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Forest fire history in Norway: from fire-disturbed pine forests to fire-free spruce forests

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I have used occurrence of macroscopic charcoal particles, pollen analyses and radiocarbon datings to examine local forest fire abundance in southern and central Norway. Peat cores, covering the last 1000 to 6000 yr, were sampled from 20 bog margin and swamp forest sites, and the charcoal records documented local fire occurrence in 10 of the sites. Forest fires have not occurred in the sites located in central Norway, whereas the fire occurrence in southern Norway showed large variation among the sites. However, forest fires ceased prior to the establishment of Norway spruce *Picea abies* in seven of the sites, whereas the establishment of spruce preceded the fire decline in three of the sites. Odds ratio calculations indicated that it is several hundred times more likely that fires occurred prior to, than after, the spruce establishment. Although time spans between fire decline and spruce establishment showed some variation, they did not increase along a gradient from east to west in Norway, suggesting that the establishment of spruce might have initiated a change from fire-prone to fire-free ecosystems.

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In a Holocene time perspective, occurrence of forest fires and large-scale migrations of boreal forest trees are widely believed to be under broad climatic control (Huntley and Birks 1983, Bonan and Shugart 1989, Huntley and Webb 1989). The immigration of Norway spruce *Picea abies* (L.) Karst. (termed spruce from now on) into Fennoscandia, and in particular into Norway, is a controversial topic, which has been treated in many studies (e.g. Fægri 1950, Tallantire 1977, Høeg 1978, Hafsten 1992, Kullman 1995). In general, the importance of a broad climatic control has been emphasized because the spread of spruce coincided with the cooling of the climate during the last three millennia (cf. Berglund 1986). Prior to the establishment of spruce, Norwegian forest landscapes were dominated by Scots pine *Pinus sylvestris* L. (termed pine from now on), birch *Betula pubescens* Ehrh. and *B. pendula* Roth, and sometimes alder *Alnus incana* (L.) Moench and *A. glutinosa* (L.) Gaertner (Hafsten 1992). Whereas pine is well adapted to fire (Zackrisson 1977, Linder et al. 1997), spruce is considered to be a late successional species favoured by the absence of fires (Sirén 1955, Syrjänen et al. 1994) and depressed by the occurrence of fires (Bradshaw and Hannon 1992).

At finer temporal and spatial scales, disturbance processes, such as fires, seem to be of vital importance in controlling boreal forest dynamics (e.g. Bradshaw and Hannon 1992, Engelmark et al. 1993, Hörnberg et al. 1995, Segerström et al. 1996). Thus, the spread of spruce to the west may have been favoured by a decrease (or even cessation) in fire occurrence prior to the spread. However, because fire might improve seedbed conditions, the local establishment of spruce could in fact also have been facilitated by previous fire disturbances (Ohlson and Tryterud 1999). As spruce normally creates dense and moist stands, suggesting minor summer-drought effects, spruce itself might result in changed fire conditions. The extensive climatic and topographic gradients in Norway must also be considered too; different regions have probably experienced

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very different histories with respect to forest fire dynamics and spruce immigration.

The spread and establishment of spruce in Norway provides an excellent opportunity to study shifts in fire regimes and forest ecosystems. The goals of this study have been to document long-term fire history in Norway, and to investigate changes in fire occurrence in relation to the local establishment of spruce. My study is based on analysis of macroscopic charcoal, spruce pollen, and ^{14}C-datings.

Material and methods

Study areas and study sites

A total of 20 study sites were located in 13 study areas (of which 12 were nature reserves) in south and central Norway (Fig. 1). Thirteen of the sites were located in spruce-dominated swamp forests and seven sites were located at the margin of small bogs, i.e. < 5 m from mineral soil. The bog sites were surrounded by either spruce-dominated (spruce bog sites) or pine-dominated (pine bog sites) forest. The sites covered large latitudinal, longitudinal and altitudinal gradients, representing different forest ecosystems due to vegetation regions and climatic conditions (Table 1). The choice of 15 of the sites was motivated from a collaboration with monitoring projects (see Økland and Eilertsen 1993, Økland 1996) focusing on vegetation change in spruce forests. It was difficult to find swamp forests located close to monitoring sites in all areas, and consequently I had to choose some sites on small bogs. Sites 3, 12, 13, 14 and 15, represent areas supposed to be natural forests, only slightly affected by man.

