Breeding of Broadleaves in a Nordic Perspective

JAN SVEJGAARD JENSEN
The Danish Forest and Landscape Research Institute, Horsholm Kongevej 11 DK-2970 Horsholm, Denmark.

Jensen J. S. 2000. Breeding of Broadleaves in a Nordic Perspective. *Baltic Forestry*, 6 (2): 67–77.

Breeding activities are briefly reviewed for broadleaved species with relevance to the Scandinavia, Finland and Baltic region. The far most intensive breeding efforts have been carried out on *Betula pendula* in Finland, and less intensive breeding programs have been running on *Betula spp.* and *Populus spp.* both in Sweden and Finland. Breeding on hardwood species have been discontinous, but within the recent years, new recurrent selection programs have been established for a number of species in Sweden, Denmark and Finland. These programs are often combined gene conservation and breeding program. Genetic properties are shortly reviewed for a number of common broadleaves and perspectives for breeding within the Nordic and Baltic region are discussed.

Key words: breeding, genetics, conservation, broadleaves, hardwoods

Introduction

Most of Scandinavia and Finland are located in the boreal vegetation zone, and the forest is dominated by coniferous species as pine and spruces. However, deciduous species are widely common in the boreal zone of Scandinavia as silver birch (*Betula pendula*), downy birch (*Betula pubescens*), aspen (*Populus tremulus*) and alder (*Alnus glutinosa, A. incana*). The southern limit of the boreal zone is situated at the rim of southern Norway and appears along the Dalelv river north of Uppsala in Sweden. Finland is all in the Boreal zone, but several species from the broadleaved zones exist in Finland.

The southern part of Scandinavia is located within the deciduous broadleaved zone. The major broadleaved species are beech (*Fagus silvatica*), oaks, (*Quercus robur, Q. petraea*), ash (*Fraxinus excelsior*), maples (*Acer plantanoides, A. pseudoplantanus*), lime (*Tilia cordata*), wild Cherry (*Prunus avium* and Elms (*Ulmus glabra, U. laevis*). This zone is having 4 distinct different seasons and influenced by a large number of species. The deciduous zone is mainly situated in Europe and North America while it is less extended in China, Korea and Japan.

Most of the originating broadleaved forest in Scandinavia and Baltic have been cut down and replaced mainly by coniferous. Only in Eastern Denmark and the very southern part of Sweden (Skåne) broadleaved species occupy more than 30% of the forest area today. In all countries broadleaved trees are slowly regaining the lost terrain. Some of the Scandinavian broadleaved trees are of significant economic importance as they cover waste areas. This is particularly true for *Betula pendula* and *B. pubescens* and in minor degree for aspen. The resources of birch wood in Sweden and Finland today are too low, so a great amount of birch wood is imported from the Baltic countries and Russia (Stener, pers. comm). The coverage of the broadleaved in Scandinavia, Finland and the Baltic countries is presented in Table 1.

Table 1. Distribution of broadleaved species in Scandinavia and the Baltic countries. Data is based in country reports for the Noble Hardwood network (Turok *et al.* 1996, Turok *et al.* 1998). Softwoods in this Table are birch, poplar and alder.

	Broadleaved total area share	Softwood area share	Hardwoods area share
Latvia	39,5%	35,0%	5,0%
Lithuania	38,4%	33,7%	4,7%
Estonia	38,0%	34,0%	4,0%
Denmark	34,0%	4,0%	30%
Norway	20,0%	16,0%	4,0%
Sweden	15,6%	11,8%	3,8%
Finland	8,3%	8,2%	0,1%

The broadleaved species can be divided into softwoods and hardwoods, and a specific group within hardwoods are referred to as noble hardwoods. These definitions are varying depending on different criterias in different countries (Turok et al., 1996).

The utilization of broadleaved trees in house construction and ship building requires good size and quality of timber. Heredity of specific properties of trees have been realized and utilized for centuries e.g. in nurseries who practiced strong selection for avenue trees.

In France, Duhamel de Monceau established provenance testing of pine back in 1745-55 (Morgenstern 1996). Research and small breeding experiments on broadleaved trees was initiated in the Nordic countries at the beginning of the last century, and organized breeding on a larger scale was firstly inititated in Sweden and Finland. The first programs included Norway spruce, Scotch Pine and Birch. Breeding of birch has been included in the traditional breeding programs, and has more or less continuously been part of these programs. For all other broadleaved species, early breeding initiatives have been scarce and stocastic.

Most breeding programs in the Nordic countries have been directed towards coniferous species, however, in recent years there have been increasing interest for the improvement of broadleaved species. Several reasons can be given for this development: there has been an increased interest for national tree species; there has been a decreased price of traditional wood and pulp product, whereas the price has increased for wood for floor and furniture; the forest policies in most countries have included the development of multipurpose forestry, and there have been a public awareness and of demand for many species of less economic value.

Practical gene conservation of forest trees has been implemented recently in many European countries (Turok et al., 1996). The extended use of exotic plant material in e.g. Sweden and Denmark have failed in several situations, and this has lead to an increased interest of native broadleaved species in this region.

There have been many recent activities on broadleaved species within the area around the Baltic sea, and the aim of this paper is shortly i: To review the breeding potential of broadleaves grown in the Baltic sea region. ii: To review breeding programs on broadleaved species climatically related to the Baltic sea region. iii: To discuss the choice of breeding strategy for broadleaved species in the Nordic and Baltic countries.

Genetic properties of broadleaves

By nature, broadleaved species are characterized by lack of uniformity in form and habitus. This is especially characterized by Noble hardwoods, which mainly are used for more valuable floor and furniture products. Furnitures and floors are high value products, and this multiplies the value of Noble Hardwoods much more than e.g. the mass producing species.

The highly estimated wood properties also leads to an altered priority between the breeding targets in comparison to the mass producing species.

The degree of wood utilization is decisive, and the utilization can often be improved by using trees with straight stems and low taper. Strength properties of broadleaved wood are often less important than for coniferous species, as broadleaves are less used for construction purposes, and secondly because hardwoods often are characterized by strong wood properties. On the contrary, the aesthetic appearance caused by wood structure and color can be very important. Growth rings and cell structure basically constitutes the wood structure. Wood structure is mainly dependent on uniformity of the growth and stem form, and as such affected by many environmental factors i.e. thinning.

The recent years have added substantial new results within broadleaves genetics, but still a lot of knowledge is missing. A specific problem relates to the long rotation age and age related damage e.g. moon rings on oak and black core in ash.

Betula pendula and *B. pubescens* are by for the most studied species and a Finnish review of genetic properties of these species have been presented by Hagquist and Hahl (1998).

Climatic adaptation

Flushing and budset properties are mainly used to demonstrate genetic variation and for delineation of breeding zones (Lagerström and Eriksson 1996). Frost- and drought tolerance test have been used for delineation as well, but may also be direct targets for breeding. The European broadleaved species shows wide different behaviour in adaptive properties. In forest practice *Fagus sylvatica* is quite flexible and reproductive material can be moved over large distances in Europe without large problems of climatic adaptation. On the contrary, *Quercus robur* has shown clear limitations for moving reproductive material. *Quercus* shows adaptive variation within regions and clines do exist for important properties as flushing, budset and frost resistance (Kleinschmit 1993, for review). Clinal variation has also been demonstrated on *Fraxinus* species in North America, indicating that this taxus posses limitations for seed transfer as well (Clausen and Guries, 1983). In Scandinavia, studies on adaptive/phenological variation on broadleaved species are nummerous and have e.g. been carried out on *Betula spp*, *Alnus spp*, *Populus tremula* (Linkosalo, 1999, Luomajoki, 1999), *Acer platanoides* (Myking and Kierulf 2000, Westergaard, 1998), *Quercus robur* (Jensen, 2000), *Fagus silvatica* (Jørgensen and Nielsen, not published, Paludan-Müller, 1998).

