The Direct Seeding of Temperate and Boreal Tree Species – A Review

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Summary

This essay was written as a part of my PhD project and will serve to introduce me to the subject direct seeding of forest trees.

The conventional method of using transplanted seedlings for forest regeneration is rather expensive and it would be beneficial for both commercial forestry and forest restoration projects if the costs of regeneration could be reduced. Direct seeding has the potential to be a cheaper way to create new forest, but at present there are a number of difficulties which need to be addressed before the method can be applied with a high expectancy of success. Before starting the direct seeding it is important to consider what locality is suitable and what tree species to use that is well adapted to that site. It is also essential to prepare the site carefully so that weeds are not out-competing the trees. Rodents predating on the seeds constitute a major problem to direct seeding why it is important that the area is as clean from slash and vegetation as possible, since mice and voles do not like large open places. Another important matter when dealing with direct seeding is that the seeds need to be stored and pre-treated properly. The way to do those things differ between species, but it is important to do it correctly to make the seeds germinate when expected.

There are still a lot of things concerning direct seeding that are unknown, particularly when it comes to temperate species, and more research is needed to improve the method. One of the main problems is the predation on seeds, and that is the focus of my PhD project.

Sammanfattning

Den här uppsatsen är en del av mitt doktorandprojekt och är tänkt att ge mig en introduktion i ämnet trädsådd på skogsmark.

Den konventionella metoden för skogsföryngring, att sätta plantor som är framtagna i en skogsplantskola, är ganska dyr. Därför vore det en fördel med tanke på både skogsrestaurering och kommersiellt skogsbruk om det gick att utveckla en billigare metod. Sådd på skogsmark kan bli en sådan metod, men i nuläget finns en del svårigheter som behöver uppmärksammas och åtgärdas innan metoden kan användas med tillräckligt stor säkerhet. Innan sådden påbörjas är det viktigt att tänka igenom vilka lokaler som är lämpliga och vilka trädarter som passar för den valda platsen. Det är också viktigt att markbereda så att vegetationen på föryngringsytan inte konkurrerar ut de sådda plantorna. Att smågnagare äter upp frön i sådder är ofta ett stort problem, och därför är det viktigt att ytan är så fri från hyggesrester och vegetation som möjligt, eftersom möss och sorkar inte tycker om stora öppna platser. En annan viktig sak vid sådd är att fröna lagras och förbehandlas på ett riktigt sätt. Hur detta skall gå till skiljer mellan arter, men gemensamt för alla är att fröna inte gror eller gror vid fel tidpunkt om förbehandling och lagring har misskötts.

Det är fortfarande mycket kring sådd av skogsträd som är okänt, i synnerhet när det rör sig om arter från den tempererade zonen, och mer forskning behövs för att förbättra metoden. Ett av de största problemen är fröpredation, och det är just det som mitt doktorandprojekt handlar om.

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2. Introduction

Regeneration is one of the big costs during a rotation age of a managed forest, and it is also the time when many decisions are made that will form the future stand and decide what possibilities there are to fulfil the goals of the forest owner. Therefore it is recommendable to thoroughly consider which method of regeneration to apply.

As the situation is today in many countries, it is not just the owner of a forest who have wishes and opinions concerning it. Both the local and the global society want to have a say in how the forest resources of the world should be utilised. In many places there is a wish to restore lands that formerly held forests but have been converted to farmland, pastures or mines during the expansion of mankind. Trees and forests are also a means when it comes to reducing global warming, the spread of deserts and the erosion of sensitive areas (Olschewski et al. 2005). To encourage the restoration of forests around the world it is important that the establishment does not constitute an insurmountable cost for the people who have to pay. Cheaper regeneration methods are of course also of interest in commercial forestry where the aim is to get as good a payoff from the forest as possible. Under those circumstances it is worth having a look at direct seeding as a method of forest regeneration.

This essay was written as a part of my PhD education, corresponding to 5 credits. The objectives are (1) to give me an overview of what has been done previously in my field of research and (2) to give me an idea of in what areas there is a lack of knowledge. The work is focused on the boreal and temperate tree species that are the most important ones in commercial forestry in Sweden, i.e. Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L. Karst.), Downy birch (*Betula pubescens* Ehrh.), Silver birch (*Betula pendula* Roth.), Sessile oak (*Quercus petraea* (Matt.) Liebl.), Pedunculate oak (*Quercus robur* L.), European beech (*Fagus sylvatica* L.) and European ash (*Fraxinus excelsior* L.). Henceforth the names used for these species will be pine, spruce, birch, oak, beech and ash respectively. The direct seeding of agricultural crops is not included unless it concerns techniques or machinery that can be used in forestry.

Literature searches were made with the search engine WebSPIRS in Forest Science Database, all years (1939–2005). The search terms I used were sowing, seeding, direct sowing, direct seeding, site preparation, soil preparation, oak, beech, ash, birch, pine, spruce, *Quercus robur, Quercus petrea, Fagus sylvatica, Fraxinus excelsior, Betula pendula, Betula pubescens, Pinus sylvestris* and *Picea abies* in different combinations with the Boolean search words AND and OR. I have also used literature recommended by supervisors and colleagues.

Direct seeding, direct sowing, seeding and sowing are different words for the same thing. In this essay all the terms refer to the practise where seeds are collected and then placed on the spot where they are intended to grow permanently.

3. Advantages with Direct Seeding

Direct seeding has the potential to be cheaper than planting. Seeds are not as expensive as seedlings (Madsen 2005, Bullard et al. 1992) and sowing is easier mechanized than planting (Wennström et al. 1999, Willoughby et al. 2004). In those cases where there is no need to fence the area against browsers and where the weed problem is lessened by a successful and dense-sown regeneration, the difference between the costs of direct seeding and planting will be even greater (Madsen loc cit.).

If the direct seeding is successful, Willoughby et al. (2004) claim that it will take much less time than when planting, until the seedlings provide a good ground cover and consequently suppress the competing vegetation. Hence the time when there is a need for weed-control will be shorter. The direct-seeded trees are not slowed down by a period of transplant shock the way nursery-seedlings are, which also helps speeding up establishment (Willoughby et al. loc cit.). A mixture of species among the sown seeds will further lessen the growth of weeds, if some of the seeds are from fast-growing species which are meant to provide a shelter for the main tree species (Madsen 2005).

The idea according to Willoughby et al. (2004) is that the directly seeded area will have a higher quantity of seedlings per hectare than the planted one, which gives many more opportunities when choosing quality stems for the future. When the trees are growing close together they help cleaning off branches on the lower part of the stems of the neighbouring trees, and water sprouts are kept back by the lack of light (Willoughby et al. loc cit.).

Madsen (2005) claims that the higher stocking levels also make the need of fencing less, because there are seedlings enough so some losses can be afforded. This is only accurate when the browser populations are small. According to Madsen there is also a possibility to sow several species, some of which are more preferred by the animals. This practice increases the possibility that the main species is left alone by the browsers.

The problem with pine weevils in conifer regenerations is greatest when the old stand has just been removed. Madsen (2005) claims that at this stage of the regeneration the sown seedlings are too small to suit the weevils' taste. On the other hand other observations (Edwards & Hall 2003) have found pine weevils to cause great problems also for small directly sown seedlings, probably at least during the first two years.

4. Disadvantages with Direct Seeding

Trees often produce seeds in masts, sometimes hard to predict and with many years in between, why the availability of seeds is unreliable. To get around this irregularity seeds are stored, but to do this, methods are needed to prevent the deterioration of the seeds.

Many tree species in temperate regions have seeds that fall into dormancy, which means that they will not germinate even if suitable conditions occur. This is a strategy to make sure that at least some seeds germinate at a time when the circumstances are also good for establishment. It is possible to break this dormancy beforehand, but it requires knowledge of certain properties of the seed and of course extra work (Gordon 1992b).

