Acknowledgments. – The research missions are realized through an international cooperation agreement between the University of Silésie and the University of Québec in Montréal. We thank the Science Academy of Poland and Svalbard's Norwegian authorities for their support. In the field, the Polish polar base's team has always provided us with help. Thanks to Pr. Dr. M. Pulina and Pr. Dr. J. Jania for their welcome and their support. Finally, I was successively helped by P. Gagnon, M. Tremblay, A. Tyc. and C. Paradis with glacier exploration. P. Jutras translated the manuscript.

Manuscript accepted February 1997

References

Glazovsky, A. F., Macheret, Y. Y., Moskalevsky, M. Y. & Jania, J. 1991. Tidewater glaciers of Spitsbergen. *IAHS Publication no. 208,* 229–239.

Jania, J. 1988. *Dynamic glacial processes in South Spitzbergen in the light of photointerpretation and photogrammetric research* (in Polish with English summary). Universytet Slaski, Katovice 258 pp.

Jania, J., Schroeder, J. & Bukowska-Jania, E. 1993. The drainage system of a Svalbard tidewater glacier and its meltwater contribution to its fjord. International Workshop on Glacier Hydrology, I.G.S., Jesus College, Cambridge, 8–10 Sept. 1993.

Röthlisberger, H. & Lang, H. 1987. Glacial hydrology. Gurnell, A. M. & Clark, M. J. (eds.) *Glaciofluvial Sediment Transfer.* John Wiley & Sons, New York.

Schroeder, J. 1991. Les cavités du Hansbreen creusées par les eaux de fonte. Svalbard, 77°Lat. N, pp. 21–33. Eraso, A. (ed.) *Proceedings of the First International Symposium of Glacier Caves and Karst in Polar Regions.* Inst. Technologics GeoMinero de España, Madrid.

Norsk geogr. Tidsskr. Vol. 52, 89–103. Oslo. ISSN 0029-1951

Subfossils of Scots pine (*Pinus sylvestris* L.) from the mountain area of South Norway as the basis for a long tree-ring chronology

L. SELSING

Selsing, L. 1998. Subfossils of Scots pine (*Pinus sylvestris* L.) from the mountain area of South Norway as the basis for a long tree-ring chronology. *Norsk geogr. Tidsskr.* Vol. 52, 89–103. Oslo. ISSN 0029-1951.

In order to use the South Norwegian alpine pine subfossils as the basis for dendroclimatological purposes, information about samples collected earlier is presented. The potential to construct a complete Holocene tree-ring series in this area based on pine subfossils is good. The construction of floating chronologies from the early Holocene period should be easier to achieve than chronologies from later periods. The maximum level and the changes in the Holocene pine forest level are different in the three zones defined in this paper. The gap 6400–6000 calendar yrs. BC represents a period of decreased temperature. The gap 3100–1500 calendar yrs. BC represents a period well known for its changing environment (probably climatic changes).

Lotte Selsing, Museum of Archaeology, Stavanger, Box 478, N-4001 Stavanger, Norway.

The need for high-resolution time-scales for palaeoclimatological reconstruction has increased the importance of tree-ring investigations. In Norway, dendrochronological investigations are carried out mostly using Scots pine (*Pinus sylvestris* L.) (Ording 1941, Slåstad 1955, Eidem 1953, 1959, Brandt 1975, Thun 1987, Kirchhefer & Vorren 1995, Kalela-Brundin 1996, in prep. a, in prep. b), oak (Christensen & Havemann 1992) or spruce (Ording 1941, Eidem 1953) (for a Fennoscandian view, see Eronen et al. 1991). The Scots pine samples are collected from living and dead trees, old constructions and bog subfossils (Thun 1984a, 1984b, 1987, Kirchhefer & Vorren 1995, Kalela-Brundin 1996, in prep. a, in prep. b, pers. comm.).

At the moment, the longest chronology from the South Norwegian mountain area extends back to about calendar yr. AD 1200 (Kalela-Brundin in prep. b), while the longest lowland chronology extends back to calendar yr. AD 574 (Thun 1991). It is impossible to extend the time-scale further back without using timbers from old constructions and pine subfossils. Kalela-Brundin (in prep. b) is, at the moment, upgrading these time-scales for use in dendroclimatological interpretation.

Pine subfossils from bogs and lakes in the mountain area in South Norway were collected for palaeoecological purposes (e.g. Moe 1977, Selsing 1979, Aas & Faarlund 1988, Kvamme 1993), but no dendrochronological analyses have been performed on this material. Hafsten (1981) and Roaldset (1992) tried to make a tree-ring dating of pine trunks from Dovre and Numedal, respectively, but without success, because the pine trunks predated the period represented by Scandinavian pine dendrochronological curves.

Finds of pine subfossils above the present pine forest limit were, in the 19th century, already interpreted as the effect of past warmer climates on vegetation (Grisebach 1844). Based on radiocarbon-dated pine subfossils, they were interpreted in terms of changing Holocene climate (e.g. Lundqvist 1969, Karlén 1976, Moe 1979, Selsing 1979, Selsing & Wishman 1984, Birks 1990, Kvamme 1993, Dahl & Nesje 1996, Selsing 1996).

A pine tree can live for a long time at or near the limit of its ecological requirements, and thus can survive minor climatic changes. Therefore the presence of pine subfossils is not an indicator of small climatic fluctuations. When used in dendroclimatological investigations, however, they are excellent indicators of climatic fluctuations (e.g. Briffa et al. 1990). Most of the dendrochronological series of Scots pine from the mountain areas of South Norway show good correlation with each other (Thun 1987, Kalela-Brundin in prep. a, in prep. b). Pine subfossils from this area may thus represent a subfossil data set which can be used for regional palaeoenvironmental interpretation.

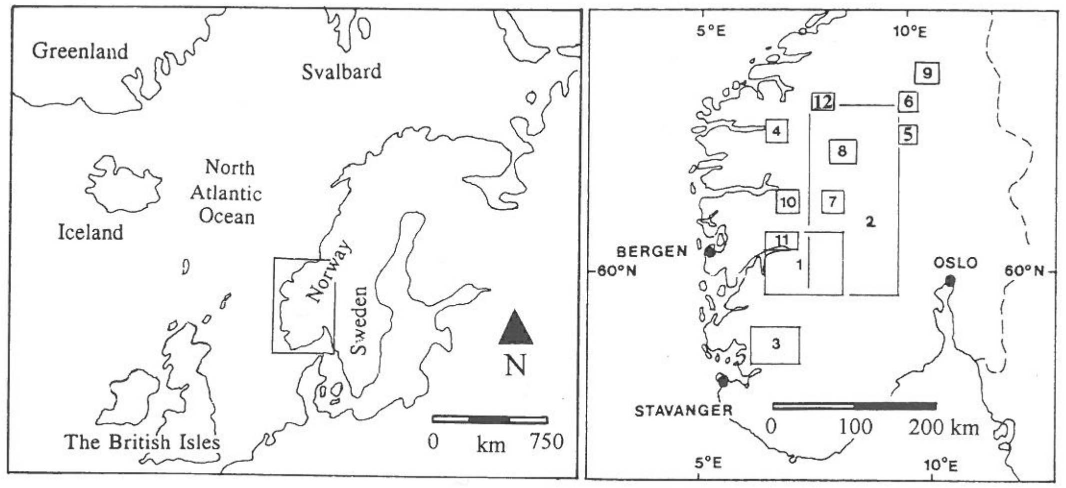

Fig. 1. Mountain areas in South Norway with radiocarbon-dated pine subfossils. Area numbers: see Table 1.

Information from earlier investigations on radiocarbon-dated pine subfossils from the mountainous area in South Norway was collected to form a base for a future Holocene tree-ring chronology and dendroclimatological investigations. Table 1 provides information about the South Norwegian mountain areas included in this investigation (see Fig. 1).

From the mountain region of South Norway, 92 ^{14}C dated subfossils of pine were collected mostly from the area above the present alpine pine forest limit. Pine subfossils can also be found in the lowlands, but only a few of these have been radiocarbon-dated (Selsing 1975, Roaldset 1992).

The investigations

The selection of area and localities for investigations

The data set included in this study was collected for various reasons (Table 2). Choice of sites for collection of pine subfossil samples were based on literature, personal reports and hypotheses about where to find subfossils. Sometimes pine subfossils were discovered during pollen analytical fieldwork (e.g. Simonsen 1980, Kvamme 1984, Gunnarsdóttir 1996a, 1996b).

During the first collection period (1976–1980) in area 3, the samples were collected systematically in order to locate the highest locality with pine subfossils in bogs and lakes along a west-east line across a mountain area above the present pine forest limit. It was assumed that the uppermost subfossils would be low in the west near the coast and higher in the east, like the present forest limits in this area. This was confirmed by the investigation (Selsing 1979, Selsing & Wishman 1978, 1984).

Moe (1977) made a survey of the geographical distribution of stumps and trunks and their vertical distribution in area 1. He collected pine subfossils in selected mountain valleys in the low alpine treeless area and the subalpine birch forest in the eastern and the western parts of Hardangervidda. His aim was to compare areas with different forest limit levels.

The sites from area 2 are located far from present forest and above the present forest limit (Aas & Faarlund 1988, p. 26).

