ORIGIN OF THE DRIFTWOOD ON THE COASTS OF ICELAND; A DENDROCHRONOLOGICAL STUDY

Ólafur Eggertsson
Department of Quaternary Geology, University of Lund
Tornavägen 13 223 63 Lund, Sweden

ABSTRACT

In many places along the extensive coastline of Iceland driftwood has been washed ashore over a long period of time. Although the amount of driftwood varies from place to place it is found on almost every beach along the coast. The wood originates in the boreal forest regions of Russia/Siberia. Rivers which drain these forested areas carry driftwood into the Arctic Ocean, where it is caught in drifting ice and transported by the oceanic currents.

A total of 343 samples of driftwood were collected from 3 areas in Iceland and analysed by wood anatomical- and dendrochronological methods, aimed at identifying the origin and age of the wood. A total of 24% of the Picea *samples and 5% of the* Pinus *samples could be directly dated via tree-ring chronologies from the White Sea region in western Russia. Additionally 54% of the* Pinus *samples could be grouped together into a mean curve, that could be dated via tree-ring chronology from the middle drainage area of the Yenisey river in Siberia. At present most of the* Pinus *and* Picea *driftwood reaching Iceland are logs that came loose during timber floating on the Russian/Siberian rivers, whereas most of the* Larix *driftwood has a "natural" origin, with their root system preserved. Although North American driftwood has been found in East Greenland it has not been encountered in Iceland, which suggests a partly different origin for the ice drifting south in the western and eastern parts, respectively, of the East Greenland Current. Because of the relatively short buoyancy time of the driftwood - most of its travel must have taken place frozen in sea ice - it can be concluded that some of the drift-ice reaching Iceland has the same origin as the driftwood i.e. the Barents and Siberian seas. The youngest dated sample indicates that it is possible for arctic driftwood to reach the coasts of Iceland in less than six years.*

INTRODUCTION

Iceland is situated at the boundary between Arctic and Atlantic waters. The south coast is affected by the warm and saline Atlantic water from the Gulf Stream which flows along the west coast where it branches into two parts, one that turns westward making a circular current in the Irminger Sea, and another that turns to the east along the north coast, mixing with a branch of the East Icelandic Current (Figure 1).

Sharp boundaries occur between the warm and cold water off the south east coast and these are even sharper in the north west, between the warm Atlantic water and the polar waters of the East Greenland Current (Stefánsson, 1961). The Irminger Current is the branch of the North Atlantic Drift that flows in a clockwise direction around Iceland (Figure 1). In cold years, the East Greenland Current can block off the surface water of the Irminger Current at the northwestern peninsula, causing the north and east coasts to be dominated by the cold Arctic surface water (Stefánsson, 1962). When this happens, drifting sea ice is common at the north coast. The east coast of Greenland is affected by the East Greenland Current (Figures 1 and 2), which brings drift ice along the coast throughout the year and may bring driftwood from the Arctic

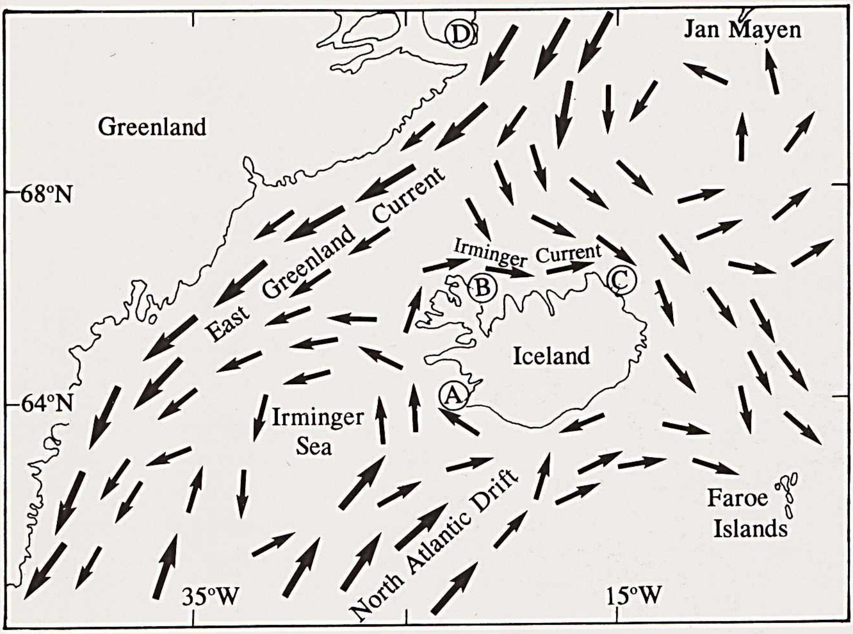

Figure 1. Surface currents in Icelandic waters and sampling sites for driftwood. A: Reykjanes, B: Strandir, C: Langanes, D: Scoresby Sund. Current pattern from Stefánsson (1961 and 1962). — *Yfirborðsstraumar í hafinu við Ísland og sýnatökustaðir rekaviðs.*

