Measuring Changes in Biomass and Shoot Density in some Dominant Field Layer Species after a Forest Fire in Western Norway

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Abstract

The biomass in four dominant field layer species was followed during six years after a fire in a pine forest in Sveio, western Norway. The overall biomass in the different species was estimated from the biomass per shoot, the shoot densities in pure stands of the investigated species and the percentage cover at medium burned sites. Corresponding measurements were made at control plots outside the burned area. The method was checked by comparing with ordinary area based sampling technique, and a general good agreement was found. The *Vaccinium* species and *Calluna* were the dominant species at the control plot. Three years after the fire the total overall biomass at the burned site was already higher than at the control site, due to improved light and nutrient conditions. A strong increase in the overall biomass of *Calluna vulgaris* and *Deschampsia flexuosa* was found in burned areas, and a slower regrowth of *Vaccinium myrtillus* and *V. vitis-idaea*. However, in the future the biomass is expected to decrease, and the species composition will probably change as nutrients are leached out of the soil and pine and deciduous trees (*Betula pubescens* and *Salix caprea*) are regenerating from seeds and roots, leading to increased competition in the field and shrub layer.

Key words: *Biomass, Coverage, Forest fire, Growth, Pine forest, Production, Shoot density, Succession.*

Introduction

Fire is shown to be an important ecological factor in boreal forests and for the turnover rates and revegetation of tree species (e.g. Zackrisson & Östlund 1991, Engelmark 1993). However, large variations exist in frequency and intensity of forest fires. Because of higher precipitation and humidity, fires seem to be less frequent in oceanic than in continental areas, but as a result of stronger accumulation of organic matter the intensity of fires tend to be higher (e.g. Klingsheim 1995). The importance of forest fire in coastal pine forests in Norway has not been well documented, although studies have been carried out on the fire as a human factor (Kaland 1986). There is therefore need for more thorough investigations on revegetation after fire in coastal pine forests as compared to more continental forests.

The present study was carried out as part of an integrated study, in order to estimate the production rates and chemical composition of some common plant species within burned and unburned sample plots in a coastal pine forest around Hopsfjellet in western Norway. The forest fire took place in June 1992 after a long dry and warm period, and the burned area was approximately 300 ha, mainly coastal pine forest with *Calluna* and *Vaccinium*-species as dominant field layer plants. As a result of fire organic matter is consumed and mineral nutrients transformed from organic to inorganic forms. The loss of organic matter in the humus layer may amount to 25% and in the mineral soil to 10-17% depending on fire intensity (Viro 1974).

Light and water conditions in the field layer are expected to improve as a result of the fire because many of the pine trees were killed by the fire (Moe 1994). Pine regeneration took place, particularly the two first years after the fire (cf. Yli-Vakkuri 1963), and in the areas least affected by the fire, where some trees were still alive and producing seeds (Moe 1997). On the other hand, loss of organic soil structure may have reduced the water holding capacity of the soil (cf. Neal et al. 1965, Mallik 1986) and soil temperatures may have increased due to increased solar radiation (Ahlgren & Ahlgren 1960). Because of the improved light and nutrient conditions, increased productivity would be expected on short terms in the least burned areas. Experiments with pine have shown that controlled burning may be a successful method of regeneration of pine (Øyen 1997), as compared with e.g. clearcutting.

In the present study we want to investigate the productivity of some dominant plants in the field and bottom layer, in order to answer the following questions:

(2) How reliable is the sampling technique for biomass determination?

(3) Has the total plant biomass of the investigated species in the field and bottom layers changed significantly after the fire?

Materials and methods

Study area

The study area is located between Bergen and Stavanger at 59°30'N, 5°20'E (see map in Figure 1). Mean temperatures vary from 2 °C in February to 14 °C in August, and annual precipitation is about 2 000 mm (Klingsheim1996). The height above see level varies between 10 and 333 m. In the western part of the burned area the pine forest was of *Vaccinium* type, while in the eastern part a nutrient-poor *Calluna* and *Molinia* type dominated. Soil characteristica for the burned area was estimated from small patches of unburned soil within the area (Moe 1994). Topography is rather variable, and the humus layer thickness varied from <2 cm in the most dry and nutrient-poor areas to >20 cm where peat accumulation had taken place. In some cases the mineral soil was almost absent, and the humus layer was burned off, leaving the underlying rock exposed.