Recorded and collected data

The data are uneven and interpretation concerning climate is difficult. Munaut (1986) recommends a set of field observations in connection with dendrochronological sampling. The collection by Selsing & Wishman (1978, 1984; see also Selsing 1979, this paper) follows the recommendations of Munaut. From the other Norwegian investigations only sporadic field observations are published. Most of them were, however, made before Munaut's recommendations in 1986.

Moe (1977) surveyed pine remains by observing bog surfaces and erosion scars. Selsing (1979) and Selsing & Wishman (1978, 1984) used both these methods in addition to a sounding stick and excavation. Aas & Faarlund (1988) searched for pine remains in lakes, bog surfaces and erosion scars in soligene peat bogs and made excavations.

Table 1. The South Norwegian mountain areas included in this investigation.

Area no.	Area	References
1	Hardangervidda	Moe 1977, 1979
2	Central South Norway	Aas & Faarlund 1988
3	Suldals-Setesdalsheiene	Selsing 1979, Selsing 1996, Selsing in prep., Selsing & Wishman 1978, 1984
4	Nyset-Steggje	Kvamme et al. 1992
5	Rondane	Lima-da-Faria 1977, Barth et al. 1980
6	Dovre	Hafsten 1981
7	Valdres	Sandmo 1960
8	East Jotunheimen	Gunnarsdottir 1996a, 1996b, pers. comm.
9	Oppdal	Hafsten, in Nydal et al. 1970
10	Breheimen-Stryn	Kvamme 1984, Nesje & Kvamme 1991
11	Ulvik, Hardanger	Simonsen 1980
12	Lodalen	Gunnarsdottir pers. comm., Gunnarsdottir & Høeg 1996

Information about the radiocarbon-dated samples is given in Table 3 (area 3) and Table 4 (other areas). For more detailed information, see the main references in Table 1.

The altitudes of the sites were determined using a topographical map with 30 m contour lines (Gradteig M711, scale 1:50 000) (Selsing 1979, this paper, Selsing & Wishman 1978, 1984). Aas & Faarlund (1988, p. 26) included the use of a Paulin aneroid barometer to get more precise information on altitude.

Most sites are soligen or topogen/soligen bogs. Stratigraphical information is available for area 3 (Selsing this paper), area 4 (Kvamme 1984, Nesje & Kvamme 1991), area 8 (Gunnarsdóttir 1996a, 1996b), area 10 (Kvamme et al. 1992), area 11 (Simonsen 1980) and for some of the samples from areas 1 and 2 (Moe 1977, Aas & Faarlund 1988). Lake finds are sparse.

The level of the samples in the peat was found by measuring from the base of the tree (origo) to the minerogenic material below the peat (Selsing this paper). Most of the pine subfossils from area 3 rest on peat, not directly on soil and minerogenic material as do subfossils in blanket bogs in Trøndelag, Central Norway (Solem 1991). This shows that peat accumulated at these localities before the establishment of pine. The pine subfossils are more abundant in the lower rather than the upper part of the peat deposits (Aas & Faarlund 1988, Selsing in prep.). Blytt (1876) investigated pine subfossil localities both in the mountains and in the lowlands, and mentioned that it was rare to find charcoal at these localities (see also Moe 1977, Selsing in prep.). He therefore excluded human activity as the reason for the decline in the pine forest limit. These observations also suggest that the subfossils were not the result of natural fire.

Samples collected include whole or partial roots, trunks, stumps, cones or bark of trees. More than half the samples are from trunks and stumps, with trunks prevailing in the eastern areas and stumps in the western areas. The outer parts of the trees are preserved from less than half of the dated samples of area 3 (Table 3). It is unknown if the outer annual rings are preserved on the dated samples from the other areas.

The diameter of the stumps (base of trunk) and trunks is taken as an indication of the size of the original tree, varying from 10–90 cm, but predominantly between 10–30 cm. As the outer annual rings are often missing, the diameter indicates minimum tree size and suggests sizeable trees. Information about length of the trunks is sometimes available (e.g. Hafsten 1981, Aas & Faarlund 1988, Selsing in prep.). For area 3 the number of annual rings, the number of dated rings and the location of the dated part is recorded for most samples (Table 3). Most of the subfossil samples have 100–200 rings, an indication of the minimum age of the living trees. The number of annual rings preserved is, however, lower than that reported by Eronen et al. (1991) who recorded 150–300 annual rings for many subfossil pine trunks. The difference may be due to better preservation and/or the more continental climate of the Northern Fennoscandian pine subfossils. Missing annual rings in the stumps of area 3 compared to trunks in Northern Fennoscandia may also be a reason for the lower number of annual rings in the material from area 3 than in Northern Fennoscandia.

Table 2. Reasons for collection of pine subfossils.

Reasons for collection	References
Paleoclimatic reconstruction	Selsing & Wishman 1978, 1984
Vegetation history	e.g. Moe 1977, Kvamme et al. 1992, Gunnarsdottir 1996a, 1996b
Reconstruction of forest limit fluctuations	e.g. Sandmo 1960, Moe 1979, Selsing 1979, Simonsen 1980, Hafsten 1981, Aas & Faarlund 1988
For long tree-ring chronologies	Selsing 1996 in prep., Kalela-Brundin in prep. a, in prep. b
To determine the radiocarbon age of the subfossils	Lima-da-Faria 1977, Barth et al. 1980
A combination of scientific aims and development plans, e.g. hydroelectric power or a National park	Selsing 1979, Kvamme 1984, Selsing & Wishman 1978, 1984, Moe 1977
A National park	Moe 1977

The samples from area 3 are in the storehouse at the Museum of Archaeology, Stavanger (together with non-dated samples), including the sample of Roaldset (1992). The material from area 1 is stored at the Botanical Institute, University of Bergen (Moe pers. comm.), while the samples from area 8 are not stored.

Radiocarbon dates

The radiocarbon dates are reported in conventional ^{14}C years BP (before present, i.e. 1950, $T_{1/2}$ 5570 ± 30 years), with one standard deviation. They are also shown in calendar years BC/AD (calibration based on Stuiver & Reimer 1993), as the aim of this paper is to use the South Norwegian subfossil data set as a basis for the construction of a Holocene Scots pine tree-ring chronology. Reporting of ages follows the recommendations of Bartlein et al. (1995). Aas & Faarlund (1988) recorded MASCA-calibrated ages for samples younger than about ^{14}C 6000 BP. The radiocarbon dates were performed by the Radiological Dating Laboratory in Trondheim, Norway, with the exception of the dates from area 5 (Lima-da-Faria 1977, Barth et al. 1980) which were carried out by the Radiocarbon Dating Laboratory in Lund, Sweden (Håkansson 1980).

Living pine trees often reach an age of more than 200 years. It is therefore important to know the location of the radiocarbon samples within the tree to correlate pine subfossil dates (Moe 1979). There are, however, no commonly accepted recommendations of where to collect samples for radiocarbon dating from the subfossils. The samples are usually taken either from the central part of the subfossil to get the 'birth date' of the tree, or from the outermost part to get the 'date of death' of the tree (Sandmo 1960, Hafsten 1981, Aas & Faarlund pers. comm., Gunnarsdóttir 1996a: T-8985, Moe pers. comm., Selsing 1979, this paper, Selsing & Wishman 1984). Both methods have drawbacks, because both the central and the outermost parts of the subfossils are often degraded. Kvamme (1984) and Moe (1977, 1979) dated bark from a stump which gives a reliable 'date of death'. Dates from the outer annual rings of roots give a good 'date of death' as well, because the collected roots probably died at the same time as the tree. Sometimes no information is available regarding which part of the subfossil was dated (Lima-da-Faria 1977, Barth et al. 1980, Selsing this paper, T-1945, T-2031 and T-2408, Gunnarsdóttir 1996a: T-8986, Gunnarsdóttir & Høeg in Gunnarsdóttir 1996b: T-8758, Kvamme pers. comm.: T-4217 and T-4218). Dates from branches (Selsing this paper, T-1945), twigs and cones (Kvamme et al. 1992) cannot be finely correlated with other pine subfossil dates, because these parts could have fallen to the ground at any time during the lifespan of the tree. No correlations have been made to take into consideration whether it was the oldest or youngest part of the tree which was used for dating, as information is not available for most samples.

The samples collected for radiocarbon dating were all in a good state of preservation. Datings from area 3 were primarily carried out on several of the youngest well-preserved annual rings, and, if possible, on a sample from a trunk, normally the trunk part of a stump (Selsing 1979, in prep., Selsing & Wishman 1978, 1984). Hafsten (1981), too, recorded the number of annual rings dated.

Discussion

The information available about the pine subfossil data set shows that the potential exists for making an annual ring time-scale based on this material. Because the samples were not collected for the purpose of making annual ring analysis, information essential for this kind of analysis does not exist for some of the samples. For example, the samples often include too few annual rings for dendrochronological purposes. Therefore, the data set is only suitable to a certain degree for this kind of analysis.

The possibilities of using the data set for tree-ring analysis

Samples collected for dendrochronological purposes ought to contain all complete annual rings from the subfossil in question: a sample should be a whole trunk transect, or should at least contain two sections from the same transect of the trunk. Only a few samples from the pine subfossil data set fulfil these requirements. Collected trunks are suitable for annual ring analysis if the number of annual rings exceeds about 100.