ocean to the coasts of Iceland and Greenland. The driftwood originates in the boreal forest regions surrounding the Arctic. Rivers which drain the forested areas carry driftwood into the Arctic Ocean. Most of the wood, caught in drifting ice and transported by the oceanic currents, probably sinks but some is eventually deposited along the shores of the Arctic. The aim of this paper is to describe how the dendrochronological method (tree-ring dating) can be applied to identify the origin and age of driftwood, and to suggest how this method can give information on the pattern and velocity of the sea ice drift. Most of the driftwood samples were collected from the shores of Iceland, and a small number from the Scoresby Sund area on the east coast of Greenland (Figure 1).

ARCTIC ICE COVER CIRCULATION

The main factors governing ice cover circulation in the Arctic Basin are a gyre in the Beaufort Sea and the Transpolar Current. The Transpolar Current carries ice from the Arctic Ocean across the North Pole and down along the east coast of Greenland (Figure 2). The estimated transportation time for the sea ice to drift from the Laptev Sea, outside the north coast of Siberia, to the Fram strait is estimated as two to three years (Vinje, 1982).

Because of the circulating character of the Beaufort Sea gyre it is possible for the ice to stay in the gyre and circulate for many years (Koerner, 1973), as can the driftwood. Some of the thickest multi-year ice is found in this region (Hibler, 1989). Ice stations in the Arctic have been found to drift at an average rate of about 6 km/day, although the drift rate varies from day to day and from year to year. One-day drifts of over 20 km have been observed (Thorndike and Colony, 1980). The ice station data are not sufficient to give detailed information of the temporal and spatial variation of ice drift. More recent measurements, available since 1966 and using satellite navigation equipment (Vinje, 1982) and laser surveying equipment, have supplied a more complete description of the temporal and spatial variation in ice drift (Thorndike and Colony, 1980).

Two main factors influence the ice drift, the wind and the currents. The steady currents play the most significant role when studying long term ice drift (Hibler, 1989).

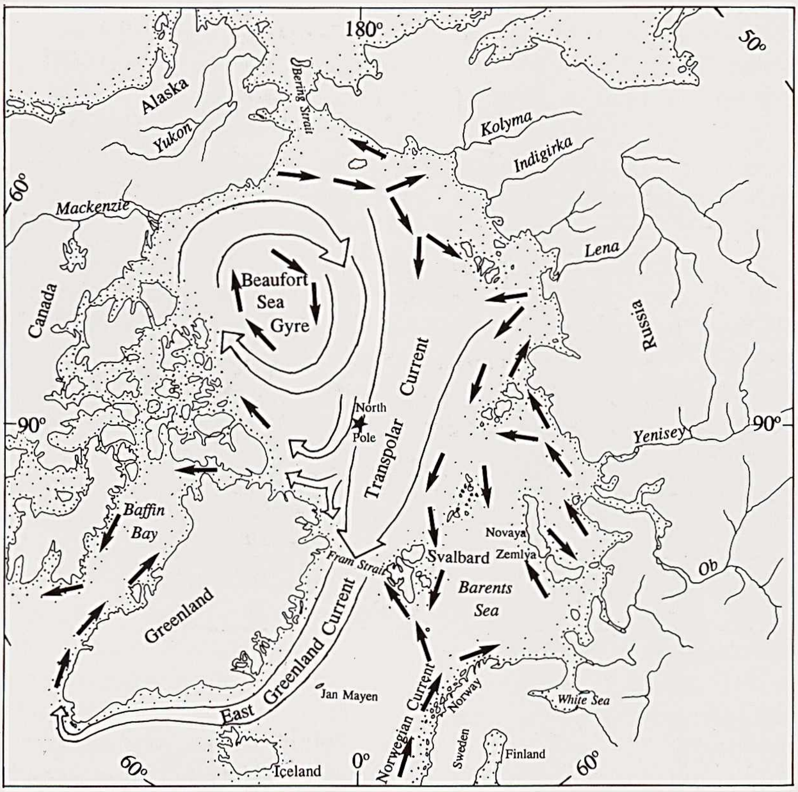

Figure 2. Surface currents of the Arctic Ocean and surroundings. Current pattern from Strubing (1968) and Bearman (1989). — *Yfirborðsstraumar í Norður-Íshafi.*

