SILVICULTURAL RESEARCH IN FINLAND
FROM 1909 TO 1959

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Contents

Abbreviations

AFF Acta Forestalia Fennica
ASFFF Acta Societatis pro Fauna et Flora Fennica
Com. For. Commentations forestales
MA Metsätaloudellinen Aikakauslehti
MTJ Publications of the Forest Research Institute in Finland (Communicationes Instituti Forestalis Fenniae).
SF Silva Fennica
SMYJ Suomen Metsänhoitoyhdistyksen Julkaisuja (Finska Forstföreningens Meddelanden)
SMYV Suomen Metsänhoitoyhdistyksen Vuosikirja

Introduction

It is justifiable to say that the forestry research as an independent branch of science began in Finland in 1909. At first this research was primarily biological, dealing with both the foundations and practice of silviculture. It is true that investigations and experiments in silviculture had been done and results published even over a hundred years before, but that older research instead of being continuous was only a scattered budding, appearing here and there. On the other hand, it indicated that both the need for and interest in the research was plentiful. The botanical research which forms the basis for silviculture also has deep roots in Finland. The physical qualifications for continuous forestry research meeting the requirements of science were created when the teaching of forestry at the University of Helsinki was begun in 1908 and the Society of Forestry in Finland, which was founded in 1909, gathered about itself the active research forces which existed in our country at that time, and together with the University it took upon itself the task of educating new research workers for the field of forestry.

Of the research work in silviculture that had been done in Finland before the founding and in the first decades of the Society of Forestry, there is a detailed review in both the Finnish and English languages (Lauri Ilvessalo 1926 AFF 31). For that reason the following review will be concentrated mainly on the development in silviculture that has occurred in our country after the appearance of the mentioned review, touching upon the earlier investigation only to the extent necessary in forming the background for further development. At first, however, it might be appropriate to recall briefly the changes that have taken place in the general conditions for research.

The first decade of the Society of Forestry, 1909—1919, can be considered a time for the organizing of silvicultural research, when the lines of investigation and groups of topics were taking shape, and in the small group of scientists there already appeared specialization into various sectors. The physical prerequisites were still quite modest; the research work was limited almost entirely

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Of the authors Esko Kangas has collected the material on forest injuries and protection and Leo Heikurainen the material on swamps and forest ditching. The rest of the material has been collected by Peitsa Mikola, who has also done the actual writing. Translation from the Finnish has been done by Mr. and Mrs. Pentti Kanerva.

to the University and the Society of Forestry. Furthermore, the time was politically restless and economical difficulties were great. Finland's gaining independence and the founding of the Forest Research Institute of Finland (1918) mark the beginning of a new era in the history of Finnish forestry. The next two decades, 1919—1939, were times of rise and development on all sides of Finnish economic and cultural life, and the forestry research also followed the development. The growing forest industry brought the importance of forestry to the knowledge of the public, and practical forestry brought ever new questions for the science to answer. The research staff was augmented both in the University and in the Forest Research Institute, in which two institutions silvicultural research was still mainly concentrated.

This development was interrupted by war in 1939, which in itself and with aftereffects suppressed research almost entirely for nearly a full decade.

The work of the last decade of the Society of Forestry, 1949—59, is too recent for a critical, comprehensive survey. It is possible, however, to examine the extent to which each line of research has advanced. Characteristic of the most recent period is the ever increasing speed of development in every field and the arising of new problems, even entirely new fields of investigation. The postwar difficulties have for the greatest part been overcome. The possibilities for research have improved, but there has been the task of making up for the years that were lost in the war. Time, the best assistant of silvicultural research, has, however, been at work. Many experiments which had been set up even decades ago have only recently yielded results, and also the amount of practical experience is considerably larger than during earlier decades, even though the most valuable research material of the earlier times, the virgin forests, in turn have been lost to a great extent. The change that has taken place is reflected clearly in the composition of the research topics.

Forest Sites and Vegetation

The Society of Forestry in Finland began its Acta Forestalia Fennica in 1909 with A. K. Cajander's »Ueber Waldtypen.» It marked the direction for the main emphasis of research in the near future. The theory of forest types presented by Cajander in which the classification of sites is made on the basis of plant communities has since then formed the base for site classification in silvicultural research, practice of silviculture, and since the appearance of Y. Ilvessalo's publication (1920 AFF 15) also in forest mensuration and management.

In his classic publication, »Ueber Waldtypen,» Cajander described forest types of mineral soils which occur in Southern Finland and in Germany. In his study, »Studien über die Moore Finnlands» (1913 AFF 2), he expanded his

system to include also peatland forests and open swamps. In his later publications Cajander (*e.g.* 1921 AFF 20, 1923 AFF 25, 1925—26 AFF 29, 1930 SF 15) further completed and clarified his theory of forest types, and in a form with his finishing touch it is presented also in English in the memorial volume following his death (1949 AFF 56).

During the past decades the research on forest vegetation and forest types has continued along a broad front. The scope of the subject and the great number of publications on the topic forces the examination to be limited principally to the papers which are most closely related to silviculture and which have appeared chiefly in the publications of the Society of Forestry and of the Forest Research Institute. The forest types occurring in Northern Finland were described rather early (Lakari 1920 AFF 14; Kujala 1921 AFF 18, 1929 MTJ 13), but supplementary studies of the types of both Southern and Northern Finland have been carried out even quite recently (Kujala 1926 MTJ 10, 1928 MTJ 13, 1936 MTJ 22; Sarvas 1951 MTJ 38; A. Kalela 1952 MTJ 40; Teivainen 1952 Ann. Bot. Vanamo 25; Sirén 1955 AFF 62; Keltikangas. 1959 AFF 69; etc.).

Finnish scientists have described forest types outside of Finland, for example in East Carelia (Linkola 1917 AFF 7; Kalliola 1943 MTJ 31), in Estonia (Linkola 1929—30 AFF 34 and 36), in Central Europe (Cajander 1909 AFF 1; Linkola 1924; Kujala 1936 MTJ 22), and in North America (Auer 1928 MTJ 13; Y. Ilvessalo 1929 AFF 34; Kujala 1945 Ann. Acad. Sci. Fenn.). In these investigations parallel series of types for different regions has been outlined (Kujala 1938 MTJ 27).

Detailed information about the area and distribution of different forest types has been received from the national forest inventories. The information based on the inventory of 1951—53 is presented both by main water system areas and by forestry board districts (Y. Ilvessalo 1957 MTJ 47).

The natural attempt was to picture and define the forest types in the characteristic form in which they occur in virgin forests, but more exact knowledge of them and use in silviculture have required the study of the development of plant communities also in forests under human activity. Thus, effects of culture on forest vegetation (Linkola 1916 ASFFF 45), the influence of grazing (Hertz 1934 AFF 40), and the effect of forest fires particularly in Northern Finland (Kujala 1926 MTJ 10; Sarvas 1937 SF 44) have been studied.

In research on forest sites and plant associations the study of swamp types forms its own broad group. Since Cajander's famous »Studien über die Moore Finnlands» (1913 AFF 2), research on swamp types has primarily been carried out independently of the research on upland forest types. There are two natural reasons for the relatively great role of swamp research: first, the swamps' share of the total land area is noticeably great, about one-third; and second, Cajander had already observed that there was a much greater number of swamp types than

of upland forest types (he distinguished over thirty peatland forest types and, in addition, over forty types of treeless swamps). Furthermore, swamps in general have remained in a more virgin condition than forests on mineral soils and therefore offer in many cases a more favourable object of investigation.