The data set includes 25 trunks (Tables 3 and 4). The 9 trunks from area 3 are suitable for annual ring analysis (though the number of annual rings is not registered for all samples as yet). Stumps are suitable for dendrochronological analysis only when part of the trunk is preserved. It is not possible to use the stumps themselves for tree-ring analysis, because they represent a section of the tree with abnormal annual rings. The samples from roots and branches are also unsuitable for tree-ring analyses.

Well-preserved pine subfossils were collected from topogen, soligen and ombrogen bogs. The pine remains in the blanket bog of Vidmyr in northern Setesdal (area 3; see Selsing in prep.) were few and in poor condition. The preservation of pine subfossils from blanket bogs in Trøndelag, Central Norway was, however, good (Solem 1991). The reason for poor preservation in the blanket bog of Vidmyr is probably that the peat deposits were too thin (less than 40 cm). The Mosstøl middle peat bog situated on a river plain contained well-preserved pine stumps.

The two youngest samples from area 3 collected at Mosstøl middle (Table 3), a bog formed on a river plain, were presumed to be of late Holocene age. The age was confirmed by two radiocarbon dates (T-9902 and T-9905). The site is the only one in this type of bog, and has not previously been used for collecting pine subfossils, presumably because of its young age. This type of bog may contain potential for providing young pine subfossils.

Only five lake sites are recorded in this study, in four of which trunks were found (area 2, Aas & Faarlund 1988). There is a greater chance of finding trunks in lakes than in peat bogs, as they would have been more immediately preserved when submerged under water than when they fell on a bog surface. The success of the North Finnish Holocene pine annual ring time-scale built up over the last decade (e.g. Eronen et al. 1991, Lindholm et al. 1996, Eronen & Zetterberg 1996, Zetterberg et al. 1996) is, amongst other things, based on the multisampling of trunks in a few selected lake sites. More than a thousand subfossil trunks were collected from small lakes and wet depressions at and beyond the present arctic limit of pine. Some relatively short floating pine chronologies from southern and eastern Finland and Russian Karelia were constructed from subfossil bog pines (Zetterberg 1987, 1988).

More detailed stratigraphical investigations from the pine subfossil sites would give a closer indication of the age of the subfossils without radiocarbon dating. Selsing (in prep.; Table 3) collected stratigraphical information about the thickness of the peat and the position of the pine subfossils within the peat. Stratigraphical information is also available for subfossil sites where samples for pollen analysis were collected (Moe 1977: T-1309 and T-1310, Simonsen 1980, Gunnarsdóttir 1996a: T-8985 and T-8986).

Some authors (Hafsten 1981, Aas & Faarlund 1988) have suggested frost heaving during the cooler climate of the last two millennia as the explanation for why old pine remains can be found close to the bog surface. This explanation is, however, not very likely, as frost heaving has existed in the Norwegian mountain areas since deglaciation, and should therefore have happened in peat bogs in all periods since deglaciation. A more plausible explanation is proposed by Moe (1977, p. 14). He reported that erosion in area 1 removed the younger layers, leaving older deposits exposed. He mentioned that a peat layer with many stumps ('stump layer') can stop erosion, or that a 'stump layer' may sometimes be a mixture of stumps from more than one 'stump layer'. It may be noted that the 'stump layer' may also be made up of stumps from several periods.

Pine subfossils were used as fuel by people living in the mountains at least from the Iron Age (Moe 1977, p. 23, 1979) and especially during

Table 3. Thirty-nine radiocarbon datings of *Pinus sylvestris* subfossils from the mountain areas of Suldal and upper Setesdal, southwestern Norway, area 3, Fig. 1 (Selsing 1979, 1996, in prep., Selsing & Wishman 1978, 1984). Calibration Stuiver & Reimer (1993). Ins. = inside.

^{14}C date reference	Locality	Age $T_{1/2}$ 5570 yr BP	Age BC/AD cal.	Zone no.	Dated part of tree	Maximum diameter of dated part (cm)	Height above sea level (m)	Present pine forest limit (m)	Geographical coordinates	Vegetation zone	Bog type	Peat depth (cm)	Location of megafossil above bottom (cm)	Outermost part preserved (p), not preserved (np)	No. of annual rings	Total no. of annual rings dated	Location of dated parts ar = annual rings
T-9900	Stråpa Sandsa	8205 ± 45	7293–7048	1	stump	30	620	620	063500E592606N	subalpine	soligen	—	—	np	—	—	[2]
T-2711	Rennedalen	8150 ± 130	7304–6828	1	stump	90	780	700	065217E593321N	upper subalpine	soligen	120	85	np	>166	16	ins. the outermost 20–30 ar
T-2558	Venehei east	8060 ± 90	7190–6774	1	root	6	620	560	062516E592204N	upper subalpine	top./sol.	125	75	p	>100[3]	30	outermost
T-2712	Olavstoggtjønn	7840 ± 100	6763–6486	2	trunk	30	1070	950	072752E593553N	upper subalpine	soligen	75	15	p	>220	65	ins. the outermost 85 ar
T-3134	Vallarmyr	7120 ± 60	5992–5884	1	stump	—	790	660	065821E593720N	upper subalpine	topogen	80	45	p	>116	23	ins. the outermost 6 ar
T-2407	Ormsa I	7010 ± 90	5956–5732	2	trunk	20	950	870	070425E593250N	upper subalpine	topogen	60	25	np	170	80	ins. the outermost 60 ar
T-2710	Ormsa II	6740 ± 130	5698–5504	2	trunk	26	940	870	070431E593250N	upper subalpine	topogen	>60	20	np	>187	42	ins. the outermost 60 ar
T-3138	Olavstoggtjønn east	6640 ± 90	5593–5443	2	trunk	30	1110	950	072837E593544N	low alpine/subalpine	top./sol.	120	110?	np	>190	15	ins. the outermost 14 ar
T-2031	Stavastøl I	6630 ± 100	5593–5440	1	root	—	680	570	062854E592544N	low alpine	soligen	100	20	p	—	—	chosen by ^{14}C lab.
T-3135	Seten east	6280 ± 80	5280–5086	2	stump	—	1000	940	072101E592559N	upper subalpine	topogen	50	10	np	>177	6	ins. the outermost 13 ar
T-10167	Steinstøl east	6130 ± 60	5202–4946	1	stump	30	720	660	064252E593023N	upper subalpine	soligen	—	—	np	—	13	[2]
T-9903[1]	Osane	6035 ± 90	5054–4814	1	stump	65	620	630	063625E592706N	subalpine	soligen	—	—	np	—	—	[2]
T-10169	Svinstølen	5920 ± 85	4907–4717	1	trunk	60	710	630	063815E592701N	subalpine	soligen	—	—	np	—	45	[2]
T-3136	Vidmyr south	5800 ± 60	4764–4549	2	stump	16	930	930	072158E593520N	upper subalpine	blanket	55	40	np	>149	22	ins. the outermost 10 ar
T-9906[1]	Osane	5800 ± 100	4784–4529	1	stump	80	620	630	063625E592706N	subalpine	soligen	—	—	np	—	—	[2]
T-10170	Væting middle	5725 ± 70	4684–4467	1	stump	—	730	630	063613E592809N	upper subalpine	soligen	—	—	np	—	>60	[2]
T-2408	Steinstøl west	5690 ± 110	4687–4369	1	root	40	730	660	064252E593023N	upper subalpine	topogen	100	25	p	—	—	—
T-9901	Jonsstøl east	5480 ± 85	4439–4245	1	stump	50	740	700	065158E593352N	subalpine	soligen	80	20	np	—	—	[2]
T10173	Fiskåimyr	5430 ± 65	4344–4229	1	stump	24?	670	620	063306E592809N	subalpine	topogen	—	—	np	—	9	[2]
T-1945	Mosvatnet	5310 ± 110	4319–3985	1	branch	—	540	570	062854E592547N	subalpine	soligen	220?	40	p	—	—	—
T-2709	Stavastøl II	5240 ± 60	4216–3977	1	root?	—	680	570	062720E592520N	low alpine	soligen	115	65	p	>162	20	outermost
T-10176[1]	Mosstøl west	5080 ± 60	3962–3791	1	trunk	29	610	680	063919E593428N	boreal coniferous	soligen	—	—	p	—	68 ± 5	[2]
T-10174[1]	Mosstøl west	5025 ± 100	3956–3700	1	trunk	28	610	680	063919E593428N	boreal coniferous	soligen	—	—	np	—	45 ± 3	[2]

Table 3. (Continued)