Growth properties

Genetic variation and breeding potential have been demonstrated by several authors on most taxus e.g. *Betula pendula* (Nepveu and Velling, 1993), *Alnus rubra* (Hook et al., 1990), *Acer rubrum* (Townsend, 1974), *Fagus silvatica* (Cervenka and Paule, 1979) and *Quercus ssp.* (Jensen et al., 1997, Rink and Coggeshall, 1995).

Most of the described inheritance for growth is low or moderate on broadleaves, compared to quality parameters. However, large plus tree gains have been demonstrated for *Fraxinus (F. pennsylvanica)* in North America (Cunningham and Polk, 1974, Byram et al., 1998)

Stem quality

For most species, this economical important property related to apical dominance is under strong genetic control. This has been demonstrated for *Quercus robur* by (Jensen et al., 1997). Large improvement in *Fraxinus pennsylvanica* have been indicated by Cunningham and Polk (1974). Genetic variation on birch stem form (and growth) has been demonstrated by Viherä and Velling (1999).

However, not all Nordic broadleave taxus are having high inheritance for stem form. Stem straightness on beech has been found to be under moderate genetic control (Cervenko and Paule 1979).

Wood quality

Normally wood quality for hardwoods can be divided into properties for non-structure products and properties which have importance for strenght and mainly aestetic properties.

In Scandinavia nummerous wood characteriscs have been described for *Betula pendula* by Nepveu and Velling (1983). The characteristics like wood density and shrinkage were reported fairly strong. Kanowski et al., (1990) reported high heritabilities for early wood, basic density and wood shrinkage on oaks. These authors also report relations between wood properties and frost cracks on oaks. Large genetic variation on fiber and gravity properties have been demonstrated on *Fraxinus spp.* by Lowe and Grene (1990) and Armstrong and Funk (1980). Aestaetic properties as colour and structure shows high variability and as a consequence large variability in prices of the final product. This has been stated for *Juglans nigra* L (Rink and Phelps 1987) and for oak color is rather reflecting soil properties than genetic control (Janin *et al.*, 1990).

Some attention has been directed to the quality of beech wood, especially concerning the false colour phenonomen, however no linkage to genetic properties have been demonstrated so far. Other wood characteristics on beech like branching and forking demonstrated significant family heritabilities (Paule et al., 1984). Spiral grain on beech have been found to be under high genetic control by Cros et al., 1980.

Epicormics is a specific problem for wood quality of several species, especially on oaks. This property is under major environmental influence, but there are large individual differences and this character is also under genetic control (Jensen et al., 1997).

Pulp- and paper quality:

A few studies of genetic parameters for pulp and paper are available (Tammisola *et al.*, 1995). Among these Nepveu and Velling (1993) who demonstrated low heritability for pulp yield on *Betula pendula.* In North America, fiber quality was studied on *Alnus* (Robison and Maze, 1987) and high genetic variation have been shown on *Fraxinus pennsylvanica* (Lowe and Greene, 1990).

Biotechnology/Propagation techniques

Modern propagation techniques have been implemented for many broadleaved species in the northern hemisphere. In Scandinavia tissue cultures were carried out on *Betula pendula* as early as 1974 (Huhtinen and Yahyaoglu, 1974), and research in this field have been conducted on *Betula* since (Viherä and Velling, 2000). Birch plants grown by tissue cultures was comercially available in 1989 (Viherä-Aarnio, 1991). Tissue techniques have been demonstrated on all broadleave genus. In Europe, the methods have been tested *on Quercus rubra, Tilia cordata, Sorbus aucuparia, Robinia pseudoacacia, Salix alba* and *Populus tremula* (Chalupa, 1990). Somatic embryogenesis has been carried on *Quercus* (Toribio et al., 1998).

However many hardwoods are recalcitrant and it is difficult and costly to propagate them whatever method is used. The oak species have been subject to major investments in propagation techniques for commercial breeding especially for cuttings. This project did suffer a major set back as due to severe problems on root quality. Clonal forestry seems less popular for hardwoods grown in natural and semi-natural conditions.

Clonal propagation is practically applied in mass propagation of softwoods for fiber farming. The methods have been practically implemented for aspen, a species with large capacity to reproduce through cuttings and tissue techniques (Beuker, 2000).

Growth properties

Genetic variation and breeding potential have been demonstrated by several authors on most taxus e.g. *Betula pendula* (Nepveu and Velling, 1993), *Alnus rubra* (Hook et al., 1990), *Acer rubrum* (Townsend, 1974), *Fagus silvatica* (Cervenka and Paule, 1979) and *Quercus ssp.* (Jensen et al., 1997, Rink and Coggeshall, 1995).

Most of the described inheritance for growth is low or moderate on broadleaves, compared to quality parameters. However, large plus tree gains have been demonstrated for *Fraxinus (F. pennsylvanica)* in North America (Cunningham and Polk, 1974, Byram et al., 1998)

Stem quality

For most species, this economical important property related to apical dominance is under strong genetic control. This has been demonstrated for *Quercus robur* by (Jensen et al., 1997). Large improvement in *Fraxinus pennsylvanica* have been indicated by Cunningham and Polk (1974). Genetic variation on birch stem form (and growth) has been demonstrated by Viherä and Velling (1999).

However, not all Nordic broadleave taxus are having high inheritance for stem form. Stem straightness on beech has been found to be under moderate genetic control (Cervenko and Paule 1979).

Wood quality

Normally wood quality for hardwoods can be divided into properties for non-structure products and properties which have importance for strenght and mainly aestetic properties.

In Scandinavia nummerous wood characteriscs have been described for *Betula pendula* by Nepveu and Velling (1983). The characteristics like wood density and shrinkage were reported fairly strong. Kanowski et al., (1990) reported high heritabilities for early wood, basic density and wood shrinkage on oaks. These authors also report relations between wood properties and frost cracks on oaks. Large genetic variation on fiber and gravity properties have been demonstrated on *Fraxinus spp.* by Lowe and Grene (1990) and Armstrong and Funk (1980). Aestaetic properties as colour and structure shows high variability and as a consequence large variability in prices of the final product. This has been stated for *Juglans nigra* L (Rink and Phelps 1987) and for oak color is rather reflecting soil properties than genetic control (Janin *et al.*, 1990).

Some attention has been directed to the quality of beech wood, especially concerning the false colour phenonomen, however no linkage to genetic properties have been demonstrated so far. Other wood characteristics on beech like branching and forking demonstrated significant family heritabilities (Paule et al., 1984). Spiral grain on beech have been found to be under high genetic control by Cros et al., 1980.

Epicormics is a specific problem for wood quality of several species, especially on oaks. This property is under major environmental influence, but there are large individual differences and this character is also under genetic control (Jensen et al., 1997).

Pulp- and paper quality:

A few studies of genetic parameters for pulp and paper are available (Tammisola *et al.*, 1995). Among these Nepveu and Velling (1993) who demonstrated low heritability for pulp yield on *Betula pendula.* In North America, fiber quality was studied on *Alnus* (Robison and Maze, 1987) and high genetic variation have been shown on *Fraxinus pennsylvanica* (Lowe and Greene, 1990).