The division into types on swamps differs from that on firm lands in that whereas the types on firm lands are distinguished from each other entirely on the basis of the ground vegetation, on svamps the main types are distinguished on the basis of tree species (*räme* forests growing pine and *korpi* forests growing spruce and broadleaf trees), and within these main types further division is made on the basis of ground cover. An essential difference is also in the fact that the forest type on mineral soil reflects the combined effect of all site factors, in other words, the site quality, while on swamps the vegetation indicates primarily only the nutrient content of the substrate. The swamp types have thus become the most important guide in estimating the swamps' suitability for forest ditching, *i.e.*, the production of wood after ditching.

After Cajander, the Finnish swamp types have been described by Warén (1926 ASFFF 55), Paasio (1933 AFF 39, 1936 AFF 44, 1941 AFF 49), Tuomikoski (1942 Ann. Bot. Vanamo 17), Heikurainen (1953 An. Bot. Vanamo 26), and others.

The use of swamp types in practical silviculture has been complicated by the great number of types and the rather thorough knowledge of plants necessary in distinguishing the types. This has given cause both for the preparation of many practical directions for type determination (the best known of them have been made by Lukkala and by Lukkala & Kotilainen) and to the attempts to simplify the type system. Most recently Huikari (1952 SF 75) has suggested a rather simple division and determination formula mainly for the use of practical forest ditching personnel.

As appears from the preceding paragraphs, vegetation as an indicator of site quality has continuously been the object of great interest in Finland. The actual site factors, forest soil and climate, and their relation to vegetation and silviculture have received much less attention. The organized study of forest soil actually began only after the founding of the Forest Research Institute and the greatest share of the work in this field has been done by V. T. Aaltonen.

The knowledge of the distribution of the Finnish forests among the different soils, primarily between mineral and peat soils, and the regional occurrence of different soils has been obtained from the national forest inventories (Aaltonen 1941 MTJ 29), and likewise regarding the variations in the thickness of the peat layer (Y. Ilvessalo 1957 MTJ 47). In the research on the properties of forest soil it has been attempted above all to determine the interrelations of the properties of the soil, forest type, and the growth of the trees. The first investigation of this kind was based on the large sample plot material which was accumulated

in the preparation of Y. Ilvessalo's yield tables (Valmari 1921 AFF 20; Y. Ilvessalo 1923 AFF 25). At about the same time Lukkala (1920 AFF 16) studied the relation between the swamp type and the properties of the surface peat layer. Aaltonen studied soil acidity (1925 MTJ 9) and the mobilization of nitrogen (1926 MTJ 10) by forest types. Furthermore, Aaltonen has dealt with the question of determining the fertility of the site on the basis of soil properties (1937 MTJ 25), and Viro (1947 MTJ 35) has investigated the relation between soil fertility — measured on the basis of forest type and height of the dominant trees — and the mechanical composition. Viro has devoted special attention to the stoniness of the soil, for the determination of which he has developed a practical method (1952 MTJ 40), and to its influence on the site fertility. A comprehensive account of the stoniness of Finnish forest soils has been obtained in connection with the third national forest inventory (Viro 1958 MTJ 49).

The amount of nutrients in forest soil and its relationship to the forest type and the growth of the trees has been under extensive investigation in the Forest Research Institute and results have been published for pine stands (Viro 1951 MTJ 39). In these investigations the closest relationship has been observed as occurring between the calcium content and the fertility of the soil. The influence of calcium as a fertility factor has received attention already in earlier investigations (*e.g.*, Pesola 1926 Ann. Soc. Vanamo 9) and as the most fertile areas in Finland there are known the places where the bed rock contains relatively more limestone and other basic minerals as is indicated, for instance, by the national forest inventories. The relationship between soil and forest type has been studied also in the light of the results of the national forest inventories (Y. Ilvessalo 1933 MTJ 18; Aaltonen 1941 MTJ 29).

Aaltonen (1950 MTJ 37, 1955 MTJ 45) has also studied the relationship between the chemical composition of tree leaves and the nutrient content of the soil. This relationship has been rather weak in coniferous forests and therefore the leaf analysis suits the measuring of the site quality on mineral soils rather poorly.

The relationship between the vegetation and the nutrient content of the soil has been studied more for swamps than for mineral lands. These investigations, whose main function has been the evaluation of the suitability of different kinds of swamps for draining, have been closely linked to the studies whose aim was the use of swamps for agricultural purposes (Kotilainen, Kivinen, etc.). Due to these studies the ecology of swamp plants is known almost better than that of upland plants. In connection with them the classification of peat has also become established as well as the methods of peat identification; the properties of peat have been seen to bear close relation to the component plant species, which in turn gives a fimr scientific basis for the use of swamp types as the indicator of the value of swamps for agricultural and forestry uses.

Comparative studies of the microbiology of different forest sites have been

first carried out by Svinhufvud (1937 AFF 44) and later by Gyllenberg, Hanioja, and Vartiovaara (1954 AFF 62). The microbial population of both mineral soils and peatlands are at the present time undergoing more extensive investigations. The soils fauna so far has received only little attention, but great differences have already been noticed among different forest types (Karppinen 1958 Ann. Zool. Vanamo 19.)

Research concerned with the origin and development of forest soil, or soil formation, has been directed especially to the podsolization characteristic of Finland. After the preliminary investigations dealing with the precipitation of iron (Aaltonen 1923 AFF 25; Lukkala 1920 AFF 16), a thorough study of the podsolization has been made at the Forest Research Institute on the basis of extensive analyses (Aaltonen 1935 MTJ 20, 1939 MTJ 27, 1941 MTJ 29, and 1947 MTJ 35). By comparing the »old» land with younger which has risen from the sea more recently, it has been possible to follow without difficulty the development of podsol profile, and it has been observed, contrary to earlier beliefs, that the B-horizon is first formed comparatively deep and it grows upwards. On the basis of the intensity of leaching, Finland can be divided into six podsolization regions. Aaltonen (1933 MTJ 18) has studied the degradation of forest soil caused by leaching and Viro (1953 MTJ 42) has attempted to calculate the total influence of leaching on the nutrient balance of Finnish forest soils by the analysis of rain and river waters.

To the topics of the development of forest soils also belongs the question of the origin and expansion of swamps. The old concept that swamps would have their origin mainly in the filling up of lakes and ponds with vegetation was proved wrong even in early investigations (Backman 1919 AFF 12; Auer 1921 MTJ 3 and 1922 MTJ 6; Kujala 1924 MTJ 8; Aario 1932 MTJ 17), according to which the paludification of firm forest lands was the primary source of swamp formation. According to the investigations of Lukkala (1933 MTJ 19) swamp formation still occurs on a large scale and measurements are also made on the growth of the peat layer of swamps (Backman 1919 AFF 12; Saarinen 1933 MTJ 19). In later studies, however, the primary swamp formation, that is, establishment of peat-forming vegetation right after emersion of land from the sea, which fact had been given attention even earlier (Kujala 1924 MTJ 8; Auer 1924 MTJ 8), has proved to be a very essential type of swamp formation (Huikari 1956 MTJ 46) alongside the paludification of firm lands, which conclusion has also been arrived at by Swedish students in their country.