^{14}Cdate reference	Locality	Age $T_{1/2}$ 5570 yr BP	Age BC/AD cal.	Zone no.	Dated part of tree	Maximum diameter of dated part (cm)	Height above sea level (m)	Present pine forest limit (m)	Geographical coordinates	Vegetation zone	Bog type	Peat depth (cm)	Location of megafossil above bottom (cm)	Outermost part preserved (p), not preserved (np)	No. of annual rings	Total no. of annual rings dated	Location of dated parts ar = annual rings
T-5153	Væting west	4750 ± 90	3642–3374	1	root	6	730	630	063613E592809N	low alpine/subalpine	top./sol.	70	50	p	125	20	ins. the outermost 30 ar
T-2409	Væting west	4740 ± 90	3639–3372	1	root	8	730	630	063613E592809N	low alpine/subalpine	soligen	70	20	p	110	—	outermost
T-5154	Væting west	4630 ± 90	3508–3335	1	root	14	730	630	061613E592809N	low alpine/subalpine	soligen	70	70	np	>210	20	ins. the outermost 50 ar
T-9904	Haugastøl	4515 ± 95	3360–3036	1	trunk	14	610	610	063328E592408N	subalpine	soligen	—	—	np	—	—	[2]
T-5152	Venehei east	4470 ± 90	3343–2925	1	root	12	620	560	062516E592204N	upper subalpine	soligen	125	90	np	>90	8	ins. the outermost 5 ar
T-3137	Stavastølsdalen	3910 ± 80	2474–2280	1	root	6	710	570	062906E592613N	low alpine	soligen	150	—	p	116	40	ins. the outermost 45 ar
T-2557	Røyneskårheia	3210 ± 50	1518–1419	1	stump	70	650	640	064016E593036N	upper subalpine	soligen	90	40	np	252	30	ins. the outermost 12 ar
T-5151	Venehei	3070 ± 70	1410–1219	1	root	5	620	560	062516E592204N	upper subalpine	soligen	125	90	p	< 130	60	ins. the outermost 5 ar
T-10172[1]	Mosstøl east	3055 ± 70	1403–1208	1	stump	16	615	680	064016E593036N	boreal coniferous	topogen	—	—	np	—	37	2
T-10175[1]	Mosstøl west	2715 ± 85	922–803	1	stump	35	610	670	062516E592204N	boreal coniferous	topogen	—	—	p	—	12 ± 1	2
T-10171	Jonsstøl west	2485 ± 50	770–423BC	1	stump	—	690	700	065142E593424N	boreal coniferous	soligen	—	—	p?	—	50	[2]
T-10168	Jonsstøl west	1965 ± 70	34BC–AD123	1	stump	22	690	700	065142E593424N	boreal coniferous	soligen	—	—	np	—	17	[2]
T-10177[1]	Mosstøl west	1870 ± 50	AD83–231	1	trunk	20	610	680	063919E593428N	boreal coniferous	soligen	—	—	np	—	36 ± 2	[2]
T-2559	Flatstøl	1710 ± 60	252–416	2	stump	40	540	770	070337E591842N	subalpine	ombrogen	195	65	—	>124	28	outermost
T-9905[1]	Mosstøl middle	285 ± 55	1520–1663	1	stump	>50	605	680	065052E593417N	boreal coniferous	ombrogen?	>100	—	np	—	—	[2]
T-9902[1]	Mosstøl middle	55 ± 50	1824–1955	1	stump	>50	605	680	065052E593417N	boreal coniferous	ombrogen?	>100	—	np	—	—	[2]

[1] Collected by Selsing, Griffin & Kalela-Brundin

[2] Selected by Maarit Kalela-Brundin

[3] Stump of this root has 226 annual-rings

Table 4. Radiocarbon dates of 53 *Pinus sylvestris* subfossils from the mountain area of South Norway (area 3, see Table 3). Area numbers: see Table 1. Calibration Stuiver & Reimer (1993).

^{14}C date reference	Locality	Age $T_{1/2}$ 5570 yrs. BP	Age BC/AD cal.	Area no.	Zone no.	Geographical position/UTM grid reference	Height above sea level (m)	Present pine forest limit (m)	Bog type/lake	Info. strat. available	Diameter trunk/stump (cm)	Dated part of tree
T-4455	Smådalen	8660 ± 80	7874–7545	2	2	32V796466	1220	1220[1]	soligen	[4]	13	trunk[2]
T-6495	Jønndalen	8640 ± 100	7873–7538	2	2	32V672875	1130	910	topogen	—	—	trunk
T-4218	Riskallsvatn	8470 ± 120	7570–7425	4	2	—	945	—	bog	—	—	trunk
?	Gravfjellet	8400 ± 200	7572–7099	7	2	—	1060	—	lake	—	30	trunk
T-1745	Veigdalen	8310 ± 110	7485–7099	1	2	LM987812	1100	—	bog[5]	—	—	trunk
T-8986	Smådalen	8255 ± 120	7474–7044	8	2	32V796466	1220	1020	soligen	[4]	—	trunk[2]
T-4461	Grønlidalen	8240 ± 110	7427–7043	2	2	32V948607	1040	—	soligen	—	30	trunk
T-3650	Nysetri	8240 ± 100	7425–7045	6	3	—	1010	—	—	[4]	30	trunk
Lu-1692	Haverdalen	8240 ± 80	7419–7048	5	3	0940E6202N	1030	—	—	—	—	trunk
T-1655	Ustevann	8180 ± 110	7411–7033	1	2	MN2814	1100	—	bog[5]	—	—	stump
T-4460	Smådalen	8160 ± 120	7304–7008	2	2	32V796466	1220	1020	soligen	[4]	—	cone[2]
T-8524	Midtvatn	8110 ± 110	7258–6816	4	2	—	984	—	—	—	—	—
T-2466	Besstrondfj.	8050 ± 100	7190–6726	2	2	32V946248	1170	—	—	—	—	—
T-4454	Storkvølven	8050 ± 60	7041–6785	2	2	32V931113	1276	920	top./sol.	[4]	13	trunk
T-6029	Dagalifjellet	7940 ± 90	7008–6609	2	2	32V692922	1159	984	—	[4]	30	root[2]
T-5468	Liafjellet	7880 ± 60	6991–6598	2	2	32V840063	1164	964	lake	—	—	trunk
T-8985	Smådalen	7825 ± 115	6763–6469	8	2	32V796466	1220	1020	soligen	[4]	—	trunk[2]
T-1437	Mårvatn	7740 ± 160	6695–6412	1	2	MM5172	1180	—	bog[5]	—	—	—
T-3352	Vesle Setaltj.	7720 ± 100	6603–6424	2	3	32V534210	1004	[3]	lake	—	15	trunk[2]
T-5466	Skurdalsåsen	7560 ± 60	6426–6267	2	2	32V636506	1100	900	lake	—	50	trunk[2]
T-1742	Berastølen	7160 ± 130	6119–5862	1	2	MM008933	920	—	bog[5]	—	—	—
T-4457	Gokkerdalen	7000 ± 110	5959–5710	2	2	32V732433	1222	1022	soligen	[4]	16	trunk
T-6758	Smådalen	6960 ± 110	5947–5685	2	2	32V796466	1222	1022	soligen	—	—	unclear[2]
T-4973	Vuludalen	6850 ± 120	5782–5593	2	3	32V562538	1070	—	—	—	—	trunk
T-5467	Ershovdtjern	6760 ± 60	5668–5582	2	2	32V612554	1220	970	soligen	—	—	unclear[2]
T-1438	Heinsæter th.	6510 ± 190	5583–5263	1	2	MM417917	1100	—	bog[5]	—	—	—
T-5605	Sygneskardvt.	6510 ± 90	5520–5332	10	1	—	690	—	bog	—	—	bark
T-1744	No name	6240 ± 100	5270–5059	1	2	MN3709	990	—	bog[5]	—	—	—
T-5469	Kalhovd	6120 ± 110	5217–4908	2	2	32V49206000	1170	950	soligen	—	40	trunk[2]
T-4970	Vallo	6090 ± 120	5210–4842	2	2	32V503379	1200	940	soligen	—	—	trunk[2]
T-790	Instavatnet	5980 ± 90	4946–4778	11	1	—	150 m above present pine forest limit			—	—	—
T-1660	Kvannabakkane	5910 ± 140	4938–4609	1	2	LM982800	1100	—	bog[5]	—	—	—
T-4217	Riskalsvatn	5670 ± 100	4670–4366	4	2	—	945	—	bog	—	—	trunk
T-662	Gjørdøla	5340 ± 120	4334–3993	9	2	—	750	—	—	—	—	—
T-1194	Hadlemyrane	5240 ± 140	4237–3829	1	2	MM048959	1005	—	bog[5]	—	—	—
T-6030	Gjendebu	5140 ± 80	4030–3808	2	2	32V724129	994	1030?	soligen	[4]	—	stump[2]
T-1658	Sysendalen	5040 ± 90	3958–3708	1	2	MM052978	800	—	bog[5]	—	—	stump
T-6496	Lesjaleira	4940 ± 90	3891–3644	2	2	32V9486	540	–	–	–	—	stump
T-1310	Vøringsfossen	4900 ± 130	3891–3535	1	2	MN037003	670	—	bog[5]	—	—	bark
Lu-995	Kåsi, Mysuseter	4890 ± 65	3750–3637	5	3	0940E6149N	1000	—	lake	—	—	stump
T-8758	Nysetri	4830 ± 95	3700–3515	6	2	–	1095	900	—	—	—	trunk
T-6494	Såleggi	4770 ± 80	3645–3381	2	2	32V751504	1200	1000	soligen	[4]	—	trunk[2]
T-1654	No name	4760 ± 90	3644–3376	1	2	MN374083	985	—	bog[5]	—	—	—
T-1435	Sysenvatnet?	4450 ± 90	3336–2921	1	2	MM121986	890	—	bog[5]	—	—	—
T-5604	Sygneskardvt.	2990 ± 80	1376–1062	10	1	—	690	—	—	—	—	bark
T-5176	Torbuvatn	2900 ± 80	1251–934	2	2	32V805229	900	750	lake	—	40	trunk[2]
T-1656	Sysendalen	2890 ± 100	1254–916	1	2	MM059987	760	760	bog[5]	—	—	—
T-1657	Sysendalen	2840 ± 80	1116–901BC	1	2	MM059987	760	760	bog[5]	—	—	—
T-1309	Vøringsfossen	1930 ± 120	41BC –AD235	1	2	MN037003	670	–	bog[5]	—	—	stump
T-1741	Sysendalen	740 ± 90	AD1225 –1373	1	2	MN036001	675	—	bog[5]	—	—	—
T-5470	Javnestølane	600 ± 70	1300–1416	2	2	32V007890	870	–	(below till)	—	—	stump
T-3595	Diprtjern	470 ± 60	1415–1464	2	2	32V938622	1200	—	topogen unclear	—	—	unclear
T-2465	Dyrtjern	300 ± 60	1511–1660	2	2	32V028264	1280	—	lake unclear	—	—	unclear[2]

