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Supplying Biomass for Small Scale Energy Production

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1. Introduction

Our sources of energy are constantly changing. In Sweden the focus is on nuclear and hydro power for producing electricity and total Swedish energy production amounts to about 612 TWh (Anon, 2010). Since Sweden has a cold climate, there is a high demand for energy to heat homes and energy sources other than oil and coal are required. Currently, fuel systems are based on oil and electrical power but there has been an increase in the use of biomass during recent decades. The support of biomass for heating provides 19% of the total Swedish energy output, (Fig. 1).

For centuries trees have been used in a domestic context for firewood and charcoal production. In Sweden, conventional forest management combined with bioenergy production has been practiced for the last 40-50 years. Currently, for economic reasons, bioenergy harvesting is mainly based on large areas of forest land. Tops and branches are harvested from clear cut areas and this biomass contributes greatly to the production of bioenergy. Special equipment is used to harvest biomass, which is used for energy production in direct heating plants. The infrastructure is well established. Most of the harvested material goes to heating plants close to cities, although some is used by individual households.

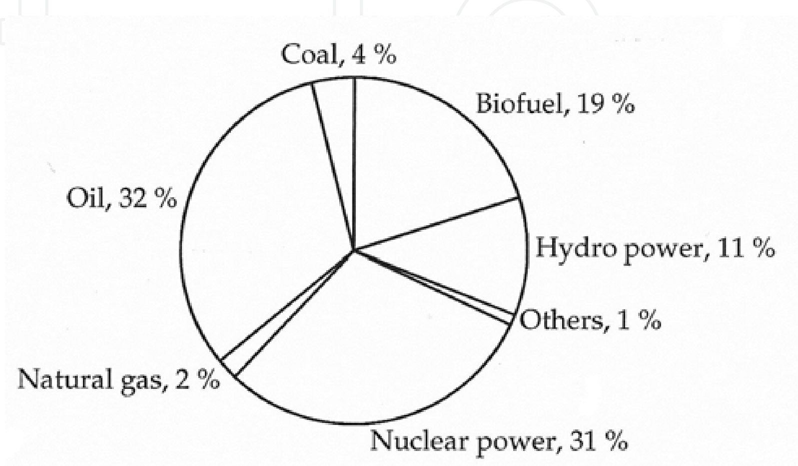

Fig. 1. Total energy use in Sweden in 2007 (Anon, 2010)

The management of forests is mainly directed towards producing pulpwood and timber. The remaining parts of the tree – branches and tops – represent raw material for bioenergy production. Over the last twenty years there has been an increased willingness to make use of these parts of the tree.

Biomass production on former farmland, using willows, poplar and hybrid aspens, is another option for energy production. In general, the Swedish people look favorably on such land use, as well as forest biomass production. There is strict regulation of the management of forest land to minimize the risks of nutrient loss, but no such regulations exist for farmland. Farmers and some sections of the public wish to maintain farmland as an open landscape and to continue with agricultural cultivation.

The Swedish government has twice proposed a reduction in farmland available for the production of cereals, in 1969 and 1986. The plan was to reduce the area by about one million hectares, out of the total of three million hectares. Both attempts failed, although since 1968 350,000 ha have been taken out of production. Some areas of this former farmland have been planted, mostly with Norway spruce and birches, but more than 200,000 hectares which were taken out of production in the period 1970-1980 have received no subsequent management. Today these areas are covered by broadleaved trees with a range of numbers of stems per hectare (Johansson, 1999a), but they are not managed to generate forest products.

2. Small-scale production of biomass

Currently, there are standard practices for the management and harvesting of biomass from large forest stands, used in state forests and by forestry companies. It is much more challenging, however, for small-scale forest owners to utilize forest biomass for bioenergy. The amount of biomass that can be harvested from forest land or farmland depends on various factors including site condition, species and management intensity. Few practical recommendations for small-scale owners have been published, and land owners may be unaware of appropriate practice. More information would enhance the use of resources available for bioenergy production.

Herein I present examples of activities and the management of farmland and forest land demonstrating how an owner can undertake small scale biomass production for their own consumption or to supply a local market (neighbors etc.).

The examples presented are:

- ingrowth, i.e. natural establishment of broadleaved trees on former farmland via seeds, sprouts or suckers;
- direct seeding on farmland;
- management of existing mixed stands;
- harvesting tops and branches after clear cutting; and
- establishing and using fast-growing species.

Finally, some recommendations for small scale bioenergy production are presented.