The fire intensity reached its maximum in these areas, while areas where the ground water level was high, were relatively undamaged, with only surface fire (cf. Moe 1997). The study area was mapped in September 1993 and classified according to fire intensity (Moe 1994) into areas with low (surface fire), medium (stem fire) and high (crown fire) intensity.

Twelve sample plots of 10 x 10 m were established in 1992 and 1993 by Moe (1994), partly on low intensity sites and partly on medium and high intensity sites, with two sample plots outside the burned area as controls. At these sites the coverage of important species and pine regeneration, as well as the natural pine regeneration by seeds was recorded annually (Moe 1994).

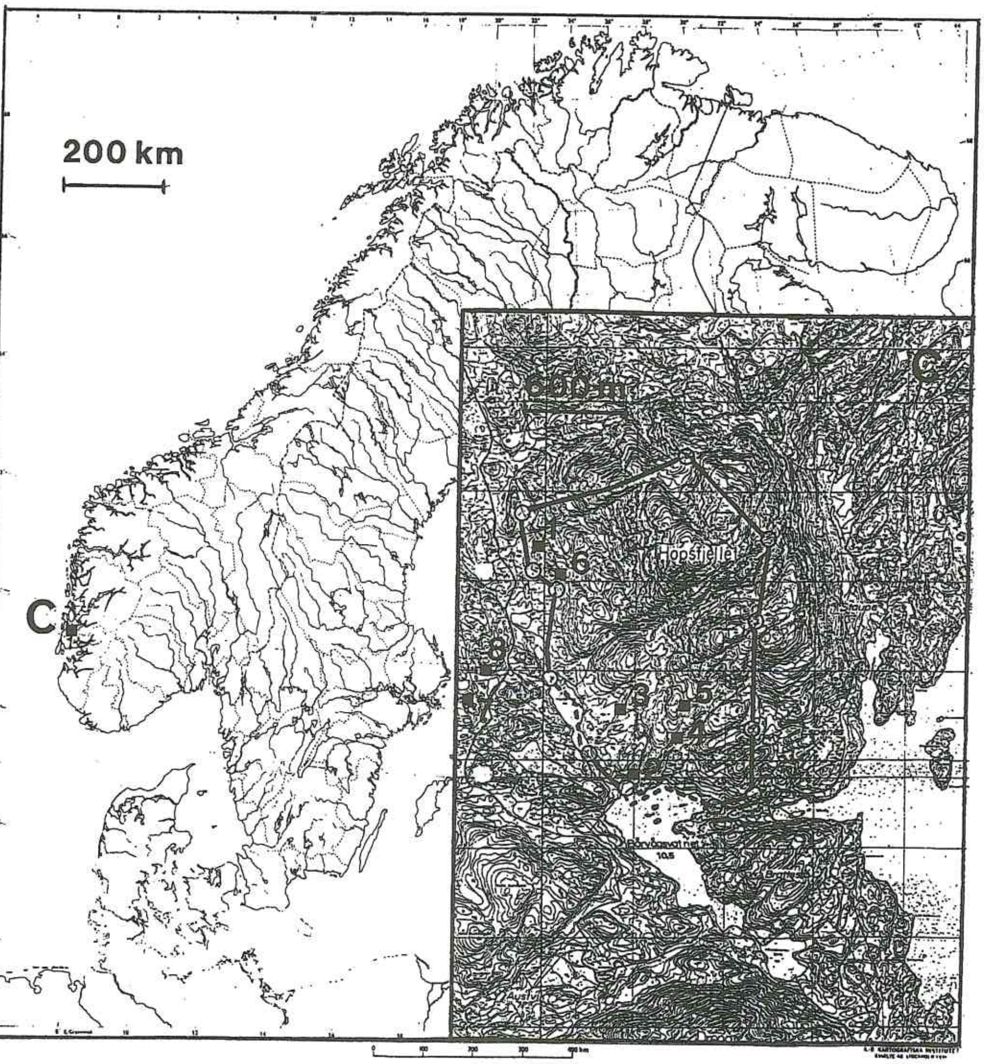

Figure 1. Map of Fennoscandia showing the location of the study site on a small-scale map within a restricted area in western Norway. The eight plots are shown on th small-scale map (C) according to the following list (cf. Moe 1994):