[1] The authors recorded potential vertical difference, i.e. assumed height difference between present climatic pine forest limit and the former pine forest limit calculated from site and topography, and taking the land level rise into consideration (Aas & Faarlund 1988, p. 26).

[2] Many observations of old pine remains.

[3] 25 km in horizontal distance to nearest pine forest.

[4] Information about stratigraphy available (Aas & Faarlund 1988, Gunnarsdottir 1996a, 1996b).

[5] Moe (pers. comm.).

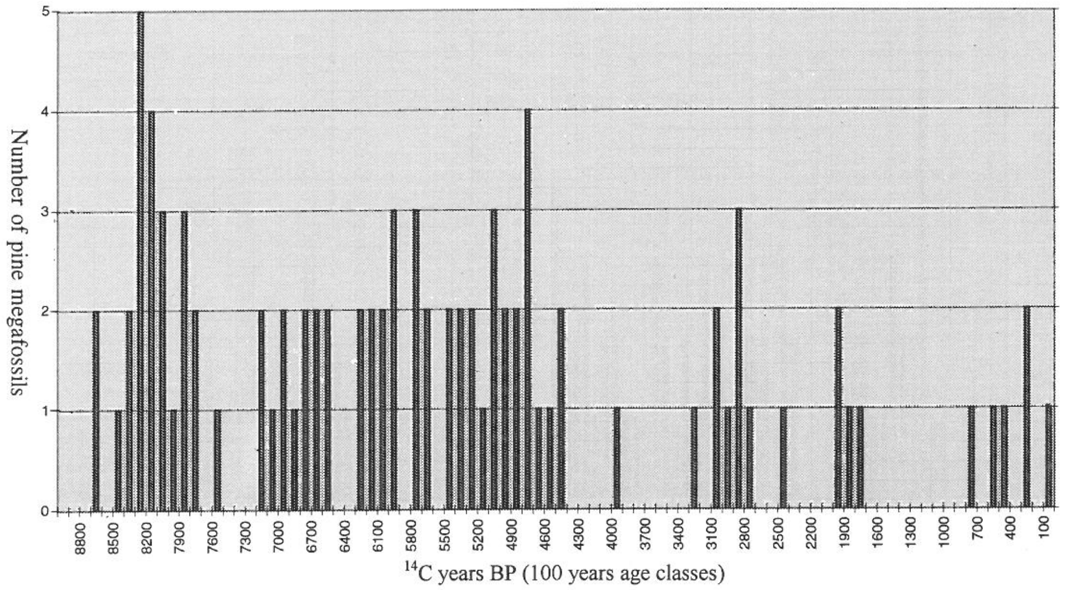

Fig. 2. A chronological view of 92 radiocarbon-dated samples of pine subfossils from South Norway. All dates are reported in ^{14}C years BP.

times of high population pressure in the lowlands. Depression of the forest limit in the 18th and 19th centuries by intensive summer farming in the mountain areas caused deforestation and made pine subfossils attractive as a source of fuel. This was confirmed by Aas & Faarlund (1995), who observed rising forest limits due to reduced population pressure in many areas in Norway during this period. It is reasonable to expect that the younger stumps were usually used before the older ones because of their higher stratigraphical position in the peat. Therefore the younger pine subfossils may not necessarily be found by collecting samples from the upper part of the peat. This may at least partly explain the over-representation of pine subfossils in the lower rather than upper part of the peat deposits.

Information provided by the radiocarbon dates

In general, the pine subfossils from the higher sites are the oldest samples in the data set (Tables 3 and 4). Most samples have been collected from above the present pine forest limit, some of them from above the present forest limit. On the other hand, the 8 youngest dates from area 3 (Table 3) are from sites below the present pine forest limit. Seventy-two samples date between ^{14}C 8700–4500 BP, and only 20 are from the period ^{14}C 4000 BP to the present. The youngest pine subfossils are under-represented in the data set.

Using the BP dates, the age distribution of the radiocarbon-dated pine subfossils (Fig. 2) shows grouped occurrences of radiocarbon-dated pine subfossils from the periods ^{14}C 8700–7600 BP, ^{14}C 7200–4500 BP, ^{14}C 3300–2800 BP, ^{14}C 2000–1800 BP and younger than ^{14}C 800 BP. The periods are separated by gaps where pine subfossils are lacking. Using calendar dates (Fig. 3), the age distribution shows grouped occurrences of pine subfossils from the periods 7700–6400 calendar yrs. BC, 6000–3100 calendar yrs. BC, 1500–600 calendar yrs. BC, 0–AD calendar yr. 300 and younger than AD calendar yr. 1200. Comparison between Figs. 2 and 3 shows that no great differences in the occurrences and gaps are obvious: only 64% of the calendar time-scale is made up of occurrences, compared to 61% of the ^{14}C yr. BP time-scale (an insignificant difference).

Taking one period at a time, some differences become apparent. Table 5 shows the periods of occurrences and gaps of pine subfossils of both calibrated and non-calibrated dates. The calendar time-scale is about 1000 years longer than the radiocarbon year BP time-scale. These 1000 calendar years are unevenly distributed among the periods of occurrences and gaps, adding 900 calendar years to the periods of occurrences and 100 calendar years to the periods of gaps. The 100

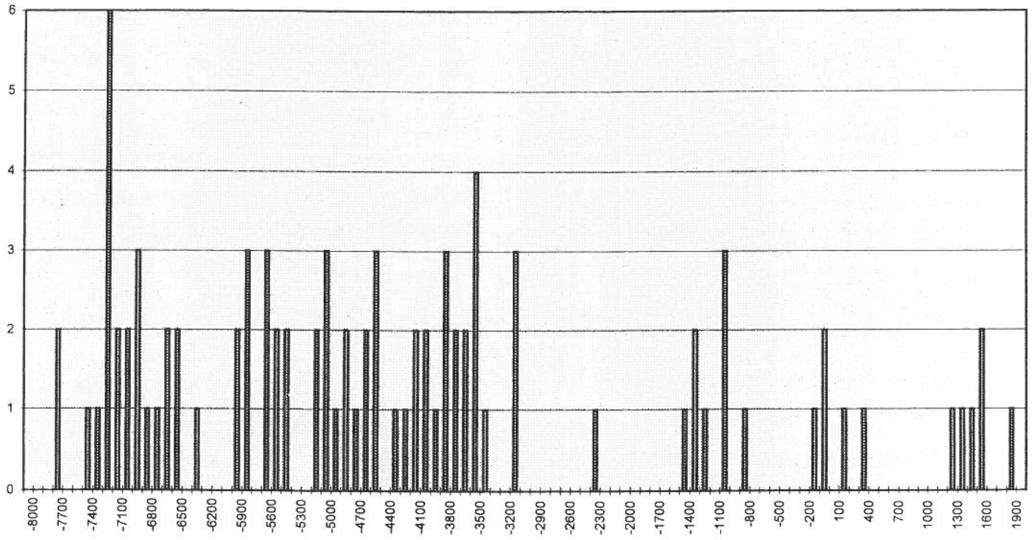

Fig. 3. A chronological view of 92 radiocarbon-dated samples of pine subfossils from South Norway. All dates are reported in calendar years BC/AD using the calibration of Stuiver & Reimer (1993).

calendar years additional to the gap periods are distributed as follows: (1) 400 additional calendar years to the gap of 3100–1500 calendar yrs. BC compared to the gap of ^{14}C 4500–3300 BP, and (2) a reduction of 200 and 100 calendar years from the periods of 600–0 calendar yrs. BC and AD calendar yrs. 300–1200, respectively, compared to the gaps of 2800–2000 and ^{14}C 1800–800 BP. The calibration to calendar years reveals that the true potential for making an annual ring time-scale is better than the radiocarbon year BP dates indicate.