Biotechnology/Propagation techniques

Modern propagation techniques have been implemented for many broadleaved species in the northern hemisphere. In Scandinavia tissue cultures were carried out on *Betula pendula* as early as 1974 (Huhtinen and Yahyaoglu, 1974), and research in this field have been conducted on *Betula* since (Viherä and Velling, 2000). Birch plants grown by tissue cultures was comercially available in 1989 (Viherä-Aarnio, 1991). Tissue techniques have been demonstrated on all broadleave genus. In Europe, the methods have been tested *on Quercus rubra, Tilia cordata, Sorbus aucuparia, Robinia pseudoacacia, Salix alba* and *Populus tremula* (Chalupa, 1990). Somatic embryogenesis has been carried on *Quercus* (Toribio et al., 1998).

However many hardwoods are recalcitrant and it is difficult and costly to propagate them whatever method is used. The oak species have been subject to major investments in propagation techniques for commercial breeding especially for cuttings. This project did suffer a major set back as due to severe problems on root quality. Clonal forestry seems less popular for hardwoods grown in natural and semi-natural conditions.

Clonal propagation is practically applied in mass propagation of softwoods for fiber farming. The methods have been practically implemented for aspen, a species with large capacity to reproduce through cuttings and tissue techniques (Beuker, 2000).

The expensive methods may be utilized for multiplication purpose within the breeding program. Tissue culture techniques and cuttings are both applied in the Swedish breeding program for birch (clonal testing).

They may also be very useful for cloning of specific individuals (niche breeding) with special properties as in the Finnish breeding program on curly birch (Metla 2000). Research on microprogation of curly birch is ongoing in Norway as well (Tore Skrøppa, pers. comm.).

The use of markers (QTL-quantitaitve trait loci) have not been implented in Nordic tree breeding research programs for braoadleaves. Some of the most advanced programs have been developed on poplar at Washington State University (Frewen et al., 2000).

Gene transformation of broadleaves

Gene transformation has been carried out on a number of forest species. Agrobacterium tranformation has been carried out on *Quercus* (Roest et al., 1992) and in Scandinavia markers have been inserted in *Betula pendula* (Aronen et al., 1997). The most advanced research on species relevant to the northern hemisphere have been carried out on poplars (Mullin and Bertrand, 1988). Genetically modified trees have not been released in commercial plantings so far. The potential use of genetically modified trees in Nordic countries have e.g. been discussed e.g. by (Tømmerås et al., 1996). At this moment there are no actual plans to incorporate genetically modified trees in the existing breeding programs.

Breeding programs on broad-leaved species in the northern hemisphere

Various types of breeding programs have been planned or implemented for broadleaves in the northern hemisphere. The intensity of the program is related to the expected output of the programs, and the available funding. Intensive breeding is carried out on a few species in the Nordic countries as well as low input breeding for a number of species.

Breeding programs for broadleaves have been running in both North America and Europe. Many programs have been initiated just to be temporarily or finally abandoned. It is only the large birch breeding programs in Sweden and Finland which have demonstrated continuity from 1950 till today. Many programs on broadleaves were initiated in North America in the sixties (Wright, 1976), but almost no activities was reported in Europe between 1955 and 1985. Tree breeding activities are vaguely documented in Scientific journals, especially in Europe. Tree breeding is mostly documented in internal reports and rarely in scientific papers. Therefore, it is easy to overlook the existing breeding initiatives. Different types of breeding programs exist in the eastern European countries, but the data on these are difficult to achieve.

Breeding of soft broadleaves

The first breeding programs were probably carried out on poplars. Poplar breeding has been done for more than 100 years, and almost all European countries participated with their own poplar breeding initiatives (Morgenstern 1996).

The most comprehensive breeding programs for broadleaves in the northern hemisphere are probably the Finnish and Swedish breeding programs for *Betula pendula*. These programs reach back to the 1940's at the time when tree breeding was extending into large scale programs in Sweden and Finland (Viharä-Arnio, 1991). Birch breeding is also done on a smaller scale in North America and in Russia.

Breeding programs on aspen (*Populus tremula*) have been established e.g. in Canada (Li and Li-Bailan, 1995), Russia (Tsarev, 1988) and Lithuania (Pliura, 1989). There was a breeding program in Sweden on hybrid aspen in 1940-1960, as aspen was used for matches. A clonal selection and testing program was initiated in 1985 by selecting 300 plus-trees from the trials and stands from the 1940-1960 period (Stener, 2000).

In general these programs are often done on a large scale. These species are grown in short rotation and are used for pulp production and construction wood. They are easily propagated – either vegetatively or through massive production of seeds and plants. A large growth potential exists within breeding of hybrids (aspen, poplar and alder) (Werner, 1993).

The birch breeding programs

Birch can be used for high quality furniture, and it is used for the production of high quality paper. Both *B. pendula* and *B. pubescens* are important as they cover vast areas. However *Betula pendula* is most interesting for breeding, as the growth rate is 30% more than that of *B. pubescens*. Breeding of *Betula pendula* is carried out more or less in the same way as *Picea abies* and *Pinus silvestris* both in Finland and Sweden, however with less intensity.

A total of 15-17 mill. seedlings of *Betula pendula* are used in Finland per year, covering 10-15% of all plant production. The Finnish breeding program for birch is among the largest and most comprehensive for broadleaved species in the world.

Several characteristics are subject to breeding. These include growth rate, stem straightness, less forking, branching habit, health (adaptedness to climate) and mammal and insect resistance (Risto Haggquist, pers. comm., 2000). Three breeding zones are practically applied in Finland for *Betula pendula*, but only the central and southern zone are practically applied.

The current Finnish strategy of silver birch breeding is described by Happanen and Mikola (1998) and Mikola (1998). As all breeding programs the birch breeding program has been subject to many major and small refinements and change of strategies. It began as a simple recurrent selection program based on large plus tree selections and a high selection intensity. The breeding programs became more complex and maintaining of genetic variation became part of the breeding programs as long term programs in 1989. In one short period, a sublining strategy was suggested. The current strategy is based on nucleus breeding. It holds a large breeding population and a specified number of nucleus.

Within the first generation of the breeding program, 250-300 unrelated full-sib families will be produced. At the age of 15-20 years two individuals from each family are selected to form the second generation breeding population of 500-600 trees per zone (Happanen and Mikola, 1998). Controlled crosses will be repeated in each generation, and the large size of the breeding population will be maintained from generation to generation. The selected parents from progeny testing creates seed orchards. The Finnish indoor seed orchards for birch are well known, and known for a remarkably high production of seeds (Hagquist et al., 1991). The orchards are almost able to cover the total Finnish demand for seed (Viherä-Aarnio, pers. comment, 2000). Realized breeding gains in the Finnish program have been reported by Hagquist and Hahl (1998) e.g. 29% increase in volume production for seed orchard material from southern Finland.

The demand for birch plants in Sweden is only 15-20% of the demand in Finland. In 1999 1.8 million broadleaved trees were planted (mainly birch) (Stener pers. comm.)