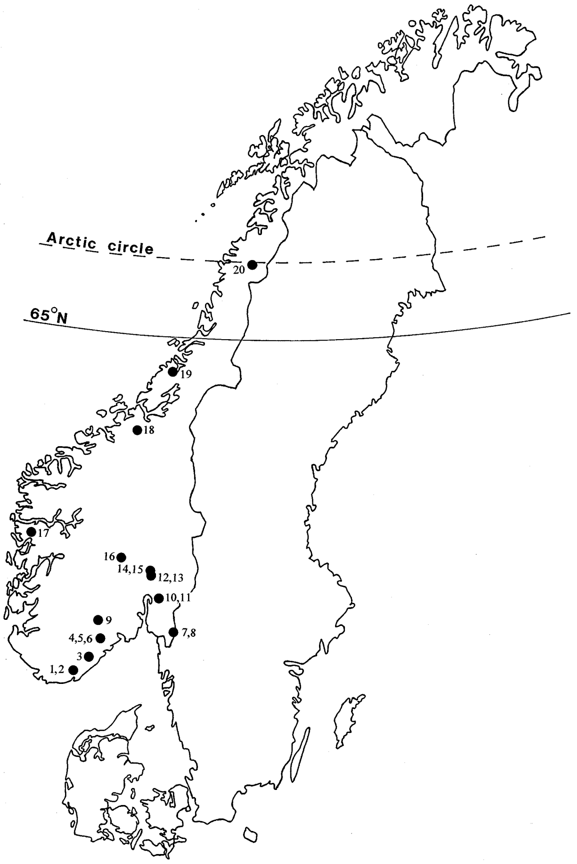


Fig. 1. Map of Scandinavia showing the study areas. Numbers refer to the sites.

Field and laboratory work

Using a Russian peat sampler (Jowsey 1966), I collected peat cores from each of the 20 sites during the summer 1996. The uppermost layer of the peat deposits, viz. the non-compressed, more or less living peat mosses, was rejected before sampling due to low bulk density, giving too small amounts of pollen per unit volume. To avoid stratigraphic contamination, the peat cores were wrapped in aluminium foil and transported from the field horizontally in a bag. The cores were then deep-frozen and cut into ca 0.5 cm thick slices (still frozen) using a kitchen slicing machine, packed in small plastic bags, and re-stored frozen. When slicing the peat cores, I established a routine that consisted of cleaning the slicing machine with drying paper after five cuttings, and washing it after twenty cuttings. Each slice thus represented a certain depth interval in the respective peat cores, and is treated as one observation. Between every fifth cutting, I measured the remaining peat core and then calculated mean thickness of the five slices.

From each slice I collected a 1.0 cm^2 subsample, and quantified the macroscopic charcoal with longest axis ≥ 0.5 mm, using a method described by Hörnberg et al. (1995). All peat cores were searched for charcoal, that was noted as number of particles subsample^{-1}. Pollen slides were prepared for every twentieth subsample using standard methods (Moore et al. 1991). In the pollen investigation, I used five categories, i.e. spruce, pine, birch, alder, and grasses, and counted at least 300 pollen at each slide. I used 2% spruce pollen (of the tree pollen sum) as the critical value indicating local spruce establishment (cf. Hafsten 1992). I also collected 33 subsamples of either large charcoal particles (> 1 g) or peat mosses from 12 of the sites for radiocarbon datings. Charcoal particles were used due to the low amount of material necessary for dating, leaving enough material for other analysis. To obtain one record with high temporal resolution, 14 of the samples were collected from site 3. The datings were performed by the Ångstrom Laboratory (Uppsala, Sweden).

Table 1. Description of the study sites. Vegetation zones are according to Dahl et al. (1986). *Picea abies* immigration is given in calibrated ages based upon results from dating sites (Nilssen and Vorren 1987, Hafsten 1992) near the study sites. Under site types, (p) and (s) means that the bog margins and the swamp forests were located in *Pinus sylvestris* or *Picea abies* dominated forests, respectively.

Site		Latitude (N)	Longitude (E)	Altitude (m)	Vegetation zone	Site types	*Picea abies* immigration
No.	Abbrev.						
1	Pau 1	58°18′	07°57′	260	Boreo-Nemoral	Bog (p)	AD 1530
2	Pau 2	58°18′	07°57′	220	Boreo-Nemoral	Bog (s)	AD 1530
3	Jom 1	58°38′	08°37′	370	Boreo-Nemoral	Swamp (s)	AD 1410
4	Sol 1	58°57′	08°49′	400	Boreo-Nemoral	Swamp (s)	AD 950
5	Sol 2	58°57′	08°50′	380	Boreo-Nemoral	Bog (p)	AD 950
6	Sol 3	58°57′	08°50′	390	Boreo-Nemoral	Swamp (s)	AD 950
7	Lun 1	59°04′	11°43′	230	Boreo-Nemoral	Swamp (s)	AD 390
8	Lun 2	59°03′	11°43′	220	Boreo-Nemoral	Swamp (s)	AD 390
9	Gry 1	59°15′	08°37′	540	Middle Boreal	Swamp (s)	AD 1060
10	Øst 1	59°49′	11°02′	240	Southern Boreal	Swamp (s)	AD 300
11	Øst 2	59°49′	11°02′	270	Southern Boreal	Swamp (s)	AD 300
12	Sko 1	60°14′	10°47′	610	Middle Boreal	Swamp (s)	AD 120
13	Sko 2	60°14′	10°47′	590	Middle Boreal	Swamp (s)	AD 120
14	Gul 1	60°21′	10°48′	750	Middle Boreal	Swamp (s)	AD 120
15	Gul 2	60°21′	10°48′	740	Middle Boreal	Bog (s)	AD 120
16	Bri 1	60°32′	09°23′	830	Middle Boreal	Bog (s)	AD 680
17	Ott 1	60°49′	05°46′	280	Southern Boreal	Bog (s)	AD 1600
18	Urv 1	63°07′	09°48′	320	Southern Boreal	Swamp (s)	AD 1350
19	Øye 1	64°17′	10°58′	210	Middle Boreal	Bog (s)	AD 860
20	Gra 1	66°31′	14°53′	290	Middle Boreal	Swamp (s)	AD 1700

