Growth and Recruitment after Mountain Forest Selective Cutting in Irregular Spruce Forest. A Case Study in Northern Norway

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Øyen, B.-H. & Nilsen, P. 2004. Growth and recruitment after mountain forest selective cutting in irregular spruce forest. A case study in Northern Norway. Silva Fennica 38(4): 383-392.

During the last thirty years the interest for the use of selective cutting in the sub-alpine spruce forests of Norway has increased. However, there have been very few investigations on the post harvesting development after such cuttings. Four plots in irregular Norway spruce (*Picea abies* (L.) Karsten) dominated forests on semi-fertile sites in Northern Norway have been the subjects of a case study. We performed a reconstruction of the stand development by means of biometric assessments and ring widths measurements of all standing trees. Tree ages, stand structure, growth and recruitment were examined. Even though a hypothetical reverse J-curve for the present diameter distribution was identified, the four plots were even-aged. Growth reactions indicate that most of the present sawtimber trees were established after heavy dimension cuttings in the late 19th century. The recruitment situation is characterized as satisfying in one of four plots. The post harvesting mean volume increment on the plots have been about two thirds of the potential yield estimated from site indices and maximum mean annual increment in regular stands. Managing strategies for irregular spruce forest stands are briefly discussed.

Keywords mountain forests, selective cutting, Norway spruce, North-Norway
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Received 5 September 2003 **Revised** 17 May 2004 **Accepted** 16 August 2004

1 Introduction

Much of the international debate on management of the boreal mountain forest has centered on the necessity, acceptability and effectiveness of different silvicultural methods (Weetman 1995, Glück and Weber 1998, Lähde et al. 1999, Lähde et al. 2002, Vyse 2002). During the last thirty years a modification of the selection system, mountain forest selective (MFS) -cutting, has increasingly become a common silvicultural method in the medium to low yielding sub-alpine and mountainous spruce forest of Norway (Skauge 1972, Børset 1977, Nilsen 1984, Børset 2002, Øyen and Nilsen 2002). In the treated forest area scattered single trees or small groups of trees are selected and harvested (Nilsen 1988, Øyen and Nilsen 2002). In mature, uneven-sized parts of a stand a high proportion of the largest trees are felled. In each intervention the removal accounts to app. 40–70 % of the standing volume, and the cutting cycle is thirty to sixty years (Nilsen 1984, Nilsen 1988, Øyen and Nilsen 2002). The MFS-cutting combines elements from several methods; the classical Central European "plentering", the shelterwood system, the group system and high thinning. In contrast to the plentering system in Central-Europe, focusing on big dimensions and cutting cycles of 5–15 years, the MFS-cutting system involves typically trees of 25–40 cm in breast height (Nilsen 1988). MFS-cutting also has certain similarities to the previous dimension cutting, i.e. harvesting all trees in an area down to a defined limit (Lie 1919, Braathe 1980).

The last years increased costs of planting and tending, more focus on conservation of biodiversity and increasing demands for non-market benefits has actualized the need of alternative methods to clear-cutting and re-planting. An ongoing international trend is that complex structures are looked upon as desirable (O'Hara 2001). MFS-cutting is a system that reduces the need for planting and possibly also maintains biodiversity and leisure activity functions in an area, although the latter are not well documented.

Even though MFS-cutting was introduced in Norway in the late 1960ies, little is known about the growth response, the structural development, productivity or the recruitment. The main objective of this paper is to describe the structure and dynamics of Norway spruce forests after previous MFS-cuttings in Northern Norway. The abundance and distribution of mature trees and recruits are emphasized in order to evaluate the production sustainability of the system.

2 Material and Methods

2.1 Site Description

The MFS-cutting plots in Northern Norway were established in 2002 in different sites as a part of a network of long-term plots in the sub-alpine spruce forest throughout the country. The plots were subjectively selected to cover different harvesting intensities and stand structures. The four reported plots in Eiterådalen (65°40'N; 13°20'E, 130–150 m elevation), Vefsn municipality, are all located on a *Dryopteris*-spruce dominated type (*Eu-Piceetum Dryopteridetosum*, Kielland-Lund 1991), known to be favorable for natural regeneration of spruce (Bergan 1971, Øyen and Nilsen 2002). Mountains reaching heights up to 900 m a.s.l. surround the valley. The upper spruce forest limit is 250–280 m. The terrain where the plots were established is rather flat, on thick glacier river deposits. The soils could be described as light silt- and sand-dominated podsols, on underlying schists.