3. Ingrowth

The most important factors affecting the colonization of open areas by plants are: the year and season of abandonment; the physical state of the site; climate; soil; the existing flora and fauna; proximity and position of source material; opportunities for vegetative regeneration;

and the presence, within a range possible for seed dispersal, of an efficient generative reproduction and a rapid, rich and long-distance dispersal of seeds (Falinski, 1980; Harmer et al., 2001). Reviews by Osbornova et al. (1990) and Myster (1993) report many studies of tree generation on abandoned farmland. Natural colonization by trees and other species have been recorded since 1882 at the Broadbalk Wilderness, UK, which has established on former farmland (Harmer et al., 2001). The first tree plants were recorded 30 years after abandonment, i.e. in 1913. The main species regenerating in the area were: common ash (*Fraxinus excelsior* L.); sycamore (*Acer pseudoplatanus* L.); field maple (*Acer campestre* L.); suckers of wild cherry (*Prunus avium* L.); blackthorn (*Prunus spinosa* L.); pedunculate oak (*Quercus robur* L.) and hazel (*Corylus avellana* L.). In 1998 the dominant and most frequent tree species were pedunculate oak, common ash, wild cherry and sycamore.

Fig. 2. Naturally seeded birch (left), sucker from aspen (right) and naturally seeded grey alder (below)

The area of farmland no longer in agricultural production increases as land owners cease activities or direct their energies towards other forms of management. When farmland is abandoned it is invaded by herbs and broadleaved tree species (alder, aspen and birch). In general, one species dominates in the new stand. Most such farmland areas are owned by private individuals. In Sweden, Johansson (1999a) found up to 10,000 broadleaved tree stems ha^{-1} on about 100,000 hectares of former farmland.

Natural tree establishment in an open area is a slow process, and it may be 5-10 years before trees 2-5 old are seen (Werner and Harbeck, 1982). Most such areas in Northern Europe are small, amounting to 0.5-2.0 ha. In the initial phase, the areas are not noticeable from the surroundings, but later a dense stand is established and the landscape is changed. In general, these areas continue to develop unnoticed by the owner or the public. Eventually, former open areas become covered by forest. Such ingrowth can be the result of natural seeding, sprouting or suckering (Fig. 2).

3.1 Natural seeding

To produce conditions that will encourage establishment of a wide range of seedlings through natural seeding, and avoid revegetation failing, an understanding of certain abiotic and biotic factors is required. The main factors that affect establishment through natural seeding are: species present, soil type, moisture, competition by grasses and herbs, available seed trees, and weather conditions (heat, dryness etc). It is important to know the timing and periodicity of seed production and dispersal. Basic knowledge about the period for the high rates of seed dispersal is necessary when practicing natural regeneration. In order to encourage natural seeding, ground preparation must be undertaken prior to seed dispersal.
Specific characteristics of a species, such as number of seeds per tree, seed weight and frost resistance, greatly influence the establishment of seedlings. Seeds from some species are wind dispersed (e.g. birch and sallow (*Salix caprea* L.)) and others water dispersed (e.g. alder); a combination of methods may be used. Studies of wind-mediated seed dispersal for different species indicate the following order of decreasing dispersal:
birch>elm=maple>alder>hornbeam>beech>oak (Augspurger and Franson, 1987; Okubo and Levin, 1989; Willson, 1990; Karlsson, 2001). Table 1 contains data on birch and alder seed dispersal.

Distance from forest stand, m				Country	Reference
<50	50-100	100-150	>150		
			Birch		
>400			>100	Sweden[1]	Fries (1982)
>200	<100			Sweden[2]	Björkroth (1973)
58 % of total	10 % of total			USA[3]	Björkbom (1971)
10,450	4,200	400		USA[4]	Hughes and Fahey (1988)
			Alder		
78-94 % of total				Sweden[5]	Johansson and Lundh (2006)
90 % of total				Sweden[5]	Karlsson (2001)

1) *Betula pendula* Roth 2) *Betula pubescens* Ehrh. 3) *Betula papyrifera* March. 4) *Betula alleghaniensis* Brit. 5) *Alnus glutinosa* (L.) Gaertner

Table 1. Dispersal of birch and alder seeds into open areas, number of seeds m^{-2} $year^{-1}$

Both downy (*Betula pubescens* Ehrh.) and silver (*Betula pendula* Roth) birch produce many seeds. In Estonia, Uri et al. (2007) recorded 3060-36,200 8-year-old birches ha^{-1} that had been produced by natural seeding on farmland. Seeds from a birch growing at the edge of a clear cut area have been found to spread at a rate of about 100 seeds m^{-2} up to 200 m from the tree (Fries, 1984). Most of these birch seeds were dispersed during September, although the process continued until December. In a study of sweet birch (*Betula lenta* L.), Matlack (1989) reported seed were dispersed 3.3 times further than the distance measured by Fries (1984). In a study of silver birch in Estonia, 21 % of the seeds were dispersed in July, 77 % in August and 2 % in September (Kohh, 1936). Heikinheimo (1932, 1937), who reported the same dispersal periods, commented that the weather during summer and autumn is the main factor affecting the period of seed dispersal. Graber and Leak (1992) presented a study on seed fall for broadleaved species in New Hampshire. The mean seed fall (million ha^{-1}) in a study lasting 11 years was: 6.58 for yellow birch (*Betula alleghaniensis* Britton); 6.38 for paper birch (*Betula papyrifera* Marsh.); 4.11 for sugar maple (*Acer saccharum* Marsh.); and 0.17 for American beech (*Fagus grandifolia* Ehrh.). The seed viability was 30-50 %, depending on species.