1-2 Low fire intensity plots
3-4 Medium fire intensity plots
5-6 High fire intensity plots
7-8 Control plots

Biomass sampling

Destructive samplings were carried out once a year, in summer (July/August) from 1993 on single species from two 10x10 m medium burned sample plots inside the burned area, and from two control plots outside the area. In order to save time and avoid difficulties separating rootsegments by species, an indirect sampling method was chosen, i.e. by harvesting intact plants with complete root system and relating the biomass to the number of shoots in the samples instead of ordinary area-based sampling technique. The following species were sampled: *Vaccinium myrtillus, V.vitis-idaea, Calluna vulgaris* and *Deschampsia flexuosa.* These species were the main revegetating species in the area. In addition the bracken (*Pteridium aquilinum*) and the pioneer mosses *Polytrichum juniperinum* and *Ceratodon purpureus* was common in the burned areas (Moe 1994) *and Polytrichum commune* at the control plots (Skre et al. 1998), but are not included in the present study.

The harvested plant material was separated into green (photosynthetic active) leaves and non-green tissue (stems + roots), or in some cases (*Vaccinium* spp.) into green leaves, green stems and non-green tissue. The number of annual shoots and/or leaves per plant was also recorded. In *Calluna* the biomass of combined leaf and green stem tissue was sampled and instead of annual shoots only the numbers of more than 1-year old shoots with >10 annual shoots were recorded, excluding the short, lateral annual shoots. The biomass was then determined after drying the plant tissue at 80 °C for 24 hours, and calculated per shoot for each species.

The green and non-green biomass per m^2 for each species was estimated from the measured biomass and numbers of annual shoots in the samples, and from the shoot density in pure stands (i.e. without competition from other plants) of the same species, making a 100% coverage. The numbers of shoots per m^2 in pure stands were extrapolated from sampling squares of 10 x 10 cm (*Calluna, Deschampsi*) or 20 x 20 cm (*Vaccinium* spp. The overall biomass per unit area was then estimated by multiplying the calculated biomass in pure stands with the corresponding coverage of the actual species, as found by Moe (1995). Because large differences in shoot density and plant coverage were found between sample plots according to fire density, while the biomass per annual shoot varied only slightly (Skre, unpubl.), the shoot density (five replicates) was recorded at six sample plots per fire intensity (see Fig. 1) while the biomass samplings were only taken at two representative medium burned plots.

The method was tested by harvesting five random samples of each species by ordinary sampling method, harvesting complete vegetation mats with known surface area down to the mineral soil, and counting the corresponding numbers of shoots and/or leaves in the sample.

The samples were taken from the same stands where the shoot density measurements and the samples for indirect biomass determination were taken.

Results and discussion

Biomass per shoot

There was a significant ($p<0.05$) correlation between estimated and observed biomass (Skre, unpubl.), and the indirect sampling method was found to give a good estimate of the biomass per m^2 in the four investigated species (Table 1). A slight underestimation of the biomass of the two *Vaccinium* species by the indirect method may be due to difficulties separating root segments of *V. myrtillus* and *V. vitis-idaea* by the direct sampling method (Skre, unpubl.)

Table 1. Biomass per m^2 in pure stands of the four investigated species (green and non-green tissue combined) sampled by the direct sampling method (A) and by the indirect method, where the biomass was measured in relation to shoot density on intact plants (B). The samples were taken from control plots outside the burned area.