Data and statistics

Data from all sites were used to document long-term forest fire dynamics, and the results are presented graphically. I used a subset of sites to test the relationship between fire occurrence and spruce establishment, and descriptive statistics are shown. The following criteria were used to select the subset: spruce establishment must have occurred, a charcoal record must be present, and, due to the focus on local scales (see Jacobson and Bradshaw 1981, Bradshaw 1988), only the swamp forest sites could be used (i.e. only one site type is represented). Eight of the sites satisfied the requirements. (Note that the results were not contradicted by using all the sites in the testing.) I used presence/absence of macroscopic charcoal particles as the binary response variable, and site and spruce (i.e. whether spruce was present or not) as the predictor variables. I first checked the data for correlation between the predictor variables (Pearson product moment correlation coefficient), and found that site and spruce could be treated independently. Assuming a binomial distribution for the response variable, I performed a logistic regression model using the backward elimination procedure (Agresti 1996).

Results

Taken together, the peat cores contained 2588 subsamples with ca 13 000 charcoal particles ≥ 0.5 mm. In total 147 pollen slides were prepared, and ca 90 000 pollen and spores were counted. Eleven datings of large charcoal particles and 22 datings of *Sphagnum* leaves were performed from 12 of the sites. Spruce pollen was present in all sites, and charcoal particles ≥ 0.5 mm were present in 16 sites (Table 2).

The charcoal record showed a large latitudinal variation, with most of the variation present in the southern part of Norway (Fig. 2). In the three northernmost sites (central Norway), I found no charcoal particles at all, whereas the mean number of charcoal particles subsample^{-1} varied between 0 and 30 among the other sites. Because the post-spruce period was almost similar in all sites, the latitudinal variation was mainly caused by the charcoal occurrence in the pre-spruce period (see Fig. 2). The variation in charcoal occurrence was large among the swamp forest sites, whereas the variation was small among the pine bog sites and the spruce bog sites, respectively. However, although small variations, the latter two site types were different, as amount of charcoal in the pine bog sites showed a figure more than 10 times higher than the spruce bog sites, indicating that different site types have been influenced by different fire regimes.

In most of the sites, pine and birch were the dominating species before spruce established, whereas alder played a dominating role in two sites only, i.e. site 8 and 11. Spruce pollen was present at all sites, but the proportion of spruce pollen did not exceed 2% in sites 1 and 2. At these two sites, the most recent period including spruce establishment was missing due to the removal of the upper peat layer before sampling (see Material and methods).

Table 2. Result of the charcoal and pollen analyses. Subsamples refers to ca 0.5 cm^3 peat samples. Tree pollen refers to pollen from *Picea abies*, *Pinus sylvestris*, *Betula pubescens/pendula* and *Alnus incana/glutinosa*.

Site	Length of peat core (cm)	Subsamples (no.)	Charcoal particles ≥0.5 mm (no.)	Pollen slides (no.)	Tree pollen (no.)	Radiocarbon datings (no.)
1	42.5	85	2576	5	2398	1
2	49.5	99	2	5	1100	0
3	94.0	188	2547	10	5014	14
4	83.2	166	275	9	2255	2
5	68.5	136	2933	7	1979	2
6	38.5	76	265	4	1495	2
7	45.5	91	222	5	1119	1
8	87.1	175	1257	7	3427	3
9	78.5	159	6	8	2927	0
10	86.5	172	915	10	2597	1
11	65.6	131	1114	12	7088	2
12	45.5	91	1314	5	3317	2
13	100.5	201	0	11	4747	0
14	24.1	49	3	3	1675	0
15	70.6	142	156	8	3008	2
16	72.0	145	2	7	1686	0
17	67.1	135	35	7	2108	1
18	93.2	188	0	15	3966	0
19	47.0	94	0	5	443	0
20	33.0	65	0	4	1099	0

