The origin and age of driftwood on Jan Mayen

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Analysis of the wood anatomy of 481 driftwood specimens from Jan Mayen shows that *Larix* spp. constitute approximately 70% of the trees, while sawn logs are dominated by *Pinus* spp. by approximately 69%. A total of 356 driftwood samples from Jan Mayen and a small number of samples from Bjørnøya in the Barents Sea and the Troynoy Island in the Kara Sea were analysed by dendrochronological methods. A driftwood *Pinus* chronology was dated absolutely using chronologies from living trees of *Pinus sylvestris* in the lower proximity of the Angara River, a tributary of the Yenisey in Siberia. About 27% of the pine logs measured on Jan Mayen were found to originate in the same region, with end years concentrated in the 1940s and 1950s. A similar source was also found for *Pinus* driftwood logs on Bjørnøya and Troynoy. The results confirm and further delimit the source areas of the Yenisey driftwood established earlier from driftwood logs on Svalbard and Iceland. A subordinate source of both *Pinus* and *Picea* logs on Jan Mayen is northwest Russia, from the Kola Peninsula to the Pechora River. The Transpolar Drift Stream is believed to be the main distributor of driftwood from Siberian and northwest Russian sources to Jan Mayen, via the East Greenland Current. Dendrochronological dating reveals a strong, continuous input of ice-rafted driftwood from the Kara Sea. Radiocarbon datings from Jan Mayen show surface deposits of driftwood to be less than 500 years old, due mainly to extensive degradation of older wood and little or no land uplift.

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Introduction

The main objectives of this study were (1) to establish the genera represented in the driftwood on Jan Mayen and compare them with those in possible source areas, and (2) to determine the age and area of origin of the different types of driftwood with the aid of dendrochronology. An increasing number of *Pinus*, *Larix* and *Picea* chronologies established in recent years concerning possible driftwood source areas in Russia enhance the opportunities for dating arctic driftwood and delimiting the source areas. Recent studies indicate that drifting arctic sea ice plays an important role in the redistribution of sediments and contaminants (Pfirman et al. 1995; Pfirman et al. 1997b). Dendrochronological dating might serve as a tool to ascertain the sources of driftwood and other ice-rafted material, including contaminants. It might also elucidate the long-range transport and potential impact of such material arriving to the North Atlantic Ocean.

Huge driftwood deposits were apparently present when Jan Mayen (Fig. 1) was discovered and Dutch whaling took place there in the first half of the seventeenth century (cf. Zorgdrager 1750). The sequence of old maps available shows that the eastern beaches of the island have expanded considerably during the last 200 years. As Jan Mayen has experienced little or no land uplift (Gabrielsen et al. 1997), an additional aim was to examine the age of the oldest surface driftwood deposits.

If the origin of the driftwood is determined, it should be possible to obtain information about the relative importance of the various source areas and the transport processes involved. Since wood has a limited capability to remain afloat, no Russian or North American driftwood could reach Jan Mayen without being rafted in, or on, drift ice (Häggblom 1982). Häggblom estimated that the maximum buoyancy time of the most common arctic driftwood types was about 17 months or less. There are two types of driftwood encountered: sawn timber logs and driftwood trees with roots. Due to mishaps such as the wrecking of rafts and spring floods, large numbers of stray logs come adrift while floating on Russian rivers which drain into the Arctic Ocean (Alekseyenko & Titova 1988). Entire trees with roots drift down the rivers following the undercutting of riverine forests during flooding or ice break-up. The logs and driftwood trees are carried by the rivers into the Arctic Basin during the summer and become frozen into the drift ice that forms off the coast in late autumn. The logs and trees drift in, or on, the

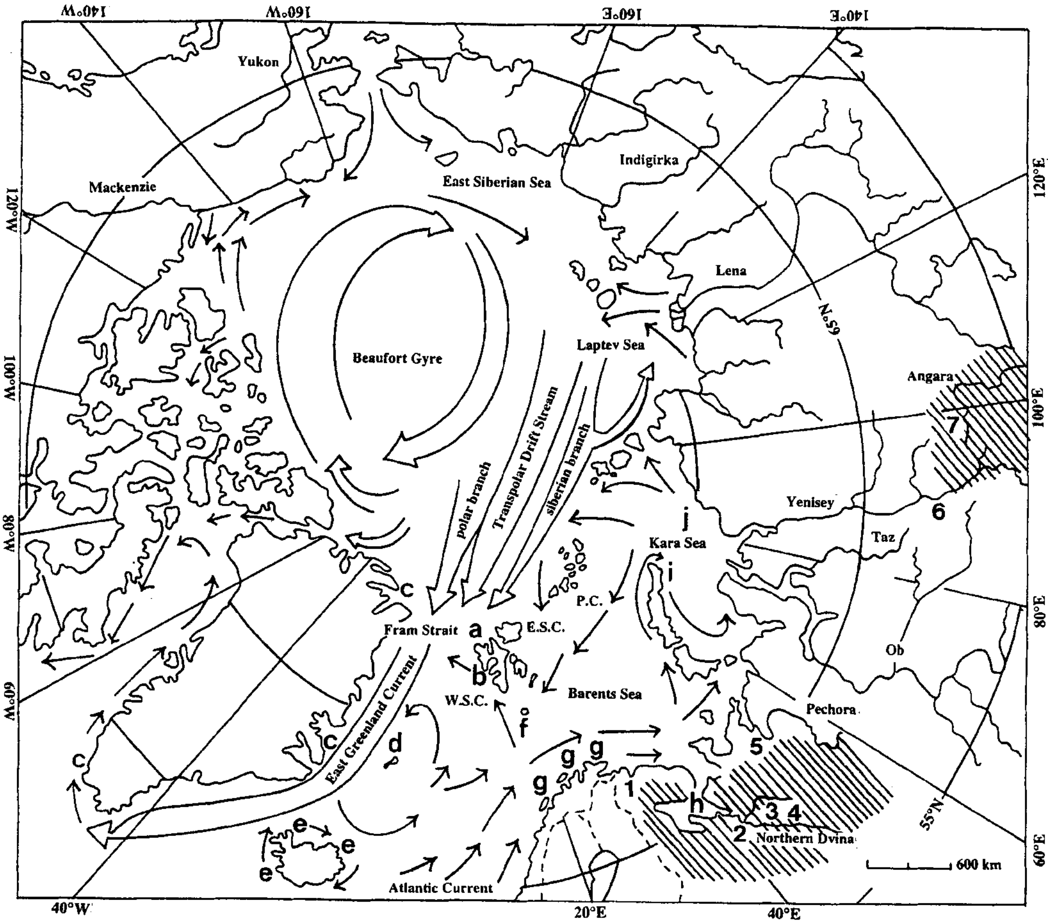

Fig. 1. Major sea ice drift patterns in the Arctic Ocean and prevailing ocean currents in adjacent seas. Redrafted after Fairbridge (1966) and Gordienko & Laktionov (1969). Abbreviations: W.S.C. = West Spitsbergen Current, E.S.C. = East Spitsbergen Current, P.C. = Persey Current. Eurasian sampling sites for dendrochronological analyses of driftwood are shown: a – Wijdefjorden, Svalbard (Eggertsson 1994b), b – Isfjorden, Svalbard (Bartholin & Hjort 1987), c – Greenland (Eggertsson (1994a, 1995), d – Jan Mayen (this publ.), e – Iceland (Eggertsson 1995), f – Bjørnøya (this publ.), g – North Norway (Johansen, unpubl.), h – Northern Dvina river (Johansen, unpubl.), i – Novaya Zemlya (Johansen unpublished), j – Troynoy Island (this publ.). The main logging areas in Russia in the 1960s are indicated by hatching as shown by Algvere (1966) and Lydolph (1970). The positions of chronologies used in the dating of Jan Mayen driftwood are indicated by numbers: (1) Murmansk, *Pinus sylvestris* Bitvinskas & Kairaitis (1978); (2) Archangelsk, *Pinus sylvestris* Anikejeva & Kudriavceva (1984); (3) Voroncy, *Picea abies* and *Pinus sylvestris* Schweingruber pers. comm. 1995; (4) Verhnaja Toima, *Pinus sylvestris* Schweingruber pers. comm. 1995; (5) lower Pechora river, *Pinus sylvestris* Schweingruber pers. comm. 1995; (6) middle Yenisey River, *Pinus sylvestris*, Vaganov pers. comm. 1994; (7) lower Angara river, *Pinus sylvestris* Vaganov pers. comm. 1995. In addition, a floating *Larix* driftwood chronology from North Norway (site g) and a *Picea* driftwood chronology from Northern Dvina river (site h) were used in dendrochronological dating of the Jan Mayen driftwood.

ice at the mercy of the wind and ocean currents and are released when the ice melts. They then drift in the sea before being finally or temporarily deposited. The ice drift and the sea surface circulation in the Arctic Ocean are driven by the Beaufort Gyre, a clockwise circulation pattern in the Beaufort Sea, and the Transpolar Drift Stream which transports ice from east to west across the Arctic Ocean (Hibler 1989) (see Fig. 1). These two major transport patterns are manifestations of the mean sea level pressure field (Gow & Tucker 1990). Dendrochronological investigations hither-to performed have emphasised two source areas of driftwood in the Eurasian Arctic, namely northwest Russia and the middle Yenisey region (Bartholin & Hjort 1987; Eggertsson 1994b; Eggertsson 1995).

