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Application of a model for tree breeding to conifers in southern Sweden

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Studia Forestalia Suecica
No. 170 · 1985

ISSN 0039-3150
ISBN 91-576-2291-4

Abstract

Gullberg, U. & Kang, H. 1985. *Application of a model for tree breeding to conifers in southern Sweden.* Studia Forestalia Suecica 170, 8 pp. ISSN 0039-3150, ISBN 91-576-2291-4.

We propose a long-term breeding program for Norway spruce and Scots pine in southern Sweden based on a model, presented in a parallel paper. For the establishment of the long-term breeding population we propose three founder populations for Norway spruce, one of Swedish origin, the others from the Carpathian mountain range and White Russia respectively. Only one founder population, Swedish, is proposed for Scots pine but we suggest further exploration of foreign sources. For all founder populations we should like two parallel schemes. One should be based on subpopulations consisting of 30 to 40 parents each, the other based on selfed lines. In the first alternative, problems with inbreeding depression are avoided; in the second, we intend to purge detrimental genes by inbreeding. The subpopulations will cover southern Sweden, that is, from the south up to 62° latitude. It is suggested that the Institute of Forest Tree Improvement takes care of the long-term breeding populations. We consider the long-term breeding effort to be an important means of managing the country's biological resources, and therefore consider it proper for the government to fund the program.

Key words: Long-term tree breeding, southern Sweden, Norway spruce, Scots pine.
ODC 165.3:174.7

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MS. accepted 28 February 1985

016.12 Tofters tryckeri ab, Östervåla 1985

Introduction

In a parallel paper (Gullberg & Kang, 1985) we developed a model for tree breeding, and in this study we present its application to southern Sweden. We limit ourselves to conifers, although the model applies to any tree species.

Today's silviculture

Commercial forestry in Sweden is based on Norway spruce (*Picea abies* (L.) Karst) and Scots pine (*Pinus sylvestris* L.). Lately lodgepolepine (*Pinus contorta* Dougl. var. *latifolia*) has become an important species in the regenerations in northern Sweden, and hardwoods have been of varying importance over time. Political decisions have recently been taken on the national level to maintain the present area and species composition of hardwoods, that is, some fifteen percent of the forestry land.

The commercial rotation times for the two major species are, with few exceptions, between 70 to 150 years, the shorter times applying to the south. The conditions in southern and northern Sweden consequently differ considerably, causing genotype-environment interaction for both species explicable by growth rhythm differences (Gullberg, 1984). Interaction has also been observed within regions but the magnitude and causes of this phenomenon are not well characterized (l.c.).

Most of the forestry land is managed in large scale operations, that is, on land units seldom less than one hectar and on average much bigger. Clearcuttings are predominant at the final harvest and containerized plants are frequently used in plantings. There are government regulations applying to all forest owners that specify the age when the final harvest must be made and the minimum numbers of coniferous plants per hectar after the establishment phase.

The first generation seed orchards largely cover the demand for Scots pine seed. For Norway spruce cuttings and provenance seed are used since the seed orchards are not very productive. The recommendations for how to distribute multiplication stock are still based on relatively young provenance trials.

Judging the effect of breeding on silvicultural operations is difficult for the moment, since most of its measures have so recently been introduced into forestry. The evaluations so far, however, indicate that an increased volume production and frost resistance could be expected as a result of breeding (Werner et al., 1981; Eriksson et al., 1980). Some negative effects of the silvicultural system could, possibly, also be caused by breeding. Thus some frost damage could have been avoided by a better distribution of the genetic material (Gullberg, 1984). The selection for volume might also have caused problems with quality (Werner et al., 1981). The major problems of today's forestry, insects and acid precipitation, however, could not be circumvented by breeding material available now or in the near future.

As regards silviculture as a whole the resources spent on breeding and its supportive research are amazingly small compared to the total investments and the risks taken (Gullberg, 1981).

Breeding organization

In Sweden four different types of organization are involved in tree breeding: the forest companies and the State Forest, the Institute for Forest Tree Improvement, forest genetics research units, and the Forestry Board.

The Forest companies, the State Forest and the Forestry Board are the users of the overall tree breeding efforts. Their needs, and the environments under which they operate, vary. Apart from being a user the Forestry Board has the function to protect national interests by means of legislation and enforcement of the laws and it also has the responsibility for gene conservation.

