Swedish seed orchards for Scots pine and Norway spruce

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Summary

Clonal seed orchards of Scots pine and Norway spruce has been established since almost six decades. Plustrees were phenotypically selected in forests. Initially most of the selections were made in natural mature forests, but since 1980 most selections were done in middle-aged plantations. The selections were grafted and the grafts planted in seed orchards. The last decades many orchard clones have been selected based on testing. Testing is often progeny-testing, earlier with complicated mating designs, but more recently often with wind-pollination. Testing for spruce often means testing with cutting-propagated clones. Currently more than 60 percent of all planted plants come from seed orchards and the figure is increasing as new orchards start producing seeds. The additional production of planted forests from seed orchards today is estimated to around ten percent, and is rising. Establishment of a new round of seed orchards has been launched, which will lead to almost complete seed orchard supply for plant production with considerable higher genetic quality than what is used today.

Introduction

This paper describes Swedish seed orchards for Scots pine and Norway spruce. There are seed orchards of other species, but Norway spruce and Scots pine dominate forest plantation. In 2005 the numbers of available forest plants in Sweden were: 125 million Scots pine; 194 million Norway spruce; and 11 million of all other species. The statistics origin from the Swedish Forest Authority and it should reflect planted plants in Sweden, even if some plants which do not do it to the actual plantation are included. Import is included with about 40 million plants; the intention is that exports should be excluded. Clonal plants of spruce are used, but much less than a million. Seed orchards are almost the only way to get tree improvement out into the forest, and even if clonal forestry is technically and biologically possible, it is not seen as an economic option and no nurseries has currently any intentions to scale up its use.

The annual growth of Norway spruce in Sweden is larger than that of Scots pine and the rotation time shorter since spruce generally grow on more fertile soils. However, the species occupy approximately equal size of forest land area, spruce somewhat more in south and pine somewhat more in north. Emphases of breeding have been similar for spruce and pine, and the effort is also basically rather similar in different parts of the country. There are no seedlings seed orchards for the two major species and vegetative propagation has been done by grafts, but recently cuttings have been used to a greater extent for Norway spruce. Most grafts are propagated in nurseries and planted, but field grafting is sometimes applied.

It is practical to describe the development of the Swedish seed orchard program as three distinct rounds at different epochs, even if the real World is less simple. There were several decision makers and the exact circumstances are case specific, and ideas change over time. The moment of the establishment of a seed orchard is often not exact and not exactly compatible for different seed orchards. There is a planning period, there are ground preparations, grafts take time to prepare, some orchards are first planted with root stocks and grafting is done subsequently in the field, the whole seed orchard is seldom planted in a single year and fill in or complementary plantations may occur, thus "establishment year" has usually character of an average and the exact definition varies sometime in records. Thus "epochs" do not have distinct borders and all events are not typical for the epoch. The three rounds are here chronologically associated to years: the first round ≈1949-1972; the second round ≈1981-1994; and the third round ≈2004-onward, although this is not to be interpreted as exact limits.

The first round (≈1949-1972)

The concept of grafted conifer seed orchards has a long history. The first development in Scandinavia was done by Syrach Larsen in Denmark about 70 years ago (Larsen, 1934). The idea was promoted in Sweden by Holger Jensen at Ramlösa nursery, and a large seed orchard program was launched mainly according to these ideas. To make grafts in a large scale was a slow procedure, the selected plus trees in the natural forest were old and could not be harvested for many scions, and the scions harvested were typically not very vital. It was more feasible - but very time consuming - to first graft a few primary grafts and then make many secondary grafts. A number of small graft archives and experimental seed orchards were established. The development in Denmark was hampered and downgraded because of the occupation during the war and the urgency to rebuild after the war, while Sweden was not much affected by the war and could accelerate the already initiated tree

breeding program immediately after, stimulated by the large request of timber for rebuilding Europe, where Sweden was the major unharmed supplier. The first full industrial scale conifer seed orchard in Scandinavia was initiated 1949 in Drögsnäs at Brunsberg in central Sweden (lat. 59˚37' N) with planting of Scots pine grafts. Another early industrial scale effort occurred around Kratte Masugn (Anonymous 1963). Still today the outlines first suggested by Larsen (1934) are usually applied when establishing new seed orchards in Sweden and elsewhere.