On many locations there is a great risk for the regeneration to be completely destroyed by predators (Armour 1963, Willoughby et al. 2004). This disadvantage is often related to seedling size, i.e. with increasing size the problem decreases. Also competition from ground vegetation is related to size, and seedlings emerging from seeds are initially very small and may therefore have greater problems with the competition than larger nursery transplants.

Normally, planting is a more reliable method than direct seeding. Even if all silvicultural measures are applied as they should, the result could still be a complete failure (Willoughby et al. 2004), in most cases because of predation (Watt 1919).

5. Where to Sow

Before sowing it is important to consider if the locality is well suited for the purpose, and what species will grow well on the site. Madsen (2005) suggests that if there are a lot of weeds from the beginning, sowing is probably not the appropriate regeneration method. Areas that are suitable are those where it is possible to use mature shelter-trees or nurse trees to reduce the growth of ground vegetation. On the other hand, Johnson (1981) found that there are drawbacks from using shelters since rodents, which are effective predators on seeds, are more active and abundant in covered areas (Fuller et al. 2004). To reduce this problem the area should be bare and quite large, because rodents avoid being out in the open if they can (Johnson 1981). In line with Johnson's findings, Madsen (loc cit.) also recommends sowing for example oak on clear-cuts after conifers to reduce the problem of seed predation.

Regarding soil texture Madsen (2005) recommends sowing on sandy soils since ground vegetation is usually not so aggressive there, which is in agreement with findings by Karlsson (1996) who has shown that the direct seeding of birch gives better results on sandier soils than where the soil is more fine-textured. Bergsten et al. (2003) recommend sowing pine and spruce on soils with medium sized particles to avoid both too dry conditions and frost heaving.

Holt Hanssen (2002) found that if spruce seed is to be sown without soil scarification, the emergence is better on *Sphagnum*-substrates than on for example *Deschampsia flexuosa* (L.) or *Vaccinium myrtillus* (L.), probably due to the moister environment in *Sphagnum.* Even better emergence can be expected on scarified soil.

Where agricultural land is planned to be converted into forest it is suitable to use direct seeding (Willoughby et al. 2004), because it most often concerns a large uncovered area and it is possible to make a thorough ground preparation and spray weeds. Some (Willoughby et al. loc cit.) even suggest that the only localities where it is recommendable with direct seeding of broadleaves is on former agricultural land. Sowing on former arable land will be discussed briefly later in this essay.

6. Choice of Suitable Species

Not only is it essential that the species and the genetic material chosen are well adapted to the site. Willoughby et al. (1996) also stress the importance to focus the seeding efforts on species with seeds that are possible to store and have a predictable germination pattern, or could be pre-treated to get those characteristics. To get an economical benefit compared to planting, the seeds should be cheap to make it possible to completely re-sow the area if the result the first time would prove to be a failure (Willoughby et al. loc cit.).

Species with reasonable prices and good establishment percentages after direct seeding are for example oak, beech, rowan (*Sorbus aucuparia* L.), spruce, Sitka spruce (*Picea sitchensis*

(Bong) Carr.), pine, Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco), European larch (*Larix decidua* Mill.), European silver fir (*Abies alba* L.) (Madsen 2005), ash, birch (Madsen loc cit., Willoughby et al. 1996), sycamore (*Acer pseudoplatanus* L.), cherry (*Prunus avium* L.) and Norway maple (*Acer platanoides* L.) (Willoughby et al. loc cit.).

7. Site Preparation

Site preparation includes all practices for preparing the site for regeneration. If there is slash left in the area to be removed, if the soil needs to be scarified or if the vegetation growth is so fierce that herbicide treatment is necessary – all those thing are included in the concept 'sitepreparation' (DiscoverTheOutdoors.com).

7.1 Weed Control

Willoughby et al. (2003) stress that weed control is essential for getting a successful regeneration through direct seeding and they claim that less time consuming and more cost efficient methods than hand weeding or the use of mulches are required. The problem with using different kinds of herbicides particularly for broadleaved species is, that some of the desired species may also be susceptible to the chemicals. Therefore it can be necessary to apply the herbicide early, which means February or at the latest early March, before the trees have started germinating or flushing. Research (Willoughby et al. 2003) indicates that at least two weeks should pass between herbicide application and the start of seed germination. Further spraying is done when necessary for as many years as is needed (around four years). Some damage can occur on the seedlings, but a high initial number accounts for this loss, which is less than the loss from competition would have been without herbicide treatment (Willoughby et al. 2004). It is important to note that for Swedish conditions the above recommendations are only valid for afforestation of farmland, since herbicides are prohibited on forest land (SFS 1998:808).

Löf et al. (2004) found that there is generally little effect of weeding on the establishment of large-seeded species (e.g. oak and beech). On the other hand they saw a marked difference in height growth, which improves radically with the removal of competition from ground vegetation. There is also a significantly decreased survival-rate if the seedlings are forced to grow in thick grass and herbs. This competition is detrimental for the young trees until they have grown above the vegetation, why it is important to continue the weed-control for several years (Löf et al. loc cit.). The main competition occurs below ground, mostly for water, and therefore it is not enough to remove vegetation through mowing (Löf 2000, Löf & Welander 2004). (figure 1)

Figure 1. Direct seeded oaks that have established themselves in vegetation. Photo: Maria Birkedal

Karlsson (1996) reports that deep ploughing, inversion of soil, and removal of top soil on abandoned fields keep the vegetation away for a longer time than rotary cultivation and ordinary ploughing do. If the vegetation is to be kept at bay, he suggests that it is necessary either to remove the top soil completely or overturn it and cover it with mineral soil, otherwise the seeds lying dormant in the uppermost part of the soil profile will start to grow. Karlsson also claims that application of herbicides has little or no effect together with soil preparation if it is done only before the scarification.

In Norberg et al. (2001) steam treatment is put forward as a measure to reduce the competition from heather (*Calluna vulgaris* (L.) Hull.) when sowing pine on nutrient-poor sites. The steaming is reported to have effect on ericaceous species, mosses and lichens even five years after treatment. Seedling biomass will be significantly larger on treated spots than on untreated spots. One of the benefits with the treatment is that the humus layer is undisturbed, why it can provide the growing seedlings with nutrients. Other benefits are that it is more environmentally friendly than herbicides and it disturbs the site less than for example ploughing does. Frost heaving is also reduced compared to treatments where the humus layer is removed (Norberg et al. loc cit.).

However, ground vegetation can actually be beneficial to the new tree generation under some circumstances. According to Karlsson (1996), grass and herbs reduce the risk of frost heaving and eliminate mechanical damage caused by rain drops on birch seedlings.

7.2 Prescribed Burning

After a fire it is sometimes appropriate to use direct seeding. It is important to spread the seeds as soon after the fire as possible since the seedlings will have problems to survive if grass and herbs are allowed to establish before the sowing (Anon. 1987).

Hancock et al. (2005) found that prescribed burning can be a suitable method of weed management and site preparation, before the direct seeding of pine on heath land covered with heather. They found the best effect following slow fires that reduce the litter layer significantly. To get this intensity to the fire they recommend burning during dry and calm weather. The results in the study indicate that even a couple of years after the fire, the conditions are good for regeneration of pine. Pohtila & Pohjola (1985) also found prescribed burning to work well together with the sowing of pine, although they propose that the time between burning and sowing should be as short as possible. On sites with a dense cover of wavy hair grass (*Deschampsia flexuosa* L.), heather or crowberry (*Empetrum nigrum* L.), it can be advantageous to burn before sowing spruce and pine because the fire successfully kills both the grass and the shrubs (Bergsten et al. 2003, Boström 2004).