The Institute for Forest Improvement is the central part of the overall organization. It has three main functions: interface with companies, central coordination and management, and interface with research.

Research related to breeding is performed in the forest genetics departments at the Swedish University of Agricultural Sciences and at other departments within and outside this university.

Initiation of long-term breeding populations

The long-term breeding population is the backbone of a breeding effort, and it must be established as soon as possible. A delay in this decision will postpone the possibilities to get a coherent tree breeding effort.

The Institute of Forest Tree Improvement has collected enough material to initiate long-term breeding populations, and our proposal for its size and structure is given in Table 1. The proposal is preliminary. Details must be worked out jointly by the Institute of Forest Tree Improvement and the Forest Genetics department in Uppsala. In drawing up the proposal we have had three general guide lines:

- make the subpopulations representative samples of the founder population so that studies in one could be extrapolated to the others;
- maintain the subpopulations under such conditions that drastic reductions in the effective population size are avoided;
- make the structure simple so that maintenance is straight forward even when the resources are limited.

Founder populations

Three different founder populations of Norway spruce will be utilized, plus trees from Sweden selected by the Institute of Forest Tree Improvement, and trees from Eastern Carpathians, and from White Russia. Of the three, only the plus tree selections are available in large enough quantities to create breeding populations at this time. The foreign provenances will be used to create two different sets of breeding populations as they become available. They have been included since they have distinctly better growth capacity than the Swedish materials, (Krutzsch, 1975 *a* & *b*) but are kept separate to avoid reduction in the effective population size of a common founder population. The target numbers of trees necessary for creating breeding populations are given in Table 1.

The Institute has collected approximately 2 700 plus trees of Norway spruce in southern Sweden. Seeds and grafts are available from many of the plus trees. The Institute will create progeny tests of these materials, and there is a possibility of combining breeding populations with the progeny tests. Of the available trees, 840 trees with a sufficient quantity of open pollinated seeds and grafts will be randomly selected. The 840 trees will be randomly subdivided into 21 subpopulations of 40 trees each. From each of the 40 trees, 100 seedlings will be developed and planted in a 5×5 square plot with 4 replications.

As soon as the grafts of the 840 trees begin to flower, they will be selfed. The selfed progeny populations will be planted in their corresponding locations. A similar procedure will be followed for the two foreign sources of Norway spruce, but the subpopulations will consist of 30 trees each.

There is one source that might be utlized to deve-

Table 1. *A proposed location of subpopulations of breeding populations for Norway spruce*

Location		Founder Population						
		Swedish		White Russian		Charpatian		
No.	Name	Out-crossing	Selfing	Out-crossing	Selfing	Out-crossing	Selfing	No. of trees★★
1	Ekebo	01*, 15*, 18*, 19*	S01	22	S22	32	S32	32 000
2	Södra Halland	02, 03	S02, S03	23	S23	33	S33	28 000
3	Älmhult	04, 05	S04, S05	24	S24	34	S34	28 000
4	Trekanten	06, 07	S06, S07	25	S25	35	S35	28 000
5	Eksjö	08, 09	S08, S09	26	S26	36	S36	28 000
6	Hensbacka	10, 11	S10, S11	27	S27	37	S37	28 000
7	Remningstorp	12	S12	28	S28	38	S38	20 000
8	Vingåker	13, 14	S13, S14	29	S29	39	S39	28 000
9	Ås (Oslo)	15*, 01*, 18*, 19*	S15					20 000
10	Brunnsberg	16, 17	S16, S17	30	S30	40	S40	28 000
11	Uppsala	18*, 01*, 15*, 19*	S18	31	S31	41	S41	32 000
12	Garpenberg	19*, 01*, 15*, 18*	S19					20 000
13	Norra Värmland	20	S20					8 000
14	Hälsingland	21	S21					8 000

* Index population.
** Total number of trees per location in the progeny generation.

lop a Scots pine breeding population. The institute has seed orchards for the area created from 300 old selections and 800 new selections that are being progeny tested. The seed orchard trees and parent trees of the progeny test can be combined to form a founder population. If the selected trees from the Institute are used 840 trees will be randomly selected and used as the breeding population. The procedure of establishing the breeding populations is the same as that for Norway spruce, but the much more regular flowering in pine would make it possible to use a crossing scheme based on known fathers.

From what we know today we consider that the founder populations for Norway spruce fulfill the demands for genetic diversity (Kang, 1979; Gregorius, 1980). The Scots pine material, however, could include a too limited range of the species diversity and the possibilities of including foreign sources should be further explored.