Karlén's interpretation of pine subfossils and the amount of organic material in lacustrine sediments in Northern Sweden (1976) indicate decreased temperature in the period of 7500–7300 radiocarbon yrs. BP. The δ^{18}O record from the GRIP ice core from the Greenland ice cap shows a drop during the same period as the gap 7600–7200 radiocarbon yrs. BP (6400–6000 calendar yrs. BC) (Dansgaard et al. 1993). These results make it plausible that the gap of 6400–6000 calendar yrs. BC in the South Norwegian pine subfossils was caused by climatic deterioration.

The gap of 3100–1500 calendar yrs. BC increased by calibration compared to the gap indicated by the radiocarbon yr. BP dates. This increased gap reduces the potential for linking future floating chronologies across this time period. It is a period well known for its changing environment (probably climatic changes) recorded both in Fennoscandia and in the British Isles (e.g. Bennett 1984, Gear & Huntley 1991, Zetterberg et al. 1996, Selsing 1996).

The gaps between 600–0 calendar yrs. BC and calendar yrs. AD 300–1200 were reduced by calibration compared to the gaps indicated by the radiocarbon year BP dates. The potential for linking future floating chronologies across these gaps is better than indicated by the ^{14}C yr. BP dates. Eronen et al. (1996) recorded a gap in part of the period 600–0 calendar yrs. BC in the annual ring time-scale of Northern Fennoscandia which has been problematic to bridge.

A strategy for further collection of pine subfossils for annual ring studies in South Norway

Good correlation between the dendrochronological series of Scots pine from the mountain areas of South Norway (Thun 1987, Kalela-Brundin in prep. a, in prep. b) makes the South Norwegian pine subfossil data set well suited to the construction of a Holocene annual ring time-scale. Considerable pine remains are available at sites mentioned in the tables, and at other sites where pine subfossils have been observed (e.g. Aas & Faarlund 1988, pers. comm., Selsing in prep.). It is therefore possible to formulate a strategy regarding the location and collection of pine trunks (stumps) for a Holocene dendrochronological curve based on pine.

Table 5. Periods with occurrences and gaps of pine megafossils of calibrated (calendar yrs. BC/AD) and non-calibrated (^{14}C yrs. BP) dates.

Occurrences and gaps	^{14}C yrs. BP	^{14}C yr.	Calendar yrs. BC/AD	Calendar yr.	A	B
Oc. 1	8700–7600	1100	7700–6400	1300	+200	+126
Gap 1	7600–7200	400	6400–6000	400	0	+46
Oc. 2	7200–4500	2700	6000–3100	2900	+200	+310
Gap 2	4500–3300	1200	3100–1500	1600	+400	+138
Oc. 3	3300–2800	500	1500–600	900	+400	+58
Gap 3	2800–2000	800	600–0 BC	600	−200	+92
Oc. 4	2000–1800	200	AD 0–300	300	+100	+23
Gap 4	1800–800	1000	300–1200	900	−100	+115
Oc. 5	800–0	800	1200–2000	800	0	+92
Σ		8700		9700	+1000	+1000

A: Difference between calendar yr. and ^{14}C yr.

B: Difference between calendar yr. and ^{14}C yr. calculated from an even distribution of the additional 1000 years from calibration of the ^{14}C yr. BP dates.

Fieldwork is time-consuming, because many of the pine subfossils were found in less accessible mountain areas without roads to the sites. It is necessary to choose areas and sites with a high potential for the discovery of many trunk (and stump) subfossils. In Northern Fennoscandia, more than 120 samples of pine subfossil trunks were recovered from small lakes within a few days (Eronen et al. 1991, Fig. 3). If future collection of new research material in the South Norwegian mountains suggests the same potential for recovering pine subfossil trunks from lakes as in Northern Fennoscandia, fieldwork will be easier. Even if there are no indications of lake sites with many old pine trunks at present in the mountains of South Norway, it is assumed that this area should have good potential.

The cited investigations (Table 1) concentrated collection in areas above the present pine forest limit, including areas in the alpine vegetation zone. Little is known about the amount or the age of pine subfossils below the present pine forest limit (Selsing 1975, in prep., Roaldset 1992).

One aim is to find out where to collect pine subfossils from a specific period. In general, the pine forest limit in the South Norwegian mountains and the Swedish part of the South Scandes rose above the present level soon after deglaciation, between ^{14}C 9000–7000 BP, after which it gradually retreated (Lundqvist 1969, Moe 1979, Selsing 1979, Kullman 1990, Kvamme 1993, Selsing 1996), perhaps with some fluctuations (Karlén 1976, Dahl & Nesje 1996, Karlén & Kuylenstierna 1996).

The recent alpine pine forest limit in South Norway increases from west to east, except in the easternmost parts of the mountain area (Aas & Faarlund 1988, fig. 10), as did the pine forest limit in earlier times (Moe 1977, Selsing & Wishman 1978, 1984). Therefore the collection of pine subfossils of specific ages should be collected at various levels in different areas in South Norway.

The data set is divided into three geographical zones from west to east (Tables 3 and 4). Zone 1 represents the sites located west of the water divide. Zone 3 is the easternmost area where the present pine forest limit declines towards the east. Zone 2 is located between zones 1 and 3, and includes the main part of the South Norwegian mountain area. For each of these zones, the main fluctuation of the pine forest limit in earlier times is reconstructed (Fig. 4).

Fig. 4 shows that the pine forest limit was lowest in zone 1 and highest in zone 2, while the level in zone 3 is on an intermediate level between zones 1 and 2. This result is in accordance with the expectations based on the present pine forest limit. The fluctuations are different from one zone to another. The maximum level of the pine forest limit occurred for zone 1 at 790 m a.s.l. at about 5900 calendar yrs. BC, for zone 2 at 1275 m about 6900 calendar yrs. BC and for zone 3 at 1070 m about 5700 calendar yrs. BC. A rise in the pine forest limit was recorded for the period from deglaciation until the maximum level was attained. After culmination, the pine forest limit declined in all zones. In zone 1, the decline was

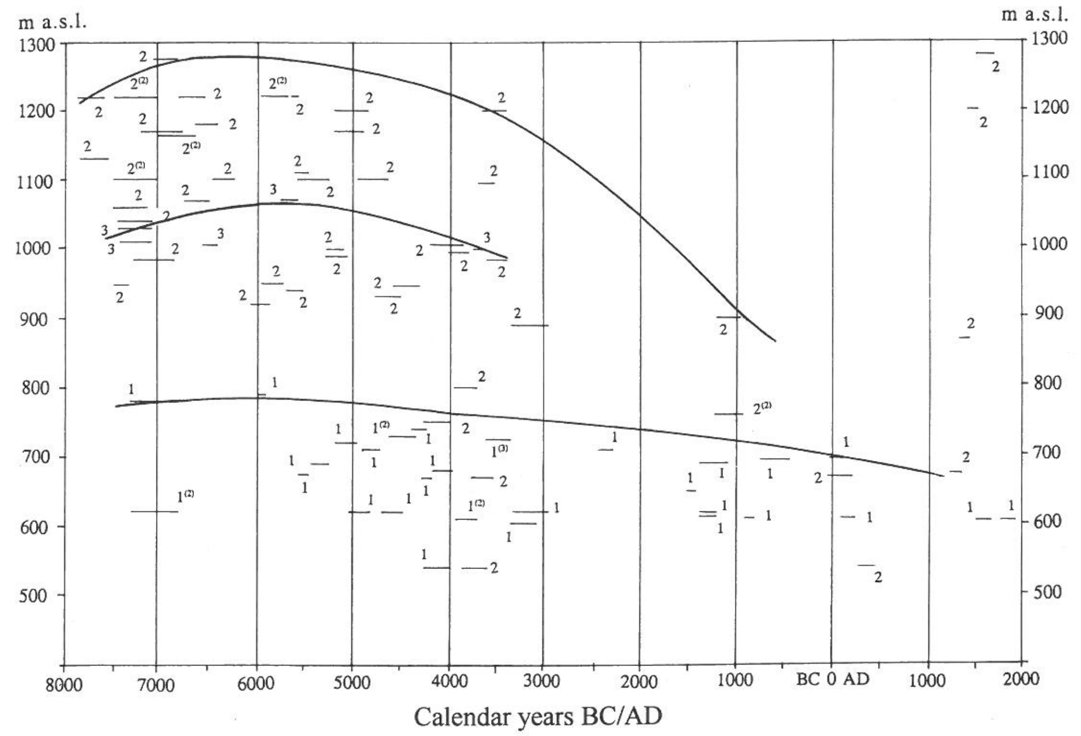

Fig. 4. Reconstruction of the Holocene pine forest limit fluctuations related to elevation. The area is divided into three geographical zones from west to east. Zone 1 represents the sites located west of the water divide. Zone 3 is the easternmost area where the present pine forest limit declines towards the east. Zone 2 is located between zones 1 and 3.

slow and may have been decreasing over the last 2000 calendar yrs.; the total decline from culmination to the present time was 185 m. In zones 2 and 3, the declines were greater. In zone 2, the decline from culmination at 6900 calendar yrs. BC to 3500 calendar yrs. BC was 75 m, followed by an acceleration from this time until 1000 calendar yrs. BC with a decline of 300 m (the three youngest samples from zone 2 are dubious). For zone 3, information is sparse. However, a decline from culmination at 5700 calendar yrs. BC to 3700 calendar yrs. BC of 70 m is recorded.