The Swedish program for birch was initiated in the forties, but almost nothing took place between 1960 and 1985. A large program was initiated in 1988 (Danell and Werner, 1991). This is the only "long term" breeding program for broadleaved species in Sweden, and the breeding targets are adaptiveness, production and quality. Sweden has been divided into 20 breeding zones defined by latitude and longitude (Danell, 1993). The birch breeding program is restricted to 7 breeding populations. A total of 1300 *Betula pendula* and 200 *Betula pubescens* plus trees have been selected in Sweden, but also complemented with trees from Finland, the Baltic countries, Germany and Poland as, following the Multiple Breeding Population System (Namkoong et al., 1988).

Within each population 50 individuals are chosen as plus trees, and each individual is crossed twice. The seed material from breeding and improvement is recommended for four large zones in Sweden. Progeny test makes the basis for selection of proper parents for the seed orchards. Indoor seed orchards are established in Ekebo Sweden (Stener, 2000).

Breeding of hardwoods

The rotation period of hardwood species is normally longer than for softwoods, they are hard to propagate and their seed production is moderate. Typically these species was among the first subject to genetic studies and breeding in Sweden and Denmark. Plus trees were selected, and in Sweden, this lead to establiment of 2 clonal seed orchards for both species (Ljunger 1955, Johnson, 1952). Seed orchards of beech and oak were established in Germany as well in the same period (Krahl-Urban, 1972, Kleinschmit et al., 1975).

This first "wave" of breeding in Europe was quickly abandoned, and for 30 years almost no breeding took place on hardwoods in Western Europe. Actually the first breeding activities on hardwoods took place in the USA. Breeding programs on various hardwoods were initiated in the Central States, South East states (North Carolina) and Texas. Among these species were *Liquidambar spp, Liriodendron spp, Fraxinus pennsylvanica, Q. rubra, Quercus spp, Populus tremula, Juglans nigra, Betula papyrifera* (Stine et al., 1995, Byram et al., 1997, Purnell and Kellison, 1987, Carter et al., 1988).

Some European broadleaved species were subject to breeding quite early in the USA (*Acer pseudoplantanus*, Tex. For. Ser. 1974) and *Quercus robur* (Steiner, 1993). Breeding has been carried on European black alder (*Alnus glutinosa*) on more occasions. The black alder is used for biomass production. It is grown for its nitrogen-fixation properties, and is easy to handle in breeding programs because it is readily propagated, and controlled crosses are easy to make (Prat, 1988, Robison et al., 1979, 1983). A review of genetics of *Alnus glutinosa* is produced by Krstinic (1994).

Breeding of broadleaved hardwoods is carried out in Canada as well (*Fraxinus spp, Acer rubrum, Juglans nigra* at Petawawa For. exp. Station, (Calvert, 1977). Some of the oldest hardwood breeding programs in North America have recently been extended into their second generation (Byram et al., 1999).

The most intensive oak breeding programs, known to the author, was constructed for *Quercus rubra* in the USA and Canada. The programs include several populations in a sublining breeding system (Mckeand and Beinike, 1980, Coggeshall and Beinike, 1986, MacKay, 1993). Oak improvement in the USA is reviewed by Steiner (1993).

At least a small number of broadleaved species (*Quercus* and *Fraxinus*) have been subject to improvement in the southern part of eastern Europe (Enescu, 1975). Breeding of *Juglans nigra* is reported from the Ukraine (Mayatski, 1977). Breeding programmes of *Quercus robur* and *Q. petraea* in the Ukraine is reported by Belorus (1982). Breeding of broadleaves was part of the genetics programs in Russia (Prokazin et al., 1998). Research on hybrids was carried out in the seventies on maple, elm and ash (Kalinina et al., 1978). Besides the breeding projects in Scandinavia only a few other early Western European projects have been reported in the literature, i.e. the *Alnus* programm in Germany (Schlenker, 1976).

At the moment, breeding of broadleaves takes place in most European countries. Especially for hardwoods, these breeding programs are combined with gene conservation (e.g. Rotach, 1999). Many of these activities have been reported in the EUFORGEN country reports for Noble Hardwood (Turok et al., 1997, 1998).

Prunus avium was one of the first northern European hardwoods to be subject for breeding. The species has been bred in many West European countries (Germany: Schlenker 1976, Italy: Ducci et al., 1988, England: Nicholl, 1993, France: Cros et al., 1989) and especially in southern Europe similar species like Chestnut and Walnut have been subjects to breeding (Ducci et al., 1990). The timber of these species has become extremely valuable, and efforts to establish breeding and seed orchards are justified alone by economic reasons. The different white oak species in Europe have also been subject to improvement in several countries, e.g in Croatia (Raus et al., 1996).

Most of the new breeding programs on hardwoods are low intensity breeding programs. The Swedish and Danish breeding programs are constructed as 1-2 generation programs with simple recurrent selection without controlled crosses or other expensive methods (Werner, 1993). The Swedish forest breeding program include 9 broadleaved species (*Quercus robur, Quercus petraea, Fraxinus excelsior, Acer pseudoplatanus, Alnus glutinosa, Prunus avium, Tilia cordata, B. pubescens* and *Sorbus aucuparia*) (Stener and Werner, 1997). Seed orchards (20-60 grafts per clone) were established in 1992-1994, based on 100 plus-trees per species. Progeny testing is suggested, but yet not established. The alder program includes two seed-orchards with untested plus-trees. These trees are now being tested together with 120 new plus-trees from Sweden and Lithuania. The best will be selected to a new seed orchard (Stener, 2000).

Four hardwood species have been included in the Danish program (*Quercus robur, Q. petraea, Fraxinus excelsior* and *Prunus avium*). The oak breeding program was initiated in 1993. The breeding potential of *Quercus robur* and *Q. petraea* has been discussed by Kleinschmit (1993) and Savill and Kanowski (1993).

The program is based on simple recurrent selection. Tree different groups were identified, one of *Quercus petraea* for western Denmark and two groups of *Quercus robur* for eastern Denmark (Dutch and Danish origin). The breeding targets are different in the 3 groups depending on the purpose. Danish oak exhibits a rather crooked stem form, and therefore Dutch oak is mostly preferred instead of Danish oak. On the other side, Dutch oak is expected to possess health problems because it originates from a milder climate.

In all tree programs a total of 100-200 plus trees have been selected in 10-20 populations. The selection intensity varies between 0.5 and 1%.The plus trees are vegetatively propagated for clonal seed orchards to improve fast seed production. Four seedling orchards have been established as combined seed orchards and breeding populations for the next generation.

Oaks of special origins (Spessart and Norwegian oak) are considered important for breeding as well. Less intensive methods as phenotypic forward selection at the nursery stages are suggested as being most cost-efficient breeding program.

The British oak breeding program is constructed as a breeding seedling orchard (BSO) system and includes plus trees selected in populations in England, Irland, Frankrig and Holland (Hubert and Savill, 1999). Oak breeding in the Netherlands was described by De Vries and Van Dam (1998). The core of the Dutch oak breeding program constitutes plus trees of roadside trees.

The hardwood breeding in Finland serves basically for the conservation purposes. Seed orchards will be established for 4 different species (*Tilia cordata*, *Ulmus laevis*, *Quercus robur*, *Acer spp.*) (Yrjana and Rusanen; 2000). Beech is a species, which has almost never been subject to breeding in Europe. A proposed breeding strategy for beech has been presented by Cros (1981).