The mature seed orchards established before ≈1972, which now supply most seed orchard based forest regeneration material, are now successively taken out of production. The following was rather typical for this first round of orchards:

- Selection of plus trees in mature forests. For Scots pine it was mostly naturally regenerated Swedish forests, while for Norway spruce in south Sweden some of the selections has been done in plantations with either indigenous or continental European origin or selected in Poland.
- The plus trees were carefully described and compared to measured comparison trees. There was a formal approval process.
- Scions were harvested and the plus-trees were multiplied as grafts. Clonal seed orchards were established using such grafts.
- Most plus trees were placed in seed orchards (1300 pine and 900 spruce clones).
- A typical seed orchard comprises 40 clones.
- The seed orchard program was associated with progeny tests of the clones in the seed orchards. Progeny tests were often done by controlled crossings in the seed orchards, when the grafts produced flowers. Thus progeny-tests established before 1980 are usually associated to specific seed orchards. Progeny tests were often performed with many (5 or more) matings per parent, large progenies (200) and replications on many sites (5).
- The seed orchards were usually established foreseeing a 50% systematic thinning. Genetic thinning, which was planned for a later stage, has been implemented sometimes but seldom. A typical object was established with 400 grafts per hectare and 40 clones in the orchard. At maturity usually somewhat less than 200 grafts per hectare remain.
- Several Norway spruce seed orchards were established to benefit from hybrid effects when provenances with rather diverse origins were brought together (Swedish and continental), but the

progeny appeared disparate and thus these seed orchards were thinned so only one component remains. Thus the idea of hybrid seed orchards failed for Norway spruce.

- Today changes in the set up of many of the mature seed orchards have occurred compared to initial plans and maps. E.g. it happens that bad clones are removed and better ones are filling their original planting space.

To optimize genetic gain more parents with less offspring each should have been tested. Further, the use of wind pollinated offspring from the plus trees in the forest would have decreased the time lag for testing. However, at that time genetic parameters and ways of inheritance were basically unknown and the large trials with dialells were (and still are) a valuable source for deriving basic data.

The first round of seed orchard program stopped around ≈1971, few seed orchards were established in the following decade. Some of the first round seed orchards are now cut down as they are replaced by newer units and more will be taken out of production soon.

The second round (established ≈1981-1994)

1982 a new nationally coordinated seed orchard program was inaugurated, the seed orchard establishment costs was paid by the state.

Since ≈1980 the results of the trials established in connection with the first round started to become evaluated and breeding values for plus-trees started to become available. Partly this material was used in the second round.

The selected plus-trees in the first round were regarded as an insufficient base for long term breeding and the tested trees were too few to support the second round program more than to a limited extent.

The main principles applied in plus tree selection and seed orchard establishment were:

- New selections were carried out in young culture stands (typically 20-40 years old). For spruce in southern Sweden it was often plantations of foreign origin. Reasonable aged plantations with known history was less frequent at the early plus tree selections, mainly because planting was less common, and did often not use what we now consider as "appropriate" provenances. Reasons for making selections in rather young plantations were:

- It is in the correct geographic and climatic environment (provenances move somewhat initially)
- It is in the correct silvicultural environment (planted and not natural regenerated)
- Imperfections in especially the stem and branch quality in the most valuable bottom trunk of stem are not hidden inside the trunk.
- Heritability can be expected to be higher in a uniform plantation than a natural regeneration, which may be unevenly aged.
- More vital grafts from younger ortets, and as more plus-trees were selected, the requirement of grafts per tree could be relaxed.