In most of the recent investigations concerning swamps suitable for forest ditching the comparison to upland forest types has been abondoned and the measuring of the tree stands on drained swamps has received intensive attention instead. This is possible because of the permanent sample plots of the Forest Research Institute (Lukkala 1951 MTJ 39, etc.), and it has been possible

to confirm the accomplished results on the basis of sample plot material collected throughout the country (Heikurainen 1959 AFF 69). Now it is already known with rather great assurance the way in which the trees on different swamp types will grow after ditching. Because the ditchings are for the most part young (under 30 years), however, the information about the later development of the growing stock on drained areas is still obscure.

As the evaluation of the swamps for suitability for ditching based on the climatic location and original swamp type has been established on dependable grounds, it has been possible to assess both the total area of swamps suitable for ditching and their distribution in Finland. According to the national forest inventory there are altogether approximately five million hectares of such swamps, of which about one million hectares have been ditched to date.

In addition to the effect of draining on the plant cover and tree growth of the swamp, also its effect on other properties of the swamp have been studied, such as the acidity of the peat (Lukkala 1929 MTJ 13), its nutrient content (Vahtera 1955 MTJ 45), and the microbiological properties (Huikari 1953 MTJ 42; Paarlahti & Vartiovaara 1959 MTJ 49).

Because strong acidity and the lack of certain nutrients commonly occur in peat, the idea of improving forest growth on ditched swamps by fertilization appeared early. The forest fertilization experiments in Finland have been done much more on drained swamps than on mineral soils. These experiments on drained swamps were begun in the experimental forest of the Forest Research Institute in 1928 and thus far they include over a thousand sample plots. In the experiments lime, ash, commercial fertilizers, and sand have been used. The results so far have been rather promising; the lime, phosphorus, and especially wood ash have had clear influence in improving tree growth (Lukkala 1951 MTJ 39; Huikari 1953 MTJ 42).

Neither is the idea of improving mineral soils by fertilization new; Valmari (1917 AFF 7) especially recommended it enthusiastically. From previous years, however, there exist only few separate trials for which Viro (1950 MTJ 37, 1958 MA) has published the results. On a large scale, the establishing of fertilization experiments on mineral soils was begun through the Forest Research Institute in 1956.

The question of site improvement through controlled burning will be discussed later in connection with the methods of silviculture.

The research on climatic site factors has been relatively little in Finnish forestry. It, too, has dealt primarily with swamp forests.

Swamps have always been known as cold habitats so that one of the objectives in earlier forest ditching was the prevention of frost, and the frosts and thermal conditions of peat as well as the effect of ditching on them have also received scientific attention, especially as an agricultural problem. The frost studies were

already begun in the last century by Homén (1894 Bidr. t. känned. af Finl. natur o. folk 54, etc.), who also published a comprehensive account of the significance of forests in hydrology (Våra skogar och vår vattenhushållning, 1917). Later, Multamäki (1942 AFF 51) has discussed in greatest detail the importance of temperature as a growth factor in swamp forests.

The studies of soil ice are closely related to those of frost (Kokkonen 1926 AFF 30, 1942 AFF 50). The damage caused by the soil's freezing has been given attention in many investigations into the first development of seedlings (*e.g.*, Aaltonen 1919 MTJ 1; Kangas 1937 MTJ 37).

Most of the other investigations on climatic factors have also determined their effect especially as a cause of forest injuries. Thus the damage by storms on mature forests has been studied (Bonsdorff 1917—18 AFF 8; Heikinheimo 1926 MTJ 12; E. Kalela 1934 AFF 40; Laitakari 1952 MTJ 40), the origin and occurrence of snow damages (Heikinheimo 1920 MTJ 3; Kangas 1956 S. Sähköl. Julk. 29; etc.), lightening as the cause of forest fires (Keränen 1929 AFF 34), and the damage caused by exceptionally cold winters (Linkola 1940 Luonn. Yst.) and dry summers (Erkamo 1958 Ann. Bot. Vanamo 30). Vaartaja (1949 Oikos) has studied with precise measurements the variation in temperature near the soil surface and its influence on seedlings.

The effect of climatic factors on the annual growth of trees has been under thorough investigation (Laitakari 1920 AFF 17; Mikola 1950 MTJ 38) where the temperature of the growing season has proved to be the most important factor. The temperature has likewise been shown to be in Finland a decisive factor in seed ripening (Kujala 1927 MTJ 12), as well as it determines the northern limit of different species (Keränen 1934 AFF 40).

The climatic factors naturally have been considered in numerous other investigations concerning the ecology of forest sites (*e.g.*, Cajander 1921 AFF 21; Sarvas 1952 MTJ 41; Sirén 1955 62).

The Biology of Trees and Stands

The study of the earlier history of Finland's forests has been connected to the plant paleontological research which has been working with the postglacial development of vegetation and has taken place mainly on the basis of pollen and other plant remains stored in peat deposits. These studies have been done partly in connection with the previously mentioned peat formation studies (Auer, Backman). The history of the tree species in different parts of our country has thus gained light over thousands of years (Hyyppä 1932 MTJ 18; Backman 1934 AFF 40; Lukkala 1934 AFF 40), and especially the arrival and advance of spruce in Finland has been an object of interest (Auer 1928 MTJ 13).

With the methods of plant paleontology the history of the northern timber

line has also been studied (Auer 1927 MTJ 12), and it has been observed that the timber line has retreated somewhat toward the south due to disadvantageous climatic development. At later times the lowering of the timber line has further taken place through human influence (Renvall 1919 AFF 11). The latest studies, on the other hand, seem to indicate that the timber line would be moving again toward the north due to the observed change toward warmer climate (Hustich 1948 Acta Bot. Fenn. 42 and 1958 Fennia 82; Mikola 1952 MTJ 40).

The latest history of Finland's forests is broadly discussed in Heikinheimo's (1915 AFF 4) extensive investigation which showed the essential influence of burn-over agriculture and forest fires, for example, on the tree species relations, which matter had already received attention during the last century. Later, the development of tree species relations has been examined, for instance, by E. Kalela (1952 MTJ 40) after the ending of burn-over practise in the light of some examples. Similarly, E. Kalela (1949 AFF 57) has dealt with natural development of the forests' composition in the light of the ecological characteristics of the species.

The silvicultural condition of the forests and the reasons leading to it have been considered both as an individual problem (e.g., Multamäki 1919 AFF 9) and in conjunction with investigations concerning the methods of silviculture, which will be discussed later. Of the development of the most recent decades as well as silvicultural condition a many-sided and detailed picture is given by the repeated national forest inventories (Heikinheimo 1924 MTJ 9; Y. Ilvessalo 1927 MTJ 11; 1942 MTJ 30, and 1957 MTJ 47).

The study of the biological properties of our main tree species was begun by A. G. Blomquist, »The Father of Finnish Silviculture», with monographs of pine and spruce (1881, 1883 SMYJ 3). Comprehensive monographic presentations have been published later by Kujala (1924 MTJ 7) on the black alder and by Huldén (1941 Acta Bot. Fenn. 28) on ash, and in addition there have appeared many smaller descriptions on the range of different species. Ollinmaa (1952 SF 77) has collected the information about the natural occurrence of several hardwood species in Finland and their success under cultivation, on the basis of which there can be drawn conclusions about the possibility of growing them as forest or park trees.