There are no significant breeding activities for hardwoods in Norway and Estonia (Skrøppa pers. comm., Tamm 1996). Breeding activities of hardwoods in other Baltic countries are few, but several activities related to combined conservation and breeding has just recently been initiated. Trials and orchards of oak and ash are under establisment in Latvia (Baumanis, 1998). A breeding program on alder (*Alnus glutinosa*) is under establishment in Lithuania (Pliūra, 1998). A few plus tree selections have been carried out on oak and ash in Lithuania and clonal archives are planned (Baliuckas et al., 1998).

Low input breeding of broadleaved species

Most breeding programs for broadleaved species are characterized by low intensity input. The economic outcome from most broadleaved species are expected to be insignificant, and there will be critical economical constraints for breeding, especially as number of species will increase. In many countries, gene conservation programs will include all major native species (Turok et al., 1996). Lagerström and Eriksson (1996) proposed a strategy for more than 50 woody species in Sweden.

High intensity breeding programs for specific valuable species normally includes several collections of genetic resources, each serving a restricted objective: "in situ" conservation, seed production, progeny trials, clone banks etc. Such programs will only be relevant for a species like *Betula pendula* in the Baltic sea region,

In several recent breeding programs, these objectives have been combined in order to optimize the restricted sources of money. In its most comprehensive constitution, the breedling seedling orchard (BSO) combines gene conservation and breeding. This implies many compromises discussed by Barnes (1995). BSO's have been implemented for ash and oaks in England (Savill, 1993), and is also applied as a model for integrated conservation and application of Noble hardwoods and shrubs in Denmark, Sweden and Finland.

Traditionally breeding goals have been quantitative traits of direct economic importance, however, breeding could include targets as "genetic diversity", adaptability and breaking of possible inbreeding as basis for future adaptation and evolution (Eriksson et al., 1993), e.g. breeding for fertility (Lindgren, 2000).

Several species have scattered distribution of natural populations and are exposed to fragmentation and possible inbreeding. For most species, there is a lack of available information about the genetic characteristics. Therefore combined conservation and breeding programs will also serve as an object for future research.

An even less intensive system was suggested by Lagerstrom and Eriksson (1996) for hardwood species in Sweden. This program included 5 different intensity levels of breeding. The most intensive level implies breeding and recurrent selection and the least intensive methods involve studies of phenological properties in nurseries in order to describe and define seed zones. The task of the breeding program includes handling of a large number of species and puts restrictions on the effort of the species itself. Selection for urban and landscape properties have been carried out in Denmark at various intensity since 1975. Probably this kind of horticultural breeding has been carried out in many places for some time, but only recently subject to specific breeding programs (Byram and Lowe, 1996).

The theory and basic idea of low intensity breeding programs is discussed e.g. by Barnes (1995) and Lindgren (2000). The less intensive breeding brings larger theoretical challenges to design and breeding layouts than to practical breeding efforts. The breeding programs should include methods, which do not depend on stable funding, technical expertise and technical equipment. As conservation of genetic variability is a target of breeding, there will often be constraints to effective population size. This would favour low intensity breeding in some situations. One example is phenotypic selection, which often appears to be more efficient than genotypic selection, especially in the long term breeding programs (Anderson et al., 2000, Kingswell and Davey, 1998). A Danish experiment on oak has demonstrated, that under restrictions of clonal numbers (10-20), breeding for height or stem form in seedling seed orchards would be more effective than in clonal seed orchards (Kjær and Jensen, unpublished)

Phenotypic forward selection would be expected to be quite effective for properties of high heritability. This should be most efficient for *Quercus robur* as shown by (Jensen et al., 1997). Strong phenotypic selection of oaks have been practiced in Dutch nurseries for many years, as the stem form of Dutch oaks is remarkably better than that of other oaks coming from neighboring countries.

Deviations from ordinary breeding programs

Some woody species requires alternative and more expensive strategies, often including vegetative propagation, e.g. species having special reproduction patterns, polyploidy, apomixis, hybridisation etc.

High intensity breeding will be relevant for when breeding for specific valuable properties as curly wood, extreme epicormic formation and wood colour. These programs may be among the first breeding programs or commercial programs to include biotechnology methods as marker aided selection or genetically modifications.

Selection of single or few clones with specific properties has been carried out within horticulture for years. These specific properties – aesthetic, resistance, fruit size are a result of specific gene combinations and these will often be broken when transformed into the next generation.

Many of the broadleaved species are used as ornamentals and are used in shelterbelts where they are exposed to climatic extremes. They are often very difficult to test in extreme conditions. Some breeding programs incorporate selection of trees under extreme natural selection. This have been done for elm, oak, robinia and ash for frost resistance in Russia (Heybroek 1979, Maslov *et al.*, 1983). This is a strategy also tried on Ulmus (Collin 1999), but it has yet to prove its efficiency.

Conclusions

Breeding of broadleaves is carried out on a larger scale than ever – mainly integrated in applied gene conservation strategies in most countries. Most programs are based on native plant material, but few programs also include domesticated or imported material. As the need for local seed sources probably will increase, there will be a need to develop proper breeding and improvement programs.

Breeding programs are often national, however resources could often be better invested in cooperative breeding and conservation programs. The SNS and EUFORGEN network have positively promoted cooperation between countries in the Nordic and Baltic region.

Low intensity breeding will challenge tree breeders. Even if less intensity is put on each tree species, there will be a substantial need for basic knowledge on several of the broadleaved species, as their biology often is vaguely described. It will be important for breeders to optimize breeding strategies and designs within a restricted economic frame (Cotteril, 1986).

Any long term tree breeding has an uncertain future – especially hardwood programs. Breeding programs will periodically suffer from discontinuity (Steiner, 1993) and restricted resources, and, therefore, most breeding programs will be low intensity programs (Werner, 1993). Breeding programs for many broadleaved species should be constructed, simple, robust, cost-efficient in order to cope with this discontinuity due to funding and methods (Steiner, 1993, Lindgren, 2000).

References

Anderson E. W., Spanos K. A., Mullin T. J. & Lindgren D. 2000. Phenotypic selection compared to restricted combined index selection for many generations. Silva. Fenn. 32: 111-120.

Armstrong J. E. and Funk D. T. 1980. Genetic variation in the wood of *Fraxinus americana*. Wood and Fiber. 12, 2: 112-120.

Aronen T. S., Nikkanen O., Haggman H. M. 1997. Assessment of benefits and drawbacks of pollen transformation. Abstracts from the Joint Meeting of the IUFRO Working Parties 2.04-07 and 2.04-06 Somatic Cell Genetics and Molecular Genetics of Trees Quebec City, Canada August 12-16, 1997 WFGA Meeting Program. http://dendrome.ucdavis.edu/Meetings/iufroabstracts.html#AB-STRACT73

Baliuckas V., Danusevicius J., Gabrilavicius R. 1998 Genetic conservation of Noble Hardwoods and their conservation in Lithuania, with special emphasis on *Fraxinus excelsior* L. and *Quercus robur* L. In. Turok, J., G. Eriksson, J. Kleinschmit and S. Canger, compilers. 1996. Noble Hardwoods Network. Report of the first meeting, 24-27 March 1996, Echerode, Germany. IPGRI, Rome, Italy. ISBN 92-9043-291-8 172 pp. 125-132.

Barnes R. D. 1995. The breeding seedling orchard in the multiple population breeding strategy. Silvae Genetica 44: 81-88.

Baumanis I. 1998. Creating the basis for producing genetically improved seed for the economically most important forest tree species. http://www.silava.lv/projects/pr_baum.htm.

Belous V. I. 1982. Development of elite seed production of oak in the forest of west Ukraine. Lesnoe-Khozyaistvo No. 11: 27-30.