HISTORY OF ARCTIC DRIFTWOOD RESEARCH

The occurrence of driftwood on the Arctic shores has been known for thousands of years by the people of the Arctic cultures. The first Europeans to notice the wood in Iceland were the Norwegian vikings when they colonised the island in the 9th century. The Arctic "trees" have probably saved many early explorers from freezing to death, since driftwood was their main source of fuel and was also useful for building huts (Häggblom, 1983).

Willem Barents, the discoverer of Spitsbergen and Novaya Zemlya, used driftwood as the main fuel source when he was forced to spend the winter of 1596-97 on Novaya Zemlya. Hudson found driftwood on Spitsbergen in 1607, as did Baffin in 1613, who also estimated the quantity of the wood (Eurola, 1971).

The earliest systematic investigation of driftwood was made by Olavius (1780) when he travelled around Iceland on behalf of the Danish crown on an economical survey. He described the type, amount, usefulness and origin of the driftwood.

The Swede I. G. Agardh (1869) is generally considered the pioneer of driftwood research because his work was the earliest that involved the determination of wood species by applying the wood anatomical method. In a paper published in 1869 he demonstrated that his material, 18 samples collected from Spitsbergen, was probably of Siberian origin. Because no systematic research into the anatomical structure of wood had been carried out at that time, Agardh must have made all the comparisons himself (Eurola, 1971). He also studied the tree rings in the driftwood, in order to estimate the climatic conditions under which the trees had grown and hence estimated the latitude and origin of the wood (Agardh, 1869). The methods described in Agardh's work were later utilised by many driftwood researchers.

Örtenblad (1881) analyzed over 100 driftwood samples from the south coast of Greenland, collected by the geologist Holst in 1880. He applied similar methods as described by Agardh (1869), but made more detailed studies. He measured and counted the tree rings, compared the mean tree-ring widths with that of trees living in different places in Sweden and concluded that the origin of the driftwood was north of 66°latitude. He also made a systematic identification of the samples by using colour differences and analysis of the wood anatomy. Örtenblad calculated the following distribution of species: *Larix* 44%, *Picea* 28%, broad leaf trees 21%, *Pinus* 4% and *Abies* 3%. He concluded that Siberia was the main origin of the driftwood on Greenland and that the samples had drifted from the Ob-Yenisey rivers, north of Svalbard and southwards to Greenland (Figure 2). The results of Örtenblad's studies were later used by Nansen when planning the FRAM-expedition. The samples used by Örtenblad were partly re-analysed in Eggertsson (1994a) using the dendrochronological method.

Lindman (1883) studied driftwood from the coast of Norway. He also identified fruit and seeds native to the West Indies and Central America and therefore concluded that the Larix driftwood he found on the same coast was a Gulf Stream product from the St. Lawrence river in Canada. Lindman's conclusions on the origin of the driftwood were later criticised by Ingvarson (1903) who argued that the *Larix* driftwood probably originated in the Siberian forests.

Ingvarson (1903 and 1910) made a thorough review of earlier investigations of driftwood and analysed wood from Kung Karls Land, Svalbard, Jan Mayen, northeast Greenland, the Yenisey river mouth at Dickson harbour and from Ellesmere Island. He was able to identify differences between the wood anatomy of *Larix* and *Picea*, which had been and still remains a problem in driftwood studies (Bartholin, 1979). He concluded that the driftwood found on the Arctic islands had not been transported by the Gulf Stream, but that some, primarily that found on Ellesmere Island, might have originated from rivers draining into the Arctic seas from the boreal forest areas of North America (Ingvarson, 1910).