Besides wind dispersal, there are some reports of secondary dispersal of seeds (Hesselman, 1934; Matlack, 1989; Greene and Johansson, 1997). The most common is by movement on snow, but for this to occur, seed fall must happen during winter months when snow is on the ground. The seeds can be damaged by friction on frozen snow, thus reducing viability.

The level of seed production by alder depends on the number of hours of sunshine in the period April-September in the year before fruiting, the number of hours of sunshine in the seeding year and the level of seed production in the preceding year (MacVean, 1955). According to MacVean (1955), common alder (*Alnus glutinosa* (L.) Gaertner) seeds are generally dispersed within a radius of 30-60 m of the mother tree. Karlsson (2001) found that 50 % of the total number of alder seeds produced fell within 5 m and 90 % within 20 m of the stand. In a study by Johansson and Lundh (2006), 50 % of the common alder seeds were found to have fallen before December and 75 % before February. Alder seeds can also be transported by water in spring at the time of snow melt.

Seeds from European aspen (*Populus tremula* L.) are extremely small (low weight) with a limited growing capacity (Blumenthal, 1942, Latva-Karjanmaa et al., 2006). A large aspen growing close to Tartu city, Estonia, produced 49 kg or 54 million seeds (Reim, 1930). Only a small proportion of the aspen seeds produced will grow; success depends on site conditions, seed size and the level of competition. Aspen seeds can grow on poor sandy sites, burned areas and small patches without vegetation (Blumenthal, 1942). Seeds of sallow are also small and have a plume to aid dispersal (Grime et al., 1988). Seeds of both species can be dispersed over long distances.

The most favorable soil types for rapid establishment of seedlings are fine sand, silt and light clay, sandy-silty till and light clay till. Even peat soils can provide an ideal site, providing there is sufficient water. A mixture of mineral soil and humus is common on farmland, where the area has been cultivated for many years.

Birch seeds establish well on undisturbed sites with a high level of moisture (Mork, 1948; Fries, 1982). During the first part of the growing season in Nordic countries (April-May) soil moisture tends to be low. The lack of rain combined with the sunshine during this period results in a dry soil. Therefore any soil treatment (plowing, harrowing or screefing) should be undertaken in autumn or very early in spring. Studies to determine the best soil treatment to ensure limited cover of competitive vegetation indicate that removal of topsoil is preferable (Karlsson, 1996).

3.2 Sprouting and suckering

The main difference between sprouting and suckering is that sprouts emerge from a stump whilst suckers originate from roots, (Fig. 3). Both types of regeneration result in fast-growing individual stems. In studies of dormant buds on birch, most have been found close to the ground: 0-10 cm above or 0-5 cm below ground level (Kauppi, 1989; Kauppi et al., 1987; 1988 Johansson, 1992a). The number of sprouts per living birch stump has been found to vary between 1 and 52, mean 10±8, decreasing to 3-8 sprouts per stump after five years (Johansson, 1992 b, c). Rydberg (2000) found the number of birch sprouts had decreased by >40 % of the initial number two years after stump creation nine years after cutting, Johansson (2008) found that the initial number of sprouting birch stumps had decreased to 61 and 55 % respectively for downy and silver birch stumps. In a study of downy birch growing in central Finland, the number of sprouts decreased from an average of 9.5 one year after cutting to 5 after three years and 3 after seven years. The sprouting abilities of red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), black cherry (*Prunus serotina* Ehrh.), sugar maple and yellow poplar (*Liriodendron tulipifera* L.) growing in West Virginia were studied by Wendel (1974). After ten years the number of sprouts per living stump was 15-20 % of the initial number produced. In another study of yellow poplar, the average number of sprouts recorded six years after cutting was 7.0 per stump (Beck, 1977). Sprouting capacity is highest when a tree is young (Johansson, 1992c). Kauppi et al. (1988) reported the poorest sprouting results from old (40 year) downy birch stumps. Older trees have thicker stem bark, so the buds cannot penetrate the bark and develop into sprouts (Mikola, 1942). Sprouting capacity may depend on carbohydrates in the roots. However, Johansson (1993) found no pronounced peaks in the carbohydrate content in birch roots during the year. Sprouting capacity may also depend on the cutting date. Johansson (1992b) found the highest number of living birch stumps producing sprouts cut in all months but June-October. Etholén (1974) found no effect of cutting time on the sprouting ability of young downy birch stumps.