Flowering and seeding — the basic requirement for reproduction of forests — has long been under investigation. It was begun by Renvall (1912 AFF 1) with the study of the periodicity of seed years of pine at the northern timber line. The study was based on the investigation of the age class relations of forests, and by using the same method Lakari (1915 AFF 5) studied the cyclic variation of seed years in the pine forests of Lappland. The repetition of seed years and its causes in Southern Finland were discussed by L. Ilvessalo (1917 AFF 6) and Lakari (1921 MTJ 4). The continuous measurement of seed crops

in different kinds of stands has been made by the Forest Research Institute since its founding, and the results have been published by Heikinheimo (1932, 1937, and 1948 MTJ 17, 24, and 35).

In other studies the attempt has been to determine the causes affecting the quantity and quality of seed crops. Kujala (1927 MTJ 12) showed the decisive influence of the summer temperature on the ripening of pine and spruce seed, and still more recently Sarvas (1952 MTJ 40, 1955 MTJ 45) has followed the actual flowering itself and the effect of the conditions at the time of flowering on the seed crop. These investigations are complemented by studies on the germination of pollen (Saarnijoki 1941 MTJ 29) and its spread (Sarvas 1956 MTJ 46), which also have given necessary basic information for the practice of forest tree breeding. The influence of the site on the quality of seed has been studied by Lukkala (1936 MTJ 22).

The studies of cone and seed injuries and their role also belong to the research explaining the quantity and quality of seed crop. In Finland it has been observed that the insect and fungus damage has a very great influence on the seed crop of spruce (Kangas 1940 MTJ 29), whereas the significance in other tree species is smaller. In these investigations the relative importance and the biology of different insect species have been studied in particular (Kangas & Lovaszy 1940 S. Hyönt. Aikak. 6; Kangas & Leskinen 1943 S. Hyönt. Aikak. 9; Rummukainen 1954 MTJ 42; etc.). Also the role of the squirrel and the crossbill in causing the seed damage of spruce has been clarified through investigations (Juutinen 1953 MTJ 41).

After the seed has fallen to the ground the germination and development of the seedling depend upon many different factors. The germination and first development have been studied during recent years by Vaartaja (1954 AFF 62) and Lehto (1956 AFF 66), for instance, dealing particularly with the microclimatic and biological injuries which threaten the seedlings at that stage of development.

The significance of the substrate and the ground vegetation in the early development of seedlings has been studied by Hertz (Tertti) for both spruce (1932 MTJ 17) and pine (1934 MTJ 20). In these investigations humus has especially proved to be inferior germination substrate to mineral soils and *Hylocomium* moss the most serious competitor of spruce seedlings. The forest fire has been noticed to improve conditions for seedling development (Sarvas 1937 AFF 46; Lehto 1956 AFF 66), which in turn has given support for the use of controlled burning in silviculture. In the natural afforestation of rocky ground the ants appear to have a marked influence (Oinonen 1956 Acta Ent. Fenn. 12). Extensive investigations on the reproduction of pine in Northern Finland, taking into consideration all the phases of reproduction from seeding to the final establishment of seedling stand, were carried out by Aaltonen (1919 MTJ 1) and Lassila (1920 AFF 14). Sarvas (1947 MTJ 35) in turn has studied the different phases of the reproduction of birch in Southern Finland, observing the difficulties to be considerably greater than was generally assumed. Likewise, the vegetative reproduction of birch has been an object of investigation (Mikola 1942 AFF 50).

In comparison to the main tree species the reproduction of others has naturally been studied less. There should be mentioned, however, Hertz's (1925 AFF 29) investigation on the regeneration of basswood, and in many of the investigations on aspen and alder both sexual and vegetative reproduction have also been dealt with.

In the establishment and development of reproduction various types of injuries play a decisive role. The damages on pine seedling stands of dry heath lands became the object of attention already in the beginning of this century (T. G. Blomquist 1905 SMYJ 22; Elfving 1905 SMYJ 22), but more detailed investigations were carried out first by Kangas (1931 SF 17, 1938 S. Hyönt. Aikak. 4, 1940 AFF 49) who presented an overall synthesis of their causes, occurrence, and development and the entire process of damage (1937 MTJ 24).

With the research on the biology of tree seedlings there still belongs the accounts of the struggle of undergrown seedlings and their recovery after being released, which in turn form valuable bases for the methods of practical silviculture (E. Kalela 1934 MTJ 19; Sirén 1950 AFF 58; Vaartaja 1951 AFF 59).

The later development of stands and the biological properties of our tree species have received light from many mensurational investigations, the attempt in which has been to determine the growth and yield of stands composed of different tree species and which are discussed elsewhere (Nyyssönen 1959 AFF 70). In this way the entire natural development of pine stands, for instance, have been clarified in Southern Finland (Lönnroth 1925 AFF 30) and the development of stands of all the three main species in both Northern and Southern Finland (Y. Ilvessalo 1920 AFF 15, 1937 MTJ 24). Furthermore, the spruce thickets of Eastern Finland (Pöntynen 1929 AFF 35) and the spruce stands of *Hylocomium-Myrtillus* type in Northern Finland (Lakari 1920 MTJ 2; Sirén 1955 AFF 62), for instance, have been the objects of special investigations, as well as gray alder (Miettinen 1932 MTJ 18), black alder (Hildén 1929 AFF 34), and aspen (Tikka 1954 MTJ 44).

The growing space required by trees and natural thinning of stands have been studied by Aaltonen (1925 MTJ 9). The differences among tree species and their interrelations have been clarified especially by the studies on mixed stands, the most thorough of which have been done by Lappi-Seppälä (1930 MTJ 15) for mixed stands of pine and birch and by E. Kalela (1936 AFF 44) for stands of spruce and gray alder.

A noticeable part of the research on the ecology of stands has been directed

especially to the root systems of trees, to their structure, amount, and function. Aaltonen already gave special consideration in his afore-mentioned extensive investigations (1919 MTJ 1) to root competition as an ecological factor. Later he has dealt with the same question through additional experiments and studies (1920 AFF 14, 1923 AFF 25, 1942 AFF 50). Laitakari's thorough studies on the morphology of the roots of pine (1927 AFF 33) and birch (1934 AFF 41) have shown, for example, the dependence of the structure and extent of the root system on the site. The structure of root system from the standpoint of the tree's endurance against wind has also been given attention (Heikinheimo 1926 MTJ 12; Laitakari 1929 AFF 34).

Later E. Kalela (1949 AFF 57) in particular has carried out quantitative root studies on different sites determining, for instance, the depth distribution of roots and the difference among trees, as well as the changes in the density of roots throughout the growing season (1955 AFF 65). In addition, Kalela has discussed the root relations of pine in seed-tree stands (1954 AFF 61) and the relationship between the root systems of the seedlings and mother trees (1942 AFF 50), which questions are important from the standpoint of forest regeneration. Similarly, the effects of thinning and selective cutting on the root system have been defined (E. Kalela 1955 AFF 65), which gives basis for the judging of these cutting methods. The structure and amount of the roots as well as the changes during the growing season in pine stands on moors have correspondingly been studied by Heikurainen (1955 AFF 65) by giving special attention also to the effect of draining on the root systems. The influence of draining on the depth of roots had been considered even in earlier investigations on the effects of draining (Multamäki 1920 AFF 16; Kokkonen 1923 AFF 25).