Since Ingvarson (1910) no paper was published which in detail discussed the identification of driftwood species, until Eurola (1971) made a summary of earlier investigations. This accompanied his own work on 19 driftwood samples from Agardhbukta on the east coast of Spitsbergen. Eurola plotted on a map the locations of species-identified driftwood from previous literature, plus his own collection. He summarised the methods used in driftwood studies, made comments on the origin of the Arctic driftwood and divided the area north of the Arctic Circle into two, the American and the Siberian driftwood regions. Häggblom (1982) estimated the amount and type of driftwood logs on raised beaches at different elevations a.s.l. on the island of Hopen, in the Svalbard archipelago and concluded that they probably reflected variations in sea ice conditions over time. His idea was based on the fact that floating wood gradually loses its buoyancy.

Samset (1991) studied driftwood from the northwest coast of Iceland, dominated by *Pinus* and *Larix* logs, which according to him probably originated in the boreal forest regions of Siberia.

DENDROCHRONOLOGY AND DRIFTWOOD

Dendrochronology (or tree-ring dating) (e.g. Schweingruber, 1988) is based on the yearly variation of tree-ring widths. The tree rings are wide or narrow depending on limiting growth factors. If trees in the same area show similar tree-ring patterns, the limiting growth factor is the same over the whole area (e.g. summer temperature). When this is the case, it is possible to build up mean tree-ring chronologies that can be used to date wood material with an unknown age which originates from the same area.

Giddings (1941) was the first to apply the dendrochronological method to driftwood. During his dendrochronological studies in Alaska he noticed that the tree-ring record at the timberline did not change rapidly from one locality to another in the Alaskan interior. Giddings assumed that cross-dating was applicable to dead logs. He made a collection of samples from old houses and standing structures built of driftwood by eskimos on the coasts of St. Lawrence Island which made it possible to (a) date Eskimo sites, (b) to detect the source of the driftwood, and (c) to extend the previous living tree-ring chronologies from the Alaskan interior further back in time. When this extension was achieved Giddings realised the possibility to use the driftwood dates as an aid to map the Arctic sea currents (Giddings 1941 and 1943). Later on he found that logs from the shores west of Point Barrow, on the north coast of Alaska, had a tree-ring pattern restricted to the Yukon region, and that east of Point Barrow the driftwood had a similar pattern as the trees from the Mackenzie delta. From this comparison he was able to map the coastal currents (Giddings, 1952).

Oswalt (1951) was able to trace the origin of driftwood logs at Hooper Bay, Alaska by cross-dating them with his own samples from the lower Yukon River and with Gidding's (1941) living tree-ring chronologies from the Alaskan interior. Van Stone (1958) made similar studies on the Nunivak Island driftwood, to provide additional information for the study of ocean currents in the Bering Sea.

Bartholin and Hjort (1987) analysed driftwood from Isfjorden on the west coast of Spitsbergen, to further evaluate the potential for constructing dendrochronological series on Arctic driftwood samples. They were able to date most of the logs, via master chronologies from the Arkhangelsk region and their work showed the potential of further tree-ring studies on Arctic driftwood and provided the impetus for the present study.

Eggertsson (1994a) made a study on the origin of the Mackenzie river driftwood and was able to identify and date American driftwood in collections from the coasts of Greenland. Eggertsson (1994b) also studied the origin of the driftwood on the northern coast of Spitsbergen, and compared his results with those of Bartholin and Hjort (1987), gaining information on changes in the relative influence of the currents - Atlantic versus Transpolar - in the Svalbard area.

DRIFTWOOD FROM RAISED BEACHES

When studying the isostatic rebound after the last glaciation and Holocene eustatic transgressions in the Arctic, driftwood on raised beaches is commonly dated along with bones and molluscs by the Carbon-14 method (e.g. Blake, 1972; Salvigsen, 1981). The decomposition of driftwood is slow in the dry and cold arctic climate and it is therefore commonly preserved. Driftwood is preferred as a dating material because bones and molluscs often give too old ages, due to contamination of the marine samples with old carbon. The mollusc and other marine animal datings thus have to be corrected for a marine reservoir effect (e.g. Mangerud and Gulliksen 1975; Salvigsen, 1978).

The oldest post-glacial driftwood dates from Svalbard range from 9800 to 9500 ^{14}C years BP, and come from a beach on Kong Karls Land situated 100 m a.s.l. (Salvigsen, 1981). Driftwood dates ranging from 8800-8500 BP have also been reported from high beaches on the Arctic islands of Canada (Blake, 1972; Stewart and England, 1983). These dates indicate the early re-establishment of the boreal forest after the last glaciation.