Estimates have been made for the time required for drift ice from various sources bordering the Arctic Ocean to reach specific locations. For instance, ice from the Kara Sea could reach the Fram Strait after 2–2.5 years via the Transpolar Drift Stream (Rigor 1992; Romanov 1995; Pfirman et al. 1997a). The other main transport mechanism in the Arctic Basin, the Beaufort Gyre, transports North American drift ice and wood (Koerner 1973). It would take ice 4–5 years to drift from, for example, Alaska to the Fram Strait (Rigor 1992; Romanov 1995; Pfirman et al. 1997a). North American driftwood could reach Jan Mayen across the Arctic Basin by drifting either westwards in the Siberian Ice Massif or eastwards in the Beaufort Gyre (Fig. 1).

According to Blake (1972), the amount of driftwood concentrated at a given locality is a function of (1) the distance from the source of supply, (2) the duration and extent of the open-water season, (3) the nature of the coast, (4) the exposure, and (5) the rate at which the land is emerging from the sea. For modern driftwood, which consists mainly of sawn logs, variations in the logging activity as well as in the intensity of the spring flood in the source rivers must also be taken into account. Häggblom (1982) assumed that a high influx of driftwood during the Holocene correlated with periods with much drift ice in the Arctic Ocean. On the other hand, Dyke et al. (1997) argued that periods when little driftwood was deposited in Arctic Canada could, instead, reflect changes in provenance or transportation routes. Both statements could make sense depending on the geographical location of the driftwood locations examined. However, knowledge about the paleoceanographic conditions in the Arctic Ocean and adjacent seas are still scarce.

The history of driftwood research

Systematic studies of driftwood as a natural resource in the Arctic can be traced back to Iceland in the eighteenth century (Olavius 1780). Scientific studies of arctic driftwood involving microscopic identification began in the mid-nineteenth century with investigations in Svalbard (Agardh 1869; Wiesner 1872), Greenland (Örtenblad 1881) and Novaya Zemlya (Kraus 1873; von Nördlinger 1873). Eurola (1971) summarised the history of the earliest driftwood research.

Since the Second World War, interest for driftwood research in the European sector of the Arctic has been sporadic and has mainly functioned as a tool for studying strandline displacement, e.g. Blake (1961). Häggblom (1982, 1987) initiated a new period of interest in driftwood research in the European Arctic by studying wood and other flotsam in Svalbard. By discussing the buoyancy of different tree species, the transport time from possible source areas and the variations of driftwood in shore profiles, he contributed to the idea that driftwood frequencies on raised beaches reflected changes in the extent of the ice cover in the Arctic Ocean. Giddings (1941, 1943, 1952) introduced the use of dendrochronology to identify the origin of driftwood in Alaska and Canada followed by Oswalt (1951) and van Stone (1958). Bartholin & Hjort (1987) utilised dendrochronology for the first time in European driftwood research, identifying source areas of driftwood logs in Isfjorden, Svalbard, by cross-dating with chronologies in Russia. Samset (1991) investigated the driftwood resources in northern and western Iceland from the viewpoint of forestry science. Eggertsson (1994a,b; 1995) and Eggertsson & Leayendecker (1995) undertook systematic studies in Svalbard, Iceland and Canada involving the dendrochronological dating and origin of arctic driftwood.

Jan Mayen

Jan Mayen has an isolated position at 71°N and 8°30′W, 540 km northeast of Iceland and approximately two-thirds of the way between North Norway and Greenland (Figs. 1 and 2). The island lies on the Mid-Atlantic Ridge and is entirely volcanic (Fitch et al. 1965). Having an area of 380 km^2, Jan Mayen is long and narrow, measuring 54 km from southwest to northeast and 3–16 km wide (Fig. 2). In the northern half, the landscape is dominated by the 2,277 m high glaciated, cone-shaped volcano Beerenberg. The southern half of the island consists of rugged mountainous terrain with small volcanoes and craters reaching 400–800 m. The middle of the island is dominated by low plains, especially on

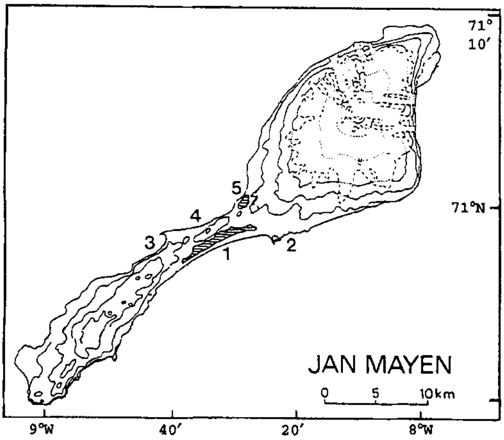

Fig. 2. Sampling sites on Jan Mayen indicated by numbers, redrawn from Anda et al. (1985): (1) Rekvedbukta with Sørlaguna lagoon with Lagunevollen bar, Helenesanden and Vesle Vedbukta; (2) Ullerengsanden and Jameson Bay; (3) Kvalrossbukta Bay; (4) Haugenstranda and Kveisdalen bays; and (5) Nordlaguna lagoon.

the southeastern side. Two lagoons exist, one on the western and one on the eastern side of the island.

Meteorology and oceanography

The climate is cool oceanic or mid-arctic (Steffensen 1982). Fog is very frequent, especially in summer. The annual mean precipitation for the period 1963–1980 was 685 mm, and the mean annual temperature for the same period was never lower than −1.2°C. Jan Mayen is washed by the East Greenland Current, which brings cold arctic water from the Fram Strait (Fig. 1). North of the island is the eastward-flowing Jan Mayen Current, which originates from the merging of the East Greenland Current and the Norwegian Atlantic Current towards the west (Bourke et al. 1992). Jan Mayen is usually surrounded by drift ice from November until May (Steffensen 1982). The tidal range varies between 50 and 120 cm (Den Norske Los 1988). The action of the drift ice, the spring tide and strong storm waves upon the flat beaches is apparently able to rearrange and transport driftwood from its original stranding sites.

Earlier driftwood studies

The first maps of the island were made by Dutch explorers in the early seventeenth century. The large amounts of driftwood were described by early visitors to the island (e.g. Zorgdrager 1750; Scoresby 1820).

The first investigations of Jan Mayen driftwood started with the collections made by the Austrian Polar Expedition to the island during the 1st International Polar Year, 1882–1883. The composition and mean widths of tree rings of 8 samples from the northwest coast and 5 from the southeast coast were examined by Schneider (1886). A more detailed study was made by Ingvarson (1903), who examined 39 driftwood specimens collected by Nathorst's expedition on its way to East Greenland in 1899 (Nathorst 1900). Ingvarson identified and measured the width of the tree rings of samples from the northwestern beaches (Ingvarson 1903). This took place at a time prior to the introduction of dendrochronology as a dating method. In 1990, the present author re-examined the driftwood samples from the Nathorst expedition at Naturhistoriska Riksmuseet, Stockholm, Sweden. It transpired that the large majority of the 39 samples collected in 1899 were just small twigs and thin branches, and were thus not suitable for dendrochronological analysis. A Norwegian trapper wintering on Jan Mayen in 1933–1934 investigated the possibilities of exploiting the large amounts of driftwood (Matheson 1936), but no identification of the wood was performed. The Imperial College Expedition to Jan Mayen in 1938, collected 45 specimens of driftwood and these were later identified by their anatomy (Russell & Wellington 1940). Almost all the samples came from sawn logs and planks in Jameson Bay (P. S. Wellington pers. comm. 1990). Common to the earliest studies of arctic driftwood has been the assumption that investigation of its anatomy and estimation of the mean ring widths could indicate the areas of origin.

The occurrence of archaeological remains dating from the whaling period, wreckage and driftwood on various Jan Mayen beaches was described by van Franeker (1990) on the basis of field work carried out in 1983 and 1985. Whaling during the period 1614–1642, and trapping and the building of roads and houses during the present century have to some extent interfered with the Jan Mayen driftwood, mainly through its use as fuel and building material. However, due to the remoteness of the island, this has occurred on a smaller scale than, for example, on Iceland. A complete sawmill was raised in the southeastern bay, Båtvika, in 1959 during the construction of the Loran C navigation station (Barr 1991). Slight exploitation of driftwood resources by Icelandic timber expeditions is known to have taken place twice this century, in 1918 and 1957 (Lindal 1980).

The author visited Jan Mayen from 29 July to 6 August 1989, on 20 October 1990 and from 27 July to 9 August 1991. In addition, personnel from the telecommunication and meteorological stations on Jan Mayen collected samples in accordance with instructions from the author in 1994 and 1995.

Samples

All the samples collected on Jan Mayen were obtained from the central part of the island, which is dominated by low plains of volcanic sands and the two lagoons (Fig. 2). A total of 228 driftwood specimens came from the western beaches and 253 from the eastern beaches.