Anon. (2004) has shown that the direct seeding of pine and Lodgepole pine gives better results than planting after burning. The result is further improved if the burning is supplemented by soil scarification.

A too frequent use of prescribed fire may deteriorate the nutrient status of the soil, and the fungus *Rhizina undulata* (Fr.) might establish and kill young seedlings (Bergsten et al. 2003).

7.3 Protection-Culture

A protection-culture provides different benefits for the regeneration. It can protect from drought (Löf et al. 1998, Anon. 1947), frost, winds (Anon. 1947), and sun scorch (Watson 1994). When designing shelters, the different characteristics of the species at hand should be taken into account. The major factor, which separates the trees dealt with here, is whether they are a pioneer or a secondary species. The special properties of these two types of trees can shortly be described as follows (Anon. 1996) (table 1):

Table 1. Tree species showing pioneer and secondary characteristics (after Anon. 1996).

Pioneer	Intermediate	Secondary
	Ash	
		Beech
	Oak	
Birch		
		Spruce
Pine		

Pioneers are light demanding and are the first to come up after natural disturbances in a forest, like wildfires or storms. These trees are generally not very sensitive to frost and most often grow rapidly, particularly when they are young. When regenerating pioneer species under a shelter, this should be sparse. Examples of pioneer trees are pine and birch (Anon. 1996).

Secondary species on the contrary, often grow slowly but can sustain themselves under quite dense canopies. Under natural conditions these kinds of trees come up under the pioneers and consequently are protected from frost events and direct sunlight. Therefore it is appropriate to use a denser shelter when regenerating secondary species. Examples are beech and spruce (Anon. 1996).

Oak show the characteristics typical of each of the above groups and therefore is difficult to place. For example oak seedlings are rather tolerant to shadow but older trees are very light demanding (Anon. 1996).

As mentioned above, beech is a shade tolerant species that preferably should be regenerated under a shelter so that it does not get damaged by frost. In southern Germany, Ammer et al. (2002) tried sowing beech nuts under a canopy of spruce and found that the main restraint on germination is soil moisture. To improve the conditions they recommend a thinning of the overstorey just before the sowing takes place. This way the underground competition for water from the mature trees will be less, and the amount of precipitation that reaches the ground increases. Ammer et al. did not experience seed predation to be the major problem to prevent germination, even though they used a shelterwood and detected remnants of seeds left by rodents. In a similar study Leder et al. (2003) found that young beeches had a higher growth rate the sparser the canopies of spruce were. The result was the same even when the beeches were growing without any cover at all. The total number of seedlings, on the other hand, was higher under a medium dense canopy.

Oak too, is tolerant to low light levels during the first year after sowing, why it is good to use a shelter for oak as well (Welander & Ottosson 1998). According to Welander & Ottosson it is then important to open up the shelter quite soon, since oaks become more and more light-demanding with age. The shelter should be thinned with care during a longer period of time so it does not get too sparse, because then the ground vegetation will cause more problems for the young oaks than the canopy trees would have done. The ground vegetation reduces not only the incoming light, but also the availability of water and nutrients (Welander & Ottosson loc cit.). Von Lüpke (1998) argues that for oaks of around ten years of age, the growth does not decrease until the rate of incoming light falls below 40%. Accordingly, it should be possible to retain the shelter for at least this long without severely restraining the growth of the young oaks.

Although a pioneer, pine might also benefit from sowing under a shelter. The small pine seeds are highly dependent on moisture to be able to germinate, and the conditions on a clear-cut are unstable and often too dry (Oleskog & Sahlén 2000a). If the seeding is done under a partially cut stand the canopy will reduce the variations in temperature between day and night. It will also change the amount of direct incoming solar radiation which otherwise might dry out the seeds and the seedbed (Oleskog & Sahlén 2000b).

When it comes to the density of the shelter, it depends very much on the site properties and what species that are to be regenerated. If the location is very rich, it is preferable to leave a denser shelter so that it will be able to hold back the competition from ground vegetation. As an example Béland et al. (2000) show that for pine in southern Sweden a shelter of 200 stems per hectare is adequate.

One reason for the use of nurse trees, particularly when hardwoods are the main species, is to get an early return from thinning the nurse trees (Anon. 1947). The idea with using nurse trees is that a faster growing species should be used to provide a shelter for the main trees and therefore earlier incomes from larger trees in thinnings can be expected. It has been suggested (Anon. loc cit.) that larch is a good nurse species for oak, while for beech pine and birch are better suited since the beech soils are not good for larch.

Madsen (2005) strongly recommends the sowing of mixtures of different species, since it increases the chance for at least one or a couple of the species to manage to come up with a satisfactory amount of seedlings. This recommendation is particularly important when sowing conifers. Another benefit with mixtures, Madsen claims, is if some of the seeds are from species intended as nurse trees for the main species and consequently grow fast and decrease the competition from ground vegetation. Beech, for example, can preferably be sown together with other more fast growing species which can provide frost protection quite rapidly.

If seeds from many different species are sown together, Willoughby et al. (2004) recommend trying to get them in species-groups. This will increase the possibility for the species to be present in the final stand. It will of course be difficult to do if the seeds are machine-sown (Willoughby et al. loc cit.).

7.4 Mechanical Site Preparation

If the seed is placed in organic matter there is a great risk that it will never germinate, because the ability of the material to hold water available to the seed is poor (Béland et al 2000). The problem of frost heaving is more urgent when seedlings are established in mineral soil (de Chantal et al. 2003), particularly if the soil particles belong to the finer fractions. Frost heaving also depends on the local climate and the amount of water held in the soil (Karlsson 1996), as well as on snow cover and the size of scarification patches (Goulet 2000). Not all seedlings die immediately when subjected to frost heaving, but de Chantal et al. (loc cit.) found that the root systems may be severely damaged and therefore the seedlings might die from drought during the following growing season.

Béland et al. (2000) found that the proportion of pine seeds that germinated was higher when the seeds landed in pure mineral soil than when it was mixed with humus. On the other hand Bergsten et al. (2003) propose that the best substrate for the germination and establishment of conifer seeds is a mixture of mineral soil and humus, since both the need of oxygen and the water supply can be satisfied in such seedbeds. After birch seedlings are established on abandoned fields, growth might be better if the mineral soil that the seedlings grow in is mixed with organic matter (Karlsson 1996).

Silfverberg (1995) found a positive effect on the germination of birch and pine when seeds were sown on mounds on drained peat land, compared to the same conditions but unmounded. The positive effect was probably due to a reduction of the competition from ground vegetation and an increased mineralization of nutrients (Mannerkoski 1975 cited in Silfverberg 1995). Bergsten et al. (2003) propose that the sowing of conifers on mineral soil upturned on the humus layer is not to be recommended, since the capillarity of the soil is interrupted by the treatment.

In Karlsson (1996) it is stated that ploughing to different depths on abandoned fields can be beneficial for regeneration, because the ground vegetation is disturbed quite severely, though it does not last for very long if the ploughing is shallow. The benefit can be seen both on establishment and growth after deep ploughing (Karlsson loc cit.). However, frost heaving may be troublesome when using this method of scarification (de Chantal et al. 2003), and Pohtila & Pohjola (1985) suggest that ploughing is not a good soil preparation method when sowing pine.

For the sowing of conifer seeds de Chantal et al. (2003) recommend the use of a soil preparation method in which the humus layer is removed, so the seeds are put on mineral soil mixed with organic matter. This is because of the beneficial water-holding capacities of such a layer, and its availability of nutrients. Of the different commercial soil preparation methods this is the one most similar to disc-trenching. Results in Pohtila & Pohjola (1985) also show this method to work well in combination with the sowing of pine.