In Iceland, "old" driftwood logs are commonly detected when digging drainage ditches on the lowland (Kristjánsson, 1980), but no datings have been carried out on such material. The most common driftwood taxa present on the raised beaches of the Arctic are: *Larix*, *Picea*, *Salix* and *Populus*. *Pinus* is rare in these old driftwood collections.

Parker et al. (1983) applied dendrochronological studies on driftwood from raised beaches on the Hudson Bay coast in Canada, for examining the potential for extending the living tree-ring records from the area by dating driftwood. Almost all samples obtained from the youngest beaches could be dated, extending the tree-ring record for the area back 50 years to 1656. However, none of the driftwood samples from the older beaches fitted into the living tree-ring record.

Driftwood deposited at the margins of glacier-dammed lakes have been dated by matching the tree rings in the driftwood with those of nearby living old trees. An example of this was the study of Clague et al. (1982) who reconstructed the history of filling and emptying of a former glacial-dammed lake in southwestern Yukon Territory, Canada.

DRIFTWOOD IN ICELAND

Kristjánsson (1980) discussed in detail the usefulness of the driftwood to the Icelanders in earlier times and refers to the Icelandic literature that deals with driftwood.

When the vikings colonized Iceland at the beginning of the 9th century the lowlands were covered with birch forest. The wood was used as fuel and the domestic animals grazed on the seedlings, so that the sensitive birch forest was soon destroyed. The only wood that was left was the driftwood on the beaches and probably became the most important material for houses, boats, bridges, farm implements and household utensils (Kristjánsson, 1980). The oldest written records such as lawbooks contain many references to driftwood. All owners of driftwood bearing beaches were required to have their personal driftwood mark. The logs were marked so that the owner might claim them if they were carried out to sea and redeposited on somebody else's beach (Kristjánsson, 1980).

In many places on the extensive coastline of Iceland a great deal of driftwood has been washed ashore and many place-names bear witness to this. The driftwood input varies from place to place but at present, driftwood can be found on nearly every beach. Today, driftwood is occasionally still used for buildings, but mostly it is turned into fence posts. Driftwood is now most common in the depopulated areas of the Vestfirðir peninsula in the northwest and on Langanes in the northeast (Figure 1).

The origin of the Icelandic driftwood has been unclear. Some people thought it reasonable to conclude that the wood originated from the south because it was difficult for them to imagine that the wood was from the "cold" north. The name "Red Wood" (Rauðviður) was commonly used (and still is) by farmers on reddish driftwood and they assumed that it had drifted from America. Olavius (1780) studied the wood and concluded that the "Red Wood" was in fact *Larix* that probably originated in Siberia.

In literature from the 16th, 17th and 18th centuries, the view is often expressed that if it had not been for the driftwood, Iceland would have proved almost uninhabitable (Kristjánsson, 1980).

METHODS

IDENTIFICATION OF THE DRIFTWOOD TREE SPECIES

Trees can often be identified by macroscopic characteristics, particulary the colour and morphology of the bark. Such characteristics are generally destroyed in fossil and subfossil wood, but recent driftwood logs are often well preserved, except that in most cases the bark has been eroded. However, occasionally bark may be preserved in combination with the root system. Only a few species or species groups can be identified with the aid of a magnifying glass. In coniferous wood it is only possible to distinguish the species which have resin canals (*Picea*, *Larix*, *Pinus*) from those which do not (*Abies, Taxus, Juniperus*).

On an Arctic driftwood beach it is often possible to identify *Larix* from the other driftwood species because of the reddish colour of the *Larix* wood.

Sometimes it is possible to distinguish between *Pinus* and *Picea* based on the morphology of the stem (trunk). It is common for *Picea* to have many more twigs on the stem than *Pinus*. From the morphology of the root system it is possible to see if the tree has been growing on permafrost ground with a shallow or a deep active layer (the soil horizon that thaws during summer). The penetration of the root system of trees growing on permafrost depends on the thickness of this active layer. If the layer is thin the root system is flat and vice-versa. The most exact method available to identify the driftwood tree species, used here, is to analyse with a microscope the anatomical characteristics of the wood (e.g. Schweingruber, 1978). The anatomical differences between *Pinus* and *Picea/Larix* are distinct. The differentiation of *Picea* and *Larix* is not as easy (Bartholin, 1979), although, for example, colour can help distinguishing between these two species. Table 1 summarises the main anatomical differences of the most common driftwood species.