Rekvedbukta

This locality comprises the southeastern sampling sites: Vesle Vedbukta, Helenesanden and the Lagunevollen bar, along with the Sørlaguna lagoon (Fig. 2). Rekvedbukta is a bay consisting of an almost straight stretch of sandy beach, approximately 10 km long and 1.2 km broad at its widest point, backed by a sand bar which is 300–700 m wide and rises 6–8 m above sea level. Behind the bar is an almost dried-out lagoon – Sørlaguna (Fig. 2). A total of 129 dendrochronological samples and 117 samples for anatomical analysis were obtained from this bay.

Ullerengsanden

This is an approximately 2.5 km long, sandy beach located northeast of Sørlaguna lagoon. Three dendrochronological samples and four other samples were collected here to study their anatomy.

Kvalrossbukta

A total of 36 dendrochronological samples and one sample for studying the wood anatomy were obtained in this bay. The bay, which is about 1 km long, was one of the foci of the local whaling industry during the first half of the seventeenth century (Barr 1991).

Haugenstranda and Kveisdalen

Approximately 5 km long, Haugenstranda is a beach situated north of Kvalrossbukta (Fig. 2). The driftwood is concentrated in a 30–50 m wide belt about 80 m from the present seashore. A wide terrace of volcanic sand and a gravel plain separates the narrow driftwood belt from the mountains. Kveisdalen is a smaller beach, about 0.5 km long, and is connected to Haugenstranda in the south. The driftwood is heavily concentrated in a 30–40 m wide belt starting about 30 m from the present shore. A total of 138 dendrochronological samples and three to study the anatomy of the wood were obtained from these two locations.

Nordlaguna

This lagoon is 1720 m long and 950 m wide. The surface is approximately 0.5 m above present sea level (Skreslet 1967). The lagoon is the remains of a bay that has been closed off from the sea by the Bommen bar, the latter which rises to a maximum height of about 5 m (Klemsdal 1986). In common with the Sørlaguna lagoon, large quantities of driftwood are present on the 200-m wide bar. The 50 dendrochronological samples were collected from the landward beaches and the lagoon bar.

Bjørnøya

Bjørnøya (74°30′N, 19°01′E) is situated in the Barents Sea, approximately 400 km northwest of Norway and some 300 km south of Svalbard (Fig. 1). The island is roughly circular in shape, having a diameter of about 20 km and an area of 178 km^2. Bjørnøya is influenced by the East Spitsbergen Current and the Persey Current, which transport arctic water and drift ice from the north and northeast, and by a branch of the Norwegian Atlantic Current coming from the south (cf. Loeng 1991). In 1992, Georg Bangjord took core samples from 20 driftwood logs at Russehamna on the south coast of the island.

Troynoy Island

During the joint Russian–Norwegian ornithological expedition to Troynoy Island in the Kara Sea (75°58′N, 82°39′E), Georg Bangjord collected increment cores from 10 sawn logs. Troynoy Island is situated approximately 250 km north of the estuary of the River Yenisey on the mainland. The total size of the island is approximately 61 km^2 and the coastline has an irregular form, 26 km long and with an average width of 4.3 km (Bangjord et al. 1994). It is heavily influenced by the discharges from the Yenisey and Ob rivers, especially during the spring flood (cf. Pavlov & Pfirman 1995). The driftwood samples were collected close to the sea, in Polarnic Bay, on the eastern side of the island.

Methods

All the samples that have been measured and examined are stored at the Department of Botany, Norwegian University of Science and Technology in Trondheim, Norway.

Dendrochronological sampling

All the samples were collected within the altitude of 1–7 m above present sea level. Their approximate distance from the sea and altitude were determined in relation to a topographical map. The samples consisted of sawn disks and increment borings, which were obtained approximately 1.5 m above the root end on sawn logs or trees with roots. Decaying specimens or trees with a strongly eccentric growth pattern were usually avoided. Samples were obtained using a chainsaw, a Finnish 5-mm increment corer (Suunto) and two Swedish increment corers (Haglöf), both 8 mm.

Measurements and statistical treatment

Before examination, the increment cores and sectors on the disks were cut with a sharp razor blade to expose the tree rings, which were coloured with chalk prior to measurement. All the measurements were performed with an ADDO Tree Ring Machine Model 2A (Parker Instruments, Sweden) to an accuracy of 0.01 mm. One radius, or where possible two radii, were measured on each log. The radius and tree curves were synchronised using the CATRAS statistical program package (Aniol 1983). This program package performs the t-test (Baillie & Pilcher 1973) and the sign test or percentages agreement test (Eckstein & Bauch 1969). All positions of overlap between two chronologies are investigated, taking no account of the magnitude of year-to-year changes in ring width, while a simple standardisation of the growth curves is performed (Eggertsson 1994a). The t-test indicates whether two curves are related, i.e. when the level of statistical confidence is high enough, it gives the synchronous position of two curves indisputably. Before being used to build a chronology, or dated, curves showing high intercorrelation were checked visually by comparing graphical plots. The quality of the chronologies constructed and the datings performed were verified by the COFECHA program (Holmes et al. 1986). The curves building up the driftwood chronologies were standardised with a negative exponential function to smooth the growth trends, using the CRONOL program (Holmes unpubl.).

Wood anatomy

Most driftwood on Jan Mayen consists of sawn logs. However, trees with roots, together with branches and various other fragments of wood, predominate in the uppermost deposits.

In the early phase of the project, collections were also made from sawn timber logs and driftwood trees with roots to obtain sufficient material to study the wood anatomy. A total of 375 specimens were collected from sawn logs, 300 for dendrochronological study and 75 specially for wood anatomy. A total of 56 dendrochronological samples were collected from driftwood trees with roots. Additional smaller samples obtained from whole trees with roots brought the total number to 106 (Table 1). Approximately 10-cm long, boat-shaped pieces of wood were cut 1.5 m above the root end of the logs or trees to provide these samples, which were solely to study the anatomy of the wood.

All identification relating to the wood anatomy took place after thin sections (transverse, longitudinal and tangential) had been cut with a sharp razor blade. The identification was undertaken in accordance with descriptions and identification keys provided by Greguss (1959, 1972) and Schweingruber (1990). Where possible, all driftwood samples were identified to the genus level. The microscopical identification of the genera *Picea* and *Larix* was carried out in accordance with the guidelines given by Bartholin (1979) and later verified by Anagnost et al. (1994). In a few

Table 1. Genera identified among samples from driftwood trees with roots at Jan Mayen, Iceland (Eggertsson 1994c: 8), and Wijdefjorden, northern Svalbard (Eggertsson 1994c: 8).

Taxon	Jan Mayen n = 106	Iceland n = 65	Svalbard n = 59
Larix sp.	69.8%	54%	80%
Picea sp.	12.3%	18%	17%
Pinus (diploxyl)	9.4%	27%	3%
Pinus (haploxyl)	0.9%		
Picea/Larix	3.8%		
Salix sp.	2.8%		
Populus sp.	1.0%		
Sum	100.0%	99%	100%

samples, the two genera were indistinguishable. The microscopical examination was carried out with a Zeiss Standard Microscope using a magnification of 250–400×.

Dendrochronological dating

The total number of samples examined by dendrochronology on Jan Mayen was 356, composed of 300 logs and 56 driftwood trees with roots. In addition 10 samples from Troynoy and 20 samples from Bjørnøya, all from timber logs, were examined by dendrochronology. Driftwood trees with roots often exhibited eccentric growth and compression wood, making measurement and synchronisation difficult. The driftwood chronologies that were constructed, together with the tree-ring series from individual logs and trees, were tested against master chronologies available from living trees of the same genera in possible source areas in the boreal circumpolar forest belt. The statistical correlation values generated by the CATRAS program package, followed by visual comparison of graphical plots, were screened in the hope of finding evidence to enable the construction of chronologies and the consequent absolute dating of the logs.

The driftwood pine chronology was constructed and individual logs and trees were tested against *Pinus* chronologies from living trees available from a number of locations from the Kola Peninsula in the west, through the Russian boreal conifer forest belt to Lake Baikal in the east. In northwest Russia, pine chronologies were used which had been published in Bitvinskas & Kairaitis (1978), Feklistov (1978), Komin (1981), Anikejeva & Kudriavceva (1984), Jevdokimov (1984) as well as chronologies made available by Schweingruber pers. comm. 1995. Potential sources of pine driftwood from the Ural Mountains and eastward were screened using pine chronologies published in Shiyatov (1973, 1978, 1984a, 1986, 1997), Komin (1981), Galazij (1981), Nesvetaylo (1987) and by master chronologies made available by Vaganov pers. comm. 1994 and 1995, Schweingruber pers. comm. 1995, and by Shiyatov pers. comm. 1997. Similarly, the driftwood spruce chronology and individual logs and trees were tested against *Picea* chronologies from various locations from the White Sea region in the west, through the Russian boreal conifer belt, to Alaska and northern Canada i.e. from Oswalt (1951), Giddings (1953,) van Stone (1958), Feklistov (1978), Anikejeva & Kudriavceva (1984), Semenov & Certovskoj (1984), Jevdokimov (1984), Shiyatov (1981, 1984a, b, 1986), Cropper & Fritts (1981), Jacoby & Cook (1981), Schweingruber pers. comm. (1995) and Johansen (unpublished). All *Larix* logs and trees were treated in a similar manner using chronologies from potential source areas from the White Sea region to Alaska and Canada, i.e. from Shvets (1977), Galazij (1981), Shiyatov (1984a, 1984b, 1986), Rozanov (1987), Johansen (1994), Lovelius (1997), Schweingruber pers. comm. 1995 and 1997.