Fig. 3. Sprouts of birch (left) and suckers of aspen (right)

In southeastern New York, Kays and Canham (1991) studied the sprouting ability of four hardwood species: red maple (*Acer rubrum* L.), gray birch (*Betula populifolia* Marsh.), white ash (*Fraxinus Americana* L.) and black cherry (*Prunus serotina* Ehrh.). They reported that gray birch had the highest mortality (87 %) of stumps after cutting in May but the other species only had mortalities of 10-20 % depending on cutting date. In a study of the suckering capacity of parent trees of American beech, a mean of 41,365 (3,924-89,765) suckers ha^{-1} was found (Jones and Raynal, 1986).

European aspen and trembling aspen (*Populus tremuloides* Michx.) are two *Populus* species with a high capacity for sucker production. The number of suckers after cutting the mother tree differs depending on the cutting date (Johansson, 1993) and on site, stand and management factors (Frey et al., 2003). The age of the mother tree also influences the suckering ability (Brinkman and Roe, 1975). A trembling aspen stand was found to produce 8000 suckers ha^{-1} after cutting (Tew, 1970). In a study by Alban et al. (1994) of trembling aspen growing in Minnesota, the number of suckers the first year after disturbance was >250,000 per hectare. The number had decreased to 40,000 after five years (Stone and Elioff, 1998). Trembling aspen stands growing on similar soils in Minnesota and British Columbia produced 50,000 suckers ha^{-1} after five years and the mean sucker height was 2.1 m (Stone and Kabzems, 2002). The root system of an individual aspen is widely spread, with root lengths up to 20 m (Reim, 1930). In a Swedish study, about 70 % of the suckers occurred within 10 m of the parent aspen tree (Bärring, 1988). In a study by Johansson (1993) the content of starch in roots of European aspens fluctuated during the year with the lowest levels in May-July. The same pattern has been reported for trembling aspen by Baker (1925), Zehngraff (1946), Tew (1970) and Brinkman and Roe (1975).The lowest content has been recorded in late May and early June. When aspen is cut in the winter the highest numbers of suckers are produced (Stoeckler and Macon, 1956; Steneker, 1976; Peterson and Peterson, 1992). In other studies (Shier and Zasada, 1973; Fraser et al., 2002) on trembling aspen, no relationships have been identified between carbohydrate content in roots and the number of suckers initiated.

Alder regenerate vegetatively by sprouts or suckers depending on species. In a study of red alder (*Alnus rubra* Bong.), the number of sprouts per living stump ranged between 5 and 9 (Harrington, 1989). In another study of the same species, the number of sprouts was in the range 9-13 (DeBell and Turpin, 1989). According to Rytter (1996), young grey alders (*Alnus incana* (L.) Moench) produce sprouts after cutting, but the old trees produce suckers. In a Finnish study, grey alder stumps sprouted within three weeks of cutting (Paukkkonen and Kauppi, 1992). Sucker production by grey alder is the main means of vegetative regeneration when the trees are more than 25-30 years old (Schrötter, 1983). In a study of seasonal variation of carbohydrates in the roots of common and grey alders, levels were found to be highest during September-November (Johansson, 1998). In a study of the influence of felling time on sprout and sucker production by common and grey alder, the carbohydrate content in the roots was found to influence biomass production (Johansson, 2009). The highest number of sprouts from common alder stumps was produced after cutting in August-October (23-24 sprouts $stump^{-1}$). Ten years later, the number of sprouts had decreased to 1.3-2.3 sprouts $stump^{-1}$. The average number of sprouts on living grey alder stumps was highest after cutting in March (3.0), August (3.4) and September (3.4), with a reduction to an average of 2.0 after five years. The number of grey alder suckers per m^2 was highest, 21.0, after cutting in September with a reduction to 1.5 after five years. The recommendation, therefore, is to cut grey alder in August and September ad common alder in August-October when the largest number of sprouts and suckers will result. In a study on the initial sprouting of 4-year-old red alders, the percentage of sprouting stumps was highest when the alders were cut in January (Harrington, 1984).

In a study of the spouting ability of *Eucalyptus* in plantations, the number of sprouts per living stump varied, but the highest number was 5-6 sprouts $stump^{-1}$ (Sims, 1999). The stumps have the capacity to resprout several times, depending on their vigor.