The seemingly low degree of geographical structuring of the genetic variation in the areas concerned (Gullberg, 1984) and the still imprecise characterization of the breeding material have made us avoid any classification of the material below the founder population level. Consequently we have proposed a random division into subpopulations for the long-term breeding and have thereby achieved a simple structure that makes it possible to extrapolate concentrated studies on a part to the whole material. In the short-term program, however, the continuously improving knowledge about today's material will be used for making the most profitable measures, in terms of selection and creation of material, independently of the structure of the long-term population.

The utilization of open pollinated material in the establishment of the long-term breeding population for Norway spruce will not give a population of the best possible quality, but an alternative using known fathers would probably delay the establishment more than a decade. We have judged that a postponement of the long-term breeding effort a decade or more is a bigger drawback to the program than not using known fathers in the first generation.

Our suggestion of using the founder material in two parallel programs, one with subpopulations consisting of 30–40 parents, the other using selfing, that is the size one of the parent population, will give options to future breeders. The size of 30–40 parents per subpopulation will make the problems with inbreeding negligible (Kang, 1979). Selfing will, it is hoped, create a breeding population where detrimental genes are purged. It will be up to future breeders to determine whether both these program should be maintained or if a reduction is feasible.

Gene bank

The gene bank for forest trees has collected Norway spruce seeds from natural populations, and will continue to do so. We propose to grow up to 10 000 offspring in both Ekebo and Uppsala. One hundred seedlings from one stand will be grown and planted. The seed bank, therefore, has the capability of including 100 different stands. The same stands will be represented in both locations. Although it will be a long time before decisions can be made on the regeneration procedures we assume that 1 000 trees will be randomly picked and 10 offspring from each mother tree will be planted to create the following generation.

A gene bank of the same magnitude should be established for Scots pine also.

Our reason for keeping a separate set of gene bank material is twofold. Firstly our present knowledge is too limited to guarantee that the proposed long-term breeding population is sufficient to replace the existing natural variation. We therefore want to keep this option, of further exploiting the natural variation, available to future breeders despite our judgement that it will play a minor role in their breeding. Secondly, the gene bank material could be used as a check on the development of the breeding population.

Clonal archives

No number limit is set for clonal archives. It works by the following operating rule. Materials that are considered extraordinary will be put into clonal archives by vegetative propagation. The genotype will be reproduced and vegetatively regenerated for a period equivalent to five sexual cycles of breeding populations. If the genotype is not used during that period, it will be discarded. Ten copies will be maintained in both Ekebo and Uppsala. Since five generations is a very long time the selected clones must meet a very high standard.

Locations

Fourteen locations are suggested (Fig. 1). Within each location representative sites for the two species will have to be found. When there is more than one subpopulation per species and location they should

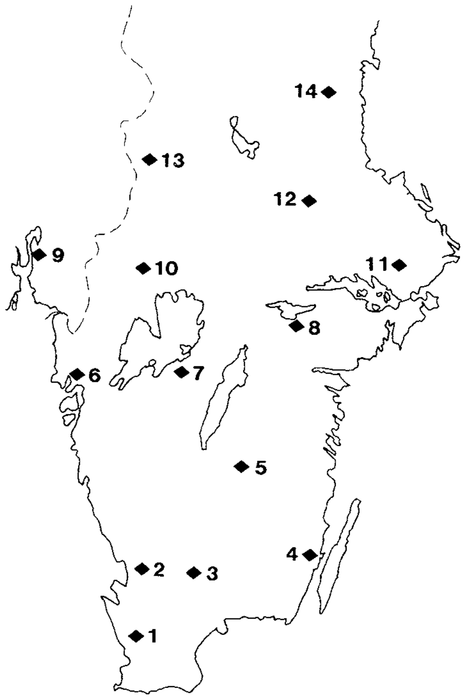

Fig. 1. Proposed locations of breeding populations for Norway spruce and Scots pine.
1: Ekebo, 2: Southern Halland, 3: Älmhult, 4: Trekanten, 5: Eksjö, 6: Hensbacka, 7: Remningstorp, 8: Vingåker, 9: Ås (Oslo), 10: Brunnsberg, 11: Uppsala, 12: Garpenberg, 13: Northern Värmland, 14: Hälsingland.

be on different site types, so that even microgeographic variation in site conditions is represented.