Beuker E. 2000. Aspen breeding in Finland; New challenges, this issue.

Byram T. D., Lowe W. J. 1996. Forty-fourth progress report of the Cooperative Forest Tree Improvement Program. Cirkular Tex. For. Ser. 296, 25 pp.

Byram T. D., Brigdwater F. E., Gooding G. D., Lowe W. J. 1997. Forty-fifth progress report of the Cooperative Forest Tree Improvement Program. Cirkular Tex. For. Ser. 297, 30 pp.

Byram T. D., Brigdwater F. E., Gooding G. D., Lowe W. J. 1998. Forty-six progress report of the Cooperative Forest Tree Improvement Program. Cirkular Tex. For. Ser. 297, 30 pp.

Byram T. D., Brigdwater F. E., Gooding G. D., Lowe W. J. 1999. Forty-seventh progress report of the Cooperative Forest Tree Improvement Program. Cirkular Tex. For. Ser. 297, 30 pp.

Calvert R. F. 1977. Tree improvement and hardwood silviculture. Forestry Chronicle 53: 226-228.

Carter K. K., DeHayes D. H., Demeritt M.E., Eckert R.T., Garrett P. W., Gerhold H. D., Kuser J. E. Steiner K. C. 1988. Tree improvement in the Northeast: interim summary and recommendations for selected species. Technical bulletin – Maine Agricultural Experiment Station. No. 131, 50 pp.

Cervenka E., Paule L. 1979. Der Wachstum der freiabgebluhten Nachkommenschaften der Auslesebaume der Buche (*Fagus silvatica* L.). Acta. Fac. for. Zvolen 21: 47-66.

Chalupa V. 1990. Biotechnology in forest tree improvement: trees of the future. Plant-aging. Basic and apllied approaches. 1990, 311-318; NATO ASI Series A, Life Sciences vol. 186. Plenum Press N.Y. 0-306-43518-7.

Clausen K. E. and Guries R. P. 1983. Variation among white ash families in flushing and spring frost susceptibility. Proceedings of the second North Central Improvement Conference, Lincoln, Nebraska, August 5—7, 1981, p. 86-93.

Coggeshall M., Beinike W. F. 1986. The use of multiple breeding populations to improve northern red oak (Quercus rubra L.) In: Proceedings of the IUFRO Joint Meeting of Working Parties on Breeding Theory, Progeny Testing and Seed Orchards. Williamsburg, October 1986, p. 540-456.

Collin E. 1999. Strategies and guidelines for the conservation of the genetic resources of the European elms. *In:* J. Turok, J. Jensen, Ch. Palmberg-Lerche, M. Rusanen, K. Russel, S. de Vries, E. Lipman (compilers). Noble Hardwoods Network Report of the 3rd meeting 13-16 June 1998, Sagadi, Estonia.

Cotteril P. P. 1986. Genetic gains expected from alternative breeding strategies including simple low cost options. Silv. Sen. 35: 212-223.

Cros E. T. du, Auclair D., Bouvarel L. Kremer A. Slak M. F., Dumas C., Tessier du Cros E., Crassi G., Pirrwitz D., Zibetta H. 1989. Genetic improvement and modified conventional culture of forest trees for short term biomass production. Fift intermediate report. Energy from biomass 4. Proceedings of the third contractors meeting, Ppaestum, 25-27 May 1988, p. 47-50.

Cros E. T., Kleinschmit J., Azeouf P., Hoslin R. 1980. Spriral grain in Beech. Variability and heredity. Silvae Genet., 29(1): 5-13.

Cros E. T. 1981 Genetic improvement of beech. In Le-hetre. 1981, 445-466; 3 pl. (1 col.);

Cunningham R. A., Polk R. B. 1974. Selection and seed orchard establishment of superior green ash. Proceedings of the Eighth Central States Forest Tree Improvement Conference, October 11-13, 1972, Columbia, Missouri. 1974, p. 67-72.

Danell O. 1993. Breeding programmes in Sweden. Corrected reprint from: Lee, S.J. (ed.), Progeny testing and breeding strategies, Proceedings of the Nordic group of tree breeding, October 1993. Edinburgh, Forestry Commission Scotland, p. 1-4.

Danell O., Werner M. 1991. Svensk bjorkforadling – forvantede framsteg under forsta generationen (Report No. 22, The Institute for Forest Improvement, Uppsala, 18 pp.

De Vries S. M. G. and Van Dam B. 1998. Selection programme of oak in the Netherlands. In. K.C. Steiner (Ed.) Proceedings of the second meeting of Working Party 2.08.05 Genetics of Quercus, of the International Union of Forest Research Organizations. October 12-17, 1997. University Park (State College), Pennsylvania, USA, pp 202-208.

Ducci F., Tocci A., Veracini A. 1988. Summary list of basic plant material of Prunus avium collected in N. and S. Italy. Annali Istituto Sperimentale per la Selvicoltura. 19: 263-303.

Ducci F. and Veracini A. 1990. Selection criteria and evaluation of superior phenotypes in the genetic improvement of high quality broadleaves. Annali dell Istituto Sperimentale per la Serviccultura, 1990, 21: 57-80.

Enescu V. 1975 Forest tree improvement. Vol. II. The improvement of the principal forest tree species. Ameliorarea principalelor specii forestiere. Partea speciala. 1975, 314 pp.

Eriksson G., Namkoong G., Roberds J. 1993. Dynamic gene conservation for uncertain futures. For. Ecol. Manage. 62: 15-27.

Frewen B. E., Chen T. H. H., Howe G., Davis J., Rohde A., Boerjan W., & Bradshaw, H. D. Jr. (2000) QTL and candidate gene mapping of bud set and bud flush in *Populus. Genetics* 154: 837-845.

Happanen M., Mikkola J. 1998. Combining genetic gain and diversity by means of open nucleus breeding system. In Proceedings of the Meeting of the Nordic Group for Tree Breeding in Biri, Norway, June 25-26, 1998. Report submitted from NISK 1998.

Hagquist R., Velling P., Viherä-Arnio A. 1991. Finnish birches and their seed production technology. Note from The Foundation of Forest Tree Breeding. sept. 12, 1991 (unpublished).

Hagquist R. Hahl, J. 1998. Genetic gain provided by the seed orchards of Silver birch in Southern and Central Finland. Rep. Found. For. Tree. Breed 13, 30 p.

Heybroek H. M. 1979. Elms and shelterbelts; report on a study tour to two forest research institutes in the USSR. Rijksinstituut-voor-Onderzoek-in-de-Bosen-Landschapsbouw-"De-Dorschkamp"-Wageningen. 1979, No. 184, 24pp.

Hook D. D., DeBell D.S., Ager A., Johnson D. 1990. Dry weight partitioning among 36 open pollinated red alder families. Biomass-London. 21: 1, 11-25.

Hubert J. and Savill P. 1999. Improving oak: the first steps towards a breeding programme. Quarterly Journal of Forestry, 93: 2, 117-125.

Huhtinen O., Yahyaogly Z. 1974. Die fruhe Bluhen von aqua Kalluskulturen herangezogenen Pflanzchen bei der Birke (*Betula pendula* Roth) Silv. Gen. 23: 32-34.

Janin G., Mazet J. F., Flot J. L., Hoffmann P. 1990. Coulour et qualité de la colour du bois de chźne de thrancage: chźne sessile, chźne pédonculé, chźne rouge. Rev For. Fr. XLII: 134-139.