The ^{14}C-datings (Appendix 1) documented fire records ranging from ca 1000 to ca 7000 yr BP among the dated sites. Mean peat accumulation rates were highly different among the sites, ranging from 11 to 222 yr cm^{-1}, with the exception of sites 8 and 11. In these latter two sites, the dating results were a bit confusing because of an inconsistent relationship between age and depth (Fig. 3). In general, spruce established after the decline in fire occurrence, but at site 5, 7 and 10, the fire decline was located above the spruce establishment level. In some cases there were long time spans between cessation of fires and spruce establishment, but in other cases spruce pollen amounts increased immediately after the end of the charcoal record. The times when fire occurrence declined ranged from ca 500 to ca 2300 yr BP, with the oldest fire-free records in the eastern sites.

Descriptive statistics emphasized that in the 8 sites involved in the statistical tests, charcoal was much more common before than after the spruce establishment (Table 3). The backward elimination procedure (using likelihood ratio statistics) suggested that the model

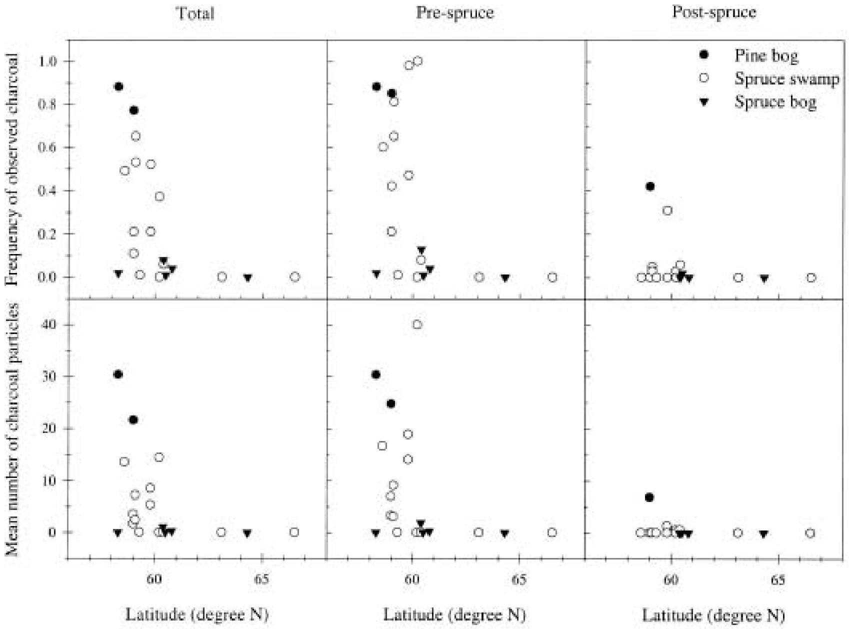
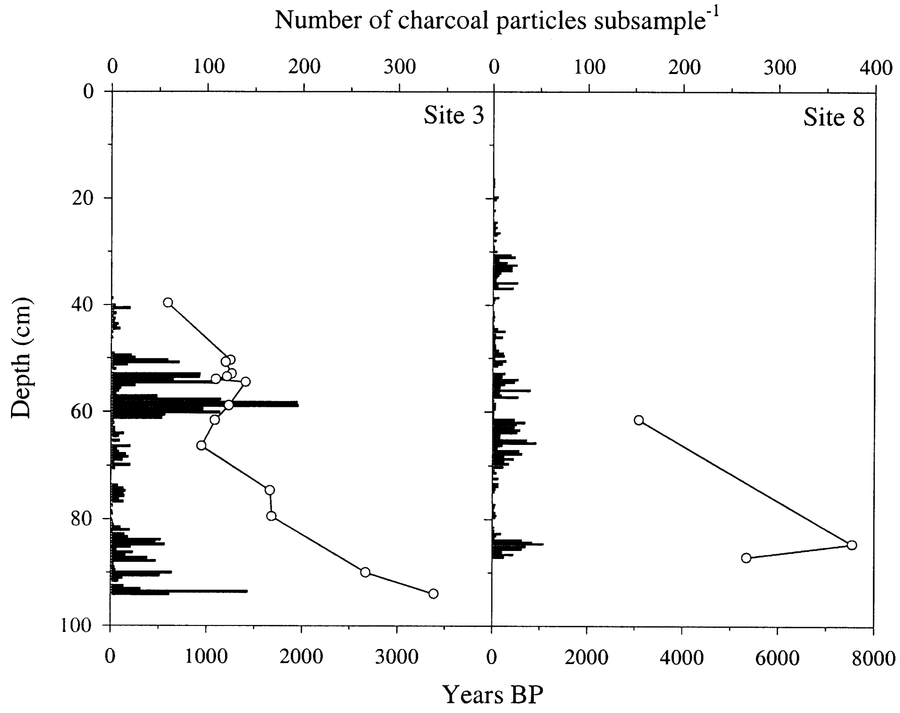


Fig. 2. Amount of charcoal recorded in the sites according to site type and latitude before (pre-spruce), after (post-spruce) and ignoring (total) the *Picea abies* establishment at the sites. Charcoal amount is given both as number of particles and as frequency of observing one particle or more.