Naturally one wants the breeding population to cover as wide an area as possible, since this will lower the overall cost for breeding in a region. Since our information on genotype-environment interaction is so weak for the proposed founder populations (Gullberg, 1984) we have chosen to distribute it all over the whole of southern Sweden, assuming that the interaction is so low that no drastic reductions will take place in the effective population size. It may very well be that the same founders could also be located further north, but we have considered this outside our frame of reference.

The responsibility for creating and maintaining the populations may be divided as follows.

Populations 1–8, 10, 13, 14. Institute for Forest Improvement.
Population 9, Norwegian Forest Research Institute
Population 11, SLU, Department of Forest Genetics, Uppsala and
Population 12, SLU, Department of Forest Genetics, Garpenberg.

The index populations are located at 1, 9, 11 and 12, that is, at research stations. In addition to the breeding populations, a seed bank and a clonal archive will be created at both Ekebo and Uppsala.

Responsibilities will be allocated by the various organizations involved, and it is quite possible that the above arrangement will change.

Coordination of long- and short-term programs

Earlier we subdivided the breeding stock into long-term breeding population, short-term breeding population and multiplication stock. Physically, however, these three funtions could in part or even in whole be performed on the long-term breeding population. Thus a species of limited economic importance for southern Sweden could be kept according to the structure we have proposed for Norway spruce and Scots pine whith adaptations depending on population structure and site demands. Besides being the long-term breeding population the subpopulations could also function as progeny tests for the area surounding the location in question. Finally the best parents or the best progeny families could function as multiplication stock by producing seeds or cuttings.

The relatively advanced programs existing for Norway spruce and Scots pine in southern Sweden and their high economic importance makes it necessary to have short-term populations and multiplication stock in addition to the long-term breeding population, but a coordination of the three activities is necessary. We therefore propose that the present short-term breeding program is reviewed and coordinated with the long-term breeding populations in the near future. Once the long-term breeding populations mature, subsequent generations of short-term populations can be sampled from long-term populations. Until that time, however, Swedish tree breeders must use currently available breeding material to obtain maximum possible genetic gain.

Developments in the organization

All the organizations related to tree breeding in southern Sweden geared their activities to short-term improvement. Consequently none of the organizations can carry out all the functions of a comprehensive breeding program independently. The organizations, however, can develop a good coordinated system for performing all the tree breeding functions. To develop such a system they must define their functions relative to long-term breeding, short-term activity and supportive research, and find ways of enhancing information transfer among themselves.

Justifications for different functions and the corresponding types of organizations have already been discussed. Detailed functions of different organizations should be defined later by the parties concerned through joint efforts.

As we discussed in Gullberg & Kang (1985) the tree breeding model we outline will require both generalists and specialists and we feel that there are too few specialists in the system today. To remedy this we think the Swedish forestry education system should analyse the mix of specialists and generalists it should educate. To develop their implementation capabilities, we further argue that the forest companies, the State Forest and the operational side of the Forestry Board need personnel trained in forest genetics.

In the coordination of the system the Institute of Forest Tree Improvement plays a major role since it is the central part of the overall organisation.

To interface with companies the Institute should continuously seek out types of research that are common to all the companies and carry out such researches, and help companies to develop their independent implementation capabilities. The Institute should concentrate on research with broad scope, such as testing of various breeding stocks at different locations, different selection types, and mating types, carying out inbreeding and hybridization, and developing alternative means of producing propagules.

The central function of the Institute includes the management of long-term breeding populations, and the storage of data. It should engage in the research necessary to generate both long- and short-term breeding prescriptions. It should also engage in the further education of managers and field personnel by providing short courses and arranging various planning meetings.

To interface with researchers, the Institute should create many joint projects with forest genetics departments on subjects such as growth rhythm, early testing selection methods, economics, long-term breeding, and mathematical modelling.

The Forest Genetics department in Uppsala must interface with the Institute of Forest Tree Improvement by participating in the coordination of long-term breeding, managing a small proportion of the breeding populations, and developing joint projects.

They should diversify their research efforts, with emphasis on long-term breeding. The level of research should be basic and futuristic.

The departments must also look out for new techniques from many different research fields and introduce those that are useful to tree breeding.

Funding

In theory the optimum size of the technical system can be determined relative to the size of the silvicultural effort and the importance of managing biological resources. In practice, it is difficult to define the optimal size, and the actual size is likely to be decided on practical, rather than ideal, reasons. It is, however, self-evident that the current Swedish breeding system is smaller than the size of the task it should carry out.