Radiocarbon datings

The activity of approximately the 10 outermost tree rings was measured at the Radiological Dating Laboratory in Trondheim (ref. nos. T-9097–9102, T-11081–T11085, T-12306–12308).

Results and discussion

Wood anatomy of driftwood trees

Larix dominated (about 70%) among the driftwood trees with roots (Table 1) This agrees with results from East Greenland (Örtenblad 1881), Iceland (Eggertsson 1995) and Svalbard (Agardh 1869; Häggblom 1987; Eggertsson 1994b). Schneider (1886) and Ingvarson (1903) also found *Larix* to be the most common driftwood among the branches and twigs they examined from Jan Mayen, and all the samples came from one species, *Larix sibirica.* According to Budkevich (1955), a number of *Larix* species can be identified by their anatomy. Bondevik et al. (1995) reported finding sub-fossil *L. gmelinii* and *L. laricina* at Kapp Ziehen on Barentsøya, but they did not give their identification procedure. Identification of the various species of *Larix* which, theoretically, could be present among the driftwood, i.e. *L. sibirica*, *L. gmelinii* and *L. laricina*, would provide valuable information about which source areas are represented. However, in agreement with Phillips (1941) and Anagnost et al. (1994), a detailed taxonomical identification of the *Larix* specimens on the basis of wood anatomy was found to be impossible.

The percentage of *Larix* driftwood trees is somewhat smaller on Jan Mayen than in northern Svalbard (Eggertsson 1994b), but larger than on Iceland (Eggertsson 1995), (Table 1). All three locations are influenced by the Transpolar Drift Stream feeding the East Greenland Current. The difference in representation of *Larix* driftwood trees is not easily explained, as no similar variations can be found in the frequencies of *Picea* or *Pinus* trees. The collections obtained from driftwood trees on the flat beaches of Jan Mayen may cover a greater time span than on northern Svalbard where only the most recent driftwood trees have been sampled. This could favour the larch driftwood, as it is more resistant to degradation.

The composition of the genera represented, with a predominance of *Larix*, shows that the influx of driftwood trees from Russia must be substantial. Agardh (1869) was one of the first to identify Siberia as a main source area of driftwood on Svalbard, on the basis of the anatomical identification of *Larix*. Reaction wood in the outermost tree rings, as well as an eccentric growth pattern of the tree rings, was frequently observed in the *Larix* trees from Jan Mayen. These growth distortions show that the larch trees grew on unstable slopes close to rivers where they are susceptible to undercutting and uprooting by fluvial erosion or flooding.

Microscopical examination of the anatomy of the *Pinus* samples collected from driftwood trees revealed that two groups are represented: diploxyl pines identified by their ray tracheids with dentated walls, and haploxyl pines, which have ray tracheids without dentated walls and little late wood (cf. Farjon 1984; Schweingruber 1990). The diploxyl pines include pines with two vascular bundles per needle, such as *P. sylvestris*, while the haploxyl pines have one vascular bundle per needle, such as *P. strobus* and *P. sibirica*. Only one haploxyl pine specimen was identified from Jan Mayen (Table 1). The circumpolar distribution of pines shows that the source areas of the diploxyl type, i.e. *P. sylvestris*, must be sought for in Siberia as there are no likely sources of diploxyl pine trees along the rivers in North America that drain to the Arctic Ocean (cf. Mirov 1967; Farjon 1984). The other species of diploxyl pines found in Siberia, *P. pumila*, is an unlikely source since it is a dwarf tree (Farjon 1984). The haploxyl pine specimen that was identified is most likely to be *P. sibirica*, which is common in the lowlands along the Siberian rivers east of the Urals (Farjon 1984).

Salix and *Populus* were the only genera of deciduous trees represented in the samples from driftwood trees with roots. These observations confirm the earlier findings on Jan Mayen of 'Salicinee' by Schneider (1886) and of *Salix* and *Populus* by Ingvarson (1903). However, it is not possible to distinguish the different species of *Populus*, or the various tree-habit species of *Salix*, by their anatomy (Schweingruber 1990). Low buoyancy certainly reduces the chance of these hardwoods reaching Jan Mayen (Häggblom 1982).

The genera represented among the driftwood trees beached on Jan Mayen are believed to mainly reflect the composition of riparian forests in a variety of sources, aided by differences in buoyancy among the species. The predominance of *Larix* shows that the Russian boreal forest is the main source area. Siberian ice drifting towards the Fram Strait, north of Spitsbergen, is known to carry driftwood, especially Siberian larch, together with sediments, pellets and sand (Koch 1945). Moreover, driftwood from the most likely

Table 2. Genera identified among samples from sawn driftwood logs at Jan Mayen, Iceland (Eggertsson 1994c: 8), Wijdefjorden, northern Svalbard (Eggertsson 1994c: 8), and Isfjorden, western Svalbard (Bartholin & Hjort 1987).

Taxon	Jan Mayen n = 375	Iceland n = 271	Wijdefjorden, Svalbard n = 213	Isfjorden, Svalbard n = 145
Pinus (diploxyl)	67.7%	79%	77%	60.7%
Pinus (haploxyl)	1.6%			
Larix	16.5%	6%	11%	0.7%
Picea	10.1%	15%	12%	38.6%
Abies	1.6%			
Picea/Larix	1.1%			
Betula	0.8%			
Quercus	0.3%			
Populus	0.3%			
Sum	100.0%	100%	100%	100.0%

North American driftwood source that is carried to the Arctic Ocean by the Mackenzie River is totally dominated by *Picea* (Eggertsson 1994a).

Wood anatomy of sawn timber logs

The dominance of *Pinus* (diploxyl and haploxyl type) among the sawn logs (about 69%) is similar to that of *Larix* among the driftwood trees (about 70%), (Tables 1 and 2). The representation of genera among the sawn logs examined at Jan Mayen reflects the tree species that are of commercial interest in the source areas, along with some influence from variations in buoyancy. Since there is no large-scale logging and rafting of timber in North American areas that drain to the Arctic Ocean (Eggertsson 1994a; PAME 1996), it may be assumed that the main areas supplying sawn timber logs to the Arctic Ocean are found in Russia.

Diploxyl type pines (*Pinus sylvestris-type*) predominate among the sawn logs from Jan Mayen that have been examined, making up about 68% of the total. Only six samples of haploxyl type were identified (Table 2), and *Pinus sibirica* is the most likely species here since it is felled in lowland areas east of the Urals (Farjon 1984). The predominance of *Pinus* among the sawn logs at Jan Mayen agrees with findings from Iceland (Samset 1991; Eggertsson 1995) and northern and western Svalbard (Bartholin & Hjort 1987; Eggertsson 1994b).

Larix is the second most common genus among the logs at Jan Mayen, whereas Bartholin & Hjort (1987) and Eggertsson (1994b, 1995) found *Picea* to be more common than *Larix*, in western Svalbard and Iceland. The higher frequencies of *Picea* as compared to *Larix* especially in western Svalbard and Iceland might be influenced by earlier removal by humans as described for both locations (Bartholin & Hjort; Eggertsson 1995).

Russell & Wellington (1940) found *Picea* to be the dominating genus (53.3%) among the 45 driftwood samples collected on Jan Mayen in 1938. However, these results are not directly comparable with those obtained now, since the samples came from both logs and planks (P. S. Wellington pers. comm. 1990). The only specimen identified from Jan Mayen that has a North American, not Russian, distribution, was also reported by Russell & Wellington (1940), namely *Tsuga canadensis*.

Six driftwood logs from Jan Mayen (Table 2), and one from Bjørnøya (Table 3), belonged to the genus *Abies*. The genus has not been reported in Svalbard or from Iceland (Bartholin & Hjort 1987; Eggertsson 1994b, 1995). These logs are

Table 3. Genera identified among sawn driftwood logs collected in Russehavna Bay, Bjørnøya, in 1992 and in Polarnich Bay on Troynoy Island, Kara Sea, in 1994.

Taxon	Bjørnøya	Troynoy
Pinus (diploxyl)	13	9
Picea	3	
Larix	3	1
Abies	1	
Sum	20	10

Table 4. Statistics of the constructed *Pinus* and *Picea* driftwood chronologies.