The climate in the area is super humid, annual precipitation is app. 1600 mm of which 440 mm falls within the growth season. The average air temperature from June to September is about 11.0 °C, and the vegetation season (> 5 °C) accounts to 140–150 days. Snow cover during winter could be more than 2 m (DNMI 1998).

2.2 Forest History

The forest history in the area is poorly known, but the first reported large-scale exploitation took place in the late 19th century, and further dimension cuttings were done between 1900 and 1945. The tree ring analyses of the four investigated stands and previous work of Nilsen and Haveraaen (1983) indicates that many of the large trees established in the late 19th century. In the 1960ies a network of forest roads were build in the valley, and clear-cuts and re-planting were introduced as the main silvicultural system. However, in a few sites selection systems (like MFS-cutting) has been practiced up to present time. The previous MFS-cuttings have occurred without proper management plans, and little effort has been taken to ensure regeneration, control tree damage agents or encourage stand growth.

2.3 Assessments

Each plot was 30×30 m (900 m^2), and outlay of the plots and all the fieldwork took place in August 2002. All trees (>2 dm in height) and stumps on the plots were marked and mapped. Little concern was put on finding seedlings shorter than 2 dm, because of the great time consumption this would have required, but also because such seedling is rather unstable with a considerable death rate. Stems with diameters above 5 cm in breast height (defined as large trees for the study) were cored to pith from south. These trees were also assessed for dbh, bark, height, leaders length, crown length and width. In every third large tree we measured diameter in stump height (3 dm above ground). Smaller trees (dbh ≤5 cm, in this study named recruits) were mapped and measured for height, crown width and leaders length. All trees were examined for butt rot, recent snow damage to top of the tree, stem damage or other damages. Tree volumes of Norway spruce (*Picea abies* L. Karst) and Downy birch (*Betula pubéscens* Ehrh.) were calculated according to functions given by Vestjordet (1967) and Braastad (1966), respectively. Site quality is described according to the Norwegian site index (H_{40}) system in Norway spruce, which is based on the dominant height in m at breast height 40 yrs (Tveite 1977), i.e. the corrected age (housekeeping age) and dominant height of the 9 largest trees per plot. General yield class was estimated from site indices and potential maximum mean annual increment in regular even-aged stands (Braastad 1975, Tveite and Braastad 1981). The core samples were stored in plastic holders at –20 °C until measurement in spring 2003. The ring widths were measured by means of WinDendro linked to a scanner and supplied with visual control (Horntvedt et al. 2000).

2.4 Calculations and Analyses

Effects of growth and yield associated with the MFS-cutting were examined using both figures from the same forests (Nilsen and Haveraaen 1983), and an annual ring reconstruction method. Based on measurements on the plots, diameter for the harvested trees was estimated by using the relationship between stump diameter and diameter in breast height:

$$\text{DBH (cm)} = 0.233 + 0.75 \times \text{Stump diameter (cm)} \quad (1)$$
$R^2 = 0.96$, CV = 10.7%, n = 133

A height curve was prepared for estimating heights of the harvested trees:

$$\text{Tree height (dm)} = -224.87 + 0.1503 \times (\text{DBH in cm}) + 65.056 \times \ln(\text{DBH in cm}) \quad (2)$$
$R^2 = 0.87$, CV = 13.3%, n = 555

For estimating the thickness of the bark on standing and removed trees a bark function was suggested:

$$\text{Double bark (in mm)} = 7.895 + 0.557 \times \text{DBH (in cm)} \quad (3)$$
$R^2 = 0.40$, CV = 26.3%, n = 356

The growth of each single tree was estimated backwards using DBH in 2002, the measured ring widths and functions no. 1, 2 and 3, combined with the specified volume functions.

