ripe seed which can be easily harvested. In spite of all the experience gained so far the seed orchard activities are still in the experimental stage and the need for continued investigations is obvious.

4. Protection of forest trees and timber.

In rational silviculture trees and timber must be effectively protected against damage from pests of the plant and the animal world. It is possible here to touch only briefly upon the investigations in the important fields of mycology and entomology.

Research in mycology has considerably extended our knowledge concerning the biology of damaging fungi, and in many instances it has been possible to develop control methods. A few examples may be given. *Snow-blight (Ph. infestans)* constitutes a serious obstacle to the regeneration of pine at certain altitudes in northern Sweden. The biology of this fungus has been clarified and valuable instructions on suitable control methods have been given. Increased possibilities are also available for controlling certain fungal diseases in nurseries.

The most prevalent fungal disease in our forests is problably *root rot (F. annosus)* which severely attacks spruce in certain regions and sometimes pine. Considerable efforts have been made to elucidate the biology of fungal infection and to discover means for eliminating root rot. Our knowledge in this respect, however, is still inadequate. This is a problem the solution of which is of outstanding importance to forestry, particularly in the southern part of the country.

Fungi cause storage losses in timber and pulpwood which may amount to large sums. Extensive investigations have shown that the damage can be kept within reasonable limits by suitable methods of storage and handling during transport and in the wood yard. Many detail problems still await their solution, however.

Considerable damage is caused on timber by *blue stain*. Research has shown that an interesting biological relation exists between certain bark beetles and the fungi causing blue stain. Spraying timber with a DDT-preparation has yielded good results in eliminating blue stain.

In the field of entomology *dusting from aircraft* has been found an effective method for controlling certain insect pests. Prognostical survey methods have been developed in connection with defoliator epidemics. Old methods have been modernized and made more effective by employing new substances that have been developed by chemical research.

Increased knowledge of preventative measures and methods for control of damaging fungi and insect pests is needed if the gains achieved by silviculture are to be utilized effectively.

A detail of timber treatment which falls within the branch of wood technology should be mentioned. The studies concern the *buoyancy* of the timber during water transport and the reduction of losses caused by sinking. This is a field of research offering numerous detail problems.

5. Development of forest work techniques.

All forms of production have a debit and a credit side. The balance between the two will decide whether the production is profitable or not.

The main item on the debit side of forestry is the labour cost. Research on work techniques increases our knowledge of the procedures and provides better conditions for a rapid improvement of work methods in the forest. Improved work techniques make forestry more profitable and thus contributes towards improved work conditions and a higher standard of living for forest labour. In consequence of this the labour market is also improved.

Research on work techniques started relatively recently. The central field of interest is the *felling and transport of timber.* Comprehensive experiments and research work has been carried on in this field during the past 15 years. During this time it has been possible to undertake only a preliminary examination of the most urgent problems. Nevertheless, important results have already been obtained.

In large scale forest management in northern Sweden and in the province of Dalecarlia it has been found that the individual output in forestry work of a purely manual nature has risen during the past ten years by about 25 per cent for felling and 15 per cent for horse transport. No mechanization of the work is included in the figures. A corresponding investigation has not yet been made for small scale forest management. The improvement in manual operations can undoubtedly be attributed in no small part to results of research on work techniques. *The gains derived from mechanization must be added to an improvement in individual performance of 2 per cent annually.*

The main forms of research on work techniques may be divided into three groups:

1. The improvement and refinement of existing methods and equipment, such as the development of felling techniques and the practical coordination of transport.
2. Research aimed at far reaching changes in the work, such as mechanized skidding of the timber, bundling, construction of various special machines for forestry work, etc.
3. Physiological work studies for the development of correct, energy economizing work methods, protection against occupational injuries, retention of working capacity at higher ages, etc.

Research on work techniques is a diversified and extremely important field of work which has been only outlined in this review.

6. Regional research tasks in connection with the national forest survey.

The two first Swedish national surveys took the form of provincial surveys. One or two provinces were inventoried each year. The method had several disadvantages. When compiling the results for the whole country part of the data consisted of up-to-date figures and part of the data were as much as fifteen years old. In the third national survey which started in 1953 this disadvantage has been eliminated by covering the whole country each year with a low percentage inventory comprising 1/10th of the area surveyed during the second national forest survey. The survey now in progress includes in other words a whole series of annual national forest surveys.

The new survey will provide reliable data each year for the entire country, and after two years, for the country divided into two halves, northern and southern Sweden. At the end of the fourth year figures can be obtained for each of five separate regions, and at the end of ten years, on the conclusion of the survey cycle, for all provinces and, in certain cases, for parts of provinces.

The reorganization of the national forest survey to cover the whole country each year has provided ample opportunities for *regional forest research*. During the survey about 1,000 areas with 10,000 sample plots are examined annually. The areas, known as survey tracts, are uniformly distributed over the country. A new set of tracts is surveyed each year. Supplementary observations can be made in many instances in conjunction with the detailed description of the forest conditions that is carried out during the survey. The additional data may throw light on current research problems, particularly those of a regional nature. The special investigations will, of course, only be carried on until sufficiently comprehensive material has been obtained. The collection of this material can frequently be undertaken at a relatively insignificant extra cost.

The following examples of regional investigation that are being carried out or planned at the present time in coordination with the national forest survey may be mentioned:

1. The annual variation in growth due to climatic conditions in different regions (climatic regions)
2. Occurrence of various types of forest and soils
3. Occurrence of various races
4. Occurence of certain forms of rot
5. Occurrence of spruce bark beetles
6. Cone crop in various regions
7. Regional investigations on the quality of the wood, etc.
8. Density and conditions of the forest road system.

The importance of regional research carried out along these lines cannot be overestimated.

In this connection it should also be pointed out that, on undertaking special scientific investigations, the material obtained from the national forest survey may throw light on numerous important questions of interest in the field of forest inventory. The following examples may be mentioned: empirical volume tables, growth and bark percentages, intensities of survey, yield tables, etc.

Concluding remarks.

Work in the young science of forestry may be compared to mountaineering. We have set about climbing the mountain from all sides investigating its nature systematically. We do not know how far we are from the peak but we hope to obtain an ever widening outlook.

The progress made in the realm of forest research strengthens the long chain of links from sowing to harvesting. Although the improvements achieved may be of a relatively modest nature they represent enormous values. To illustrate the economic background of forest research a few interesting figures may be cited. They are merely intended to show the magnitude of the amounts.

The total volume cut annually in the country during the past few years was approximately 50 million m^3 including bark with a value for industrial or other uses of 2,500 to 3,000 million Kr.Sw. The costs of felling and transport exceeded 1,000 million Kr.Sw. Research may evolve measures that increase the yield by ten per cent, and by suitable treatment improve the quality of the timber in terms of an increase in gross value of five per cent. Furthermore the costs of felling and transport may be reduced by ten per cent by improved techniques and mechanization. At current timber prices and labour costs a gain of about 400 million Kr.Sw. annually could be transferred to the national economy in various forms. The assumptions regarding these relative improvements are made on a conservative basis. *Forest research is aiming still higher.*

Den svenska skogsforskningens mål och medel

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