	Time span	No. logs	Intercorrelation	Autocorrelation	Mean sensitivity
Pinus1	1739–1955	16	0.594	0.850	0.174
Pinus2	1783–1970	5	0.533	0.853	0.193
Picea	1821–1979	5	0.566	0.755	0.244

likely to originate from *Abies sibirica* trees, which are exploited as timber on a small scale in Russia (e.g. in the Yenisey–Angara Basin) (Hartung 1982). Sources in North America containing *A. balsamea* and *A. lasiocarpa* are located too far from any river that might potentially transport such driftwood to the Arctic Ocean (Farjon 1990). According to Schweingruber (1990), the species in this genus are indistinguishable using wood anatomy.

The hardwoods, *Betula*, *Populus* and *Quercus*, accounted for 1.4% of the sawn logs from Jan Mayen that were examined (Table 2). Eggertsson (1994b, 1995) reported similar amounts of broad-leaved trees (1.5–2%) in Iceland and northern Svalbard, but did not specify the genera. *Betula* floats very poorly in water, but *Salix* and *Populus* float somewhat better (Sandmo 1948; Häggblom 1982). Both *Betula* and *Populus* are commercially felled in potential source areas in Siberia (Hartung 1982) and northwest Russia (Algvere 1966).

Wood anatomy samples from Bjørnøya and Troynoy Island

The sawn logs sampled on Bjørnøya and Troynoy Island mirror the same dominance of *Pinus* as found on Jan Mayen (Table 3). Thus, the 20 logs examined from Bjørnøya represent all the conifer genera hitherto identified among recent driftwood logs on Jan Mayen, Iceland (Eggertsson 1995) and Svalbard (Bartholin & Hjort 1987; Eggertsson 1994b).

Dendrochronological dating of the driftwood

A *Quercus* log collected on the landward side of Sørlaguna in 1995 was dated by Esther Jansma (pers. comm. 1996) with the aid of a Dutch oak chronology and was confirmed by matching against German oak chronologies. The outermost of the 144 rings measured was dated to AD 1633. Seven more rings, which could not be measured, gave the age the outermost tree-ring observed of AD 1640. However, as the total number of heartwood and sapwood rings were not possible to determine, the absolute age of the specimen is not possible to estimate. The log is probably not driftwood, but is more likely to be derived from either a shipwreck or the local whaling industry which took place during 1614 to 1655 (Barr 1991).

Pinus driftwood

Area of origin

A total of 15 *Pinus* logs from Jan Mayen could be accurately, internally synchronised to enable a chronology to be constructed, and one *Pinus* log from Bjørnøya fit well into this chronology (*Pinus1*), which covers a span of 217 years (Table 4).

The driftwood *Pinus* chronology from Jan Mayen (*Pinus1*) could be dated absolutely with the aid of an unpublished *Pinus* chronology obtained from a location north of the settlement of Yartsevo (61°03′N, 89°45′E), around the middle reaches of the Yenisey River (E. Vaganov pers. comm. 1994). It dated the driftwood chronology as being within the time span of AD 1739–1955, with a correlation value of $t = 6.49$ and a sign test value of 70.1%, at 99.9% significance. Eggertsson (1994b, 1995) obtained similar statistical correlation levels when dating *Pinus* driftwood chronologies from Iceland (based on 15 logs) and northern Svalbard (based on nine logs) using this master chronology from the middle reaches of the Yenisey. The correlation values between the Jan Mayen *Pinus* driftwood chronology (*Pinus1*) and the northern Svalbard

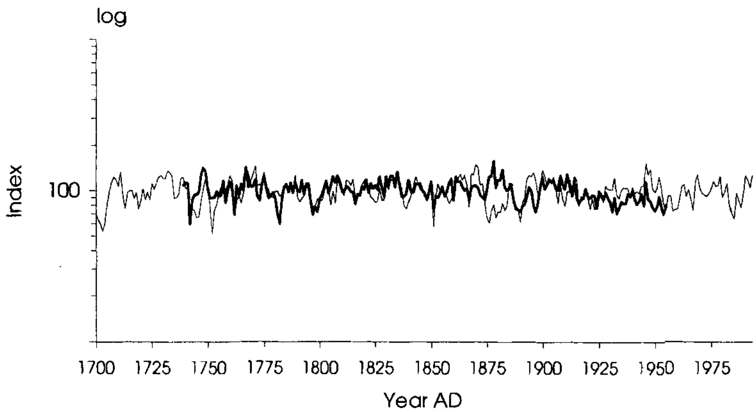

Fig. 3. Pinus driftwood chronology (*Pinus1*) from Jan Mayen (thick line) and master chronology from the lower Angara region (thin line).

chronology was t = 16.03 and a sign test value of 77.3%, at 99.9% significance, and t = 16.20 and a sign test value of 78.0%, at 99.9% significance, with the Iceland chronology (Eggertsson pers. comm. 1995).

Three new *Pinus* chronologies have subsequently become available (E. Vaganov pers. comm. 1995) from locations further south-southeast in the lower reaches of the Angara River, a large tributary of the Yenisey (Fig. 1). They verify and repeat the earlier dating of the Jan Mayen driftwood *Pinus* chronology, and both the statistical and visual correlations are considerably improved (Fig. 3). The best statistical correlation attained was t = 10.62 and a sign test value of 71.3%, at 99.9% significance, with one chronology from 58°50′N, 95°05′E.

The absolute dating of the Jan Mayen *Pinus* driftwood chronology to AD 1739–1955 made it possible to further date a total of 42 *Pinus* samples from Jan Mayen (Table 5). Including the 15 logs making up the driftwood pine chronology, about 27% of the 212 *Pinus* logs examined by dendrochronology were shown to have originated

Table 5. Frequency distribution of end years of Angara *Pinus* driftwood logs from Jan Mayen including end years of *Pinus* logs from Bjørnøya (marked B) and Troynoy Island (marked T), dated with the Jan Mayen driftwood *Pinus* chronology. In some logs, the age of the outermost tree-ring is estimated, i.e. it includes the outermost dated ring and the number of additional rings that could be counted but not measured are marked with an asterisk. The year of sampling on Jan Mayen is indicated by a – 1989, b – 1990, c – 1991, d – 1994, e – 1995. Bjørnøya was sampled in 1992 and Troynoy in 1994.

1800–99	1900–09	1910–19	1920–29	1930–39	1940–49	1950–59	1960–69	1970–79
						1959[c]		
					1949[c]	1959[c]		
					1949[b]	1958[d]		
					1949[c]	1956[c]		
					1949*[b]	1956[e]		
					1948[c]	1955[c]		
					1948[c]	1955[d]		
					1947[e]	1955[c]		
					1946[d]	1954[c]		
				1938B*	1945[b]	1953[c]	1968*[b]	
				1937[c]	1944T	1953[a]	1967[c]	1981[d]
				1937[d]	1944[c]	1952T	1964T	1975[c]
				1936[c]	1942B	1952[c]	1964[c]	1975[c]
		1917T		1936[b]	1942[a]	1951[c]	1963[c]	1974[d]
	1906*[c]	1914[c]		1932[b]	1942[c]	1951[c]	1962[e]	1971[d]
1880B	1904[c]	1914[c]		1932[c]	1941[e]	1950[c]	1961[c]	1970[c]
1865B	1902[c]	1912[d]		1930[c]	1940[c]	1950[e]	1960[d]	1970[d]

in the lower Angara region. One driftwood tree with roots was among the *Pinus* samples dated, and it's the only tree dated by dendrochronology in the present study.

Eggertsson (1994b, 1995) found that approximately 25% of the *Pinus* samples collected in the Wijdefjorden area in northern Svalbard and 54% of the *Pinus* samples from Iceland originated in the middle reaches of the Yenisey River. By using the new *Pinus* chronologies from the Angara region, he has now refined this conclusion, showing that they, too, originated from the lower Angara region (O. Eggertsson pers. comm. 1997).

Four of the 13 *Pinus* log samples from Bjørnøya and four of the nine *Pinus* logs from Troynoy Island could be dated using the *Pinus* chronology that had been constructed from Jan Mayen (Table 5). Although the material examined is limited, much of the *Pinus* driftwood on Bjørnøya and Troynoy Island apparently derives from the same source area in the lower Angara region as that revealed at Jan Mayen.

Age and dating

The majority (72%) of the end years of pine logs dated from Jan Mayen are later than 1940, peaking in the 1950s and 1960s (Table 5). Eggertsson (1994b, 1995) dated the end years of Yenisey *Pinus* logs from Wijdefjorden in Svalbard and Iceland to a somewhat later time span, around the 1950–60s and 1970s, respectively. The younger ages of Yenisey driftwood obtained in Svalbard and Iceland may be due to more systematic sampling of 'fresh' logs, relatively recently washed ashore. On Jan Mayen, logs of different ages were collected in greater quantities, as the sampling sites were located on wide, flat beaches where the logs have frequently been redeposited. In Iceland logs have also been more subject to continuously removal by humans than is the case on Jan Mayen.