The funds already available are certainly needed for short-term activities. To finance the long-term breeding population we therefore find it appropriate to look for some governmental funding. A measure to guarantee the continuity of such funds would be to state the necessity of long-term breeding in the Forestry Act.

Concluding remarks

Unorthodox approaches were used to define, develop, and describe breeding strategy of Norway spruce and Scots pine for southern Sweden (Gullberg & Kang, 1985). Few technical details that are unique for Norway spruce and Scots pine for southern Sweden were introduced. Instead, broad philosophical arguments that could apply to any species of commercial value were used.

Such a philosophical approach was necessary to reflect the transitional nature of tree breeding today. Swedish tree breeders have completed their first generation of tree breeding efforts, and are about to enter the second generation. Such transition is equivalent to moving from one dimensional short-term activities to two dimensional long- and short-term activities. The addition of a new dimension makes the breeding much more complex than it was before.

To prepare for the complex activities it its necessary to redefine the founding concepts of tree breeding. The strategy for the first generation of breeding could have been a brainchild of a breeder with a vision, and the success of the breeding activity needed strong leadership. The breeding strategy for the long- and short-term breeding cannot be developed the same way. The strategy itself must become a subject of continuing research.

The success of future breeding depends on the presence of a group of specialists working in harmony as well as a strong leadership. When the Swedish breeders agree on such fundamentals and develop a coherent group approach, the necessary action plans for breeding can be generated and executed efficiently.

Developing such a coherent group is, of course, extremely difficult and could be frustrating to the parties involved. Once a good tradition is established, however, it will have a long lasting effect.

The need for the group approach is not unique to tree breeding. It applies to all biological resource management. Unfortunately, little is known about managing biological resources. Biological resources are different from physical resources. Failure to understand this is one of the reasons why conflicts between development an conservation are so common today. Tree breeders cannot expect to obtain management ideas from outside very often. They must develop ideas and experiment on them while keeping their minds open.

Some recommendations that can stimulate the group approach are as follows:

1. The long-term breeding populations must be established as soon as possible.
2. The present breeding activities must be reviewed and related to the long-term view.
3. The researchers must define their research emphases and coordinate them.
4. A formula for long-term cooperation among various tree breeding institutes must be developed.
5. A combined data management system must be developed.

References

Eriksson, G., Andersson, S., Eiche, V., Ifver, J. & Persson, A. 1980. *Severity index and transfer effects on survival and volume production of Pinus sylvestris in Northern Sweden* (Studia For. Suec. 156). 32 pp. Uppsala.

Gregorius, H.-R. 1980. The probability of losing an allele when diploid genotypes are sampled. *Biometrics 36*, 643–652.

Gullberg, U. 1981. Ett första inlägg om genetik – ekonomi inom skogsträdsförädling (A preleminary study of genetics—Economy in forest tree breeding). *Swedish University of Agricultural Sciences. Dept. of Forest Genetics, Res. Notes 31*, 39–84.

Gullberg, U. 1984. *Charaterizing environments in Swedish forestry in order to minimize the effects of genotype × environment interaction* (Studia For. Suec. 166), 25–34. Uppsala.

Gullberg, U. & Kang, H. 1985. *A model for tree breeding.* (Studia For. Suec. 169). Uppsala.

Krutzsch, P. 1975 *a. Die Pflanzenschulenergebnisse eines inventierenden Fichten herkunft versuches (Picea abies Karst. und Picea obovata ledeb.)* (Swedish University of Agricultural Sciences, Dept. of Forest Genetics, Res. Notes 14). 104 pp. Stockholm.

Krutzsch, P. 1975 *b. Zwei Herkunftsversuche mit Fichte in Schweden (IUFRO 1938)* (Swedish University of Agricultural Sciences, Dept. of Forest Genetics. Res. Notes 16). 93 pp. Stockholm.

Werner, M., Hadders, G. & Rosvall, O. 1981. *Förädlingsprogram för tall, gran och contortatall. (Breeding program for Scots pine, Norway spruce and Lodgepole pine).* Year book. Inst. for Forest Tree Improvement, Uppsala, Sweden 1980, 59-111.

Acknowledgement. We are indebted to all the participants in the workshop series. This study was supported by grants from the Swedish Council for Forestry and Agricultural Research.