Species	Sample #	Biomass (gm^{-2}) A	B
Calluna vulgaris	1	699	639
	2	696	790
	3	797	617
	4	607	795
	5	772	906
	Mean	714	749
Vaccinium myrtillus	1	595	685
	2	724	622
	3	532	549
	4	887	545
	5	499	371
	Mean	647	554
Vaccinium vitis-idaea	1	169	236
	2	236	156
	3	457	289
	4	209	135
	5	142	137
	Mean	243	191
Deschampsia flexuosa	1	493	468
	2	660	613
	3	561	593
	4	632	577
	5	545	624
	Mean	538	575

The results from the summer samplings 1993 and 1995 were analysed statistically. In green *Calluna*, non-green *Pteridium* and green and non-green *Deschampsia* significant higher biomass per shoot was recorded within the burned area as compared with unburned control plots (Table 2). On the other hand, in non-green *Calluna*, green *Vaccinium myrtillus* stems and green *V. vitis-idaea* tissue the highest biomass per shoot was found outside the burned area. The biomass per shoot decreased from 1993 to 1998 in green *Calluna* and *Deschampsia* tissue, while a strong increase had taken place in non-green *Calluna* tissue.

Shoot density

In stands of *Deschampsia* and *Calluna*, the shoot densities were significantly lower outside than inside the burned area (Table 3). Only in these two species there was a significant treatment effect due to different fire intensity (Skre et al. 1998), while in the two *Vaccinium* species no significant effects were found. In Calluna there was a slight increase in shoot density during the period 1995-98, while there was no clear trend in the three remaining species (Table 3).

According to Moe (1995) there was a strong regrowth and increased coverage of *Pteridium*, *Deschampsia*, *Calluna* and *Polytrichum* during the two-year period from 1993 to 1995 at medium burned sites, and a slower regrowth of the two *Vaccinium* species.

*Table 2.Biomass per shoot or leaf (*Pteridium*) in green and non-green tissue (mg) in pure stands at burned sites and control plots, all three fire intensities combined. Similarly the results from the 1993 and 1995 harvestings at the control plots were combined. Mean values plus standard error (1993 and 1995) from the summer samplings (July/August) are shown. Asterisks indicate significant differences from control plots (p<0.05) for the two mentioned years. The values are based on six repli-cate samples per species and year from burned sites and a total of eight samples from control plots.*

Species	Burned green 1993	1995	1997	1998	Unburned control green	
Calluna vulgaris	148*+22	87+14	105	108	57+27	112+24
Vaccinium myrtillus	80+5	92+6	96	134	152*+9	122+17
Vaccinium vitis-idaea	136+23	187+19	140	126	245*+16	151+9
Deschampsia flexuosa	156*+9	78+7	41	44	89+11	22+6

Species	Burned non-green 1993	1995	1997	1998	Unburned control green	non-green
Calluna vulgaris	17*+5	60+16	114	133	57+27	112+24
Vaccinium myrtillus	107+21	69+19	84	104	152*+9	122+17
Vaccinium vitis-idaea	116+27	76+13	107	92	245*+16	151+9
Deschampsia flexuosa	49+7	31+4	27	21	89+11	22+6

*Table 3.Density of shoots per m^2 in pure stands of the investigated species. Means of five replicates from each of two plots per fire intensity. The result are based on an ANOVA test (Skre et al. 1998). The significance levels in relation to the control plots for the year 1995 are shown as asterisks where *p<0.05.*

Species	1995	1997	1998	control
Calluna vulgaris	8 746	10 100	12 250	5 370
Vaccinium myrtillus	2 912	2 958	3 625	2 082
Vaccinium vitis-idaea	1 216	1 277	1 361	990
Deschampsia flexuosa	10 143*	9 986	9 870	4 630

Overall biomass

The density of annual shoots per square meter in pure stands of the investigated species (Table 3) and the corresponding percentage cover each year during the period 1992-95 (Moe 1995) was combined with the biomass data from Table 2 to estimate the biomass in gm^{-2} every year at a medium burned site, and at two control plots outside the burned area (Fig. 2). A strong increase in the green and non-green biomass of *Calluna* and *Deschampsia* was observed during the period. Similarly there was also regrowth of *Pteridium* and *Polytrichum* (Skre et al. 1998). The total biomass of the six investigated species was in 1995 already higher than the corresponding biomass at the control site, where *Vaccinium myrtillus* and *Calluna vulgaris* were the two dominant species in the field layer. The ratio between green and non-green tissue of *Calluna* was much higher inside than outside the burned area, but decreased during the five years after the fire (Table 2).