The lower Angara source area

The dating of 27% of the driftwood pine logs from Jan Mayen by dendrochronology, and of a few logs from Bjørnøya and Troynoy Island, demonstrates that a major source area for *Pinus* driftwood is the region east of the confluence between the Angara and Yenisey rivers. This is also the source area of most of the *Pinus* logs sampled in northern Svalbard and Iceland, which Eggertsson (1994b, 1995) showed had their origin in the middle reaches of the Yenisey. The Angara region has also proved to be a major source area for *Pinus* driftwood logs found at various places in north Norway (Johansen unpubl.). A combination of Cyrillic letters and Roman numerals is occasionally observed on the end of sawn *Pinus* logs. Five of the *Pinus* logs from Jan Mayen dated as being from the lower Angara region showed such markings. However, these letters and numerals provide no information about the origin of the logs, as they mainly refer to their sorting and volume (E. Vaganov pers. comm. 1996). Nevertheless, these kinds of markings have not been observed by the author on driftwood logs in the delta of the Northern Dvina, the major driftwood river in northwest Russia.

The removal of a timber float in a flood is an important way by which logs escape into rivers and start their journey to the Arctic Ocean to become incorporated into the drift ice. In Siberia, substantial numbers of logs break free from log booms and rafts in spring and accumulate along the great rivers (Alekseyenko & Titova 1988). Timber is also placed on the frozen rivers during the winter and floated loose, or in rafts, when they thaw in spring (Blandon 1983). This practice will certainly lead to driftwood escaping into the Arctic Ocean. Log booms, still containing iron chains in holes on their ends, were occasionally noted on Jan Mayen. The practice of loose floating declined during the late 1970s, and the use of rafts and transport with boats increased (Blandon 1983). This may have contributed to the reduction in driftwood logs dated to after 1970 observed in northern Svalbard (Eggertsson 1994b), on Jan Mayen and in Iceland (Eggertsson 1995).

The lower Angara region, identified by dendrochronology as the source area for the driftwood *Pinus* logs (Fig. 1), has many sawmills and was one of the primary logging areas in the late 1960s (Lydolph 1970) and the major region in Siberia for lumber export (Algvere 1966). The importance of the lower Angara region for the driftwood input into the Arctic Ocean could also be influenced by the extensive clear felling of forests in connection with the construction of hydroelectric power plants along the upper stretches of the Angara, which began at Irkutsk in the 1950s and continued at Bratsk and Ust-Ilimsk (Lydolph 1970; Grigoriev et al. 1993). Vast areas of forest were cleared when the

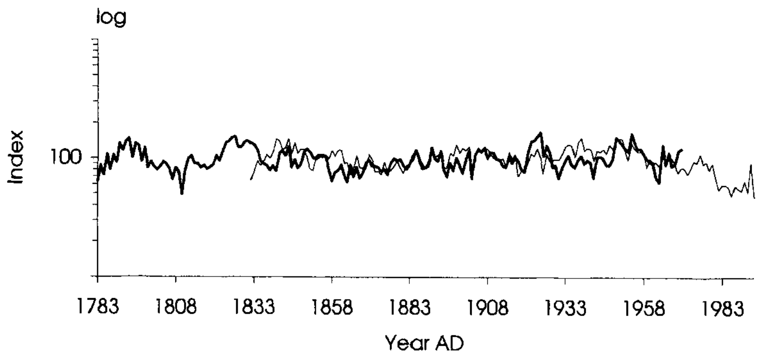

Fig. 4. Pinus driftwood chronology (*Pinus2*) from Jan Mayen (thick line) and driftwood chronology from the Northern Dvina delta (thin line).

hydroelectric reservoirs were constructed. In the 1960s, approximately 10 million cubic metres of timber were inundated in the basin of the Bratsk hydroelectric plant, and such inundation also occurred when other hydroelectric stations were built (Grigoriev et al. 1993).

These large-scale clearances from the 1950s onwards, and the enormous increase in logging activity along the Angara River, are probably the main reasons for the many post-1940 datings of *Pinus* logs obtained on Jan Mayen, Svalbard and Iceland. Large-scale log floating has taken place on the Angara River. Hartung (1982) reported that the industrial complex at Bratsk, alone, floated approximately 3 mill. m^3 per year and its timber was dominated by *Pinus* (60%), followed by *Populus* (14%), *Larix* (13%), *Betula* (11%), *Picea* (2%) and *Abies* (2%). Assuming that *Larix*, like *Pinus*, is also extensively floated on the river and is prone to escape from the region, large quantities of*Larix* driftwood logs might also originate from the Angara region. This remains to be determined by dendrochronological dating, as no chronologies for *Larix* are available from this region. Since little *Picea* is felled in this area (Algvere 1966; Hartung 1982), it may be expected that the *Picea* logs found on Jan Mayen originate from other sources than the Angara and Krasnoyarsk regions.

The northwest Russian source area

In the search for the absolute dating and origin of the remaining *Pinus* driftwood, the individual logs were first tested against the master chronologies available for the genus. Nine *Pinus* logs from Jan Mayen (approximately 4%) and one from Bjørnøya were found to originate in northwest Russia (Table 6). Seven of these logs were dated using unpublished master chronologies (F. H. Schweingruber pers. comm. 1995) from areas draining to the Northern Dvina river, i.e. from Voroncy (four logs) and Verhnaja Toima (three logs). One log was dated by a master chronology from close to Murmansk (Bitvinskas & Kairaitis 1978), a second from near Archangelsk (Anikejeva & Kudriavceva 1984), and a third from the lower Pechora region (F. H. Schweingruber pers. comm. 1995). Four pine logs from Jan Mayen and one from Bjørnøya dated with master chronologies located east and south of Archangelsk could be internally synchronised to a driftwood chronology (*Pinus2*), covering the time span AD 1783–1970 (Table 4). This second *Pinus* chronology from Jan Mayen could also be dated with a driftwood pine chronology from the delta of Northern Dvina (Johansen unpublished) showing $t = 8.20$ and a sign test value of 69.9%, at 99.9% significance (Fig. 4). The dating could be repeated with unpublished master chronologies (F. H. Schweingruber pers. comm. 1995) from Voroncy with $t = 7.42$ and a sign test value of 74.1%, at 99.9% significance and from Verhnaja Toima further south with $t = 8.20$ and a sign test value of 71.7%, at 99.9% significance.

Far fewer pine logs on Jan Mayen originate in northwest Russia than in the Angara region. This supports Eggertsson's (1995) observations that the influx of *Pinus* driftwood logs from northwest Russian sources to Iceland is subordinate to the influx from the middle Yenisey region, amounting to only 5% of the pine logs examined. The frequency distribution of dated end years of the White Sea *Pinus* driftwood dated on Jan Mayen also agrees with the observations from Iceland (cf. Eggertsson 1995).

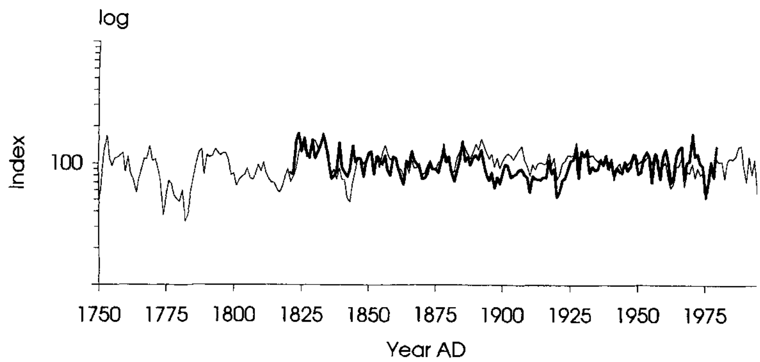

Fig. 5. Picea driftwood chronology from Jan Mayen (thick line) and driftwood chronology from Northern Dvina delta (thin line).

Summary regarding Pinus driftwood

Northwest Russia is relatively well covered with master chronologies, so the influence of this driftwood source on the supply of pine logs to Jan Mayen is unlikely to be underestimated. The results also show that *Pinus* logs from the middle Yenisey–Angara region are relatively easily datable. Although complacent tree-ring patterns were generally avoided, some driftwood logs may certainly not be datable, due to the local growing conditions. A number of logs may also not be datable because they are older than the chronologies available.

Approximately 68% of the *Pinus* timber logs from Jan Mayen could not be dated with the chronologies available. Thus, it was not possible to construct a chronology based on these logs. This might also imply that the majority of logs beached on Jan Mayen originate from a wide variety of sources. The lack of a proper network of chronologies in many potential source areas reduces the chances of dating these individual logs. Source areas where there has been a substantial increase in logging after 1945 are still to be found east of the Ural Mountains (Algvere 1966).

Picea driftwood

A chronology based on four logs of *Picea* driftwood from Jan Mayen and one from Bjørnøya was constructed (Table 4). This could be repeatedly dated over a time span of AD 1821–1979 using various spruce master chronologies available from living trees in northwest Russia. The best visual and statistical correlation was obtained with a *Picea* driftwood chronology from the Northern Dvina delta (Johansen unpubl.) with statistical correlations of $t = 13.15$ and a sign test value of 77.5%, at 99.9% significance (Fig. 5). The best correlation obtained with a spruce chronology from living trees was from Voroncy (F. H. Schweingruber pers. comm. 1995) with $t = 10.82$ and a sign test value of 73.1%, at 99.9% significance. This derives from an area draining to the River Pinega, a tributary of the Northern Dvina (Fig. 1). Eight more *Picea* logs from Jan Mayen and one from Bjørnøya could be dated using the constructed driftwood spruce chronology, or the *Picea* driftwood chronology from the delta of the Northern Dvina. Twelve of 27 (44%) *Picea* logs from Jan Mayen examined by dendrochronology could be dated to prove their origin in northwest Russia. Eggertsson (1994b, 1995) found that approximately 24% of the *Picea* driftwood on Iceland and about 47% of *Picea* logs from northern Svalbard could be absolutely dated with master chronologies from the White Sea region.