Jensen J. S. 1993. Provenances of *Quercus robur* and *Q. petraea* in Denmark. The Royal Agricultural and Veterinary University, Copenhagen & The Danish Forest and Landscape Research Institute. Dissertation. Forskningsserien 2, 275 pp. ISBN/ISSN 87-89822-16-1. (In Danish with English summary.)

Jensen J. S., Wellendorf, H., Jager, K., De Vries, S.M.G., Jensen, V. 1997. Analysis of a 17-year old dutch open-pollinated progeny trial with *Quercus robur* (L.) Forest Genetics 4(3): 139-147.

Jensen J. S. 2000. Adaptive traits on oak. The Danish Forest and Landscape Research Institute, Research report. 26 pp.

Johnson H. 1952. Ungdomsutvecklingen hos stjälkek, druvek, och rödek. Svensk Skogvärdsforen. Tidsk. 2: 168-193.

Jørgensen F. V., Nielsen C. N. 2000. A drought stress trial on provenances and open-pollinated progenies of Beech (*Fagus sylvatica* L.) The Arboretum, The Royal and Veterinatry Agricultural University. (Manuscript).

Kanovski P. J., Mather R. A., Savill P. 1991. Genetic control of oak shake; some prelimanary results. Silvae Genet. 40: 166-168.

Kalinina I. V., Krasnova T. S., Shutilova V. A. 1978. Growth rate in hybrids of maple elm and ash bred by the all-Union Institute of Agricultural and Forest Improovement. Byul. VNII agrolesomelior No. 1, 3-5.

Kingswell G., Davey M. R. 1998. Wild cherry (*Prunus avium* L.) – the benefits and costs of planting genetically improved stock. Tree biotechnology: towards the millennium. 23-29.

Kjær E. D. and Jensen J. S. (unpublished). Comparing gains obtainable from alternative seedling seed orchard and clonal seed orchard strategies in Danish oak breeding. Internal working note.

Kleinschmit J., Otto H., Sauer A. 1975. Possibilities of genetic improvement of *Quercus robur* and *Q. petraea*. I. Inventories of Oak seed orchards. Allg. For. U. J.zeit. 146(9): 157-166.

Kleinschmit J. 1993. Intraspecific variation of growth and adaptive traits in European oak species. Ann. Sci. For. 50 Suppl 1: 166-185.

Krahl-Urban J. 1972. Die Eignung von Propfplanzen der Traubeneiche, der Stieleiche und der Rotbuche zu Veranlagnungs-Klonprüfungen. Silv. Genet. 21(5): 198-202.

Krstinic A. 1994. Genetics of black alder (*Alnus glutinosa* (L.) Gaertn.). Anali za Sumarstvo. 19: 2, 33-72.

Lagerstrom T. and Eriksson, G. 1996. Improvement of trees and shrubs by genotypic selection for landscaping in urban and rural areas – a Swedish example. Forest and Landscape Research. 1996. 1: 4, 349-366.

Li B. L., Li-Bailan. 1995. Aspen improvement strategies for western Canada - Alberta and Saskatchewan. Forestry-Chronicle. 1995, 71: 6, 720-724.

Linkosalo T. 1999. Regularities and patterns in the spring phenology of some boreal trees. Silva Fennica 33(4): 237–24

Ljunger Å. 1955. Böken i fröplantager. Skogen 42: 362-364.

Lowe W. J. and Greene, T.A. 1990. Geographic variaotion in specific gravity and fiber length of green ash (Fraxinus pennsylvanica Marsh.) in east Texas. Sil. Gen. 39, 5-6 194-198.

Luomajoki A. 1999. Differences in the climatic adaptation of silver birch *(Betula pendula)* and downy birch *(B. pubescens)* in Finland based on male flowering phenology. Acta Forestalia Fennica 263. 35 p.

MacKay J. 1993. Seed source selection and genetic improvement of red oak (*Quercus rubra* L) in Quebec. Ann. Sci. For. 50, Suppl. 1: 420-424.

Maslov A. D., Dorn J. van, Van Dorn J. 1983. The pest of elm and measures for their control. An annotated translation of a Russian oublication with the same title by A. D. Maslov. Rijksinstituut-voor-Onderzoek-in-de-Bosen-Landschapsbouw-"De-Dorschkamp"-Wageningen. No. 276, 270pp.

Mayattski I. N. 1977. Black Walnut at the Vladimirovka agroforestry land experiment station. Lesovodstvo i Agrolesomelioratsiya No. 48, 70-75.

McKeand E., Beinike F. 1980. Sublining for half-sib breeding populations of forest trees. Silv. Gen. 29: 14-17.

Metla 2000. Website hhtp://www.metla.fi/projects/treebreeding.

Mikola J. Long-term strategies for Finnish Tree Breeding. In Metsanjalostussaatio 1998 p 25-26. The Foundation for Forest Tree Breeding. ISSN-0355-1024. 36 pp.

Morgenstern E. K. 1996. Geographic Variation in Forest Trees. UBC Press Vancouver, B.C. 209 p.

Mullin T., Bertrand S. 1998. Environmental release of transgenic trees in Canada – potential benefits and assessment of biosafety. The Forestry Chronicle 74(2): 203-219.

Myking T. and Kierluf C. 2000. Genetic variation in budburst time in *Acer platanoides* and *Betula pendula* cuttings. In Proceedings from the SNS meeting, July 1-3, 1999, in Uppsala, Sweden. Department of Forest Genetics, SLU. Research Notes 55: 50.

Namkoong G., Kang H. C., Brouard J. S. 1988. Tree Breeding: Principles and Strategies. Springer Verlag, 177 p.

Nepveu G., Velling P. 1983. Individual genetic variability of wood quality in *Betula pendula*. Folia Forestalia 575: 21 p. (In Finnish).

Nicholl F. J. 1993. Genetic improvement of cherry for farm woodlands. Quarterly Jour. of Forestry 87: 3, 187-194.

Paludan-Muller G. 1998. Physical and growth responses of Eurpean beech and Norway spruce genotypes exposed to long-term, low-levels of ozone in open-top chambers. Ph.D. thesis. The Royal Veterinary and Agricultural University. Copenhagen. 143 pp.

Paule L., Krizo M., Pagan J. 1984 Genetics and improvement of common beech (*Fagus sylvatica* L.). Anali-za-Sumarstvo. 1984, 11: 1, 1-26; 109 ref.

Pliura A. 1989. Diagnostic value of characters and indices in the individual selection of aspen. Novoe-v-Lesnom-Khozyaistve. 1989, No. 31, 39-44; 5 ref.

Pliura A. 1998. Activity report. Lithuanian Forest Research Institute. Activity in 1996-98. Kaunas-Girinys. ISBN 9986-756-66-9. 132 pp.

Prat D. 1988. Interspecific hybridisation and vegetative propagation: Alder. Actes du 2e colloque Sciences et industries du bois, Nancy, 22-24 avril, 1987. Volume I, 161-168.

Prokazin A., Routkovsky, Shchegunova N. 1998. Noble Hardwoods in Russia: conservation of genetic resources. In: Turok, J., Collin, E., Demesure, B., Eriksson,. Kleinschmit, J., Rusanen, M., Stephan, R., (compilers). 1998. Noble Hardwoods Network. Report of the second meeting, 22-25 March 1997, Lourizan, Spain. International Plant Genetic Resources Institute, Rome, Italy, ISBN 92-9043-363-9. 27-35.