4. Direct seeding

When practicing direct seeding on forest land there are practical recommendations considering among others Norway spruce (*Picea abies* (L.) Karst.) , Scots pine (*Pinus sylvestris* L.), birch, beech (*Fagus sylvatica* L.) and oak in relation to the target species. There are, however, few recommendations available for seeding on farmland, although the factors associated with successful establishment are the same as for natural seeding (species, mineral soil, moisture, competition by grasses and herbs, and weather conditions).
The success of establishment of seedlings after direct seeding depends on the nature of the soil treatment and the date of seeding. The critical phase is the emergence of seedlings during the first days or weeks after seeding and the moisture conditions in the treated spots. Generally, precipitation is low in late spring and therefore seeding must be undertaken early in spring.
High quality seeds are expensive and therefore a natural seed source close to the planting site can allow collection from mature seed trees of the appropriate species. Birch and alder are suitable species for producing stands for bioenergy harvest, with subsequent vigorous sprouting or suckering. Depending on seeding method the amount of seeds is 0.5-1.0 kg ha^{-1}.

5. Management of mixed stands on farmland

Using a mixture of species in forest management has been common in Europe for the last three centuries. Hegre and Langhammer (1967) and Stewart et al. (2000) have presented overviews of the importance of mixed stands and their management in different countries worldwide.

Fig. 4. Mixed stand of alder and Norway spruce (left), aspen and Norway spruce (middle) and birch and Norway spruce (right)

In Finland and Norway, a forest stand is defined as being mixed if 20 % of its basal area is made up of broadleaved species, with conifers comprising the dominant species (Frivold, 1982). In Sweden, the proportion is 30 % and in Italy 10 % of the basal area. The Swedish definition of a mixed broadleaved and coniferous stand is "a type of stand in which the total percentage of broadleaved species is 30-70 % of the growing stock" (Anon., 2010). In Nordic countries mixed stands are the most frequent type of stand.

Mixed stands mostly establish spontaneously i.e. a planted or naturally regenerated conifer stand is mixed with naturally regenerated broadleaves. Areas of clear felling that are moist are readily colonized by broadleaves, which can establish from seeds, sprouts or suckers. The number of stems can amount to 5000 to 50,000 per hectare. However there is a conflict between broadleaf cover preventing frost damage to young spruce trees and the strong competition between broadleaves and conifer seedlings. In older stands, both species become established, competition is stabilized and the risk of frost damage declines (Johansson, 2003).

Mostly, Nordic forestry is focused on the management of stands for the production of softwood. A large number of young broadleaves are likely to compete with the conifer seedlings in such stands. In the past, the broadleaves were cut or treated with herbicides. Nowadays, with increasing interest in the supply of biomass for bioenergy production, other management systems have been introduced.

When managing mixed forest stands, a stratified mixture of shade-tolerant, late-successional species in the lower stratum and early successional species in the upper stratum is recommended (Assmann, 1970; Kelty, 1992). Mixed stands may contain alder, aspen or birch and Norway spruce (Johansson, 2003), (Fig. 4). The management of mixed stands is often based on stands which have not been cleaned at the correct time. The spontaneous establishment of broadleaved trees takes up to10 years.

5.1 Mixed forest management

A number of methods are practiced in the Nordic countries, most commonly the shelter method (Tham, 1988; Johansson and Lundh, 1991) and the "Kronoberg" method (Anon., 1985). The descriptions in the sections below are based on a mixed stand of birch and Norway spruce, since this is the most common situation, but the same techniques can be used for other broadleaved species with Norway spruce.

When managing this type of stand it is important that the density of the broadleaved stems is not too high once the spruces have been established. According to Braathe (1988), the competition is too strong for spruces if there are more than 1200 birches ha^{-1} and they are >3 m tall. In that case, he postulated a 30 % decrease in the height increment of the spruce.

5.1.1 The shelter method

This method is common in Finland, Norway and Sweden. It was introduced in Sweden by Tham (1988) with some modifications by Johansson and Lundh (1991). Currently, the same technique is used for birch and Norway spruce in Finland, Norway and Sweden. The principal aim is to create an initial mixed stand with an optimal density of birch.

The method involves two or three steps:

1. When the spruces are 1.5-2 m tall, the density of birch is reduced by cleaning to 800-1000 stems ha^{-1}.
2. The "birch shelter" is cut when the birches are 30-35 years old with a diameter at breast height (dbh) of 15-20 cm.
3. An alternative is to cut all 30-35-year-old birches except 50-100 stems ha^{-1}. The remaining stems should be evenly spread through the stand. These birches will produce high-quality timber during the following 20 years.

5.1.2 The "Kronoberg" method

This method was first introduced in southern Sweden (Anon., 1985). The aims are to avoid frost damage to Norway spruce plants and to control the number of sprouts that are able to establish after the removal of birch in each step.

The method involves three steps:

1. When the birches are 3-4 m tall the stand is cleaned. A total of 3000-4000 birch stems ha^{-1} should be retained. The Norway spruce is not cleaned.
2. When the birches are 6-9 m tall the stand is cleaned again. A total of 1000-1500 birch stems ha^{-1} should be retained; the dbh of the birches should be about 5 cm.
3. When the birch stand is 20-25 years old the birches are felled. They will be 8-12 m tall with a dbh of 8 cm. The mean height of the Norway spruce will be 3-4 m. The spruce stand should be thinned to 2000-2500 stems ha^{-1}.