The dated end years of the *Picea* driftwood logs show a range from 1914 to the late 1970s, with a concentration in the 1960s (Table 6). A similar post-1950 concentration of *Picea* is found in driftwood on Iceland (Eggertsson 1995) and at Isfjorden in Svalbard (Bartholin & Hjort 1987). This probably reflects the increased logging activity on spruce in the White Sea region in this period (Algvere 1966).

The remaining *Picea* driftwood logs and trees were tested against *Picea* chronologies from the White Sea region and the boreal forest belt in Russia and North America, including those from the major North American driftwood rivers, the Yukon and the Mackenzie. Investigations from

Table 6. Frequency distribution of end years of *Pinus* and *Picea* driftwood (marked by an asterisk) from Jan Mayen and Bjørnøya (marked B) dated by unpublished northwest Russian *Pinus* chronologies (Schweingruber pers. comm. 1995) and *Pinus* chronologies published in Anikejeva & Kudriavceva (1984) and Bitvinskas & Kairaitis (1978). The *Picea* logs are dated by the constructed driftwood chronology or a *Picea* driftwood chronology from the Dvina delta (Johansen unpubl.). The year of sampling on Jan Mayen is indicated by a – 1990, b – 1991, c – 1994, d – 1995. Bjørnøya was sampled in 1992.

1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–1969	1970–1979
					1969*[c]	
					1968*[b]	
					1967[b]	
					1965[c]	
				1959*[b]	1963B*	1979*[d]
		1937*[c]	1949B*	1959[b]	1962[b]	1973*[d]
		1936[c]	1948*[c]	1959[c]	1962*[c]	1971*[b]
1914[b]	1923*[d]	1934[d]	1944B	1956*[c]	1962*[c]	1970[a]

the major source basin in northern Canada, the Mackenzie, have revealed that *Picea* dominates among the driftwood (Eggertsson 1994a). As dendrochronological screening using master chronologies from these locations gave no datings, the influx of North American *Picea* driftwood to Jan Mayen is believed to be minimal.

Larix driftwood

Frequently missing rings and growth distortions in the *Larix* samples reduce the chances of obtaining dendrochronological datings of this driftwood. Thus, no chronology could be constructed on the basis of the 46 samples from driftwood trees and 57 samples from logs examined by dendrochronological analysis. Neither could any of the individual *Larix* samples be dendrochronologically dated with chronologies available from potential source areas in Russia or North America. However, using a floating *Larix* chronology based on driftwood logs collected in northern Norway (Johansen unpubl.), 11 *Larix* logs and one *Larix* driftwood tree from Jan Mayen could be relatively dated. The *Larix* driftwood from Jan Mayen was older (14–77 years) than the youngest Norwegian specimens dated. It was also possible to relatively date a driftwood *Larix* log from Bjørnøya. The results show that *Larix* driftwood logs from both Jan Mayen and northern Norway derive from the same source area.

Larix species are highly sensitive to temperature fluctuations (Schweingruber 1992). This is reflected e.g. in the standard deviation and sensitivity of tree-ring widths and late wood densities of larch site chronologies (*Larix sibirica*) which are found to be higher than in spruce (*Picea obovata*) in northern Siberia (Kirdjanov & Zaharjevsky 1996). The driftwood trees, which constitute nearly half of the *Larix* specimens examined by dendrochronology, also represent more randomly dispersed sources than the driftwood logs, whose sources are restricted to logging areas selected by people who produce a large number of logs from the same locations with more or less uniform growing conditions. The production of driftwood trees, on the other hand, is not uniform between the rivers, or within a single river system, as a braided stream in flat terrain will uproot many more trees than a stable, downward-cutting channel (Giddings 1952). All these factors contribute to the difficulties of dendrochronological dating of *Larix* driftwood trees.

Long-range transport of driftwood to Jan Mayen

Northwest Russia

The *Picea* and *Pinus* driftwood logs on Jan Mayen which have been found to originate in northwest Russia could have been carried by ice export taking place from the Barents Sea into the Siberian branch of the Transpolar Drift Stream through the passages east of Svalbard (cf. Vinje & Kvambekk 1991). Indeed, the Siberian branch of the Transpolar Drift Stream north of Svalbard can be expected to carry drift ice with driftwood from sources draining to the Barents Sea as well as from the Kara Sea, Laptev Sea and East Siberian Sea. When it enters the Fram Strait, the driftwood is carried southwestwards by the East Greenland Current, and is released when the drift ice melts near Jan Mayen some 2–3 years later (Romanov 1995; Pfirman et al. 1997a). In this transport route, the driftwood is mainly rafting with drift ice from the northern Barents Sea until it is released in the melting zones in the Greenland Sea. Due to the limited floatability of the wood in water (Häggblom 1982), this transport risks less loss from sinking than in an alternative route within the Barents Sea and along the western coast of Spitsbergen, a route which partly takes place in open water (Fig. 1). Although less driftwood occurs on the western than on the eastern or northern coasts of Svalbard, dendrochronological dating by Bartholin & Hjort (1987) shows a substantial influx from sources draining to the Barents Sea. The higher influx of White Sea driftwood to Northern Svalbard is explained with an increased influx of Atlantic water via the West Spitsbergen Current (Eggertsson 1994b).

Siberia

The Transpolar Drift Stream (Fig. 1) is the prevailing current system responsible for the long-term delivery of ice-rafted driftwood from many Eurasian sources converging in the Fram Strait. There is an annual cycle in the flux of ice in the Fram Strait, as well as significant variations from year to year caused by increased atmospheric forcing (Vinje et al. in press). This may be reflected in the yearly fluctuations in the amount of driftwood delivered by the East Greenland Current noted at northern Iceland (Samset 1991). Calculations of backward trajectories have shown that the north-central to eastern Kara Sea is a major contributor of ice to the Barents Sea and the southern limb of the Transpolar Drift Stream (Pfirman et al. 1997a). The results from dendrochronological dating of *Pinus* driftwood from Jan Mayen have demonstrated that ice-rafted material is effectively transported from the Kara Sea and Barents Sea into the East Greenland Current.

A wooden buoy discovered on Jan Mayen in 1991 by Mr. G. I. Bessias contained a glass tube with a postcard from the Polar Institute in Murmansk bearing instructions to the finder. The buoy most likely originated from an experiment by Vize (1937), who released several drifters in the Kara Sea between 1930 and 1934. Several of these were found on the northeastern coast of Iceland (Vize 1937), in the general vicinity of the locations where *Pinus* driftwood logs were dendrochronologically dated to originate in the middle Yenisey region (Eggertsson 1995). The drifters probably followed a similar route as the driftwood, locked in the drift ice in the Transpolar Drift Stream which carries sediment and biogenic particles towards the Fram Strait.

Studies have shown that contaminants released in the Barents Sea and the Siberian seas will largely be transported out of the Arctic Ocean with the Transpolar Drift Stream and the East Greenland Current (Schlosser et al. 1995). Of all the shelves bordering the Arctic Ocean, the Kara Sea is the most likely one to receive inputs of pollution (Pavlov & Pfirman 1995). This is due to the great discharges of the Ob and Yenisey rivers and the heavy industrialisation in their drainage basins, which includes nuclear power plants and pulp and paper factories (PAME 1996). The dendrochronological dating of driftwood has shown that sources far south in Siberia continuously feed Jan Mayen with driftwood. This implies a potential for contaminated sediments and other pollutants to reach the same area with the East Greenland Current. It must also be taken into consideration that the radionuclides discharged from European sources also reach the East Greenland Current (Aarkrog et al. 1987; Dahlgaard 1995).

The Laptev Sea discharges the greatest volume of sea ice into the central Arctic. This ice mostly leaves through the Fram Strait (Pavlov & Pfirman 1995), whereas ice from the East Siberian Sea either leaves through the Fram Strait or is caught in the Beaufort Gyre (Pfirman et al. 1997a). No driftwood on Jan Mayen could be dated by master chronologies from areas draining to the Laptev Sea or the East Siberian Sea. However, much less logging takes place in these areas east of Taymyr than in the Yenisey–Angara basin, which drains to the Kara Sea. More master chronologies for *Larix* in eastern Siberia will increase the chances of determining whether these areas are the sources of the predominantly *Larix* driftwood trees on Jan Mayen.

The transport time for driftwood

The time elapsing from when the driftwood left its growing sites cannot be determined precisely because of the unknown number of missing tree rings. Since none of the driftwood logs investigated had intact bark; their felling date is

Table 7. Radiocarbon dating of driftwood specimens collected on Jan Mayen in 1989–1995. The samples were collected from trees with roots, or from logs, in the uppermost driftwood zone. The activity in the 10 outermost tree rings was measured.