When sowing in strips, the seeds are put one by one a little distance apart in the scarified furrow. This is a good way to sow if intra-specific competition is to be reduced (Wennström et al. 2001). If the direct seeding of pine is to be done in scarified patches, Wennström et al. (2001) suggest that it is better to make many small patches that are closer to each other than to make larger ones with many seeds in each. In the smaller spots just a few seeds are put together and thus the competition and the consequent reduction in growth will be less (Wennström et al. loc cit.). The need for pre-commercial thinnings in the future will also be less.

A way to prepare an abandoned field for regeneration of birch is presented by Karlsson (1996) and consists of the complete removal of the top layer of the soil. The advantage with this is that the competing vegetation is completely destroyed and will not be invading again for rather a long time. The problem is that when all the ground vegetation and all the organic material is gone from the site, the seeds and the young seedlings are damaged by the mechanical force from raindrops. Apart from the direct impact when the drops land on the birch seeds, rain can be detrimental through erosion. Small seedlings with shallow root systems can also be swept away by the running water (Karlsson loc cit.). Larger seeds like acorns and beech nuts do not suffer as badly from this as the smaller seeds do.

According to Bergsten (1988), pine seeds benefit from being sown in small indentations in the ground. The holes are shaped like pyramids turned upside down, and the idea is that the seed is placed at the bottom of the hole and then the soil will erode down on top of the seed and provide it with a cover. This type of preparation also improves the moisture conditions on the micro-level. Better germination has been shown for pine when using microsite preparation

(Bergsten loc cit., Winsa & Bergsten 1994). Wennström et al. (1999) got the best results on establishment and survival of pine when the ground was first scarified to mix the mineral soil with organic matter, and the microsite then prepared with the upside down pyramids. If orchard seed was used the effect was even better.

8. Seed Handling

8.1 The Collection of Seeds

Seed collection routines depend on species (table 2).

Table 2. Seed characteristics of the different species (after Anon 2005, Gordon & Faulkner 1992, Övergaard 2004).

	Ash	Beech	Oak	Birch	Spruce	Pine
Periodicity of mast years	2–3 years	2–7 years	2–7 years	1–2 years	4–5 years	2–3 years
Time of seed/cone collection	Oct–Nov	Sept–Oct	Oct–Nov	Jul–Aug	Dec–Feb	Dec–Feb
Moisture content of seeds during storage	8%	8%	35%	5%	7%	7%
Temperature of seeds during storage	-4ºC	-5ºC	-2ºC – 4ºC	-3ºC	-4ºC – 4ºC	-4ºC – 4ºC
Maximum storage time for seeds	5 years	5 years	2 years	5 years	15 years	10 years
Pre-treatment needed	yes	yes (can be done before storage)	no (only imbibition)	no (only imbibition)	no (only imbibition)	no (only imbibition)

Recommendations (Anon. 2005) are that seeds from ash should be collected when they have attained a brown colour, which usually occurs from the middle of October until the end of November. If they are collected earlier, when still green, they cannot be stored. Good seed crops occur every two to three years. The gathering of seeds is most often done by hand. A tree-shaker can be used, but then the collecting has to be performed close to the natural seed fall (Anon. loc cit.).

Beech seeds can be gathered from the ground, after the natural seed fall, from the middle of September to the end of October (Anon. 2005). If the seeds are collected this way Simak (1993) claims that it becomes much easier if the ground has been cleared in advance or if a tarpaulin is spread out to catch the seeds. For beech as well as for ash it is possible to use a machine that shakes down the seeds. Putting up nets where the seeds are caught when they fall from the tree is another possibility. The first seeds to fall are usually empty, why it is good to wait for two weeks after the seed fall has begun before starting the collection (Simak loc cit.). If nets are to be used they should be removed at the beginning of December. Good beech mast years occur with three to seven years in between (Anon. loc cit.), or even every second year (Övergaard 2004).

According to Anon. (2005) there is usually a good oak-mast with two to seven years in between. In a seed year the collection starts when the acorns have turned from green to brown, which normally occurs from the middle of October until the beginning of November. Collection can be done either in nets or on the cleared ground under the trees. It is important that the collection is done in dry weather, so the acorns are not covered by wet soil which is hard to remove. The acorns should be picked off the ground as soon as possible to lessen the risk of infection from fungus (Anon. 2005). For acorns as well as for beech nuts it is better to wait until the seed fall has been going on for a while, before the collection starts. That is because the first seeds to fall are usually poor (Anon. 1947). Signs of bad seeds are pale pericarps or very light acorns (Johnson & Krinard 1985).

In the recommendations by Anon. (2005) it can be seen, that birch seeds are ready to collect when they turn from green to brown, which occur from July to the beginning of August. A good seed year for birch can be expected, if not every year, so at least every second year (Anon. loc cit.). Gordon (1992a) recommends collecting the seeds by hand, through ripping the catkins off the branch together with the leaves or through cutting off entire branches. It is also possible to put tarpaulins under the trees and shake until the catkins fall off (Gordon loc cit.). To get the seeds out of the catkins they are crushed and then tumbled in a net-tumbler to sort the seeds from leaves and twigs (Anon. loc cit.).

The seeds of spruce should, in accordance with the recommendations by Anon. (2005), be collected between December and February when the cones have turned from green-violet in colour to brown. A good spruce-mast can be expected every four to five years (Gordon & Faulkner 1992). To gather the cones it is possible to climb the trees, to use a lift or to fell the trees (Gordon 1992a). The cones should then be left to mature for another three to four weeks. After that they are dried and tumbled so that the seeds fall out (Anon. loc cit.).

For the collection of pine seeds there is the same procedure as for spruce (Gordon 1992a) – climb the trees, use a lift or fell the trees to get the cones. This is also to be done between December and February, when the cones have turned from dark green to grey. Leave the cones to mature for one to one and a half months before drying and tumbling (Anon. 2005). Seed years happen every second or every third year (Gordon & Faulkner 1992).

8.2 The Pre-treatment and Storage of Seeds

The requirements of the treatment of seeds between collection and sowing are, just as the collecting, different depending on what species it concerns. Some seeds (for example acorns) need to keep a high moisture content (table 2) through the whole storage period (Gosling 2002), why they are much more difficult to handle than for example pine seed.

Ash seeds can, according to recommendations by Anon. (2005), be stored for three to five years if they are kept at a moisture content of around 8% and put in plastic bags without air contact. The temperature should be approximately -4ºC. After storage they need to be pre-treated to be able to germinate. First the seeds are kept in running water for two days to imbibe (Anon. loc cit.). After that the way to get most seeds germinable is to stratify them in a moist medium (peat moss) and subject them to warm treatment (25ºC) for ten weeks and then cold treatment (5ºC) for twelve weeks (Piotto 1994).

When beech nuts are stored they should have a water content of about 8% and be stored at around -5ºC in airtight plastic bags. This way they can be stored for up to five years (Anon. 2005). Formerly the dormancy was broken through keeping the seeds at a temperature of 3ºC for at least eight weeks and in a wet medium. Falleri et al. (2004) propose a method where it is possible to break the dormancy without having to keep the seeds in a medium. The seeds are just kept moist (~30%) at a low (3–4ºC (Anon. loc cit.)) temperature and this way they come out of dormancy, but they do not risk germinating too early. This makes it possible to keep the seeds in pre-treatment until even the slowest ones are non-dormant. This procedure can be performed either before or after their time in storage (Falleri et al. loc cit.). It is dependent on the quality of the seed lot how long time this will take (Anon. loc cit.). Falleri et al. (loc cit.) argue that it is more beneficial to pre-treat the beech nuts before they are put to store. The reason is, that the seeds then are ready to sow as soon as the time and weather is suitable. It is no longer necessary to undertake pre-treatment well in advance in the spring, and thereby be dependent on how long the seeds have been subjected to treatment before they can be sown. Instead the seeds can be taken directly from imbibition to the field and be ready to germinate at once.