Fig. 3. Curves illustrating the radiocarbon datings from site 3 and 8 compared with the charcoal particle data (horizontal bars). Years BP refers to radiocarbon years before AD 1950. Note different horizontal scales.



containing the main predictors site and spruce, was the only one giving acceptable goodness of fit (deviance = 8.633, DF = 7 and p = 0.28). Further, the adjusted residuals were $\leq |2|$ in 14 of 16 observations (the final two adjusted residuals = 2.7), supporting the acceptance of model fit, and my interpretations were thus based on this model. The odds of observing charcoal showed large differences between the sites, and the odds of observing charcoal before the spruce establishment was ca 325 times larger than the odds of observing charcoal after the spruce establishment (Table 4). Note the large 95% confidence intervals for site and spruce, emphazising the variation. However, the odds of observing charcoal particles ≥ 0.5 mm was significantly larger before than after the spruce establishment (Wald-statistic: Z = 9.08, $p < 0.001$).

Discussion

Shift from fire-prone to fire-free ecosystems

Tree species respond differently to different fire regimes. Areas where fires are common will, in general, be dominated by pine, whereas spruce is most often the dominating tree species in areas where fires occur rarely or not at all (Linder et al. 1997). This is mainly based upon ground and moisture conditions, which is a result of geology, climate, topography, and vegetation composition. However, spruce sites in Norway were dominated by other species before the spruce immigration. As spruce is a shade-tolerant species with dense crown canopy, its establishment might change the microclimatic conditions at the site, i.e. on the local scale. Thus,

Table 3. Descriptive statistics given as number of charcoal particles subsample^{-1} based on n subsamples from the swamp forest sites recording both spruce establishment and a clear charcoal occurrence.

Site	Pre-spruce						Post-spruce					
	n	Mean	SD	Median	Max	Min	n	Mean	SD	Median	Max	Min
3	153	16.65	33.44	3	195	0	35	0	0	0	0	0
4	84	3.27	8.46	0	46	0	82	0	0	0	0	0
6	38	6.97	15.02	0	77	0	38	0	0	0	0	0
7	72	3.07	4.20	2	24	0	19	0.05	0.11	0	0.25	0
8	138	9.10	11.35	4	54	0	37	0.03	0.08	0	0.25	0
10	54	14.02	24.49	8	175	0	118	1.34	3.09	0	21	0
11	59	18.88	36.47	0	181	0	72	0	0	0	0	0
12	32	39.94	49.88	19.5	225	2	59	0.61	4.56	0	35	0

Table 4. Logistic regression model describing the relationship between the probability of observing charcoal particles ≥0.5 mm and the coefficients of the predictor variables site and spruce. Coefficients and corresponding odds ratios are given as contrasts to the first predictor value reported.

Predictors		Wald statistics			Odds ratio	95% confidence interval	
Variable	Value	Coefficient	Z-value	p-value		Lower	Upper
Site	4	0.0000			1.00		
	6	0.9766	2.32	0.021	2.66	1.16	6.07
	11	1.1890	3.20	0.001	3.28	1.59	6.80
	3	1.7107	5.47	0.000	5.53	3.00	10.21
	7	1.9901	5.47	0.000	7.32	3.58	14.93
	8	2.7886	8.13	0.000	16.26	8.30	31.85
	12	4.3215	6.25	0.000	75.31	19.43	291.81
	10	6.2395	8.83	0.000	512.61	128.26	2048.74
Spruce	After	0.0000			1.00		
	Before	5.7833	9.08	0.000	324.82	93.25	1131.48

also the fire conditions could be changed due to the establishment of spruce, suggesting that other ecological processes would become the dominating disturbance agents. The establishment of spruce in swamp forests was correlated with changes in fire occurrence. The odds ratio of 325 was extremely high, and even considering the large confidence interval ([93,1131]), the odds ratio emphasized the change in fire regime.