- Emphasis on many selections (instead of accuracy of the individual selections, no comparison trees, except a few "unselected" checks). Around 5000 new plus trees of pine and spruce were selected. As many selections were done and genetic thinning was planned it was also natural to have many clones in seed orchards, typically more than a hundred.
- After selection, scions for grafting and wind pollinated seeds were harvested from individual trees and used for progeny testing. Thus the connection between specific seed orchards and the progeny test was relaxed. It was seen as too time consuming to wait till controlled crosses could be made on grafts, but still it was necessary to make grafts to store the selections and produce secondary scions for production of grafts for the seed orchards. When seeds were not available from open pollination in the selection stands, seeds from archive trees were also used for progeny testing.
- Seed orchards were often established foreseeing genetic thinning based on progeny test. However, the foreseen genetic thinning has until now rather seldom been realized.
- For some plus trees growth rhythm of progeny in green house or nursery has been guiding.
- Many seed orchards used some tested material and a few were established with only tested material. Three of the second round Scots pine seed orchards are based on result from short term adaptation/autumn frost hardiness tests. Also plus trees from the Finnish orchard program was tested, selected, and included. Some Norway spruce seed orchards in south Sweden were established after phenological test of the clones in the nursery.
- A few Norway spruce seed orchards are based on clones tested in clone tests (not progeny-tests), these are among the second round seed orchards with highest predicted gain, but have not yet reached the national list.

- The design of seed orchards become more variable than in the first round and depending on special circumstances, in particular the availability of bred material. It was also an intentional effort to try different models to widen the experience. As a consequence the clone number of second round seed orchards varies among ten and several hundreds.
- Almost half of the second round pine seed orchards on the National list (Table 1) are regarded as tested, while none of the spruce seed orchards. In spite of that the calculated gains is some percent higher for the spruce seed orchards than the pine seed orchards (Figure 1). This is probably as many of the second round spruce seed orchards which have (clone-)tested clones are not yet in the National list.

Table 1. Number of seed orchards in Sweden. The seed orchards where seeds are marketed or planned to be marketed soon are in the Swedish National List (read 2006) of approved basic materials. There exist new seed orchards, which are not on the list, as the seeds are not on the market yet. Old seed orchards are taken out of production, but seeds can still occur on the market. The category "Qualified" means phenotypically selected plus trees and the category "Tested" in the Table means progeny-tested Scots pine plus trees (sometime the test may be short-term). If only a minor part of seed orchard trees are tested it becomes "qualified". The number of seed orchards in the list is compared to all seed orchards.

	In Swedish National List of Approved Materials				All established	
Species	Qualified	Tested	≈ -1980	≈1981-2000	≈1981-2000	2004-
Scots pine	61	9	50	20	24	2
Norway spruce	27	0	22	5	12	3

When the second round coordinated program was initiated 1982, the intended area was 510 hectares of pine and 550 hectare spruce orchards, what actually became established was 350 hectares of pine and 200 hectares of spruce (Table 3). The largest reduction was for spruce in southern Sweden, which will lead to a lack of improved seeds decennia ahead.

This second round program can be seen as completed around 1994 even if a few seed orchards were established 1994-2003. Establishment of seed orchards was supported by governmental funds 1982-1994. This funding was discontinued 1992/93. The funding was derived from a tax on forest land, which was removed, and when also the benefits connected to it. The socialistic idea with a tax is that

the state can use the money earned by forest owners and companies wiser than the they can do themselves. It took a decade for the Swedish forestry to find an administrative solution for paying the costs for seed orchard themselves after the money became available by releasing the tax from the shoulders of the forest owners, but in the end they did it and the third round of seed orchards started.