The search for pine subfossils for tree-ring analysis should include the upper level of the Holocene pine forest limits in the three zones. Fig. 4 shows that the areas with the best potential for providing material for a pine tree-ring curve differ in the three zones. The limits up to which pine subfossils may be found and collected in each zone also differ. As the present data set has not been collected systematically (except within area 1) and is restricted to only 92 samples, it presumably represents minimum levels of the pine forest limit in earlier times. The possibility of finding pine subfossils at higher levels exists. (Pine forest limits recorded by pine subfossils are presumably at minimum levels of the pine forest limit in earlier times.)

As indicated in Fig. 4, close to the highest pine forest limit in earlier times, the oldest pine subfossils are most likely to be found. However, Fig. 4 shows that the oldest finds may also be collected at lower levels, as indicated by subfossil finds. For example, two of the three oldest samples from area 3, zone 1 (T-9900 and T-2558) were located 120 and 160 m, respectively, below the highest pine forest limit. The subfossils were found far below the upper pine forest limit in earlier times, as indicated in Fig. 4 and also by subfossil finds in the lowlands (Selsing 1975, Roaldset 1992).

Fig. 4 also gives more detailed information about the age of subfossils compared to the range of elevation for each zone:

- Zone 1: Samples collected above 750 m a.s.l. are older than 6900 calendar yrs. BC, while samples collected above 700 m a.s.l. are older than calendar yr. AD 100. Samples collected at a level of 600–700 m have ages from 7300 calendar yrs. BC to the present. It is therefore impossible to indicate the age of a subfossil find in this range of elevation without stratigraphical information, a radiocarbon date or dendrochronological data. This is due to the fact that only small fluctuations of the Holocene pine forest limit are evident in this zone.
- Zone 2: Samples collected above 1200 m are older than 3500 calendar yrs. BC. Samples collected below 975 m are younger than 6100 calendar yrs. BC. Samples below 900 m are younger than 4300 calendar yrs. BC.

Recommendations for construction of a long tree-ring chronology for South Norway

Pine subfossils from different Holocene periods are common in the South Norwegian mountain peat bogs, except in those areas where they have been removed by humans. The conversion to calendar years reveals that the true potential for making an annual ring time-scale is better than the radiocarbon BP dates suggest. The present data set is not sufficient to start annual ring work without additional collection, but the potential for building up a pine annual ring chronology is good. The construction would probably entail the collection of about 1500–2000 new samples, and perhaps a few hundred radiocarbon dates would be needed to build up a continuous pine chronology extending back to shortly after deglaciation in the mountain area, about 10 000 calendar years ago. Future collection should be made systematically. An annual time-scale should preferably be built on lake finds of trunks, judging from the experience of Eronen et al. (1996) in Northern Fennoscandia. However, the potential for making an annual ring time-scale based on lake finds in South Norway is unknown; recommendations may be built on pine trunks (and stumps) older than calendar yrs. AD 1100–1400 from all types of sites. Presumably the eastern mountain areas (especially in zone 2) have better potential than the western mountain areas for recovering a large amount of old pine trunks (and stumps).

The possibility exists of finding pine subfossils at higher levels than indicated by the data set. Collection of pine subfossils should be carried out at different ranges of elevation in the three zones defined above:

(1) The older pine subfossils may preferably be collected close to upper pine forest limit of earlier times.
(2) In the area between the upper Holocene pine forest limit and the present pine forest limit, pine subfossils of all ages may be found.
(3) The youngest pine subfossils may be found in the area below the present pine forest limit.

Samples for floating chronologies from the early Holocene period should be easier to obtain than samples from later periods, and they may normally be found in greater abundance in the lower rather than the upper part of the peat deposits. The gap of 3100–1500 calendar yrs. BC may suggest that linking floating chronologies across this time period in the future may be problematic.

Conclusions

1. The potential to extend the existing dendrochronological curves in South Norway back to shortly after deglaciation is good, but such extension entails the collection of about 1500–2000 new samples. The construction of floating chronologies from the early Holocene period should be easier to obtain than chronologies from later periods. Recommendations for collection are given.

2. The maximum level and the changes in the Holocene pine forest level are different in the three zones defined in this paper. However, as with the present-day pine forest limit, the Holocene pine forest levels were lowest in the western zone, highest in the middle zone, and intermediate in the eastern zone.

3. The gap 6400–6000 calendar yrs. BC represents a period of decreased temperature recorded in Northern Sweden and indicated in the Greenland ice cap as well. The gap 3100–1500 calendar yrs. BC represents a period well known for its changing environment (probably climatic changes), recorded in Fennoscandia and in the British Isles.

4. Collecting samples for radiocarbon dating of pine subfossils from a known number of the outermost annual rings to get the 'date of death' of the tree is recommended.

Acknowledgements. – This paper is based on a talk at the meeting 'Dendrochronology in Norway' at the Museum of Archaeology, Stavanger, 22-23 April 1993 (Griffin & Selsing 1998). Astrid Hølland Berg and Leif Kjetil Skjæveland helped to convert the figures into finished drawings. Aud Simonsen counted the annual rings on pine subfossils from area 3. Tordis T. Guldhav made the tables. The calibration to calendar yr. BC/AD dates was carried out using the facilities of Gerry McCormac, The Radiocarbon Laboratory, The Queen's University of Belfast, especially radiocarbon calibration program 1987, rev. 2.0 from the Quaternary Isotope Lab, University of Washington. Gillian Plunkett corrected the English language, and Kerstin Griffin suggested a number of improvements of earlier drafts of the text. To these persons I offer my sincere thanks.

Manuscript accepted June 1997

References

Aas, B. & Faarlund, T. 1988. Postglasiale skoggrenser i sentrale sørnorske fjelltrakter. ^{14}C-datering av subfossile furu- og bjørkerester (Post-glacial forest limits in the central south Norwegian mountains. Radiocarbon datings of subfossil pine and birch specimens). *Norsk geogr. Tidsskr. 42*, 25–61.

Aas, B. & Faarlund, T. 1995. Skoggrenseutviklingen i Norge, særlig i det 20. århundre (Forest limit development in Norway, with special regard to the 20th century). Selsing, L. (ed.) Kilder for klimadata i Norden fortrinnsvis i perioden 1860–1993 (Sources for climate data in Norden, mainly in the period 1860–1993). *AmS-Varia 24*, 89–100.

Barth, E. K., Lima-de-Faria, A. & Berglund, B. E. 1980. Two ^{14}C dates of wood samples from Rondane, Norway. *Botaniske Notiser 133*, 643–644.

Bartlein, P. J., Edwards, M. E., Shafer, S. L. & Barker Jr., E. D. 1995. Calibration of radiocarbon ages and the interpretation of paleoenvironmental records. *Quaternary Research 44*, 417–424.

Bennett, K. D. 1984. The post-glacial history of *Pinus sylvestris* in the British Isles. *Quaternary Science Review 3*, 133–155.

Birks, H. J. B. 1990. Changes in vegetation and climate during the Holocene of Europe, pp. 133–157. Boer, M. M. & de Groot, R. S. (eds.) *Landscape-ecological Impact of Climatic Change*. IOS Press, Amsterdam.

Blytt, A. 1876. Forsøg til en theori om indvandringen af Norges flora under vexlande regnfulde og tørre tider. *Nytt magasin for naturvidenskaberne 21*, 279–362.

Brandt, N. 1975. Årringundersøkelser på furu (*Pinus sylvestris*): metode og anvendelse (Growth-ring investigations on Scots pine (*Pinus sylvestris*): method and application). *Norsk institutt for skogforskning 32*, 235–335.

Briffa, K. R., Bartholin, T. S., Eckstein, D., Jones, P. D., Karlén, W., Schweingruber, F. H. & Zetterberg, P. 1990. A 1400-year tree-ring record of summer temperatures in Fennoscandia. *Nature 346*, 434–439.

Christensen, K. & Havemann, K. 1992. Modern oak chronologies from Norway. *Dendrochronologia 10*, 137–146.

Dahl, S. O. & Nesje, A. 1996. A new approach to calculating Holocene winter precipitation by combining glacier equilibrium-line altitudes and pine-tree limits: a case study from Hardangerjøkulen, central southern Norway. *The Holocene 6*, 381–398.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S. & Steffensen, J. P. 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature 364*, 218–220.

Eidem, P. 1953. Om svingninger i tykkelsestilveksten hos gran (*Picea abies*) og furu (*Pinus sylvestris*) i Trøndelag (On variations in the annual ring widths in Norway Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) in Trøndelag). *Det norske skogforsøksvesen 12*, 1–155.

Eidem, P. 1959. En grunnskala til tidfesting av trevirke fra Flesberg i Numedal. *Blyttia 17*, 69–81.

Eronen, M., Huttunen, P. & Zetterberg, P. 1991. Opportunities for dendroclimatological research in Fennoscandia. *Paläoklimaforschung/Palaeoclimate Research 6*, 81–92.

Eronen, M. & Zetterberg, P. 1996. Expanding megafossil data on Holocene changes at the polar/alpine pine limit in northern Fennoscandia. *Paläoklimaforschung/Palaeoclimate Research 20*, 127–134.