The unreduced crown projection area (CPA) in m^2 ha^{-1} was determined by:

$$\text{CPA} = \sum_{i=1}^{n} CR^2\pi \quad (4)$$

where the crown radius is denoted *CR* and the projected area are summarized for stem number i, i = 1…n. Since almost all spruce trees on the plots had living crowns next to ground, the unreduced crown volume was estimated by the simple formula of a circular cone:

$$\text{CPV} = \sum_{i=1}^{n} CPA\frac{1}{3}h \quad (5)$$

where *h* is tree height in meter, *CPA* was calculated from formula 4 and volume were summarized for stem number i, i = 1...n. The formula of

Bøhmer (1922, 1957) was applied for comparing the observed diameter distribution on the plots with a theoretical equilibrium curve:

$$A = \frac{\frac{CPA}{ND}}{C} \tag{6}$$

where A is the number of trees in a specific diameter class (ha^{-1}), *CPA* is the total unreduced crown projection area (m^2 ha^{-1}), *ND* is the number of diameter classes, and *C* is the average crown projection area (m^2) in the specified diameter class. The density of the regeneration was measured by use of zero-square percentages (Braathe 1982). These were calculated as the proportion of squares (in percent) without spruce recruits when the plots are divided into 225 squares of 2×2 m.

3 Results

3.1 Structure

The spatial structure of the spruce populations consisted of groves of juvenile and small-sized trees in a matrix of widely spaced mature individuals or small groups. A calculation of the total unreduced crown projection area indicated that between 51 and 33 % of the plots was open space. The zero-square percentages for the spruce recruits were in the range from 76–85%, and indicated a slightly aggregated distribution pattern. In plot F1 and F2 the birch proportion was less than one per cent, in plot F3 and F4 the birch accounted for 11 and 15% of the basal area, respectively (Table 1).

The largest standing tree had a dbh of 32 cm and the largest stump is 48 cm in diameter corresponding to a dbh of about 36 cm. The diameter distribution of the standing trees could be described as a reversed J for all plots (Fig. 1.).

The mean heights and crown projections displayed the highest values in plot F3 and F4, and in all plots the H/D-ratio decreased with increasing dbh (Table 2).

Most of the largest trees have been removed in the cuttings and despite the reversed J dbh-structure, the age distributions were rather narrow; about 2/3 of the trees was between 61 and 100 years old at breast height (Table 3). The oldest tree

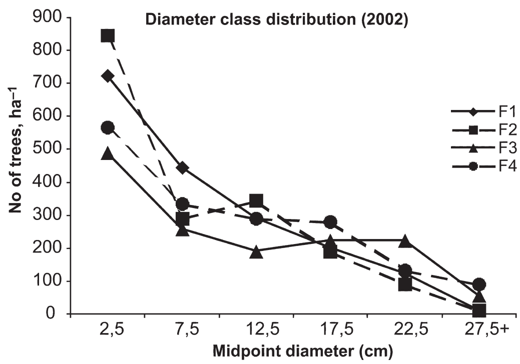

Fig. 1. Diameter distribution for the four plots. The dbh-classes are 5 cm.

Table 1. Stand parameters in 2002, 16 years (F1 and F2) and 33 years (F3 and F4) after the last MFS-cutting.

Stand properties	Plot F1	F2	F3	F4
Site index, H_{40}, m	9.8	9.1	10.3	11.0
Potential yield class, m^3 ha^{-1} yr^{-1}	2.8	2.5	3.0	3.5
Stem number, ha^{-1}	1100	978	1022	1233
Basal area, m^2 ha^{-1}	15.1	14.1	24.0	25.5
Standing volume, m^3 ha^{-1}	87.2	86.3	170.9	176.4
Proportion of birch, % of basal area	0.9	1.1	11.5	15.1
Number of recruits, ha^{-1}	722	844	489	567
Number of recruits < 1 m height, ha^{-1}	210	210	88	22
Zero-square percentage, recruits, %	76	76	85	81
Unreduced crown projection area, m^2 ha^{-1}	6400	4911	7380	7711
Unreduced crown volume, m^3 ha^{-1}	17870	13560	28150	23960

Table 2. Biometric data for the four plots in 5 cm dbh classes. Mean height (m), mean height/dbh-ratio, mean tree volume (dm^3), mean age in breast height (yrs), mean crown projection area (m^2) and number of stems (ha^{-1}) is given.