It has been known for many years that pollen deposition within forests mainly reflects the local vegetation (e.g. Andersen 1979, Jacobson and Bradshaw 1981, Prentice 1985), and Bradshaw (1988) concluded that closed canopy sites recruit their pollen from small source areas (radius 20–30 m) and thus record patterns and processes not resolved by regional sites. Because forest fires in general have been a major disturbance factor, scientists have tried to perform charcoal analyses so that they match the spatial scale reflected in pollen analyses from closed canopy sites (Bradshaw and Hannon 1992, Hörnberg et al. 1995, Segerström et al. 1996). Unfortunately, the term local scale has been used without a clear definition of the scale (Tolonen 1985, 1987, Patterson et al. 1987, Clark 1988, Whitlock and Millspaugh 1996), and the strength of the interpretation basis has suffered from the lack of a spatial definition.

However, recent studies have documented the deposition of charcoal produced by experimental burns, and consequently, new interpretation possibilities have arised. The results show in general that macroscopic charcoal indicates fire with higher spatial precision than previously believed. Both Clark et al. (1998) and Ohlson and Tryterud (2000) found that macroscopic charcoal particles (≥ 180 μm) allow for an even finer spatial resolution (radius 1–5 m) than pollen analysis from closed canopy sites. Note that the experimental burning reported by Clark et al. (1998) was a high intensity fire. However, Ohlson and Tryterud (2000) also found that fire could burn over a potential sampling point without depositing any macroscopic charcoal particles ≥ 500 μm, suggesting that the conservative use of one single sampling point (Hörnberg et al. 1995, Ohlson et al. 1997, Ohlson and Tryterud 1999) might result in underestimation of fire events. Nevertheless, the fact that previously frequent charcoal occurrence in the peat cores was followed by a dramatic change to non-occurrence is a reliable indication of a real change in fire occurrence. Consequently, macroscopic charcoal analyses and pollen analyses from peat cores collected in closed canopy sites, should match quite well, because both analyses focus on small spatial scales. In Norwegian swamp forests influenced by historical fires, the establishment and spread of spruce might have entailed a shift from fire-prone to fire-free ecosystems.

Forest fires and the spread of the spruce forest

It is important to note that I found no charcoal at all in four of the sites, and that only small amounts of charcoal occurred in six other sites (Fig. 4), suggesting that swamp forest fires in Norway have never been an ubiquitous ecological phenomenon. The charcoal data showed large variation both among site types, within one site type (swamp forests) and along the latitudinal gradient (Fig. 2). This is not surprising, as fire frequency generally might vary considerably with vegetation type, topography and geographic region (Zackrisson 1977). In the spruce bog sites I found almost no charcoal particles at all, probably explained by the distance between the sampling point and the mineral soil (< 5 m). Because the particle size used in this study mainly reflects fire occurrence within 1 m radius (cf. Ohlson and Tryterud 2000), I argue that fires on the dry ground have deposited no, or only small amounts of, macroscopic charcoal particles at the sampling points on the spruce bogs, see also Segerström et al. (1996). On the contrary, two of the three sites expressing the highest mean number of charcoal particles, were the two pine bog sites. These two sites were located on plateaus, which were more likely to experience frequent summer droughts (creating good fire con-