Gear, A. J. & Huntley, B. 1991. Rapid changes in the range limits of Scots pine 4000 years ago. *Science 251*, 544–547.

Griffin, K. & Selsing, L. (1998). Dendrokronologi i Norge. (Dendrochronology in Norway) *AmS-Varia 32.*

Grisebach, A. 1844. Über den Vegetationscharacter von Hardanger in Bergens Stift. *Archiv Naturgeschichte 10*, 1–28.

Gunnarsdóttir, H. 1996a. Holocene vegetation history and forest-limit fluctuations in Smådalen, eastern Jotunheimen, South Norway. *Paläoklimaforschung/Palaeoclimate Research 20*, 233–256.

Gunnarsdóttir, H. 1996b. Holocene vegetation history in the northern parts of the Gudbrandsdalen valley, south central Norway. Dissertation for the degree Doctor Scientiarum, University of Oslo.

Gunnarsdóttir, H. & Høeg, H. I. 1996. Holocene vegetation history and human impact in the mountainous areas of Lesja and Dovre, south central Norway. In Gunnarsdóttir, H. 1996b. Holocene vegetation history in the northern parts of the Gudbrandsdalen valley, south central Norway. Dissertation for the degree Doctor Scientiarum, University of Oslo. 1–55.

Hafsten, U. 1981. An 8000-year-old pine trunk from Dovre, South Norway. *Norsk geogr. Tidsskr. 35*, 161–165.

Håkansson, S. 1980. University of Lund radiocarbon dates XIII. *Radiocarbon 22*, 1045–1063.

Kalela-Brundin, M. 1996. The narrow ring of 1784 in tree-ring series of Scots pine (*Pinus sylvestris*) in southwest Norway – a possible result of volcanic eruptions in Iceland. *Paläoklimaforschung/Palaeoclimate Research 20*, 107–118.

Kalela-Brundin, M. 1998. Reconstructions of summer temperatures AD 1500–1870 using PLS analysis based on tree rings of *Pinus sylvestris* L. in Femundsmarka, eastern Norway. *The Holocene 8.*

Kalela-Brundin, M. in prep. (b). Reconstruction of summer temperatures since AD 1650 in the mountains in SW Norway (Suldal og Hovden) derived from tree rings of *Pinus sylvestris* L.

Karlén, W. 1976. Lacustrine sediments and tree-limit variations as indicators of Holocene climatic fluctuations in Lappland, northern Sweden. *Geografiska Annaler 58A*, 1–34.

Karlén, W. & Kuylenstierna, J. 1996. On solar forcing of Holocene climate: evidence from Scandinavia. *The Holocene 6*, 359–365.

Kirchhefer, A. & Vorren K.-D. 1995. Årringer på furu, *Pinus sylvestris* L., som kilde for klimainformasjon i Vesterålen, 79–85. Selsing, L. (ed.) Kilder for klimadata i Norden fortrinnsvis i perioden 1860–1993. *AmS-Varia 24.*

Kullman, L. 1990. Dynamics of altitudinal tree limits in Sweden: a review. *Norsk geogr. Tidsskr. 44*, 103–116.

Kvamme, M. 1984. Vegetasjonshistoriske undersøkelser, 238–275. Meyer, O. B. (ed.) Breheimen - Stryn. Konsesjonsavgjørende botaniske undersøkelser. *Rapport 34.* Botanisk Institutt, Universitetet i Bergen.

Kvamme, M. 1993. Holocene forest limit fluctuations and glacier development in the mountains of Southern Norway, and their relevance to climate history. *Paläoklimaforschung/Palaeoclimate Research 9*, 99–113.

Kvamme, M., Berge, J. & Kaland, P. E. 1992. Vegetasjonshistoriske undersøkelser i Nyset-Steggjevassdragene. *Arkeologiske rapporter 17.* Historisk Museum, Universitetet i Bergen, 1–132.

Lima-da-Faria, A. 1977. Femtusenårige rester av tal vid Rondanes nationalpark. *Svensk Botanisk Tidsskrift 71*, 29–30.

Lindholm, M., Meriläinen, J., Eronen, M. & Zetterberg, P. 1996. Summer temperatures recontructed from tree rings of pine in northern Lapland. *Paläoklimaforschung/Palaeoclimate Research 20*, 83–92.

Lundqvist, J. 1969. Beskrivning till jordartskarta över Jämtlands län. *Sveriges Geologiska Undersökning Ca45*, 1–418.

Moe, D. 1977. *Studier over vegetasjonsutviklingen gjennom Holocene på Hardangervidda. II. Generell utvikling og tregrensevariasjoner.* Universitetet i Bergen. 99 pp.

Moe, D. 1979. Tregrense-fluktuasjoner på Hardangervidda etter siste istid, pp. 199–208. Nydal, R., Westin, S., Hafsten, U. & Gulliksen, S. (eds.) *Fortiden i søkelyset.* Universitetet i Trondheim.

Munaut, A. V. 1986. Dendrochronology applied to mire environments, pp. 371–385. Berglund, B. E. (ed.) *Handbook of Holocene Palaeoecology and Palaeohydrology.* John Wiley & Sons, Chichester.

Nesje, A. & Kvamme, M. 1991. Holocene glacier and climate variations in western Norway: evidence for early Holocene glacier demise and multiple neoglacial events. *Geology 19*, 610–612.

Nydal, R., Løvseth, K. & Syrstad, O. 1970. Trondheim natural radiocarbon measurements V. *Radiocarbon 12*, 205–237.

Ording, A. 1941. Årringanalyser på gran og furu. *Meddelelser fra det norske skogforsøksvesen 7*, 101–354.

Roaldset, E. 1992. Geologien i Nore og Uvdal, pp. 19–45. Solhjell, O. (ed.) *Bygdehistorie for Nore og Uvdal.* Nore og Uvdal kommune.

Sandmo, J. K. 1960. Problemer omkring furuskogens innvandring og dens senere tilbakegang. *Tidsskrift for Skogbruk 68*, 204–207.

Selsing, L. 1975. Stubber og stammer. *Fra haug og heidni 5*, 342–350.

Selsing, L. 1979. Gamle furustubber i fjellet. *AmS-Småtrykk 3*, 71–85.

Selsing, L. 1996. The climatic interpretation of Holocene megafossils of pine (*Pinus sylvestris* L.) from the mountain area of southern Norway: the importance of the precession in controlling Holocene climate. *Paläoklimaforschung/Palaeoclimate Research 20*, 147–156.

Selsing, L. in prep. Reconstruction of the Holocene pine forest limit in the mountain area of Suldal-Setesdalsheiene, southwest Norway, based on pine subfossil finds in bogs.

Selsing, L. & Wishman, E. H. 1978. An approach to the understanding of the summer climate 7000–6000 BP in Ryfylke, southwest Norway, pp. 145–153. Frydendahl, K. (ed.) *Proceedings of the Nordic Symposium on Climatic Changes and Related Problems. Klimatiske meddelelser 4.* Det danske meteorologiske institut, København.

Selsing, L. & Wishman, E. 1984. Mean summer temperatures and circulation in a southwest Norwegian mountain area during the Atlantic period, based upon changes of the alpine pine-forest limit. *Annals of Glaciology 5*, 127–132.

Simonsen, A. 1980. Vertikale variasjoner i Holocen pollen sedimentasjon i Ulvik, Hardanger (Vertical variations of Holocene pollen sedimentation at Ulvik, Hardanger, SW-Norway). *AmS-Varia 8*, 1–68.

Slåstad, T. 1955. Årringundersøkelser i Gudbrandsdalen. *Meddelelser fra det Norske Skogforsøksvesen 14*, 571–620.

Solem, T. 1991. Blanket mire formation on a drumlin in Nord Trøndelag, central Norway. *The Holocene 1*, 121–127.

Stuiver, M. & Reimer, P. J. 1993. A computer program for radiocarbon age calibration. *Radiocarbon 28*, 1022–1030.

Thun, T. 1984a. A floating tree-ring chronology from Bryggen in Bergen based upon dendrochronological studies of 42 pine logs. *The Bryggen Papers, Supplementary Series 1*, 96–100.

Thun, T. 1984b. Dendrochronological dating of a harbour construction in Trondheim. *Norsk geogr. Tidsskr. 38*, 19–26.

Thun, T. 1987. Comparison of tree-ring chronologies from southern Norway. *Annales Acad. Sci. Fennicae A III 145*, 89–95.

Thun, T. 1991. Tree rings of Scots pine (*Pinus sylvestris* L.) as indicators of past climate in Central Norway. *Norsk Geol. Tidsskr. 71*, 229–230.

Zetterberg, P. 1987. Site chronologies from Eastern Finland and Soviet Karelia. *Annales Acad. Sci. Fennicae A III 145*, 49–55.

Zetterberg, P. 1988. Dendrochronology and archaeology: dating of a wooden causeway in Renko (Southern Finland). *Fennoscandia Archaeologica V*, 92–104.

Zetterberg, P., Eronen, M. & Lindholm, M. 1996. The mid-Holocene climatic change around 3800 BC: tree-ring evidence from northern Fennoscandia. *Paläoklimaforschung/Palaeoclimate Research 20*, 135–146.