Laboratory number	^{14}C years B.P.	Calibr. age	Description/species
T-9097	235 ± 60	Younger than AD 1640	Helenesanden, ca. 250 m from the sea, *Larix* tree
T-9098	175 ± 75	Younger than AD 1655	Helenesanden, ca. 250 m from the sea, *Larix* tree
T-9099	210 ± 70	Younger than AD 1650	Helenesanden, ca. 250 m from the sea, *Pinus* tree
T-12306	330 ± 30	AD 1510–1640	Sørlaguna, NW shore, near Søyla pillar 1 km from the sea, *Pinus* log or tree, partly in sand
T-12307	145 ± 55	Younger than AD 1675	Sørlaguna, NW shore, near Søyla pillar ca. 1 km from the sea, *Pinus* tree or log, partly in sand
T-12308	290 ± 50	AD 1520–1660	Sørlaguna, NW shore, near Søyla pillar, ca. 1 km from the sea, *Pinus* tree or log, partly in sand
T-11081	125 ± 45	Younger than AD 1680	Ullerengsanden, ca. 200 m from the sea, *Larix* tree
T-11082	235 ± 50	Younger than AD 1645	Ullerengsanden, ca. 150 m from the sea, *Larix/Picea* tree
T-11083	195 ± 35	Younger than AD 1660	Ullerengsanden, ca. 200 m from the sea, *Picea* tree
T-9100	85 ± 85	Younger than AD 1680	Kvalrossbukta, ca. 250 m from the sea, *Picea* tree
T-9101	150 ± 75	Younger than AD 1665	Kvalrossbukta, ca. 250 m from the sea, *Pinus* tree
T-11085	145 ± 50	Younger than AD 1675	Haugenstranda, northern part, ca. 80 m from the sea, *Pinus* tree
T-11084	175 ± 60	Younger than AD 1660	Haugenstranda, northern part, ca. 80 m from the sea, *Picea* tree
T-9102	240 ± 90	Younger than AD 1525	Nordlaguna, landward side near road, ca. 1 km from the sea, *Picea* tree

unknown. The age of the outermost tree ring is therefore the minimum age of the log. Based on his datings of eskimo dwellings built of driftwood, Giddings (1941) suggested that up to 30 rings are frequently eroded away. Few other pertinent data exist on this question. The difference observed between the dated end year and the sampling year for recently washed-ashore driftwood logs of more than 10 years may result from a combination of several delaying factors including a circulation in the Arctic Ocean, redeposition/refloating and the loss of some tree rings.

Age of surface driftwood deposits of Jan Mayen

Several beaches containing great accumulations of driftwood are found on Jan Mayen, mainly in the central part of the island. Radiocarbon datings were obtained to date the uppermost and presumably oldest surface deposits of driftwood on the beaches examined. Hitherto, no radiocarbon datings of Jan Mayen driftwood have been published.

All the 14 radiocarbon datings obtained show ages younger than 330 ± 30 ^{14}C years B.P. (Table 7). Distinct raised beaches are not present on Jan Mayen, as land uplift is believed to have been minimal (Gabrielsen et al. 1997). Old historical maps and travel accounts from Jan Mayen show that parts of the beaches containing driftwood on the central eastern part of the island have been formed during the last 400 years. A survey by the author of available maps dating back to the early seventeenth century shows that the coastline, especially on the central-southeastern coast of Jan Mayen, has changed considerably. Maps dating from 1663–1817 (Teunisz 1663; Zorgdrager 1750; Scoresby 1820) do not depict the lagoon named Sørlaguna and the vast sandy plains, which are prominent features of today's landscape. Great quantities of driftwood apparently lay on these smaller, southeastern beaches when they were named; this is indicated by the names on these old maps, for example 'Great Wood Bay' and 'Little Wood Bay' (Zorgdrager 1750). Scoresby (1820) mentioned the great quantities of driftwood found there. Vogt (1863) also remarked on the large amounts of driftwood in Rekvedbukta in 1861. Sørlaguna appears for the first time on a map published by Vogt (1863). Vogt's map shows a long sandbar that had closed off the sea, in contrast to Scoresby's map (Scoresby 1820). These two maps are based on field surveys undertaken only 43 years apart, i.e. in 1817 (Scoresby 1820) and 1860 (Vogt 1863), respectively. These maps and travel accounts show that the lagoon and sandbar developed their present form during this time interval.

The radiocarbon datings obtained for this study from Sørlaguna and the Ullerengsanden beach cover the time span of 330 ± 50 ^{14}C years B.P. to 125 ± 45 ^{14}C years B.P., respectively (Table 7). Additional datings from the same locations gave only slightly older ages, i.e. 460 ± 50 ^{14}C years B.P. (J. Mangerud pers. comm. 1997). A total of eight driftwood specimens subject to radiocarbon dating were also analysed by dendrochronology. However, no internal correlations or absolute datings could be obtained.

Large quantities of driftwood are also stranded on the 200 m-wide bar of the Nordlaguna lagoon and the beaches landward of it. Since a map published by Zorgdrager (1750) shows this lagoon, it might be assumed that its formation and closure pre-date those of Sørlaguna (Droste 1989). However, one driftwood sample from the southern, landward beaches of the lagoon (Table 7) and another from just south of the lagoon (J. Mangerud pers. comm. 1997) gave radiocarbon ages that were no older than the oldest driftwood deposits from the eastern beaches of the island.

The driftwood limit on Haugenstranda, one of the westernmost beaches, is a marked line. The radiocarbon dates obtained from the uppermost surface driftwood found there, and from the nearby Kvalrossbukta beach, show similar young ages to those recorded from the southeastern beaches (Table 7). However, the geomorphological history of these beaches is not known.

An important factor in the lack of older surface driftwood on the beaches examined is the decomposition of wood. The moist, relatively mild climate on Jan Mayen might favour more rapid decomposition of the driftwood compared, for instance, with many locations in eastern and northern Svalbard where the climate is drier and colder and land uplift has preserved the wood from the reach of storm waves. Decomposing 'old' driftwood at the uppermost level on the southeastern beaches in Rekvedbukta were commented on by Boldva (1886). The growth of fungi is probably favoured by the mild arctic climate. Eolian erosion by volcanic sands will also make the surface of the wood porous and susceptible to decay.

Conclusions

This study has shown that dendrochronological analysis of ice-rafted driftwood on Jan Mayen can identify source areas with rather good precision. The two source areas identified, a subordinate one in northwest Russia and the main source area in the lower Angara region, are the primary logging areas in Russia, and the Northern Dvina, Angara and Yenisey rivers are the initial transport media. The dendrochronologically dated Angara *Pinus* logs on Troynoy Island beached while they were passing through the Kara Sea, before they became frozen into the ice and entered the Transpolar Drift Stream. Drift ice from the Barents and Kara Seas fed into the Transpolar Drift Stream is believed to be the main transportation medium for driftwood from the two sources identified on Jan Mayen. The ice is carried by the Transpolar Drift Stream to the Fram Strait, where it enters the East Greenland Current which takes it and its driftwood load towards Jan Mayen, in which vicinity it melts. Eggertsson (1995) argued that the driftwood transport to Iceland takes place within the eastern part of the East Greenland Current that originates in the Siberian branch of the Transpolar Drift Stream and carries no material from North America. The dendrochronological datings obtained on Jan Mayen show that the same transport pattern is also predominant there, 540 km further north. The results indicate that the same two source areas found on Jan Mayen are represented on Bjørnøya, where the Angara driftwood component predominates. Whether the transport of Angara driftwood to Bjørnøya takes place mainly with the North Atlantic Current from a prior release in the East Greenland Current followed by an eastward drift in the Norwegian Sea or through the passages east of Svalbard remains to be determined.

The precision in the delimitation of the driftwood sources depends on the degree of intercorrelation between the source area chronologies, i.e. the homogeneity of the climate in the source areas. The increasing correlation and repeated dating demonstrated for the *Pinus* driftwood chronology from Jan Mayen, using the new chronologies available from the River Angara, show that a more precise identification of the source area depends on an extensive network of source chronologies. The relatively large percentage of datings of *Pinus* logs from the Angara region concentrated after the 1940s reflects a source area with relatively homogeneous growing conditions which is heavily exploited by logging where timber floating is practised and loss of timber is frequent. This constitutes very favourable conditions for the production of datable driftwood.

It was only possible to dendrochronologically date one of the driftwood trees, which proved to originate in the lower Angara region. The origin of driftwood trees is believed to be more dispersed than that of logs. As they are not subject to human selection and are also extensively used to radiocarbon date raised beaches, they should receive more focus in future dendrochronological studies of driftwood.

Radiocarbon dating shows that the oldest surface deposits of driftwood encountered on Jan Mayen arrived during the last 400–300 years. This is mainly due to more rapid decomposition of the wood on Jan Mayen due to the climate and no shelter from land uplift.

Finally, the results demonstrate a considerable potential for pollutants to reach Jan Mayen from the Kara and Barents Seas. Judging by the age distribution of dated driftwood logs, this impact is continuous.

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