For beech nuts that are to be kept for long term storage, Tylkowski (2002) stresses that it is crucial to know that it is a good seed lot, not carrying too much fungal infection. Therefore it is good to test the seed lots after collection. A sample of seeds is removed from their pericarps and kept at 25ºC in moist tissue paper for 120 hours. After that they are checked to see how many of the seeds are infected with mould or fungi. If the viability after the test has decreased by more than 20%, the batch should not be designated for long term storage (Tylkowski loc cit.).

According to Gosling (2002), storage of acorns is difficult since they need to have a high (at least 35%) moisture content at all times and consequently are prone to fungal infection. Seeds cannot be kept in an airtight environment because respiration never ceases. Temperatures have to be low so that the growth of fungus is slow, but the acorns cannot tolerate temperatures below -3ºC without dying. Therefore, somewhere between -2ºC and 4ºC is optimal. It is preferable to store the acorns spread out in a cool place in rather shallow layers, and to spray them with water and turn them at regular intervals. To avoid destruction of the stored acorns by fungi, Gosling suggests a couple of possible treatments: fungicides, thermotherapy or a combination of the two. Fungicides have the drawback that they can harm the seeds and thermotherapy is difficult with large quantities of acorns. This is why neither of the treatments is used to prevent infection but only to stop or at least slow it down once it has already begun. Thermotherapy means that the acorns are kept in water at 41ºC for two and a half hours. The temperature must be exact, otherwise the acorns might die or the fungus might survive (Gosling loc cit.). There is also the possibility to fight the fungus biologically. Finch-Savage et al. (2003) found that *Trichoderma virens* (belonging to a subclass of fungi (Doe Joint Genome Institute)) can prevent fungi from infecting healthy acorns if it is applied in a coating on the seeds. If the seeds are already infected, thermotherapy is more efficient. The best effect is obtained when *T. virens* is applied on the seeds after they have gone through thermotherapy (Finch-Savage et al. loc cit.). When it is time to sow, it is possible to take the acorns directly from storage and put them out into the field, but according to Anon. (2005) the germination will be sped up if they first are kept in running water for one or two days. Another possibility is to increase the moisture content more slowly over three to four weeks. Acorns can be stored for maximum two years (Anon. loc cit.).

Because of the difficulties to keep the acorns from fungi, it is important that seed lots with high initial infection are not chosen for long term storage. The problem is, that it can be hard to tell from newly collected seeds how many are carrying fungi. Schröder et al. (2004) developed two methods to quickly determine the rate of acorns infected by the fungus *Ciboria batschiana* (Zopf.) Buch. The first method means that a visual examination of the cotyledons is done. After careful removal of the pericarp it is possible to see dark lesions on the cotyledons of infected acorns. If many of the seeds in one lot are infected it should not be used for long time storage. Their second method requires more work and space in a laboratory. The cotyledons are placed on moist paper in 15ºC for one to two weeks, and then the rate of infection is decided from the number of cotyledons from which a dark mycelium of *C. batschiana* has grown. Highly infected batches should be subjected to thermotherapy and not stored long term (Schröder et al. loc cit.).

Anon. (2005) recommends that birch seeds are best stored in an airtight environment at about 5% moisture content and a temperature of -3ºC. This way they will keep for up to five years. Before sowing it is best to put the seeds in running water for one or two days. If they are moistened over a longer period there is a great risk that they will germinate beforehand (Anon. loc cit.).

If spruce and pine seeds are kept in an airtight cold (-4ºC to 4ºC) environment at a moisture content of around 7%, spruce can be stored for up to fifteen years and pine for at least ten years. No pre-treatment except imbibition in running water for 24 hours, is required before sowing (Anon. 2005).

Winsa & Sahlén (2001) showed that pine has a higher germination rate if the seeds are invigorated before sowing. The invigoration is done by keeping the seeds at 30% moisture content for 7 days in 15ºC. Together with microsite preparation this improves the germination significantly (Winsa & Sahlén loc cit.).

Results from Wennström et al. (2001) show that pine sowings benefit from the use of a mixture of orchard seed and stand seed. Orchard seed is more expensive but the height and volume growth is higher than for stand seed. Mixing the two kinds of seeds is good because then the orchard seed can provide seedlings with good growth, and the stand seed will add the numbers so that there is a possibility for quality production (Wennström et al. loc cit.). A great part of the reason why orchard seed grows better than stand seed is that the orchard seeds are heavier (Wennström et al. 2002).

9. At the Site

9.1 The Time of Sowing

Seeds that have not yet broken dormancy completely can, according to Madsen (2005), preferably be sown in the wet and cold soil of early spring to be given the opportunity to come out of the dormant state. For oak and beech though, this may cause major losses of seeds to hungry rodents. If the year before was a good mast year the populations could still be high in early spring, but the food resources are running out. Therefore the seeded nuts might appear at a perfect time for the rodents to sustain them, until the new production of food starts later in the spring. Early spring sowing may also cause problems for the small seedlings because the risk of frosts is greater. If the seeds are properly pre-treated, there is no problem sowing in May–June when the soil is warm, unless the soil is sandy and therefore risk drying out (Madsen loc cit.).

de Chantal et al. (2003) found that if the soil is fine-textured, it is better to sow in the spring than in the summer, so the root systems have more time to develop and consequently reduce the risk of frost heaving. Overall it is recommended to sow conifer seeds in the spring (table 3) to reduce the problem of too dry conditions for germination (de Chantal et al. loc cit.).

The autumn sowing of temperate tree species has according to Madsen (2005) the benefit that no storage is needed, and the seeds break dormancy during winter. Drawbacks are the longer period the seeds are exposed to predation from animals. Moreover, the risk of attacks by insects and fungi also increases. Furthermore there is the problem of frost damage to early germinated seedlings (Madsen loc cit.).

Table 3. Suitable months to sow the different species (after Anon. 1947, Karlsson 1996, Winsa & Sahlén 2001, Anon. 2005, Viherä-Aarnio 2005).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ash				x								
Beech				x	x					x	x	
Oak		x	x	x	x					x	x	
Birch	x			x	x							x
Spruce					x							
Pine					x	x						

It is recommended (Anon. 2005) to sow ash from the beginning to the middle of April (table 3), before the soil temperature exceeds 15ºC. Piotto (1994) recommends sowing ash during a time of year when the temperature variations between night and day are as big as possible, which implies early spring. If the soil is too warm when the seeds are put out in the field, a second dormancy may be induced (Piotto loc cit.).

The sowing of beech and oak could according to Anon. (2005) be done either in the autumn, when a higher risk for great seed losses has to be considered, or in the spring (table 3). Beech nuts should then be sown between the middle of April and the middle of May, and for oak the end of March until May is recommended by some (Anon. 2005), while February/March is suggested by others (Anon. 1947).

Birch can be successfully sown on snow around the New Year, if the temperature is about -5ºC (Anon. 2005). Other possibilities are autumn sowing (Anon. 2005) or spring sowing from April (Anon. 1947) until the middle of May (Anon. 2005) (table 3). Karlsson (1996) found that direct seeding of birch gave better results when done in the spring than in the autumn. Birches sown at the end of May get a longer vegetation period than those sown in June or July, even if those later sown prolong their season in the autumn (Viherä-Aarnio et al. 2005). In addition to the height of the later sown seedlings being lesser than the earlier sown after the first year, the risk of frost damage in the autumn increases with later sowings because of the later growth cessation (Viherä-Aarnio et al. loc cit.).

Spruce and pine seeds are to be sown in May (table 3), as are most conifer seeds (Anon. 2005). Winsa & Sahlén (2001) found that the germination of pine in northern Sweden was best for seeds sown at the end of May and in June. The survival of seedlings sown in July and later was low, why their recommendations are not to sow later than the end of June.