Alternatively, instead of felling all the birches, 600-800 birches ha^{-1} could be left for 10-15 years. When the birches are finally cut, their mean dbh will be 15-20 cm.

5.1.3 Mixed stands of birch and Norway spruce

The most common type of young stands in Nordic countries is mixed birch and Norway spruce, Fig. 5. Many reports describe how to manage birch and Norway spruce. In Finland, Norway and Sweden the management of mixed stands is common (Mielikänen, 1985; Braathe, 1988; Tham, 1988; Mård, 1997; Klang and Ekö, 1999). Frivold and Groven (1996) discussed the importance of managing mixed stands for future high timber quality. The competition between the taller birches and Norway spruce may adversely affect spruce growth. Therefore the birches must be carefully managed with respect to both numbers of stems removed and controlling competition. A common recommendation is to leave 500-1000 stems ha^{-1} when the birches are 10-15 years old. A Finnish study of a mixed stand of birches (downy and silver) and Norway spruce examined the influence of competition (Valkonen and Valsta, 2001). A reduction of 7-15 % by volume production was reduced by 7-15 % in mixed stands with 1000 birches ha^{-1} compared to pure spruce stands.

Fig. 5. Managed mixed stand of birch and Norway spruce.

Below an experiment in mixed stands of birch and Norway spruce is described (Johansson, 2000b). The experiment was started in 1983 and was based on trials established at eight localities in central and southern Sweden. The experimental stands were 20-30 years old. They were dense, 1520-20,280 stems ha^{-1}, and self regenerated.

The experiment included three thinning regimes:
- Thinning of the birch overstory to create a shelter of 500 stems ha^{-1}.
- Total removal of the birch trees
- Only Norway spruces

At the first cutting, to create the shelter and the pure Norway stands, 1520 to 20,280 birch stems ha^{-1} with a mean diameter of 5.2 cm were removed. After 5 years, 373 to 507 birch stems ha^{-1} with a mean diameter of 15.7 cm were recorded.
Data collected five years after the experiment started are presented in Table 2. The competition by the birch shelter did not influence the growth of Norway spruce. As shown in the table, the mean diameter of the Norway spruce trees was almost the same in the shelter as in the pure stands, 7.6 and 7.0 cm respectively.

		dbh, cm	Height, m	Stocking level, stems ha^{-1}
		Shelter		
Birch				
	Mean ± SE	13.3±0.4	14.2±0.5	499±5
	Range	8.1-19.9	8.2-20.0	480-574
Norway spruce				
	Mean ± SE	7.6±0.3	9.7±0.5	2811±110
	Range	4.6-9.9	5.3-13.5	1693-3373
		No shelter		
Norway spruce				
Mean ± SE	Mean ± SE	7.0±0.1	8.5±1.0	2517±154
Range	Range	3.3-9.2	4.2-11.2	1293-3453

Table 2. Stand characteristics of the trees remaining five years after cutting

Fig. 6. Managed mixed stand of European aspen and Norway spruce

5.1.4 Mixed stands of aspen and Norway spruce

Mixed stands of European aspen and Norway spruce are usually established on rich soils, (Fig. 6). Hegre and Langhammer (1967) and Langhammer (1982) presented results from a

Norwegian experiment on farmland that involved planted European aspen and Norway spruce. Aspens and Norway spruces were planted each at a density of 2000 stems ha^{-1}. The aspens were thinned 30 years later and 580 stems ha^{-1} were retained. Recommendations based on the study stated that planting densities of 2000 Norway spruce and 1000 aspen ha^{-1} would avoid strong competition by the aspens.

5.1.5 Mixed stands of alder and Norway spruce

Naturally established mixed stands of alder are common on wet or moist sites, (Fig. 7). Few studies have examined mixed stands of alder and Norway spruce; those which do exist are based on stands that were not managed correctly during the first ten years after establishment (Lines, 1982; Johansson, 1999d).

Fig. 7. Managed mixed stand of grey alder and Norway spruce

6. Harvesting tops and branches after clear cutting

After clear cutting, tops and branches from felled trees are traditionally left on site together with small trees (Fig. 8). On nutrient-limited sites this slash should not be removed because that would reduce the nutrients present on site. The amount of biomass present in tops and branches is estimated to amount to 20-30 % of the total harvest. The supply of biomass from tops and branches is the main source of bioenergy production in Sweden.

Fig. 8. Clear cut area with branches and tops (left) and stacks of branches and tops (right)

7. Fast-growing species

Besides conventional forestry management, there is increasing interest in management of so-called fast-growing species. Depending on geographical location, different species can be considered fast-growing. There are at least three types of tree suitable and frequently used for management in Europe, the USA and Canada: *Salix* clones, poplar and hybrid aspen. In areas with higher temperatures than northern Europe, species of *Eucalyptus* are also planted.