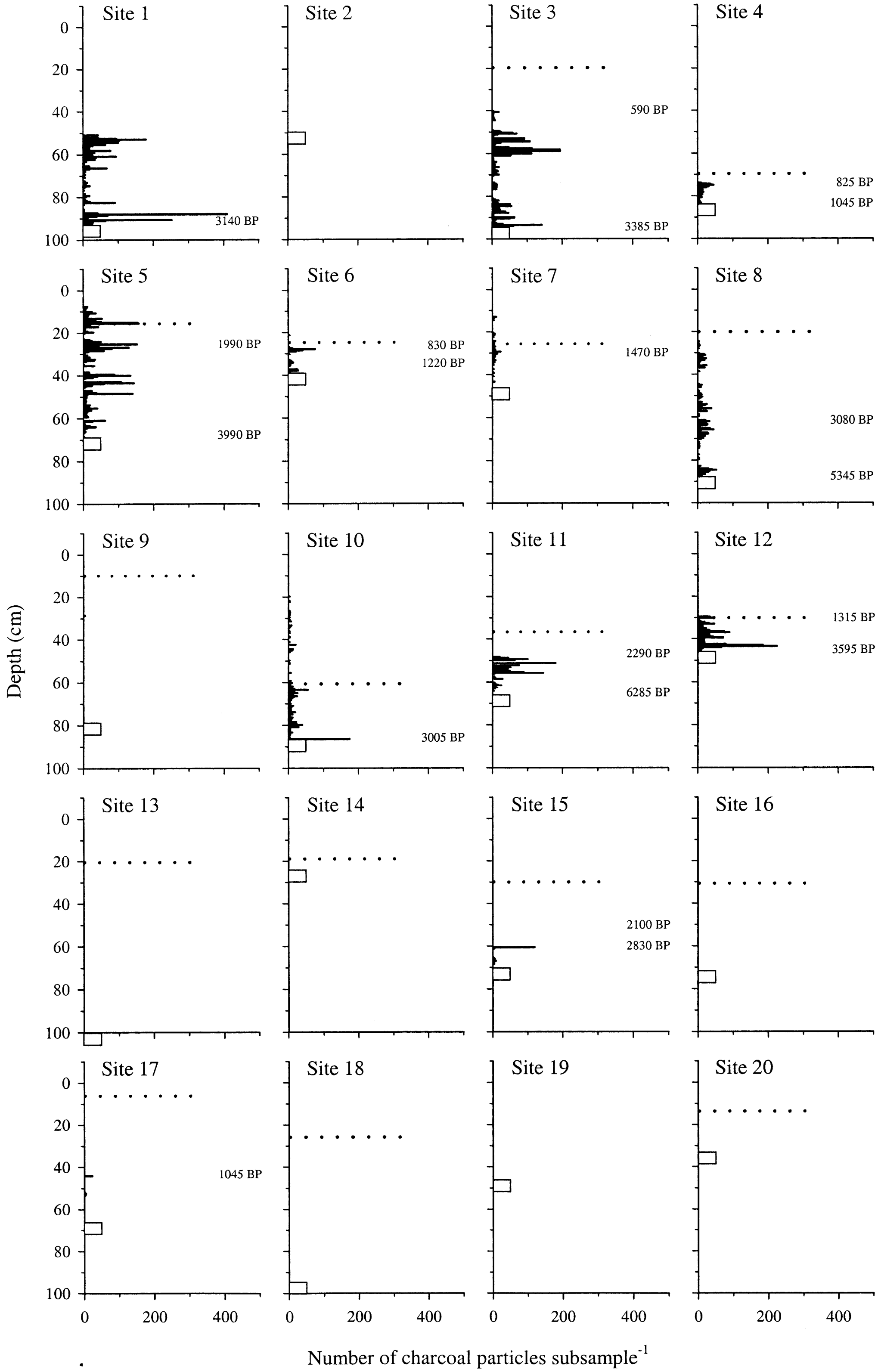


Fig. 4. Fire influence (number of charcoal particles) during several thousand years, and *Picea abies* establishment (2% marked with dotted lines) recorded. At sites 1, 2 and 19, there are no data for the *Picea* establishment. Years BP refers to radiocarbon years before AD 1950. The rectangles mark the transition between peat and mineral soil.

ditions) than the spruce bog sites. The spruce bogs were either surrounded by, or located in more or less gentle hillsides, suggesting a higher influence of surface water and ground water, which could maintain moist conditions even during summer droughts. Within the 13 swamp forest sites, the charcoal occurrence varied considerably from no particles counted (three sites) to the highest mean number of particles counted, regardless of site type. These sites were located on plateaus, on hillsides and in depressions, and the fire conditions might consequently have shown large variation among the sites. However, swamp forest specific factors should also be regarded. Swamp forest floors provide a multitude of ecological niches due to microtopographic variation, expressing wide hydrological gradients from dry hummocks to water-filled hollows (Ohlson 1990). Consequently, both large and small-scale topographic variation might be explanatiory factors, suggesting that we can not generalize about fire regimes in Norway (see Bleken et al. 1997). Annual number of days with precipitation (200–250 d) might explain the non-occurrence of charcoal in the three northernmost sites; the ground rarely dried so much that fire could occur.

Hafsten (1992) synthesized a large amount of pollen-analytical investigations of peat cores from ca one hundred bogs in the Norwegian spruce forest domain, and found that pine, birch, and sometimes alder, were the co-dominating species in all sites until spruce established in the area. The immigration of spruce into Norway started ca 2200 yr BP (Hafsten 1992), and the species is still occupying new areas in the western part of Norway. My pollen data in general support Hafsten (1992), but there also were local differences compared with the broad-scaled spruce immigration. As an example, site 7 and 8 were located only 1 km from each other in the southeastern part of Norway, and I estimated the establishment of spruce at the sites to 500 and 1000 yr BP, respectively. In comparison, Hafsten (1992) dated the spruce immigration in the same area to 1400–1700 yr BP. In the light of Kullman's (1995) findings, my results should not be surprising; local establishment of spruce is not neccesarily reflected on broad-scale data from open mires. The use of 2% spruce pollen to indicate local establishment of spruce has been discussed (e.g. Hafsten 1992). He argued that a steep slope on the spruce pollen curve should be a reliable evidence for spruce establishment, and that 2% spruce pollen could be used in such cases. In my study, the spruce pollen data showed this pattern.