9.2 Seed Dosage

To decide the appropriate amount of seed that should be used for a particular seed lot, it is good to have an idea not just about the viability of the seeds but also how many are likely to really emerge and form seedlings in the field. A method to do just this, for beechnuts, was developed by Jensen (2002). The seeds should be sown in a moist paper roll and kept at 15°C for twenty days. After that the length of the roots is measured. There might be differences from one place to another as to how long the roots must have grown to correspond to a seedling established in the field, but the critical root length can be determined from place to place. Jensen found it to be 45 mm.

In addition to estimating how many seeds in the seed lot are likely to emerge it is important to consider how many seedlings that are wanted per hectare. It is recommendable to aim for two to three times as many seedlings as when planting (Madsen 2005).

To account for all possibilities Willoughby et al. (2004) recommend sowing at least 200 000 viable seeds of broadleaves per hectare, both main species and help species included. Depending on the viability of the particular seed lot to be used, the number should be accommodated. When sowing large-seeded species like oak Willoughby et al. suggest that the number could be reduced by half. Johnson & Krinard (1985a) recommend sowing around 3 750 acorns per hectare (1 500 per acre) for southern American conditions and southern American oak species. Almgren et al. (2003) suggest 20 000 oak seeds per hectare for Sweden, which is about the same amount as Møller-Madsen (1992) proposes.

Wennström et al. (1999) conclude that if the target density for the regeneration of pine in northern Sweden is 5 000 stems per hectare established after four years, which is recommendable, the amount of germinable orchard seeds per hectare needs to be 28 100. If stand seeds are used the corresponding amount is 41 100. Those numbers are practicable with microsite preparation. Without that, the amount should be doubled. If another density is wanted the numbers have to be adjusted accordingly.

9.3 The Covering of Seeds

It is good to consider what type of soil the seeding is to take place in and how high the humidity is in the area, before deciding on seeding depth. When sowing pine seeds on sand or organic matter, Oleskog et al. (2000) found that it is beneficial to cover the seeds at least partially, if the area is normally dry. This is to stop the seeds from being desiccated since soils with coarse particles dry out easily. If the soil particles are small, it is better to leave the seeds uncovered unless the area is very dry. Silts and other soils with finer particles hold water better and therefore the risk of oxygen deficit is greater, since the soil pores are filled with water (Oleskog et al. loc cit.).

Species recommendations (table 4) are that beech should be buried to a depth of 2 cm (Anon. 1947, Anon. 2005) and oak at 5 cm (Anon. 1947, Johnson & Krinard 1985b, Nilsson et al. 1996). Other suggestions for oak are 10 cm (Willoughby et al. 2004) and 2.5 cm (Johnson 1981). Smaller seeds like birch do not need to be covered at all, and conifer seeds should just be covered by a thin sheet of soil – 0.5 to 1 cm is enough (Madsen 2005).

Table 4. Seeding depths of the different species (after Anon. 1947, Johnson 1981, Johnson & Krinard 1985b, Nilsson et al. 1996, Willoughby et al. 2004, , Madsen 2005, Anon. 2005).

	Ash	Beech	Oak	Birch	Spruce	Pine
Seeding depth	-	2 cm	2.5–10 cm	0 cm	0.5–1 cm	0.5–1 cm

9.4 Protection from Predation

There are many species of animals that are prospective seed- or seedling-eaters. The most detrimental ones are roe deer (*Capreolus capreolus* L.), rabbit (*Oryctolagus cuniculus* L.), bank vole (*Cletrionomys glareolus* Schreber) (Ashby 1959, Willoughby et al. 2004), yellow-necked mouse (*Apodemus flavicollis* Melchior), wood mouse (*Apodemus sylvaticus* L.) (Ashby loc cit.) and a variety of bird species (Tanton 1965) (Watt 1919).

Nolte & Barnett (2000) suggest that methods to keep predators away work differently on different species. Repellents may have more effect on animal groups like birds that have larger home ranges and easier to move to other foraging areas, while for example rodents have smaller territories and consequently are more dependent on the food sources available in their home area.

9.4.1 Mechanical

Figure 2. Complete removal of ground cover reduces rodent damage. Photo: Magnus Löf

The complete removal of ground cover is one mechanical treatment reported to have a good effect on rodents (Johnson 1981, Karlsson 1996) (figure 2). Larsson (1975) tested several different site preparation methods and their effect on rodent populations. He found prescribed burning to have some effect, and treatment with herbicides led to a slight decrease in rodent occurrence. Generally the effects of soil scarification were negligible, and the effects of the burning and herbicide treatments were over in just a few years.

The burying of seeds is a good way to minimize seed eating by birds since they use eyesight for finding the seeds. Normally, rodents will find even buried seeds since they use their olfaction to locate their food (Vander Wall 1998). In spite of this Nilson & Hjältén (2003) found that the amount of pine seeds taken by bank voles was reduced when the seeds were covered.

Fences are the most frequently used mechanical obstruction for keeping out large animals like deer, and a fence with a very small mesh size (9×5 mm^2) buried to the depth of about 30 cm would be effective against the small mammals as well (Shaw 1968). Unfortunately this is not economically possible (Hayes 1913) except for fencing nurseries and seed orchards.

9.4.2 Chemical

Anon. (1947) suggests that acorns and beech nuts should be treated with a mixture of paraffin, water and soft soap and then be coated with a thin layer of red lead (an oxide of lead) before they are sown. This is supposed to prevent predation from both rodents and birds. After reviewing available literature, Armour (1963) reported that the most efficient chemicals for repelling rodents seemed to be thiram, endrin, ziram and hexachlorophene. For birds thiram, anthraquinone or coating with lime-wash showed the best effects. Nolte & Barnett (2000) found a mixture of thiram and capsicum to work as a repellent on two rodent species (house mouse (*Mus musculus* L.) and deer mouse (*Peromyscus maniculatus* Wagner)) when applied to longleaf pine (*Pinus palustris* P. Mill) seeds.

9.4.3 Biological

One biological way to reduce rodent damage in broadleaf sowings is to use large open areas for direct seeding. Regeneration sites should be one hectare or more, and they should be clear of ground vegetation and slash (Johnson & Krinard 1985a). If surrounding forests consist of broadleaves, it is better to sow in the spring following a good mast year (Baumhauer et al. 2005), because then there is plenty of food for the rodents already. In line with this idea is the practise of putting out supplementary food to keep the animals away from the intended crop. It has been successfully attempted by Sullivan (1979) in conifer sowings where deer mice are usually a problem. The alternative fodder he used was sunflower seeds and oats.

Another way to decrease the populations of one species is predation from other species. There are several predators feeding on small rodents, and Jędrzejewski & Jędrzejewska (1993) concluded that this was the major reason for decreases in populations in wintertime. Because of this, one possible way to protect seeds and seedlings from rodent damage would be to, in one way or another, increase the predator populations.

Biological control of birds has been tested (Knight & Robinson 1978) through recording the warning call of a detrimental species (e.g. *Zosterops lateralis* Latham) and then broadcasting it over plantations where the protection is needed. It will only work over smaller areas where the sound can be thoroughly heard and on species that have certain calls for warning against dangers. Under those circumstances effect could be seen from the method. It has also been found (Armour 1963) to work for other bird species, for example starlings (*Sturnus vulgaris* L.).

Ashby (1959) proposes that monocultures and uniform landscapes increase the damage done by rodents, since population sizes increase drastically in certain places where the habitat is favourable, why a more heterogeneous management could reduce the impact. Watt (1919) also considers it the fault of mankind that the regeneration of oak is unsuccessful. He suggests that either humans must take total control and decrease the populations of the small mammals or their predators must be allowed to live.