In Table 4 the shoot densities from Table 3 and the mean coverages (Moe 1995) have been used to estimate the total overall biomass (gm^{-2}) from the biomass per shoot or leaf in Table 2. Three years after the fire the overall biomass of green and non-green *Vaccinium myrtillus* and *V vitis-idaea* tissue was still lower within the burned area than outside, while the biomass of *Deschampsia*, *Polytrichum* and green *Calluna* was higher (cf. Fig. 2). There was a significant treatment effect on the overall green and non-green biomass (Skre et al. 1998) due to different fire intensity in all species except *Calluna*.

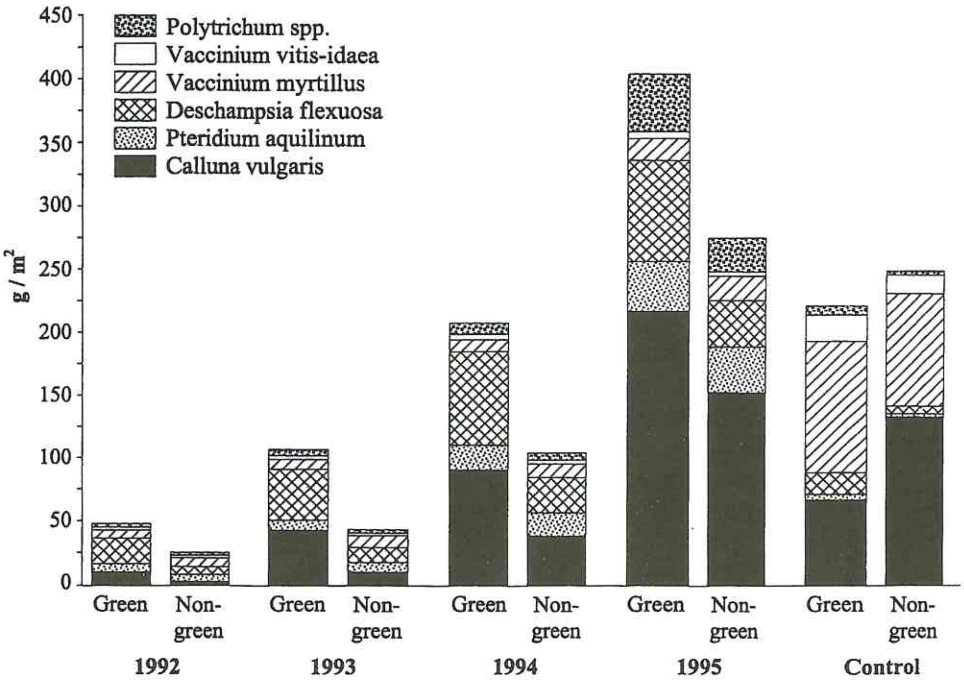

Figure 2. Mean estimated overall biomass ($g\ m^{-2}$) in green and non-green tissue of the investigated field and bottom layer species during summer (July/August) the first four years after the fire (1992-95) at medium burned sites, and at a control site outside the burned area. The results of the samplings on Pteridium *and* Polytrichum *spp. are taken from Skre et al.(1998).*

*Table 4 Total overall biomass July/August 1995 ($g\ m^{-2}$) of the investigated species at low, medium and high fire intensity as estimated from Tables 2 and 3 and the plant coverage (Moe 1995). Means of five replicates from each of two plots per fire intensity. Asterisks indicate where the biomass values from burned plots are significantly different from the control plots. The significance levels are ***p<0.001, **p<0.01, *p<0.05. The results are based on an ANOVA test (Skre et al. 1998).*