Purnell R. C., Kellison R. C. 1987. A tree improvement program for southern hardwoods. Forest Genetic Resources Information. 1987, no. 15, 72-76.

Raus D., Mayer B., Seletkovic Z., Metvedovic J., Raguz D., Vidkovic M. Trinajstic, Borzan Z., Krstinic A., Gracan J., Matic S., Orlic S., Harapin M., Komlenovic N., Orsanic M., Androic M. Fabajanic G., Prpic B., Pranjic A., Vukelic J., Spanjol Z. Sabadi R., Corkalo (Compiler) K. Klepac. 1996. Pedunculate oak (*Quercus robur*) in Croatia. 559 pp. ISBN 953-154-079-9.

Rink G., Coggeshall M. 1995. Potential height gain from selection in a five-year-old white oak progeny test. Southern-Journal-of-Applied-Forestry 19: 1, 10-13.

Rink, G., Phelps, J.E. 1987. Variation in heartwood and sapwood properties among 10-year-old black walnut trees. Wood Fiber Sci. 21: 177-182.

Rink G. and Coggeshall M.V. 1995. Potential height gain from selection in five year old white oak progeny test. Sout. Jor. Of Appl. Forestry. 19: 1, 10-13.

Robison T. L., Maynard C. A., Thomas J., Hall R. B. 1979. A germplasm collection and evaluation program for Alnus glutinosa. Proceeding of the 26[th] Northeastern Forest Tree Improvement Conference, July 25-26, 1978, Contributed Papers 73-85.

Robison T. L., Hall R. B., Guries R. P. 1983. Approaches to European alder improvement. Proceedings of the Second North Central Tree Improvement Conference, Lincoln, Nebraska, August 5-7, 1981, p. 65-77.

Robison T. L. and Maze C. W. 1987. Specific gravity and fiber length variation in a European black alder provenance study. Wood and Fiber Science. 1987, 19: 3, 225-232.

Roest S., Brueren H. G. M. J., Evers P. W., Vermeer E. 1991. Agrobacterium – mediated transformation of oak (*Quercus robur* L.). Acta-Horticulturae. 1991. No. 289, 259-260.

Rotach P. 1999. In-situ conservation and promotion of Noble Hardwoods: silvicultural management strategies. *In:* J. Turok, J. Jensen, Ch. Palmberg-Lerche, M. Rusanen, K. Russel, S. de Vries, E. Lipman (compilers). Noble Hardwoods Network Report of the 3rd meeting 13-16 June 1998, Sagadi, Estonia.

Savill P., Kanowski P. J. 1993. Tree improvement programs for European oak; goals and strategies. Ann. Sci. For. 50, suppl 1: 368-383.

Savill P. 1998. British hardwooods Improvement Programme. Quarterly Jour. Of For. 92: 3, 217-222.

Schlenker G. 1976. Forest tree breeding in Badel-Wurttemberg. Mitt., Verein fur Forstliche Standortskunde und Forstpflanzenzuchtung. 25, 3-7.

Schroeder W. R. 1994. Genetic improvement for praric tree plantings. Journal of Aboriculture. 20: 1, 46-49.

Steiner K. C. 1993. Oak improvement in North America. Ann. For. Sci. 50 suppl.1: 359-367.

Stener L. G. 2000. Breeding broad-leaved species – What is going on in Sweden. This issue.

Stener L. G. 2000. Website www.skogforsk.se/scripts/admin/projekt/index.pl?visa,156 Skogforsk. Research activities on alder and hybridaspen.

Stener L. G., Werner M. 1997. Battre frokilder for odling af adellųv. Resultat nr. 11. Skogforsk. Website www.skogforsk.se/scripts/admin/projekt/index.pl?visa,155

Stine R. A., Miller L. K., Wyckoff G., Li B., Li B. L. 1995. A compprehensive tree impprovement plan for Minnesota. Staff Paper Series, Dep. Of For. Resources, Univ. Of Minn. No. 102, 24 pp.

Tamm Ü. 1996. Conservation of genetic resources. – Forest Tree Breeding in Estonia. Tartu, 32-35.

Tammisola J., Varhimo A., Velling P., Viherä-Aarnio A., Kauppinen V., Sundquist J., Lapinjoki S. 1995. Variation in the wood and pulping properties of European white birch. Paper and Timber. 77(10): 648-654.

Torribio M., Celestino C., Fernandez-Guijarro B., Gallego F. J., Martinez I., Hornero J., Puigderrajols P., Molinas M. 1998. Somatic embryogenesis in Quercus. In Steiner, K (ed.): Diversity and adaptation in oak species. Proceedings of the second meeting of Working party 2.08.05, October 12-17, The Pennsylvania State University. 241-242.

Townsend, A.M. 1974. Preliminary results from genetic studies of Red Maple. Proceedings of the 8th Central states Forest Tree Improvement Conference, p. 54-56.

Tsarev A. P. 1988 Breeding programmes for improvement of poplars. Lesovedenie. 1988, No. 6, 64-71. (In Russian).

Turok J., G. Eriksson J. Kleinschmit and S. Canger, compilers. 1996. Noble Hardwoods Network. Report of the first meeting, 24-27 March 1996, Echerode, Germany. IPGRI, Rome, Italy. ISBN 92-9043-291-8, 172 pp.

Turok J., Collin E., Demesure B., Eriksson, Kleinschmit J., Rusanen M., Stephan R., compilers. 1998. Noble Hardwoods Network. Report of the second meeting, 22-25 March 1997, Lourizan, Spain. International Plant Genetic Resources Institute, Rome, Italy, ISBN 92-9043-363-9.

Tømmerås B., Johnsen Ø., Skrøppa T., Hindar K., Holten J., & Truffo J. 1996. Long-term environmental impact of release of transgenic Norway spruce (*Picea abies*). – NINA-NIKU Procject Report. ISBN- 82-426-0686-2, 48 pp.

Yrjana L., Rusanen M. 2000. The genetic conservation of noble hardwoods in Finland. Poster from The Nordic Group for Tree Breeding in Lithuania, June 2000.

Viherä-Arnio A. 1991. History of birch (*Betula spp.* L.) in Finland. In Proceedings of the Meeting of the Nordic Group for Tree Breeding in Finland 19-21/9 1989. Metsanjalostusaation. Tiedonantoja. Reports from the Foundation for Forest Tree Breeding, 1, p. 49-50.

Viherä-Aarnio A. & Velling P. 1999. Growth and stem quality of mature birches in a combined species and progeny trial. Silva Fennica 33(3): 225-234.

Viherä-Aarnio A. and Velling P. 2000. Micropropagated plants of silver birch (*Betula pendula*) in the field – performance and clonal differences. Poster presented at the Nordic group of tree breeding, April 4-7. Kaunas, Lithuania (this issue).

Werner M. 1993. Breeding broad-leaved species in Sweden. Corrected reprint from: Lee, S.J. (ed.), Progeny testing and breeding strategies, Proceedings of the Nordic group of tree breeding, October 1993. Edinburgh, Forestry Commission Scotland, p. 22-25.

Westergaard L. 1998. Storage temperature and time affect dormancy release and bud burst in one-year-old seedlings of Acer platanoides. Scan. Jour. of. For. Res. 13: 1-6.

Wrigth J. W. 1976. Introduction to forest genetics. ISBN 0-12-765250-7 Academic Press. 463 pp.

Received November 27. 2000