10. Machines for Direct Seeding

There are several different types of machines for the direct seeding of forest trees. Some of them are based on agricultural equipment but with modifications to be able to sow forest tree seeds. Those are perhaps more suitable for the afforestation of farmland or for easily accessible forest regeneration sites. Then there are sowing machines specially developed for the sowing of forestland, which should be more tolerant to uneven ground conditions, rocks and other complicating circumstances. Only some of the machines will be discussed here.

Egedals oldensåmaskine can both scarify the soil and sow acorns and beechnuts. It is possible to fit more than one sowing unit to the machine which is an advantage on large areas. This equipment is constructed for sowing on old fields (Møller Madsen & Honoré 1992).

Figure 3. Direct seeding can be done with a planting tube. Photo: Maria Birkedal

TTS-Sigma® is a seeding machine which blows out the pine seeds onto the ground. The seeds are shed continuously and therefore some seeds will end up in unscarified soil (Wennström et al. 1999). TTS Sigma II is another unit for sowing conifer seeds and was evaluated by Edwards & Hall (2003). It is to be mounted on a scarifier and the flow of seeds can be adjusted to come either in a constant flow or at intervals, depending on how the machine is scarifying. The results with this machine risk becoming a little patchy if there are obstacles like stumps or rocks on the site. To use this equipment, clean seedlots are necessary since resin easily sticks in the delivery tubes and this malfunction cannot be detected from the driver's cabin (Edwards & Hall loc cit.).

SeedGun is a unit to be fit onto another machine, in this case an excavator used in forestry, and it was examined by Edwards & Hall (2003). There are nozzles, through which the seeds are delivered, placed on the excavator arm. The operator of the machine pushes a button to sow the seeds when a mound has been created with the bucket. The idea is that the seeds should end up on the mound to get a good germination environment. Unfortunately there can be some difficulties with the precision of this, until the operator has got used to the equipment (Edwards & Hall loc cit.).

Baumhauer et al. (2005) used a sowing device that was pulled by a tractor. The machine first scarifies and then sows. The amount of seeds to be put into the soil is determined by the driver. The equipment can sow both conifer and broadleaf seeds. It will take approximately one hour to sow one hectare of forest with this machine.

Other less mechanized ways of getting seeds into the soil are using a planting tube (figure 3), a shovel (Madsen 2005) or seed drills (Willoughby 1996).

11. *Sowing on Former Agricultural Land*

Figure 4. Successful direct seeding of oak on farm land. Photo: Magnus Löf

The direct seeding of broadleaved forest trees on arable land is, according to Willoughby et al. (1996), associated with fewer uncertainties than the same practice on forest land. On agricultural land it is possible to use the same machines as for crops; they will just need a little modification. The soil is easier to prepare than forest land and can be ploughed in spring or autumn. To further hinder weeds from invading the area, the ground can be sprayed with herbicides prior to sowing (Willoughby et al. loc cit.). The best soil preparation method to use when sowing on former fields is deep ploughing, which gives good results for birch when it comes to both establishment and the subsequent growth (Karlsson 1996).

When preparations are finished it is possible to sow the tree-seeds either by themselves or together with the last crop. There are different opinions as to whether the crop will provide protection or competition, in the first place, to the seedlings. According to Watson (1994) the crop and the stubble will give shelter for the new trees, from browsers and rodents as well as from frost, desiccation, and sun scorch. Willoughby et al. (1996), on the other hand, claim that there is not much to gain from using an arable crop as a cover. Madsen (2005) feared that the cover-crop would provide a good protection for rodents and consequently be detrimental to the tree seeds, but experiments did not confirm his assumption. Whether or not a cover crop is used, it is good to roll the area after sowing so that the seeds get good contact with the soil (Willoughby et al. loc cit.).

Either it is possible to use a great amount of seeds to make sure there will be enough plants surviving browsing from deer and rabbits, or it is recommended to put up a fence (Willoughby et al. 1996). Which of the two options is the best one depends on how many animals the area supports.

12. The Use of Direct Seeding in Forest Restoration

The term forest restoration is according to Stanturf & Madsen (2002) the introduction of trees on land that does not at the moment hold forest, as well as changing stand structures and introducing new species where the present land use is forestry.

There is now a growing interest and need to restore some of the degraded forests. Experiments from different places in the world suggest that direct seeding is a method that can be successfully used for this purpose (Johnson & Krinard 1985b, Anon. 1987, Engel & Parrotta 2001, Kenk & Guehne 2001, Cabin et al. 2002, Twedt & Wilson 2002, Pausas et al. 2004). Sowing is appropriate for this purpose because it can be rather cheap and together with the natural seed fall it provides a sufficient and less artificial regeneration method than planting (Twedt & Wilson 2002). Even if the seeds are sown in rows, the establishment becomes less uniform than a regular plantation, because not all seeds will establish a seedling. It is common that seedlings occur in groups with more or less open spaces in between. This provides good possibilities for other tree species to establish in the gaps. This way the resulting stand will get a more uneven height-structure than a planted stand has, and there will be a greater species variation. It is also possible to include seeds from many different tree species in the sowing and thereby get even more variation. The acquired heterogeneity makes the forest more attractive to wildlife and consequently increases the biodiversity further (Twedt & Wilson loc cit.). It would be even more preferable to use broadcast sowing so the establishment would not be in rows at all (Allen 1997).

13. Discussion

This essay is a literature review, but it does not cover everything that has been written on the subject of direct seeding. If more time was available it would be appropriate to search more databases for references. Presently a lot of information has been excluded by focusing on a few tree species. Even if the main interest is those trees, it could be beneficial to look at research on other species as well, to see which findings are general and might be applied also to the management of the species in focus. There would also be advantages to reading more references from outside of Europe.

Direct seeding is a practise that was used to a higher extent at the beginning of the 20th century than it is today. In some of the literature behind this essay it can be seen (Watt 1919, Ashby 1959), that from the first decades of the 1900s there has been an ongoing concern about what is happening to the natural regeneration of broadleaved forests. Watt (loc cit.) and Ashby (loc cit.) both state that the failures in regeneration are due to changed ways of using the land, and as a consequence the seeds are eaten by seed predators. The problem is the same for direct sowing as for natural regeneration. Research has been put in and solved a lot of other problems, so how come the interest in direct seeding was not revived again until lately? I think that it might have something to do with the increasing demand for forest restoration. When forests are established on forest land it is possible to use the natural seedfall, or if an investment in improved genetic material is planned it is safer to buy nursery seedlings than to use seeds. When it comes to afforestation of land where there are no trees at present it is not possible to use natural seed sources. On fertile agricultural land it is preferable to have a dense regeneration, which is very expensive if transplanted seedlings are to be used. On places where the soil is degraded from for example mining, the land owner might not be willing to make a great initial investment, because it is unknown how well the forest can grow and what the financial return will be. As a result of this the demand for a cheap way of regeneration is increasing, and eyes are again turned towards the old practise of direct seeding.

I have found many recommendations on for example site preparation in combination with sowing in the literature, and many of those methods have other problems than those reported in the articles. For example, as I mentioned earlier, weed control through using herbicides may be efficient, but it is not allowed on Swedish forest land (SFS 1998:808) and therefore the practical use is limited. Another method of site preparation accompanied by difficulties is steam treatment. It may sound environmentally friendly and all, but the problem is that it requires a lot of energy and the equipment is ungainly, why it is not practical. Prescribed fire can work very well together with sowing on some sites, but the use in southern Sweden is rather limited because of too fertile sites with lots of ground vegetation, and often the areas are too small or too close to settlement for the method to be safe. When considering mechanical site preparation, it is important to think of both what is suitable for the species chosen, and what works for the particular site. Therefore, as with all things dealing with biological phenomena, it is impossible to give any straightforward advice that will work in every case.