Plot	Midpoint dbh	7.5	12.5	17.5	22.5	27.5+
F1	Height	5.6	9.6	12.2	14.1	15.9
	H/D-ratio	0.81	0.80	0.71	0.64	0.62
	Volume	10	60	140	250	370
	Age	50	80	95	78	69
	Crown p.	4.15	6.61	7.07	8.55	18.10
	No. ha^{-1}	444	289	200	122	11
F2	Height	6.7	9.6	13.5	14.8	16.6
	H/D-ratio	0.84	0.81	0.78	0.68	0.63
	Volume	20	60	160	260	410
	Age	65	70	100	89	87
	Crown p.	4.15	4.91	7.07	7.07	8.04
	No. ha^{-1}	289	344	189	89	11
F3	Height	6.9	11.0	14.1	16.1	18.4
	H/D-ratio	0.88	0.83	0.82	0.71	0.65
	Volume	20	80	170	300	520
	Age	62	66	80	91	93
	Crown p.	4.52	7.55	9.08	11.95	13.85
	No. ha^{-1}	256	189	222	222	56
F4	Height	7.5	10.8	14.0	16.0	17.5
	H/D-ratio	0.97	0.88	0.80	0.73	0.63
	Volume	20	70	170	290	470
	Age	64	71	80	78	89
	Crown p.	4.68	6.33	7.65	12.25	10.20
	No. ha^{-1}	333	289	278	133	89
Mean	Height	6.7	10.3	13.5	15.3	17.1
	H/D-ratio	0.88	0.83	0.78	0.69	0.63
	Volume	18	68	160	275	443
	Age	60	72	89	84	85
	Crown p.	4.38	6.35	7.72	9.96	12.55
	No. ha^{-1}	331	278	222	142	41

Table 3. Age class distribution, breast height age (frequency, in per cent).

Plot	0–20	21–40	41–60	61–80	81–100	101–120	121–140	141–160
F1 (n=90)	2.2	6.7	30.0	33.3	17.8	3.3	0.0	6.7
F2 (n=78)	0.0	1.3	23.1	41.0	15.4	9.0	10.3	0.0
F3 (n=77)	0.0	5.2	10.4	45.9	28.6	11.7	1.3	0.0
F4 (n=96)	0.0	2.1	5.2	63.5	27.1	1.0	1.0	0.0
Mean (n=341)	0.6	3.8	17.0	45.7	22.3	5.9	2.9	1.8

recorded was 158 years, and was identified among the suppressed stems in dbh-class 17.5 cm.

The diameter distributions were compared with Bøhmers equilibrium formula (6). The number of stems in diameter classes with large diameters (sawtimber trees, dbh > 17.5 cm) in the plots displayed values lower or close to Bøhmers formula, whereas slightly higher values were identified among the small-sized stems (Fig. 2). Recruitment (dbh-class 2.5 cm) is considerable lower than an "ideal situation" for the plots F1, F3 and F4. The situation in plot F2 could be characterized as satisfying.

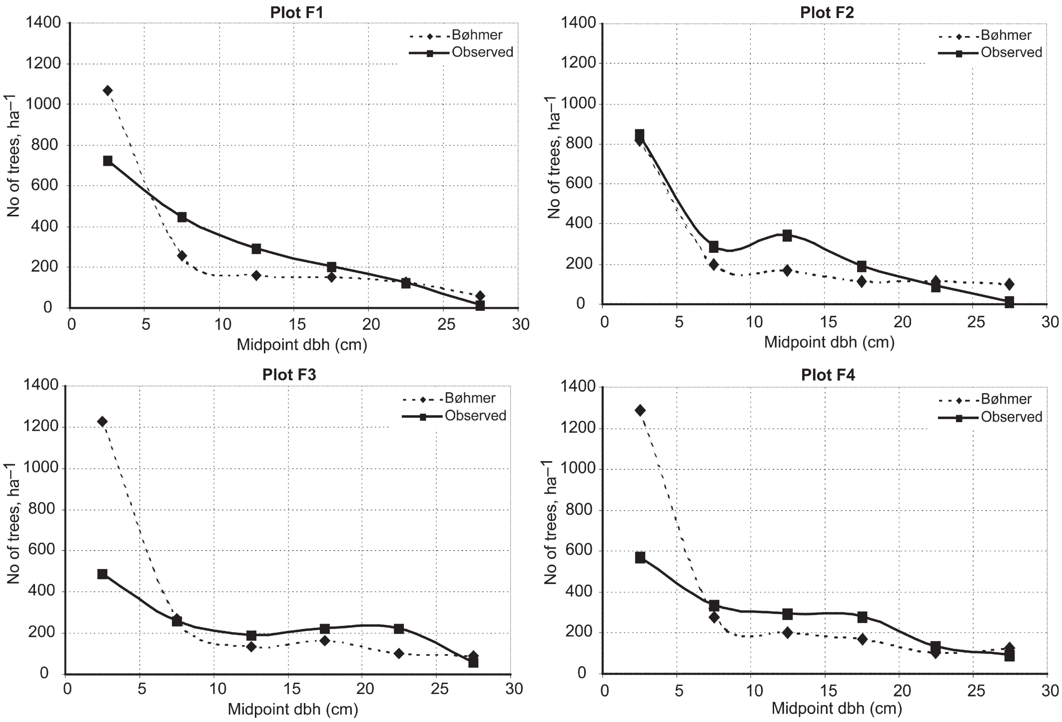

Fig. 2. Diameter distribution in 5 cm classes compared to Bøhmers formula (6).