Species	Low		Medium		High		Control	
	green	non-green	green	non-green	green	non-green	green	non-green
Calluna vulgaris	330*	227*	219	149	206	142	65	130
Vaccinium myrtillus	28**	22**	17***	20**	6***	4**	103	88
Vaccinium vitis-idaea	3**	2**	5**	3**	3**	2**	24	15
Deschampsia flexuosa	79**	29**	83**	35**	22	8	15	6

Long term succession

The increased shoot density after the fire in most of the investigated species is probably related to better light conditions and better supply of nutrients and water. According to Klingsheim (1996) there was a strong runoff of nutrients the first two years after the fire. *Betula pubescens* and *Salix caprea* were the most common deciduous trees. Where fire intensity was not too high, birch roots survived the fire and there was heavy sprouting (Skre & Wielgolaski 1997). Some pine regeneration was also found during the 1993 and 1994 seasons, and juvenile plants occurred most frequently at the lowest fire intensity (Moe 1995), where some mother trees had survived.

The main revegetating dwarf shrubs were *Calluna vulgaris, Vaccinium myrtillus* and *V. vitis-idaea*. The occurrence of *Calluna vulgaris* is probably related to the high reproduction by seeds, that appeared to be present in the soil before the fire (cf. Granström 1987). However, measurements of shoot density at different fire intensities (Skre et al. 1998) indicated that the seed bank of *Calluna* may be negatively influenced by too high fire intensities (cf. Schimmel 1993). Some of the *Calluna* regrowth may also take place vegetatively from rhizomes (Klingsheim 1996). The *Calluna* biomass increased strongly at all fire intensities. The ratio between green and non-green tissue was very high in 1993, but showed a falling tendency because of strong growth in the woody tissue.

Unlike *Calluna*, the two *Vaccinium* species reproduce mainly vegetatively by forming new rhizomes where fire severity is not too high (Schimmel & Granström 1991). According to Van der Kloet & Hill (1994) the revegetation of *Vaccinium* species after fire takes place almost exclusively from surviving rhizomes. The coverage and biomass of green *V. myrtillus* stems and of green *V. vitis-idaea* tissue per shoot seemed to have been reduced after the fire. The reduction was strongest at the highest fire intensities.

Two species that expanded strongly after the fire are *Pteridium aquilinum* and *Deschampsia flexuosa*. The bracken (*Pteridium)* has a very deep and robust rhizome system, surviving even at high fire severity (Whelan 1995) and both species seemed to have been favored by better light conditions after fire. Schimmel & Granström (1991) thought that *Deschampsia* may take advantage of the improved light and nutrient conditions after a fire and that surviving roots may produce leaves and large amounts of seeds the first years after fire (cf. Klingsheim 1996). Decreasing biomass per shoot from 1992 to 1995 indicates increasing competition between individuals within the *Deschampsia* stands.

In the *Polytrichum* moss there was a strong increase in the moss cover after the fire, and the shoot density was particularly high at high fire intensities, where the soil layer was thin or absent (Skre et al. 1998). At these sites the pioneer moss *Polytrichum juniperinum* was a dominating species, in addition to *Ceratodon purpureus* (Klingsheim 1996). However, the cover of *C. purpureus* usually culminates 2-3 years after a fire (Schimmel 1993), while the two *Polytrichum* species continue to colonize for many years (Granström 1982). The difference in shoot density between *Polytrichum* moss growing inside and outside the burned area was very high, partly due to the occurrence of *P. commune* outside the burned area, with generally lower shoot densities than its relative *P. juniperinum*. The relatively high overall biomass of *Polytrichum* at low fire intensities is probably related to the dominance of the shade-tolerant and moisture dependent *P. commune* at these sites.

A gradual increase took place in the total plant coverage in the field layer, and at low and medium burned sites it was above 90% already in 1995 (Skre et al. 1998). The total overall biomass of the investigated species had then passed the corresponding biomass at the control plot, although the biomass of the two *Vaccinium* species had decreased. However, with increasing competition for light, water and nutrients a decline is expected in the total plant production in the field layer. Further, as pine and birch is regenerating from dispersed seeds and birch stumps, the biomass of the investigated field layer species is expected to decrease slowly, until a steady stage is reached.

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