7.1 Salix

In Sweden research on short rotations using *Salix* began in the end of 1900. Today 10,000-15,000 hectares of short rotation *Salix* stands have been established and are actively managed using advanced technology. The management is based on small-scale plots, where the farmer owns the stand and manages it. Harvesting is undertaken using machinery owned by entrepreneurs and the harvested material is sold to be used for district heating. Common rotation periods are 4-5 years with 5-6 repeated rotations; a plantation lasts a total of 20-30 years before a new one must be established. The plantations must be fertilized and in some cases treated with herbicides. Pathogens (fungi and insects) damaging the leaves and shoots will cause a reduction in growth. As the seedlings represent attractive wildlife habitat, the plantations must be fenced.

Fig. 9. Harvested area of *Salix* (left) and a stack of harvested coppice (right)

7.2 Poplar

Worldwide, and for a long time, poplars have been used for, *inter alia*, pulpwood and timber production. Currently, short rotation plantations intended for biomass production are being established. In Sweden poplars have been planted in experiments or plots for practical survey for the last 20 years. Poplar plantations covering small areas of 0.5-2 ha on former farmland can produce 80-100 tonnes ha^{-1} of wood in ten years (Mean annual increment (MAI): 8-10 tonnes ha^{-1} years^{-1}). If rotations are longer than 10 years, some of the material harvested will be suitable for use as pulpwood. Nowadays short rotation plantations aiming biomass production has been established. In Sweden poplars have been planted in experiments or plots for practical survey the last 20 years. After harvesting, regeneration of older trees by suckers or sprouts is limited. Certain clones and species produce no or only a few sprouts or suckers. This may be because poplars must be young when they are cut for sprouts to be initiated. The bark on the poplar stems is thick already when the alders are 15 years old, preventing any buds from growing into sprouts.

Fig. 10. Hybrid poplar stand

7.3 Hybrid aspen

Hybrid aspen is a hybrid between European aspen and trembling aspen (Wettstein, 1933). The hybrid was introduced into Sweden in 1939. Today plantations of hybrid aspen are a potential source of bioenergy, pulpwood and timber. The MAI for hybrid aspen is the same as for poplar, 10 tonnes ha^{-1} year^{-1}. A German study compared the biomass production in repeated five-year rotations of European, trembling and hybrid aspen (Liesebach, et al., 1999). After harvest of the 5-year-old plantation the biomass was: 7 tonnes ha^{-1} year^{-1} from European aspen, 18 from trembling aspen and 16-34 from the four clones of hybrid aspen that were examined. The plants were then allowed to produce suckers, resulting in 165,000 suckers ha^{-1} during the first year and 45,000 suckers ha^{-1} five years later. During the second rotation, the production was 18 and 20 tonnes ha^{-1} for European and trembling aspen and 27-41 for the hybrid aspen clones. The amount of biomass after 5 and 10 years could amount to 50 and 100 tonnes ha^{-1} respectively. If longer rotations are preferred, the focus should be

Fig. 11. Hybrid aspen stand

on pulpwood and timber production, with bioenergy derived from tops and branches. After harvesting the trees, the stumps produce 50,000-100,000 suckers ha^{-1}. During the subsequent 5-10 year period the sucker biomass will amount to 50-100 tonnes ha^{-1}. However biomass production during a 10-year-old rotation was found to amount to 47, 51 and 87-124 tonnes ha^{-1} respectively for the aspen stands.

8. Biomass characteristics

The biomass fractions of a tree are the stump (including roots), stem, branches and foliage (needles and leaves). Broadleaved trees and conifers have different fractions of these aboveground components (Johansson 1999a, b). For birches, the mean aboveground fractions are: stem, 75 %; branches, 18 %; and leaves, 7 %. For conifers, the mean values are 63 %, 23 % and 14 % respectively (Johansson, 1999b, c). The percentage represented by needles is higher in young than old conifers, Fig. 12.