Swedish Scots pine seed orchard life time. There are 48 seed orchards on the national list established before 1971 and only 15 later 1971-1990, and most young seed orchards have not yet reached full production yet. Even when a seed orchard is established, the clones may be selected long time earlier. That probably means that much of the seedlings planted today originate from seed orchards harvested more than 35 years ago. A life time of Scots pine seed orchards above 40 years seems likely, once they are reasonable well established. Recently El-Kassaby et al. (2007) argued that Scots pine seed orchards become genetically outdated when they are aged 30, if the long term breeding functions as well as predicted. It seems desirable that Swedish Scots pine seed orchards are replaced more aggressively.

The third round (established 2004-?)

A national coordinated seed orchard program without governmental financial support was negotiated during the first years in the current millennium and launched 2003. Its structure and goals are described by Rosvall and Ståhl (2008). All genetic material is planned to be selected based on testing in one way or another. Some, but not much, will be offspring to tested clones. Until 2007 two pine seed orchard and four spruce seed orchards have been planted or planting has been started, but two of these orchards can be seen as single owner orchards, which would have been established even without the coordinated program.

Since most of the available large number of clones in the latest round of seed orchards is tested, the genetic gain will be considerably larger than in the first two rounds. Rosvall et al (2002) calculated the average ideal (no reduction for contaminating pollen etc.) possible gains to be 33 and 37% for pine and spruce respectively. A more realistic estimate is suggested to be 24 and 26%.

Retrospectively, the Swedish seed orchards have been described in terms of three distinct rounds. The cause for these phases is mainly administrative changes in the funding system by the Swedish political system, there is no “scientific” justification, and it is not rationale. The future

will hopefully not mark out a distinct "Fourth round" of Swedish seed orchards after the end of the decided third round. Hopefully, from now on a smoother and more continuous program will be driven by genetic progress in the long-term breeding (Prescher 2007). Another argument for a continuous seed orchard establishment is the different breeding generation times. Southern populations will have a faster rotation turn over due to faster testing. A rolling front within the breeding population will also influence timing. Hopefully the forestry actors will establish new orchards when there is significantly improved material available. The size of required improvement will vary with economic resources and predicted demand of wood. Seed orchard themselves will probably turn more rolling front where parts are updated and replaced rather than starting from scratch. One argument for that is to get an early improved and better known pollen cloud rather than contamination.

The impact of seed orchards on Sweden

Table 2. National statistics for percent seed orchard seedlings in Swedish plantations.

	Percentage of seedlings from seed orchards				
	1975	1990	1995	2001	2006
Scots pine	60	60	Most	62	78
Norway spruce	Small	15	14	38	49

Since 2001, the statistics is based on enquiries to plant producers by the Swedish Forestry Authority, earlier statistics is more subjective estimates based on the potential of seed production and may be slightly overestimated. Since the mid 80s, plant production has decreased from more than 500 million plants per year to about 320 millions. Furthermore, pine plantation has decreased in southern Sweden (due to game injuries) and spruce plantation increased.

For Scots pine plant production, most seeds came from seed orchards the last three decades in southern and middle Sweden. In the central part of Sweden, i.e. latitude 62-64˚ N, there is still a lack of seed orchard seed. The most significant lack is for the harshest areas in the north, and seed orchards better adapted to that area now comes into production, thus the seed orchard use may be expected to rise to 90% in a few years. The seed orchard use of Scots pine will probably rise steeply soon as the second round of seed orchards has started to produce significant amounts of seeds the last years. However, even the second round of orchards was not established to cover the whole need for plant production in the north, and the limited increase between 1975 and 2001 give reason for some worries.