The early development of the roots of spruce and adventitious roots have been discussed in special studies (Hertz 1935 AFF 41; Heikinheimo 1920 MTJ 2). The function of roots as water and nutrient absorbing organs is clarified by studies on the root grafts (Yli-Vakkuri 1953 AFF 60) as well as the experiments concerning the physiology of mycorrhizae (Mikola 1948 MTJ 36) and the significance of anaerobic conditions in the soil (Huikari 1954 MTJ 42). These investigations, however, have been only preliminary by nature; so the physiology of trees can be considered the branch of the foundations of silviculture for which our knowledge at present is most inadequate.

To the investigations of root systems there belong also the ones concerning the root rot fungus (*Fomes annosus*). This fungus has proved to be the worst enemy of spruce stands, whose common occurrence in different parts of the country has been apparent in many investigations (Heikinheimo 1920 MTJ 3; Tikka 1934 AFF 40, 1935 AFF 41); and likewise its occurrence, infection, and spread along the roots of spruce has been studied (Kangas 1952 MTJ 40).

The significance of heredity in silviculture has been mentioned even in arlier literature, and Cajander, for instance, emphasizes it in his large textbook on the foundations of silviculture (1916—1917). The prerequisite for pracical applications, however, is basic research on the taxonomy and genetics of the tree species, which in Finland is still young, and broad experimental work. Heikinheimo (1920 MTJ 2) wsa the first in Finland to study internal variation of tree species by picturing the forms of the most variable of our species, spruce. Some of the exceptional forms of spruce have offered possibilities for basic genetic studies (Saarnijoki 1954 MTJ 42). The most ex tensive genetic studies that have been carried out in Finland until now for forest trees have dealt with the lobed-leaf forms of deciduous trees and their inheritance (Saarnijoki 1946 MTJ 34, 1955 MTJ 44, 1956 MTJ 47).

The research on the taxonomy of Finnish birches (Kujala 1946 MTJ 34) has indicated that the common birch (*Betula verrucosa*) is a rather uniform species, whereas the white birch (*B. pubescens*) is more variable. In recent studies the biological and technical differences between these specie shas been seen to be considerably greater than was supposed earlier (Sarvas 1947 MTJ 35, etc.; Heiskanen 1957 MTJ 48). Special attention has been aimed at the technically valuable curly grained variety of common birch whose causes and heredity have been experimentally studied at the Forest Research Institute for decades. The experimental plantations have already yielded valuable information which can be applied in practice (Heikinheimo 1951 MTJ 39) and a comprehensive study on curly birch will be completed in the near future (Saarnijoki).

The occurrence of geographic races and the significance of the origin of seed in artificial regeneration has long been known. At first there were no precise results from experiments made in Finland, and A. Kalela's (1937 MTJ 26) synthetic review on this question was based primarily on foreign literature. Experiments on the geographic races of trees was begun at the Forest Research Institute in 1926 and valuable results from them have already been published (Heikinheimo 1949 MTJ 37). Likewise, the inheritance of the characteristic properties of moor pines has been studied by experimental plantations (Lukkala 1952 MTJ 40). The actual population-genetical research on Finnish tree species is still to be done.

The cross-breeding experiments of forest trees was started at the Forest Research Institute in the 1930's when they were connected principally with the research on curly birch and laciniated leaves, but in an early stage also larch. Attention was also given to the *Larix* hybrids occurring in nature (Saarnijoki 1942 MTJ 31).

The research aimed at practical tree breeding work became more extensive in 1947 when the Foundation for Forest Tree Breeding was set up and which established its breeding stations in connection with the Forest Research Insti-

tute. The work has dealt, for example, with the obtaining of basic materials for tree breeding work and vegetative propagation, but also the growing of hybrid aspen (*Populus tremula* × *P. tremuloides*) has been practiced, different kinds of cross-breeding experiments carried out, research and work methods developed, etc. The work, its methods and results, have been presented in several popular publications, but notable scientific papers have not yet been published during the still short lifetime of the Foundation. To the basic materials of the improvement work belongs also polyploidic aspen and birch individuals.

Experimentation with foreign tree species began in the 18th Century in Turku. Those trials of Kalm and Gadd have been lost, however. Instead, the Raivola larch stand established in 1738 has remained and has been an important object of investigation in determining the ecology and characteristics of Siberian larch (*Larix sibirica*) (L. Ilvessalo 1923 MTJ 5; Heikinheimo 1926 MTJ 12). Also Finland's second oldest larch stand (at Kitee), which had been established in the early 1840's and which consists of both European and Siberian larch, has been an object of research particularly in investigations concerning natural reproduction (Palosuo 1938 MTJ 27).

Experimental plantations of exotic trees were established on a larger scale at Evo Forestry College at the end of the 1800's. It has been possible to use their results in investigations which have primarily dealt with the growth and cultivation possibilities of larch in Finland (L. Ilvessalo 1913 AFF 2; Lappi-Seppälä 1927 MTJ 12, 1942 AFF 50).

The handbook of A. K. Cajander (Metsänhoidon perusteet II, 1917) contains practically all of the experience that had been gained in growing exotic trees in Finland until that time. At about the same time L. Ilvessalo (1920 AFF 17) dealt with the possibilities of cultivating exotics on the basis of both the experience gained in Finland and of foreign literature. The experimental cultivation of foreign species was begun on a considerable scale at estate Mustila (Elimäki in Southeastern Finland) in the beginning of the century. Of the results obtained in these experiments, A.F. Tigerstedt, the founder of the experiments, published a detailed report (1922 AFF 24). Since then the experiments have been further expanded and continued, and new valuable information gained, but only a few occasional studies have been published, for example, on lodgepole pine (C. G. Tigerstedt 1927 Forstl. Tidskr.; Miettinen 1952 MTJ 40). The experimental plantations now consist of 120 hectares. In Mustila, for instance, the following species have been tested on a large scale: *Pinus contorta latifolia, Pinus peuce, Larix gmelini japonica, Picea omorica,* and *Pseudotsuga taxifolia.*

The suitability of exotic species to Finnish conditions has also been under study in the Forest Research Institute since its founding. The experimental

plantations, whose total area now exceeds 300 hectares, are concentrated especially in the Experimental Forests of Solböle and Punkaharju, but there are also some in other experimental forests. Trials have been made on 110 species altogether of which 61 are conifers. There has recently appeared a detailed report (Heikinheimo 1956 MTJ 46) about these experiments and the results obtained, and valuable conclusions can be drawn even though the experience for many species is still relatively brief. As the plantations grow older, however, the experience continuously increases.

To the study of the ecology of tree species there belongs the research on natural enemies and their biology. During the last century and the beginning of this century there have been studies published in Finland of the injurions insects and fungi, of their biology and damage in forests. The large-scale study of insect pests, however, was not begun before Saalas' two volumes on the beetle fauna of spruce (1917, 1923 Ann. Acad. Sci. Fenn.). At about the same time he considered in separate studies the bark beetles (1919 AFF 10) and shoot beetles (*Blastophagus*) (1920 AFF 14) and beetles which live in the actual wood (1920 Tapio 13). Furthermore, he described the occurrence of mass injuries by the pine beauty moth (1929 Ann. Vanamo 8). Liro, on the other hand, collected in his textbook (Tuhosienet, 1924) the knowledge that existed at the time on the injurious fungi, their biology, occurrence, and damage in our country.