The dating results from sites 3 and 8 (Fig. 3) clearly point to the difficulties related to radiocarbon datings. Both old charcoal and organic material in a swamp forest might be consumed by new fires, resulting in a topmost layer with old and recent carbon more or less mixed. Biological activity might allow some carbon exchange in the peat, e.g. from living roots of *Carex* to fossil leaves of *Sphagnum*, suggesting that recent carbon might have been stored at deeper peat levels. Also inwash of old charcoal might occur. As a consequence, many datings might give confusing results, raising questions instead of answers. On the contrary, using few dating points might give a false sense of security. Note that the dating results from sites 3 and 8 were based on both charcoal particles and *Sphagnum*-leaves. These difficulties with dating control did not suggest a finer resolution of my data. It would have been more satisfactory to present the charcoal data as number of particles $\mathrm{cm}^{-2}\ \mathrm{yr}^{-1}$, allowing direct comparison between years and periods. However, given the dating difficulties, I found it more appropriate to present the charcoal data as number of particles $\mathrm{subsample}^{-1}$, representing specific stratigraphic levels in the peat cores.

Conclusion

Holocene forest fires in Norway have probably never been an ubiquitous ecological phenomenon as 50% of the sites contained no or only small amounts of charcoal. Large latitudinal variation among the sites was documented, suggesting that fires, in general, were rare in central Norway, whereas southern Norway experienced a variety of fire regimes. In the sites influenced by forest fires, the majority of fires occurred prior to the spruce establishment. Consequently, the fire regimes have shifted from fire-prone pine dominated forests to fire-free spruce dominated forests. I suggest that spruce has the ability to initiate a change in fire conditions because of its dense crown canopy, resulting in changed microclimatic conditions.

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Appendix 1. Radiocarbon datings from 12 study sites in Norway. Charcoal refers to large particles with weight ≥ 5 mg, and years BP refers to years before AD 1950.

Site	Sample depth (cm)	Material	^{14}C age (years BP ± SD)	Laboratory number
1	91.6–92.1	*Sphagnum* leaves	3140 ± 65	Ua-14094
3	39.2–39.7	*Sphagnum* leaves	590 ± 55	Ua-14721
3	49.9–50.4	charcoal	1245 ± 75	Ua-14095
3	50.4–50.8	charcoal	1195 ± 55	Ua-14096
3	52.5–53.0	charcoal	1260 ± 55	Ua-14097
3	53.0–53.5	charcoal	1210 ± 55	Ua-14098
3	53.5–54.0	charcoal	1095 ± 55	Ua-14099
3	54.0–54.5	charcoal	1405 ± 70	Ua-14100
3	58.3–58.9	charcoal	1230 ± 70	Ua-14101
3	61.1–61.6	*Sphagnum* leaves	1085 ± 60	Ua-14722
3	65.9–66.4	*Sphagnum* leaves	945 ± 70	Ua-14102
3	74.2–74.7	*Sphagnum* leaves	1665 ± 55	Ua-14103
3	79.0–79.5	*Sphagnum* leaves	1680 ± 75	Ua-14723
3	89.5–90.0	*Sphagnum* leaves	2670 ± 65	Ua-14104
3	93.5–94.0	*Sphagnum* leaves	3385 ± 60	Ua-14105
4	73.4–73.9	*Sphagnum* leaves	825 ± 60	Ua-14106
4	82.7–83.2	*Sphagnum* leaves	1045 ± 60	Ua-14107
5	24.7–25.3	charcoal	1990 ± 55	Ua-14108
5	67.9–68.5	*Sphagnum* leaves	3990 ± 75	Ua-14109
6	27.4–27.9	charcoal	830 ± 55	Ua-14110
6	33.7–34.2	*Sphagnum* leaves	1220 ± 55	Ua-14111
7	28.9–29.4	*Sphagnum* leaves	1470 ± 55	Ua-14112
8	61.0–61.5	*Sphagnum* leaves	3080 ± 60	Ua-14113
8	84.3–84.6	*Sphagnum* leaves	7545 ± 130	Ua-14114
8	86.6–87.1	*Sphagnum* leaves	5345 ± 80	Ua-14115
10	85.5–86.0	*Sphagnum* leaves	3005 ± 70	Ua-14116
11	47.2–47.7	*Sphagnum* leaves	2290 ± 65	Ua-14725
11	65.2–65.6	*Sphagnum* leaves	6285 ± 100	Ua-14726
12	29.1–29.6	*Sphagnum* leaves	1315 ± 60	Ua-14117
12	42.5–44.0	charcoal	3595 ± 60	Ua-14118
15	49.9–50.3	*Sphagnum* leaves	2100 ± 60	Ua-14119
15	60.0–60.6	charcoal	2830 ± 70	Ua-14120
17	43.2–43.7	*Sphagnum* leaves	1045 ± 70	Ua-14724