The situation for Norway spruce is different than for Scots pine. The first and second round spruce seed orchards were established in the end of the period and the area was insufficient for both rounds. The fructification of Norway spruce starts about five years later than for Scots pine, and thus seed from the orchards become available much later than for pine. In the late 70s and early 80s small crops were harvested, but it took until 1989 before the first big seed crop. Swedish foresters were conservative and cheap and rather good imports were available, and thus the marketing of spruce seed orchard seed was not easy when they first become available. Today the demand for seed is higher than the production capacity from the orchards in southern and northern Sweden. Unfortunately the lack of improved spruce seed will continue some decades; the withdrawn funding for establishing new orchards in the second round, mainly had impact on spruce in southern Sweden. These orchards were planned to be established in the end of the period because the progeny tests intended to be used for selection of clones, were going to be evaluated some years later. However, the changed funding situation totally stopped the establishment program of spruce orchards before it was complete. It is required that seed orchards only a few years old or not established reach full production to come close to 100% seed orchard use, and that will not occur the next decade.

Table 3. Reasonable successful established area of seed orchards (hectares)

	First round ≈-1972	Second round ≈1981-1994	Third round ≈2004- (2006)
Scots pine	575	350	28
Norway spruce	230	200	50

The genetic gain of seed orchards

Genetic gain considerations and estimates for Swedish seed orchards were presented by Rosvall et al. (2002). Gain estimates can be interpreted as gain in value production or gain in volume production at a constant quality. The gain of the early seed orchards can be said to have three sources: 1) the clones placed in a seed orchard origin from different populations and therefore trees are less related than in a stand, thus seed orchard seeds suffer less from inbreeding depression and may benefit somewhat from hybrid vigor. The gain by this is assumed to be 2%. 2) Some seed orchard phenomenon can be seen as equivalent of a gain, mainly "epigenic" effects

("aftereffects", one reason is heavier and more developed seeds and faster starting seedlings, the effect of that may hang on into productive ages) but also that it is easier to produce a more uniform and predictable plant crop in the nursery. This appears as a "genetic gain" which is assumed to be 2%. 3) The most important generator of gain is the artificial selection of superior trees. The selection gain when choosing plus trees in the forest was estimated to 6%. These generalized gain estimates build on experimental results with comparisons between artificial plus-tree crossings and commercial checks.

Considerable larger gain is achieved where selection is based on progeny or clone testing. Genetic gain after genetic thinning is rather small, but has some importance for some seed orchards.

The predicted gains of the second round seed orchards serving different areas of Sweden has been indicated on the target areas on maps of Sweden in Figure 1. These figures are based on estimates of the breeding values of the clones in the seed orchards and assume reasonable provenance transfer, thus that the seed orchard seeds are used in the intended area.

A gain thief is pollen contamination, probably only about half of the fertilizing pollen originates from seed orchard trees. Efforts to reduce this loss of gain have had only limited success. The contamination is an argument against small seed orchards, but seed orchards are anyway usually rather large for administrative and operative reasons. It is also an argument not to move seed orchards too far to the south compared with the origin of the clones. The location of the third round of seed orchards for harsh northern areas will probably be located a little more northern than the current seed orchards as the impact of the pollen contamination was not fully accepted during the second round program. Some of the valuable forest production in a stand origins from non-planted non-improved plants ("volunteers"), the currently used estimation is that on an average 80% of the forest production in plantations originate from the planted plants. Estimates of gain considering these two gain-reducing factors indicate that on average second round seed orchards of Scots pine increase forest production by 9.4 % and for Norway spruce 11.6 % compared to the production if seed orchard seeds were not used. If seed orchard seeds are used further away from where they are targeted compared to stand seeds that may reduce the realized gain somewhat, no estimates have been done.

Selfing and lack of diversity is predicted to reduce the possible gain from seed orchards, but only to a similar extent as stand seeds, and are thus not regarded as negative factors in the calculations in the study, at least not if the number of clones is not dropping lower than predicted for the third round of seed orchards (Prescher 2007). Selective harvesting where the offspring of the best

clones is used for plant production has been used in a few cases and an expanding use is predicted, but the contribution to realized gain is still small.