Part of the aim with this essay was to find in what areas of sowing there is a lack of knowledge. To many questions concerning direct seeding there are various answers and that can in some cases be ascribed to gaps in knowledge.

For example there seems to be no consensus concerning whether weeds are a greater or lesser problem when sowing than when using transplants. In this particular case, the confusion is probably related to different time perspectives. Presumably it is more essential with proper weed control at the very beginning of direct seeding. It is easy to imagine the problems that will occur for a small seed of for example birch which lands on thick grass. The seed will not be able to reach the soil and start germinating. Even if it would get down on the ground eventually, the competition will be too great for the seedling that emerges. These kinds of obstacles are less if the seed is bigger, like acorns or beech nuts; because they are heavier and probably fall through the grass more easily. They also have the benefit of a bigger energy store in the seed and therefore may survive the establishment phase. For those seeds the problems start when the stores in the seed run out, and they have to fight their way up to the sunlight through the tall ground vegetation (Löf et al. 2004). If the seedlings manage to establish themselves though, there is hopefully plenty of them and the ground will soon be covered and the weeds out competed (Willoughby et al. 2004). Transplants on the other hand have a supervised and rather easy establishment phase in the nursery. When they are put out in the field they are bigger than a newly germinated seedling and therefore are better equipped to compete with herbs and grass. On the other hand they are taken from their protected environment and subjected to harsher conditions and may therefore suffer from transplant shock (Willoughby et al. 2004). The spacing in plantations is often wide and it will take many years before the canopy is closed and the weeds can be suppressed.

The possibility to sow broadleaves without fencing is largely dependent on great numbers of seedlings which is in turn dependent on the amount of seeds that are sown. The consideration that has to be done is whether the economical benefit will be the greatest if the area does not have to be fenced or if the number of seeds can be reduced. The decision needs to be based on specific knowledge in every case. For example it matters what the goals are for the stand, the prices of seeds and fences and also the population sizes of browsers. At this point there seems to be a need to establish more sowing experiments without fences, to be able to give guidelines concerning how small the browser populations should be and how large quantities of seeds that have to be spread out, before a recommendation to refrain from the use of fences could be given.

Figure 5. Wood mouse (*Apodemus sylvaticus*). Photo: Prisca Schäffer

In the case of other contrary recommendations, for instance whether or not to use shelters, it is because different problems are considered. A shelter helps to hold back the growth of ground vegetation, but it also provides rodents with protection (Johnson 1981). In those cases it is crucial to find out what problem is the worst and try to deal with that one first. Many times it seems that the contradictions end up with rodents. Both canopy trees and ground vegetation help provide favourable environments for small mammals. One benefit with a shelter is that it holds back weed growth, but if both shelter and weeds are bad which one is the worst? When all things are summed up it quite simply seems that mice and voles are the first problem to deal with. There will be no other problems for establishment or germination to take care of, if the seeds are already gone from the site.

What possibilities are there then to get rid of or stop the rodents? Many different things have been tried, and still there seems to be no universal solution that will work in every case. This is one big gap where knowledge has to be filled in. So far there are a couple of precautions and measures to take that will at least improve the chances of success.

A large open area is one of the recommendations that seem to have the best effect (Johnson & Krinard 1985a), but it is still unclear exactly how big the area has to be. It is also unclear if some slash can be left on the area or if it is all right if there is a little vegetation still.

One tempting solution would be just to kill the mice and voles in the vicinity of the sowings and thereby be rid of the problem. This has been attempted both with poison (Hayes 1913) and with snap-traps (Fisher 2002). The effect has been variable. Fischer (loc cit.) found establishment of seedlings to be improved on sites with snap-traps compared to sites with perches for birds of prey. To achieve a beneficial effect the traps have to be operational during a long time, to take care of immigrating rodents as well as residents. To avoid the problem of immigration it would be better if the population could be regulated over a larger area, why Hayes (loc cit.) recommends putting out poison over extensive areas. Another way to reduce populations over large areas would be to increase the populations of rodent predators. It has been tried through putting up perches and nesting boxes for birds of prey (Fisher 2002). These types of precautions need to be taken well in advance of the sowing, for the birds to have time to find the equipment and build up the population. In Fischer's (loc cit.) study the perches and nesting boxes were installed just before the start of the experiment, why it is difficult to draw any conclusions from it.

Rodent population sizes vary rather much naturally, and one way to reduce their impact on sowings would be to concentrate the direct seeding efforts to years with low populations. This would be more effective in the northern part of the country, since this is where the population sizes vary the most (Hansson et al. 2000). To make this procedure possible it is necessary to be able to predict in what years there will be crashes and in what years there will be peaks. There is still no consensus about which factors are most important in regulating the rodent numbers (Alibhai & Gipps 1985, Jędrzejewski & Jędrzejewska 1993, Selås et al. 2002), and consequently such predictions are difficult to make.

To get around the problem that a large amount of the seeds disappear, it could be possible just to spread out more seeds. The drawback of that is of course that it gets more expensive and then the major benefit of direct seeding is lost.

Yet another solution to the difficulties is to put out alternative food to satisfy the appetite of the seed predators. Food that has been tried is for example oats and sunflower seed (Sullivan 1979). Unfortunately also this practise has its drawbacks. When the availability of food is good, the rodents increase in number (Angelstam et al. 1987), both through increased production of young (Jensen 1982) and through immigration from adjacent areas. A consequence of this is contradictory opinions about whether it is appropriate to sow during spring following a mast year. Baumhauer et al. (2005) recommend sowing after mast years because then the rodents will have access to other food than the sown seeds, while Jensen (1982) found that the populations of seed-eating rodents are much higher after a mast year since the mortality during winter is decreased. Madsen (2005) recommends not to sow beech and oak in the spring following a good mast, if the surrounding forest consists of those species.

One more area where there are not enough facts is concerning how much damage is caused to sown seedlings by pine weevils. There seems to be no clear idea if it is more or less of a problem than for planted seedlings (Bergsten et al. 2003, Edwards & Hall 2003, Madsen 2005).

Sometimes when site preparations are considered, the requirements of the tree species may have to be set aside. Perhaps it is easier for beech seedlings to deal with frost than it is for the seeds to avoid being eaten under a shelter. Recommendations are most often to sow in spring time, but possibly more seedlings can establish themselves if they are sown in the summer when there is more alternative food for the small mammals. These things need to be tested for each species since it is possible that conifer seeds dry out if sown in summer, while beech nuts can survive.

Not all problems are specific for direct seeding. Many of the obstacles are just the same or similar for planting and natural regeneration. Irregularity of mast years affects the production of transplants and the success of natural regeneration as well as the availability of seeds. The difference in this case is, that for transplants there are two ways to store the regeneration material, both as seeds and as seedlings. Another difficulty that appears for nursery production is to know how many seedlings will be sold each year. Sometimes the nurseries have to burn huge amounts of seedlings because the demand is too poor. This particular insecurity is actually less when dealing with seeds since they can often be stored for longer time, or they can be sown in the nursery to produce seedlings.

When listed like this there seems to be an enormous amount of problems associated with direct seeding. It is true that there are many things that can go wrong, but so there is with other kinds of regeneration methods. More research has been put into those other methods and therefore they can be practiced with more security today. There are still many things which are not investigated thoroughly enough when it comes to direct seeding and when this new knowledge is gained, direct seeding really has the potential to be a cheap way to regenerate forests. More research has been done considering sowing of conifers than broadleaves and for the former species the method can be applied with greater expectancy of success. One big problem that remains for both conifer and broadleaved sowings however, is the predation on seeds. Hopefully this is where my PhD project can add one piece to the puzzle. The focus of the project is on broadleaves, but what knowledge is gained in one area can possibly work similarly in another.

14. References

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