Table 4. Current annual volume increment (m^3 ha^{-1} yr^{-1}) calculated over 5 yrs growth periods by means of ring widths and formula 1 to 3. PH denotes average post-harvesting yield (m^3 ha^{-1} yr^{-1}) and the growth in percent of maximum mean annual increment (YC) in regular even-aged stands.

Plot	1998–2002	1997–1993	1992–1988	1987–1983	1982–1978	1977–1973	1972–1968	Mean PH	PH in % of YC
F1	2.9	2.5	2.6	0.7	–	–	–	2.0	71
F2	1.8	1.2	1.4	0.9	–	–	–	1.4	56
F3	4.1	1.6	1.6	1.7	2.1	2.4	1.5	2.2	73
F4	2.0	1.6	1.7	1.8	2.2	2.8	1.8	2.0	57

3.2 Growth and Yield

Year of MFS-cutting was determined from historical records and were also supported by growth response judgments in annual ring width measurements (cf. Storaunet et al. 2000). The average growth rings doubled within 10–15 yrs after harvesting and then gradually decreased. Three cuttings were identified in plot F1 and F2, the latest one in 1983/84. In F3 and F4 the latest MFS-cutting took place in 1968/69 (Fig.3).

Site index was low with a H_{40} between 9 m and 11 m. The corresponding potential yield varied from 2.5 m^3 ha^{-1} yr^{-1} and a rotation age 135 yrs to 3.5 m^3 ha^{-1} yr^{-1} and a rotation age of 125 yrs (Tab. 1).

Average post harvest current annual volume increment is in the range from 1.4–2.2 m^3 ha^{-1} yr^{-1}. Compared to potential mean annual increment in yield tables for regular even-aged stands the observed yield was in the range from 56–73%. The calculations of current annual increment also revealed large variations between the growth periods (Table 4).

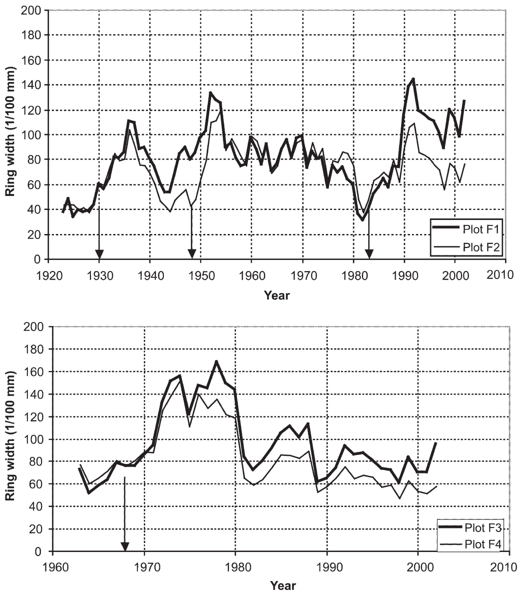

Fig. 3. Mean annual ring widths. Years of cutting are indicated with arrows.

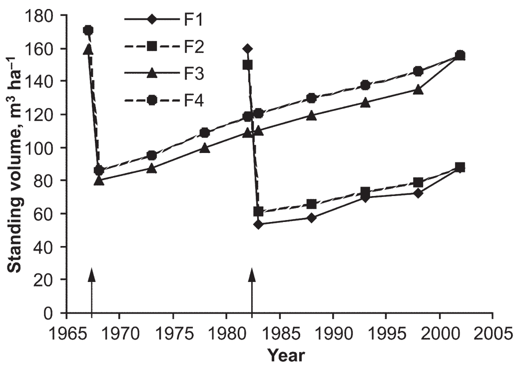

Fig. 4. A reconstruction of stand development in standing volume for the four plots included. Years of cutting are indicated with arrows.