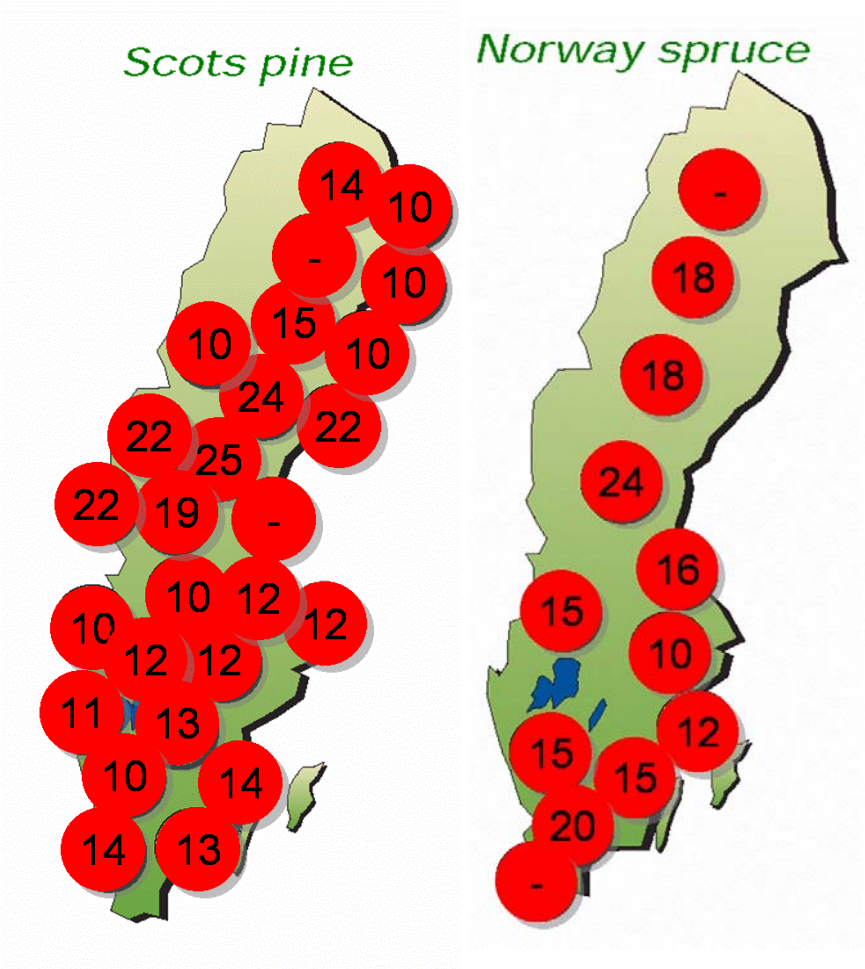

Figure 1. The genetic gain for the most modern existing seed orchards of Scots pine and Norway spruce established before 1998 (Rosvall et al 2002). The gain is an estimated percentage production advantage compared to stand seeds assuming only seed orchard progeny in the regeneration.

The added allowable harvestable timber in Sweden of seed orchards according the most probably scenario in accordance with current decisions and predictions was calculated by Rosvall (2007, personal communication). In Figure 2 this was compared with the impact of other suggested realistic methods to increase forest production (fertilization, clone forestry (SE), drainage, conversion of agricultural land to forest; contorta pine, better regeneration techniques) in a scenario considering economy, administrative constraints, likely technological development, environmental concerns,. As a reference level, the possible harvest was based on the forest maintainance and silviculture used during the 1990:s (SKA03) (Skogsstyrelsen 2004). The mentioned improvements were added to the reference level.