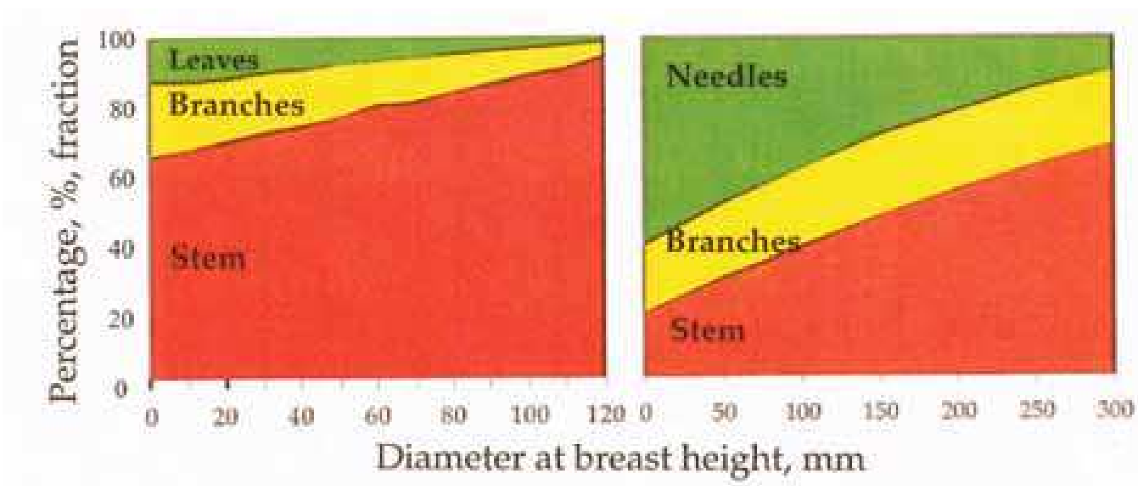

Fig. 12. Percentage biomass fractions by total d. w. %, of a tree at different diameters (DBH), mm

The effect of repeated harvesting on biomass production and sprouting of downy birches growing in central and northern Finland has been studied by Hytönen and Issakainen (2001). Different harvesting cycles of 1, 2, 4, 8, 12 and 16 years were examined. The main results were that downy birch is not suitable for biomass production using short rotations. Most of the stumps, 87 %, did not sprout in the one year rotations, but 8-year rotations produced the same number of sprouting stumps as the longer rotations.

Reim (1929) reported that European aspen growing along the borders of farmland may produce large numbers of suckers when cultivation ceases. In a study of repeated short rotations of aspen, the number of suckers per hectare decreased with every additional rotation (Perala, 1979). The study included rotations of four or eight years and, in both cases, the number of suckers decreased over the three rotations studied.

9. Conclusions

There are several establishment and management techniques available that can be applied to small-scale plots for biomass production on farmland and forest land.

The management methods presented here rely on the land owner having extensive and detailed knowledge of biological processes. The changes in growth of individual species and mixed stands must be known. Some of the methods are based on optimal rotation periods and adequate management of the stand, including cleaning and thinning at the correct time. Severe competition could drastically decrease tree growth. Besides the need for the site to be suitable for tree cultivation, the skill of the owners is important. The most important factor, however, is the enthusiasm and curiosity of the owner; without this, most of the methods will not produce the yields suggested in the present study.

Table 3 lists possible future management models for trees established on farmland and forest land. When operating on a small-scale, there are many alternatives and the owner can be more flexible than is possible in large-scale operations. As the possible rotation periods range from 5 to 40 years it is important to have stands of different ages to ensure a continuous supply. Efficient management of such small areas would make it possible to produce a certain amount of biomass for personal use or to sell to neighbors or local heating plants..

Figures for potential energy supply from different stand types and management options allow us to make comparisons and select appropriate ways to use available land.

Most of the methods are cheap, need a short time to establish and involve relatively straightforward management. The raw materials produced can be used to generate energy for the landowner or can be sold.

Activity	Rotation period, years	Biomass, tonnes ha^{-1}	MWh[1] ha^{-1}	Next generation
Ingrowth				
Natural seeding	10-20	50-110	115-255	Sprouts or suckers
Sprouting, suckering	5-15	50-120	115-275	Sprouts or suckers
Direct seeding	10-15	40-80	90-185	Sprouts or suckers
Mixed stands	35-40	100-150	230-345	
Harvesting tops and branches	-	50	135	
Fast-growing species	5-25	30-300	70-690	Sprouts or suckers

1) Conversion factor MWH/ tonnes: 2.3

Table 3. Small-scale management of tree stands on farmland and forest land and possible biomass production

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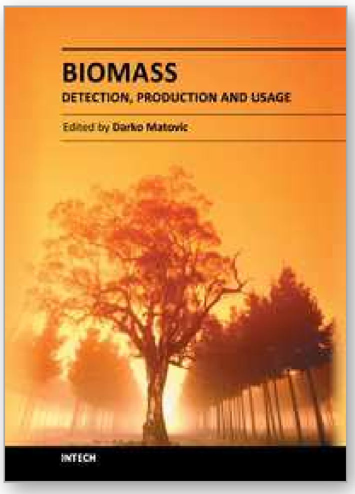

Biomass - Detection, Production and Usage

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Biomass has been an intimate companion of humans from the dawn of civilization to the present. Its use as food, energy source, body cover and as construction material established the key areas of biomass usage that extend to this day. Given the complexities of biomass as a source of multiple end products, this volume sheds new light to the whole spectrum of biomass related topics by highlighting the new and reviewing the existing methods of its detection, production and usage. We hope that the readers will find valuable information and exciting new material in its chapters.