The reconstructions of the standing volume in the plots showed that 160–175 m^3 ha^{-1} are available prior to the MFS-cuttings and that 60–80 m^3 ha^{-1} were retained (Fig. 4). In similar cutting strengths the cutting cycle could be estimated to about 40 years.

4 Discussion

4.1 Structure

The shape and structure of the individual spruce trees in Eiterådalen, Northern Norway, are typical for sub-alpine forest on its northern distribution limit; narrow crowns, low branching and high taper (e.g. Näslund 1942, Ruden 1948). Additionally, these forest plots are heterogeneous i.e. the trees are uneven-sized and spatially clustered. All the four plots had the classical reversed J diameter distribution pattern usually found in woodlands with a rather stationary regeneration/mortality (cutting) ratio (Fig.1). Plot F1 and F2 had a relatively low standing volume (87–86 m^3 ha^{-1}) and 722 and 844 recruits ha^{-1}, respectively. Plot F3 and F4 had about twice the standing volume and the recruits accounted for 489 and 567 trees ha^{-1}, respectively. Site index (H_{40}) indicated small differences in growth conditions between the plots (Table 1). Old birch trees or birch stumps were rare. Mixtures of birch in spruce dominated forests are generally assumed to stimulate spruce regeneration (Eide 1926, Øyen and Nilsen 2002).

The number of stems in the small tree diameter classes (dbh of 7.5, 12.5 and 17.5 cm), below the sawtimber limit, turned out to be rather high, e.g. three to four fold the number reported in similar post-harvested sub-alpine spruce forests in southeast Norway (Øyen and Nilsen 2002). Compared to the Bøhmers equilibrium formula the plots also displayed a slightly higher number of the smaller trees than the “ideal”. Bøhmers (1922, 1957) main idea in setting up such formula was to guide the forest managers in how to create initial conditions to ensure the persistence of a demographic sustainable recruitment in the selection system. In three of four plots the number of recruits is considerable lower than suggested (Fig. 2). The numbers of timber trees (dbh > 17,5 cm) are close to the “ideal” situation in plot F3 and F4, substantial lower in plot F1 and F2. If light conditions need to be controlled more efficient to ensure sustainable regeneration, the current situation indicate that the last MFS-cutting has been slightly too heavy in plot F1 and F2. On the contrary, the low number of saplings (< 1 m height) in plot number F3 and F4 (Table 1) are indicating that the standing volume here is presently too high to safeguard new regeneration. Further, the high number of stems in dbh-class 7.5 cm could mislead managers to draw conclusions about a rather satisfying regeneration situation a few decades ago. However, when examining forest stands to distinguish different age classes it is important to recognize that there is not always a direct relationship between size and age. The average age for the trees in dbh-class 7.5 cm is 60 years. About two thirds of the large trees (dbh > 5 cm) had a breast height age between 61 to 100 yrs, forming a rather even-aged cohort. Average breast height age was in the range of 70–76 yrs (Table 3) and standard deviation was below 30 for all plots. A maximum age variation of 20 yrs in top height trees was set by Tveite (1977) to distinguish between even-aged and uneven-aged stands. Using such definition, all the four plots should be characterized as even-aged. Less than 5 per cent of the individuals are older than 120 years.

It is remarkable that the oldest trees occurred in the 17.5 cm midpoint dbh-class. One reason for this could be that large and old valuable trees have been selected for the previous harvesting, whereas old, but small and suppressed trees were retained. By adding 30–60 years for seedlings in shade to reach breast height (cf. Bergan 1971, Bergan 1985, Storaunet et al. 2000), most of the large trees in the plots were established the years immediately after the exploitation harvesting in the late19th century. A five percent proportion of trees older than 120 yrs indicate that a certain cover remained after the heavy dimension cuttings in the second half of the 19th century. Later on, moderate to heavy interventions have successfully triggered the recruitment and have gradually, due to different growth rates and the spatial clustering, created the irregular structure. Most of the recruitment has taken place near old stumps in gaps, on dead wood or in extraction roads. Such a regeneration pattern is well known from this region, where weed competition is reported to be a hindrance to the seedling establishment (e.g. Eide 1926, Mork 1927, Bergan 1971, Bergan 1985).