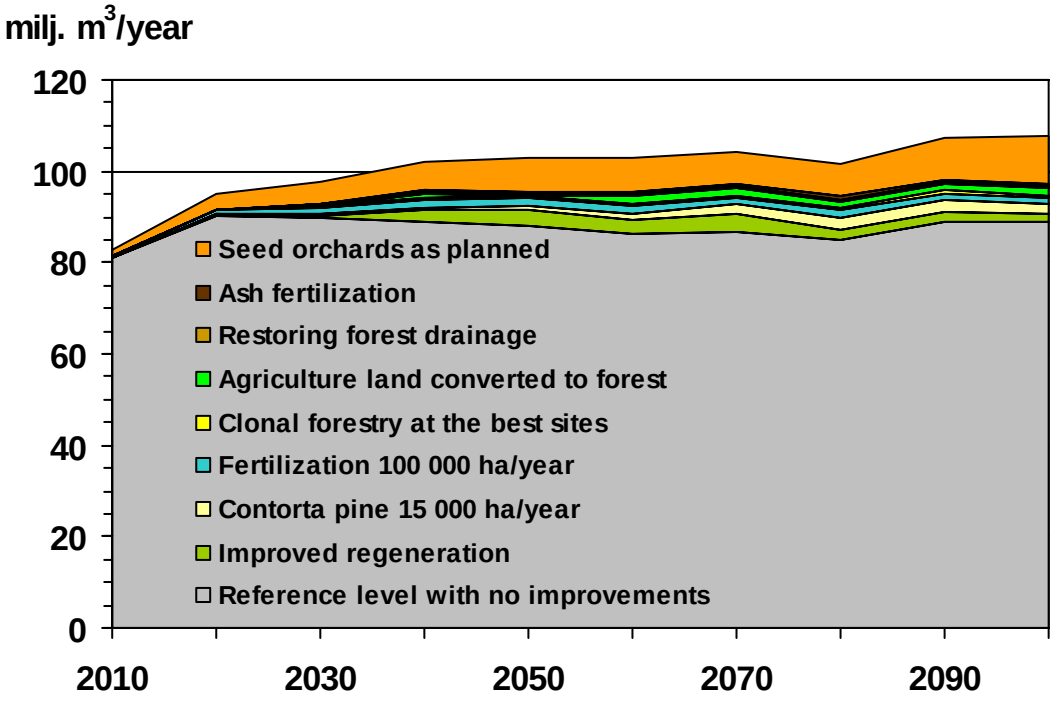

Figure 2. Allowable sustainable timber harvest in Swedish forests under different scenarios to increase production. For seed orchards it is the difference including the planned program compared to no seed orchards. The gain by seed orchards is considerable larger than all other options together.

Interaction and coordination of government, seed orchard owners, forest owners and research

The situation 2007 is that seed orchards or nurseries are not directly owned, controlled or paid for by the government or decisions under governmental control. The state controls formally Svenska Skogsplantor AB via shares in Sveaskog, but the ambition is to get it to work as a private company. Sveaskog owns about 35% of the plant production capacity and about 55% of the seed orchards. Other owners are large companies, forest owner associations, the church, and persons or companies in the plant business. Typically there are several owners to one seed orchard, but a single operative manager. The owners share seeds and costs. This shared ownership is managed in separate ownership groups for each seed orchard, and works well. A reason for shared ownership is that risks are spread; instead of one orchard per owner, the owners have shares in several orchards for the same utilization area, another reason is to get sufficiently large seed orchards and a third reason that many operators in many part of Sweden are to small to support own seed orchards.

For the second round of seed orchards (1982-1994) the coordination was lead by the government, and the establishment (but not the running costs after the first 5 years) was fully financed by governmental funds on condition that it was a part of the coordinated program. The grants originated from a forest tax, and that forest tax was discontinued 1992 and so the benefits derived from it like establishment of seed orchards. It took most of a decade till a similar coordinated program was initiated without state support.

For the third round three committees of interested organizations have been established for the three distinct geographic regions: north, middle and south Sweden. These groups meet currently around two times a year to discuss issues on the third round seed orchard program. Skogforsk has played an important role for getting a nationally coordinated third seed orchard round implemented. The state pays about half of the cost for the backing up long term tree breeding, which the current seed orchard program benefits from, through SkogForsk. The state also contributes to seed orchard research in a similar way.

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