Since then there have been made many basic studies on the injurious forest insects, their occurrence and biology, which form foundation for the research on the prevention of injuries. Mostly it has been carried out in connection with above-mentioned studies of the injuries on the cones, seeds, and seedlings and with studies on forest protection which will be discussed later. It is not possible to review here all the basic research on forest entomology that has been carried out in Finland during the last decades. The most important work in this field has been done by Saalas and Kangas, and the investigations have been published mainly in Suomen Hyönteistiet. Aikakauskirja (Annales Entomologici Fennici). Kangas (1935 MTJ 22, etc.) has treated, for instance, the heretofore rather little-known causes of the stem spottedness of broadleaf trees and in connection to that presented many insect species new to science. On the Finnish forest entomological research is based for the greater part Saalas' large handbook, Suomen Metsähyönteiset, (Finland's Forest Insects) (1949) which, in addition, contains original research results. In recent years the number of research workers in forest entomology has grown noticeably, and there have appeared new basic accounts on the insects of our forests and on their ecological significance, such as spruce longicorns (Juutinen 1955 Acta Ent. Fenn. 11), on ants (Oinonen 1956 Acta Ent. Fenn. 12), and on the possibilities of biological control (Nuorteva 1956 Acta Ent. Fenn. 13). At the

present the biology of the pine weevil is under the joint study of the Scandinavian forest entomologists.

To this basic research on the ecology of forest insects there also belongs the study of quantitative variation or population dynamics (Kangas 1941 S. Hyönt. Aikak. 7). In these studies the attention is given to the enemies of the pests, on one hand (Nuorteva 1957 S. Hyönt. Aikak. 23, etc.), and to the nutrients and other factors affecting population dynamics, on the other (Kangas 1954 L. T., 1959 Sitz. ber. Soc. Sci. Fenn.). The orientation and the selection of objects of attack by the injurious insects have also been the object of research, when it has also been possible to determine the variations that occur in the selection of objects of obligate tree-inhabitants (Kangas 1950, 1952 S. Hyönt. Aikak. 16, 18, etc.). The experimental study of the physiological nature of orientation and the stimuli directing it (Kangas 1955 Verh. d. D. Gesell. f. ang. Ent.; Perttunen 1959—58 S. Hyönt. Aikak. 23, 24) is at the present under way.

Noticeably fewer studies have been done on the injurious fungi. The most notable work in this field is Kujala's (1950 MTJ 38) investigation of the microfungi occurring on our conifers. Of individual species of injurious fungi, pine blister rust (*Cronartium*) (Hertz 1930 MTJ 15) and pine needle rust (*Coleosporium*) (Pohjakallio & Vaartaja 1958 AFF 55) have been objects of investigations.

Methods of Silviculture

The thorough knowledge of the ecological properties of trees and sites forms the scientific basis for the development of silvicultural methods. For that reason silvicultural research in Finland has hitherto been concentrated primarily on the obtaining of this basic knowledge. As an important starting point in developing methods applicable in practice, there is also the study of the condition of forests and the development which has lead to it. Investigations in these fields, in connection with which there are often suggestions for silvicultural applications, have been discussed briefly in the foregoing.

The actual research on the methods of silviculture takes place primarily through extensive and long-term experiments or by collecting information through practical experience. As silviculture in Finlands is relatively young, the practical experience and results of the experiments have not been available for use until quite recently. The earlier investigations on the silvicultural methods dealt principally with those used abroad and their application in Finland, taking into account the properties of our trees and sites and other prevailing conditions. Thus, A. G. Blomquist (1881 and 1883 SMYJ 3) already considered broadly the regeneration methods of pine and spruce appropriate for different sites. On a similar basis Cajander (1910 Maahenki) presented regeneration cuttings suitable for Finnish conditions, and German cutting methods and the

possibilities for their use in Finland were examined, for example, by Aaltonen (1942 AFF 25) and L. Ilvessalo (1925 MA).

The oldest silvicultural regeneration cutting in Finland was seed-tree method, which could be studied and evaluated on the basis of practical results rather early (Enroth 1915 SMYJ Erik. tutk. 4). The most common method in practice, however, was for a long time selective cutting of saw-timber trees, and for that reason there was abundant research material available for extensive investigation (Sarvas 1944 MTJ 33), which definitely proved the disadvantages of the method in question. On the basis of that and also other investigations there was published in 1948 an official statement by six well-known foresters where selective cuttings were strongly condemned (MA). In later studies Sarvas (1946 MTJ 33 and 1950 MTJ 38) has further discussed the effects of selective cuttings of piled wood and the reproduction of selectively cut forests in Northern Finland.

The basis and qualifications for seed-tree cutting have been discussed in many of the afore-mentioned studies on the ecology and natural reproduction of pine and birch. Because the results in applying this cutting method in practice have often been unsatisfactory (Sarvas 1949 MTJ 37), successive cuttings, instead of one heavy seed-tree cutting, are being recommended more and more for the natural reproduction of pine stands.

The methods of natural reproduction have been under continuous experimentation in experimental forests of the Forest Research Institute during its entire forty years' history. The methods have been set forth in many articles and handbooks intended for practical use and in a form that they have developed as the result of research and experimental work (*e.g.*, Heikinheimo: Metsän luontainen uudistaminen [The Natural Reproduction of Forests] first edition 1931, third edition 1948; E. Kalela: Metsänhoidon taustaa ja tekniikkaa (The Background and Techniques of Silviculture] 1951; Sarvas: Metsäkäsikirja I [Forestry Handbook I] 1956; etc.). Particular emphasis has been given to the significance of site in selecting the methods of silviculture (*e.g.*, Laitakari: Metsänhoito eri metsätyypeillä [Silviculture on Different Forest Site Types], Maa ja Metsä 1930), but recently the geographical differences due to climatic and historical factors which have to be taken into account in silviculture have also been considered.

The investigations mentioned above have been dealing with the natural reproduction of forests on mineral soils. In the studies of natural reproduction on peatlands it has been noticed that the spruce and birch stands of both unditched and ditched swamps reproduce easily, more easily than on mineral soils as a rule, because the peat permanently contains more moisture, which is necessary for reproduction (Lukkala 1946 MTJ 34). Accordingly, in those cases even clear-cutting generally leads to natural regeneration. Likewise, natural reproduction on pine moors takes place easily by clear-cutting method because there is continuously sufficient seedling material present (Heikurainen 1953 AFF 61).

The common trend in Finnish silviculture was particularly in earlier times that forests would be regenerated naturally and then artificial reforestation would be limited only to exceptional cases. Therefore, the studies on natural reproduction, on its prerequisites and various phases, have been in the foreground in research work. In the second national forest inventory, 1936—38, it was estimated that only 6 per cent of the total productive forest land was in need of artificial regeneration (Y. Ilvessalo 1942 MTJ 30). This idea, however, has later been changed on the basis of both investigations and practical experience. Natural reproduction does not always succeed with such certainty and in the way supposed earlier, and on the other hand, much positive experience was gained from older forest cultivations. In the third national forest inventory the need for artificial regeneration was thus estimated to be even 16 per cent of the area of productive forest land and approximately one-half of the reproduction cuttings would be clear-cuttings (Y. Ilvessalo 1956 MTJ 47). Correspondingly, artificial regeneration, its basis and techniques have lately received increasing attention and research. This research work, which naturally has had its foundation in the forest-biological research explained above, has been aimed both at the obtaining of afforestation material (seed, seedlings and transplants) and to the different phases in actual field work.