4.2 Growth and Yield

The single-tree reactions in ring widths were largest about 10–15 years after the harvesting (Fig. 3). However, the variation in volume increment between the different periods is great (Table 4), and supports studies claiming that growth rates in these northern areas are highly dependent on the summer temperature (e.g. Ruden 1948, Mäkinen et al. 2002). Our reconstruction of current annual volume increment shows that the post-harvest increment has been 1.4 $m^3\ ha^{-1}\ yr^{-1}$ in plot F2, whereas in the range from 2.0–2.2 $m^3\ ha^{-1}\ yr^{-1}$ in plot F1, F3 and F4. Nilsen and Haveraaen (1983) reported a standing volume of 200 $m^3\ ha^{-1}$ in the plots F3 and F4 in 1967/68 and a cutting volume of 160 $m^3\ ha^{-1}$, slightly above the figures in our study. For the plots F1 and F2 they estimated a pre-harvest volume of 180 $m^3\ ha^{-1}$ and a cutting volume of 140 $m^3\ ha^{-1}$ in 1948/49. The stumps from this cutting were now partly degraded and covered by moss and humus. To avoid confusions with the cutting in 1948/49 we made a restricted reconstruction back to the latest cutting in the early 1980-ies, where the stumps are rather fresh. However, there are several challenges in reconstructing stands, i.e. butt rot in trees, mortality in recruits and large trees, etc. Only two percent of the cored trees had rot in breast height. These trees are excluded from the age distributions.

The volume increment figures we have found accounts to approximately 2/3 of the yield table figures in dense even-aged stands, i.e. we have identified substantial growth reductions in the MFS-cutting plots compared to the development in regular even-aged stands (cf. Braastad 1975, Tveite and Braastad 1981) or plentering stands with favorable regeneration conditions (cf. Kolström 1993, Andreassen 1994). We interpret the reductions to be caused by a low initial density with an associated low photosynthetic active crown volume. The crown volumes have been reduced from approximately 30 000 $m^3\ ha^{-1}$ to less than 10 000 $m^3\ ha^{-1}$ in the interventions. There is a tendency that average stand volume increment is positively correlated with crown volume. It must be kept in mind that the last MFS-cutting was quite heavy, retaining approximately one third (F1 and F2) or half (F3 and F4) of the standing volume. The growth reductions we have identified due to MFS-cuttings are similar to heavy partial cuttings reported in other boreal forests (e.g. Näslund 1942, Groot 2002, Øyen and Nilsen 2002).

Several management issues should be taken into consideration. The irregular, but rather even-aged structure must be considered to be a result of previous heavy interventions. Only to a minor extent the present structure have been influenced by the post harvesting recruitment. To define any equilibrium growing stock (the standing volume assuming sustainable recruitment) is therefore difficult. However, recruitment is slightly better in the lower standing volumes (< 100 m^3 ha^{-1}) than in higher volumes. The relative growth reductions cased by the heaviest MFS-cuttings (F1 and F2), showed small differences compared to the least heavy interventions (F3 and F4). From similar sites in Northern Sweden, risk of severe crown deterioration, through wind and snow damage, and the problems with grass invasion and problems for seedling establishment in fertile sites, indicates that low and moderate cuttings (less than 65% of volume) prevent great losses in production (Näslund 1942).

5 Conclusion

The four stands we studied are irregular, but turned out to be even-aged. Most of the present sawtimber trees originated from heavy cuttings in the late 19th century. Mountain forest selective cutting in the late 1960ies and the early 1980ies were basically made to provide sawtimber. Cutting occurred without detailed silvicultural plans and little effort has been taken to ensure new spruce regeneration. Nevertheless, advance growth and small sized trees of Norway spruce survived the cuttings, and the stand structural diversity is now high. Post harvesting natural regeneration is scant; the recruitment situation is satisfying in one of four plots. Compared to regular and dense even-aged stands the estimated loss of yield, due to the rather heavy interventions, is about 30–40%. Overall, it seems likely that the sub-alpine irregular spruce forest on the *Dryopteris*-type with plenty of vigorous undergrowth will respond positively after MFS-cutting. However, long-term trials comparing different management approaches in a variety of sites and forest types are needed before managers can make choices based on sound information.

Acknowledgement

The authors would like to thank Sigbjørn Øen and Hans Nyeggen, Skogforsk, for their assistance in carrying out the fieldwork. Statsskog SF has permitted the establishment of the plots on their land. Tor Myking and two anonymous referees are also highly acknowledged for valuable comments.

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