Only a few studies have been published until now on the obtaining and handling of seed. In regard to seed extraction there should be mentioned Kangas' (1942 AFF 50) study on the effect of extraction temperature on the shedding and germination of seeds, and Yli-Vakkuri's (1959 AFF 68) study on the lowering of germination capacity due to removal of wings by machines.

The first forest nurseries in Finland were established patterned after foreign examples, and their developing as well as directions for nursery care (*e.g.*, Ahola: Taimitarha, sen valmistus, kunnossapito ja hoito [Forest Nursery, Its Preparation and Management), 1930, second edition 1946) have been based mainly on the practical experience. In the Forest Research Institute, however, rather extensive nursery experiments were conducted already in the 1930's which dealt with sowing, transplanting, and fertilization (Heikinheimo 1940 MTJ 29).

When the nursery studies were resumed after the war, an inventory-like account on the methods used in nurseries was first made (Mikola 1956 MTJ 48). The most detailed studies until now have been made on the properties and management of nursery soils (Mikola 1957 MTJ 49) and the packing and transport of seedlings (Yli-Vakkuri 1957 MTJ 49). Heikinheimo (1954 AFF 61) has examined the importance of the location of the nursery, especially from the standpoint of forest tree breeding. On nursery injuries and their prevention there has been published in addition to the notices in the afore-mentioned investigations only rather small studies on damage caused by moles (Kangas 1935 MA) and on winter diseases and needlecast fungi and their control (Jamalainen 1956 SF 88; Rummukainen 1956 MA). Experiments on the prevention of both diseases and weeds are under way, and especially the use of chemicals for the purpose is being tested.

The investigations and observations of the effects of burn-over agriculture and forest fires on the regeneration of forests led early to the use of controlled burning in soil preparation for regeneration. The greatest amount of experience from this practice can be found at Tuomarniemi Forestry School where it has been used continuously for almost fifty years since its initiation by Arvid Borg. Arvid Borg employed the practice of broadcast sowing on the snow after controlled burning. The results of these burnings and sowings and the experience gained from them over a period of eighteen years have been described by L. Borg (1936 SF 38) and from a later period by Blomgren (1952 MTJ 40) and Kolehmainen (1955 SF 85, 1957 SF 90). In the 1920's controlled burning was rather common particularly in State forests, but in the 1930's when the attempt of silviculture was to favor spruce in particular, the controlled burning was practised less. Due to the favorable experience of the earlier burnings at Tuomarniemi and elsewhere, also in Sweden, controlled burning became commonly used again at the end of the 1940's, even though the sowing on snow in connection with it has proved uncertain and has been replaced by other methods. Successful burnings have also been carried out on peatlands (Yli-Vakkuri 1958 AFF 67). The overall effects of controlled burning are still, however, for the most part unknown. At the present these questions are being investigated and for some parts results have been published, for example, on the effect of controlled burning on the mite population of the soil (Karppinen 1957 S. Hyönt. Aikak. 23).

The breaking of the soil surface has been used as a method of preparation of a regeneration area primarily for natural seeding. The question has been considered in many brief articles (MA, etc.), and in practice the attempt has been especially in the developing of appropriate tools, but no more extensive investigation on the results of the method has been made.

The sowing and planting methods have been under continuous experimentation at the Forest Research Institute and elsewhere, too. The drill sowing on cleared patches first suggested by the Latvian forester, Melders, (1929 Com. For. 3) has proved successful in experiments and has become commonly used. The sowing methods and the results obtained have been presented in many brief articles. Most recently, broadcast sowing from an airplane has been tested on the large-scale conditions of Lappland (Sirén 1957 MA). By the investigations into older and younger sown-plant stands, the results and causes of occasional failures of different methods have been determined (Kangas 1940 AFF 49; Sirén 1952 SF 78). The Forest Research Institute has carried on systema-

tical experiments on planting (Heikinheimo 1941 MTJ 29) which have concerned in addition to the different methods also the significance of planting season and shade trees, for example. These studies have been complemented by practical experience and numerous experiments. Additional studies are still needed, however. Lately the practical goal has been to develop especially the planting tools.

In connection with ditching and swamp research it has been attempted to find out methods of artificial afforestation appropriate for drained swamps, too (Lukkala 1934 Metsätietoa; Multamäki 1939 AFF 47), even though the chances for natural reproduction are generally good. In these studies the sensitivity of spruce seedlings to frost has been very apparent, for which reason the planting of spruce is not successful on open swamps.

Of the reports on the later development of planted stands there should be mentioned E. Kalela's (1933 MTJ 19) studies on spruce plantations which have made possible, for example, the comparison of natural and artificial regeneration on the yield basis (Vuokila 1956 MTJ 48). There is no corresponding work on the later development of pine stands but only exemplary samples (*e.g.*, Blomgren 1952 MTJ 40).

The care of young stands has received relatively little attention in investigations because they were earlier rather uncommon in our country. During the most recent years, however, many of the seedling stands have grown to thickets and new ones are constantly being formed as a result of active reforestation work. The best time and intensiveness in thinning young stands are questions for which research is expected to provide an answer. They have been dealt with in numerous brief articles and studies (*e.g.*, Sirén 1956 MA), but sufficiently long-term experiments are still lacking. The actual execution of the work and the tools used are also under investigation (Sirén 1958 SF 93). The significance of injuries and their consideration in tending young stands have been emphasized particularly by Kangas (1937 MTJ 24, etc.) The active fighting of injuries through chemicals has only undergone preliminary experiments.

The research on the actual improvement cuttings is still under way. Experimentation on different methods and graded of thinning has continued at the Forest Research Institute through 40 years. These experiments, which are related to the studies on the structure and yield of the stands, have been presented elsewhere (Nyyssönen 1959 AFF 70).

Pruning as a method of tending trees was first experimented with by A. G. Blomquist at Evo during the last century. Lakari (1920 MTJ 2) made a study of the trees pruned at that time, observing that spruce had commonly suffered rot damage as a result of pruning. In the 1930's birch and pine trees were pruned with the purpose of growing vaneer logs — even though on a relatively small scale —, pruning methods were developed, and some papers

were published of this work (Lappi-Seppälä 1934 AFF 40; Heikinheimo 1935 SMYV 5). Later, Heikinheimo (1953 MTJ 41) has studied the natural pruning of trees and artificial pruning in the light of later experiments (1953 MA).

Of the forests growing under special conditions, the protection forests near the northern timber line and their management were the first to receive attention. The report of the protection-forest committee based on considerable investigations was prepared already in 1910, and slightly later Renvall (1919 AFF 11) on the basis of his investigation outlined the management of the forests of the area, taking a stand for as careful a handling as possible.

When the Forest Research Institute was established, it, too, took at first the northern forests under special investigations. In this work both the actual timber-line forests and slightly more southerly spruce forests of Lappland and their management were considered (Heikinheimo 1921 MTJ 4, 1922 MTJ 5). After that the management of protection forests was dealt with rather little until quite recently when the areas in question came within the range of economic activities. The question of silvicultural methods suitable for the protection-forest areas has become urgent. The favorable development of climate during the last decades resulting in abundant natural reproduction in the protection-forest area has given possibilities for more active measures instead of the previous saving principle (Mikola 1952 MTJ 40).

The character and management of the protection forests on the seacoast and off-shore islands has been considered by L. Ilvessalo (1926 SF 2, 1926 MTJ 12) in his investigations.

As other special cases which required attention in silviculture and which also have been dealt with in investigations there should still be mentioned the forests either destroyed or in poor condition and their improvement, park forests and the care of landscape, the growing of valuable hardwoods, etc. Lately the question of the management of forests on drained swamps has especially appeared for which the methods based on experience obtained from uplands cannot be applied as such. The extensive inventory carried out in ditched areas has shown that a noticeable part of their forests are in unsatisfactory condition (Heikurainen 1959 AFF 69), and the finding of correct methods of tending and regeneration requires further experiments and research.

The question of the occurrence of different kinds of injuries and their control either by active or passive means is always connected to the methods of silviculture. The research on forest protection is therefore suitable to be discussed in connection with the methods of silviculture. Snow damage occurs chronically in Finland in the area north and northeast of Oulunjärvi lake, which can be outlined rather accurately and in which area the snow damage has to be taken into account as an essential factor in dealing with the forests (Heikinheimo 1920

MTJ 3). In the winter of 1947—48 there occurred a major snow damage in Central Finland and Northern Carelia giving reason for wide investigations in which not only the amount, extent, and type of damage have been determined, but also the rate of decay, ability for recovery, and secondary injuries. Results have been published regarding the recovery of pine (Juutinen 1953 MTJ 41) and on the secondary injuries (Kangas 1950 S. Hyönt. Aikak. 16). In these investigations the earlier picture has noticeably been suplemented in regard to the occurrence of snow injuries, snow-endurance of different trees, and their possible results and prevention, on which studies are now being made. The latest disaster has occurred in southernmost Finland in the winter of 1958—59, supplying material for additional studies.

A process of damage which is closely related to the fellings and oftentimes occurs as a result of them is the drying of standing trees. It has been an object of many special studies and, in addition, light has been given to the subject by much research on forest entomology. On the basis of the drying analyses made, it has been possible to distinguish different types of drying (Kangas 1934 MTJ 19, 1936 SMYV 6, 1942 S. Hyönt. Aikak. 8, 1946 AFF 52; Juutinen 1958 MTJ 50; Rummukainen 1954 MTJ 44), and the rate of drying and the role of different factors in the drying process of different trees have been determined, as well as the dependence of drying injuries on fellings and other measures. For the control of drying injuries Kangas (1946 AFF 52) has developed a special cutting method. The need for being alert in order to prevent insect pests will grow since repeated fellings create possibilities for the continuation of insect populations (Nuorteva 1956 AFF 65).

The destruction of pine seedling stands, which is caused by many factors acting simultaneously or successively, has proved to be a similar process of damage. The research on the subject has been considered earlier (Kangas 1937 MTJ 24, etc.).

The afore-mentioned root rot fungus as a cause of damage also requires essential consideration in the practice of silviculture. Its commonness and significance as well as that of other rot injuries have undergone inventory-like studies particularly in Northern Finland (Tikka 1934 AFF 40, 1935 AFF 41, 1938 AFF 46, 1947 AFF 55, 1949 AFF 57) and special attention has been given to them in investigations on the management of the northern forests (Heikinheimo 1922 MTJ 5; Tikka 1940 AFF 50). Controlled burning and change of tree species are considered the most suitable silvicultural methods of control against root rot (Kangas 1940 MA) even though sufficient experience on the results is still lacking.

The research on storm injuries and the possibilities for their prevention have also been considered previously. As far as forest fires are concerned, statistical studies have been made on the number of fires, on their causes, and damage caused by them (Saari 1923 AFF 26; E. Kalela 1937 AFF 37). The study on the

estimation of the danger of forest fires on the basis of climatic conditions (Fransila 1958 AFF 67) is significant from the standpoint of preventing forest fires.

Grazing and injuries caused thereby have been an object of interest primarily in Northern Finland where reindeer are kept. Renvall (1919 AFF 11) and many others considered the damage caused by reindeer very great in the most northerly pine seedling stands, but later the significance of the injuries has been estimated to be smaller especially on the main forest areas, even though detailed studies are lacking. In Southern Finland the effects of forest grazing and livestock injuries have been pointed out in many investigations on forest vegetation and regeneration, and these questions have even been considered as an individual topic (Lampimäki 1939 SF 50). The information about the present extent of grazing is included in the comprehensive study of grazing conditions in Finland (Jäntti 1945 AFF 53).

The forest injuries caused by elk and other game is closely connected to forest grazing. The damage caused by elk to pine seedling stands has been considered in studies both on silviculture and wildlife management in which the living habits of elk, character of injuries, prevention possibilities, and estimation of damage have been discussed (Kangas 1949 Suomen Riista; Sainio 1955 SF 88; Yli-Vakkuri 1955 SF 88). Of the other game, capercaillie, for instance, has been dealt with in studies.

An important sivicultural practice in Finland is the draining of swamps; the investigations on its basis and the results have been explained earlier. An idea of the extent of the work completed thus far is given in a historical review made by Tirkkonen (1952 SF 72). Also, many investigations have appeared on the field of ditching techniques itself, based on both practical experience and actual experiments. In regard to the planning of draining, there should be mentioned that at first a rather widely spaced system of deep ditches was used. Investigations have shown, however, that the main efficiency of draining depends on the rapid carrying away of surface water, and for that reason the change in recent times has been to a closer system of shallow ditches. As the ditching during the first decades was done entirely by hand, the norms for the shape of the ditch, its dimensions, and the wage setting for the work were developed mainly on the basis of practical experiments. However, precise work studies were also made (Lukkala 1939 MTJ 28) and thus it was possible to plan and set the wages for the ditching work in the whole country according to common and generally accepted norms (Lukkala & Tirkkonen 1939 Tapio). Lesser studies were published also on the removal of rocks in ditching (Metsänheimo 1934 AFF 40; Yli-Vakkuri 1954 SF 84).

In the last decades the change in forest ditching has been to the greatest extent to mechanical plowing, which has required broad experimentation and re-

search work. Until now there has appeared only one rather extensive publication about the work (Huikari 1958 MTJ 49), in which, for example, a review of the development is made, machine types are described, and the results of plowing experiments explained. In addition to plowing, ditches have also been made on a smaller scale by excavators and by explosives during recent decades.

The retaining of the condition of ditches has also been studied rather early. It was noticed that the ditches become considerably shallower and narrower with time due to the settling of the peat (Multamäki 1934 AFF 40). The same thing was observed later by Lukkala (1949 MTJ 37), when also the amount of sinking could be measured. In the most recent study on the question, Heikurainen (1957 AFF 65) has shown that the ditch's becoming shallow and the settling of the peat depend primarily on the depth of the ditches. Other factors affecting the condition of ditches, such as erosion and filling with vegetation, have been discussed by Kokkonen (1923 AFF 27), Saarinen (1935 MTJ 20) and Lukkala (1948 MTJ 36).

The foregoing review of the silvicultural research in Finland is not intended to be complete. The field of silviculture is too broad and indefinite by its boundaries for such an account. The survey, however, has perhaps expressed the main branches on which research work has been done during the fifty years of the Society of Forestry in Finland and the men who have done work in different fields of invetigation. It has also been attempted to list briefly the most important results in different fields, which in turn makes it possible to examine the future tasks of research. Much has been studied during the fifty years but many questions are still open.

The task of research is to serve practical silviculture. It must create scientific foundation for the practical operations, on one hand, and to answer the constantly arising questions in the practice of silviculture, on the other. The evaluation of the extent to which the science has been able to reach this goal does not belong to the authors of this article. The present condition of Finnish forests might give for its part an answer to the question.