In some publications (e.g. Eurola, 1971) different species of *Picea* and *Larix* have been distinguished. For example, Leif M. Paulssen in Norway identified *Picea mariana*, which originates in the boreal forests of Canada and Alaska, together with *Larix gmelini* and *Larix sibirica* in driftwood collections from a raised

	Abies sp.	*Pinus silvestris*	*Pinus cembra*	*Picea sp.*	*Larix sp.*
Resin canals	**absent**	**present**	present	present	present
Transversal tracheid	absent	**walls tooth-shaped**	**walls smooth**	walls smooth or tooth-shaped	walls smooth or tooth-shaped
Ray Parenchyma cells		**with large open pits**	with large open pits	**with small pits**	With small pits
Transition from earlywood to latewood	gradual	gradual	gradual	**gradual**	**sharp**

Table 1. The main anatomical characteristics of some tree species and genera occurring as driftwood. Thick letters indicate the most significant characteristics. — *Helstu einkenni nokkurra algengra viðartegunda sem finnast í reka.*

beach on Svalbard (Salvigsen and Mangerud, 1991). However, as these species can not be anatomically differentiated (Schweingruber, 1978), they must have been differentiated by some other method unknown to the present author.

THE DENDROCHRONOLOGICAL NETWORK

To be able to identify and date the Arctic driftwood by the dendrochronological method it is necessary to have access to tree-ring chronologies from the circumpolar forest regions. Such chronologies are available from some parts of the boreal forest regions. The most complete networks are from the White Sea region (Bitvinskas and Kairaitus, 1979) along with networks from Alaska (Cropper and Fritts, 1981) and the lower Mackenzie river drainage area in Canada (Eggertsson 1994a) (Figure 2). In addition, some unpublished chronologies (Fritz Schweingruber, pers. comm. 1993 and Eugene Vaganov, pers. comm. 1994) from Russia (including Siberia) have proven vital for dating the driftwood.

STATISTICAL METHODS

Sign test (Gleichläufigkeit) is a measure of the similarity between two tree-ring curves. The intervals between successive points in time are examined for an upward or downward trend. The total Sign test over all the intervals is a measure of the agreement between the interval trends of two curves, and is expressed as a percentage. Where the intervals for annual ring curves run parallel for many years it can be assumed that the factors influencing growth were similar in both cases (Schweingruber, 1988).

By comparing all the curves from one site for a given time span it is probable to see the homogeneity of the site by comparing the Sign test values (Table 2). It is often possible to synchronise samples of unknown age with dated samples by calculating the Sign test between the two samples.

Correlation coefficient (r) and t-test. The correlation coefficient is a measure of the linear relationship between pairs of values from two series and indicates the similarity between the curves. In contrast to the Sign test, correlation is based on the actual values rather than changes from one value or interval to the next.

The t-test indicates whether two curves are related and generally gives the synchronous position of two curves when the level of statistical significance is sufficiently high (Table 2). The t-value is calculated as follows:

$$t = r\sqrt{\frac{n-2}{1-r^2}}; \qquad r = \text{correlation coefficient}$$

a) *Pinus*

Site name and number	1	2	3	5	6	7	8	Ic. 2	Ic. 3	Gr.1
1. Murmansk	-----	9.42	6.53	6.39	6.66	5.86	4.75	3.86	7.51	
2. Karelia 2	69.2*	-----	8.79	6.76	4.76	4.96	5.19	3.39	5.38	3.31
3. Karelia 3	63.2	66.4*	-----	3.67	3.30	3.27	3.38	1.84	4.72	
5. Pinega	57.0	61.4	59.7	-----	7.95	11.52	9.59	7.38	4.54	3.18
6. Arkhangelsk	65.5*	65.8*	62.1	72.0*	-----	9.62	4.70	6.00		3.15
7. Voroncy	61.7	58.1	60.2	71.2*	72.4*	-----	6.70	7.91	4.43	2.85
8. Charijaga	57.5	56.1	57.2	64.2*	60.5	66.5*	-----	7.10		4.21
B/C. Iceland 2	60.6	61.6	59.6	71.5*	66.4*	72.4*	67.0	-----		
B/C. Iceland 3	67.8*	63.2*	63.2	59.1		57.2			-----	4.22
D. Greenland 1		62.3		64.3	61.7	64.3	64.3	69.5		-----

* significance 99.9 %

b) *Picea*

Site name	4	5	7	8	9	Ic. 4	Gr. 2
4. Arkhangelsk	-----	6.64	11.51	4.34	6.69	8.77	4.19
5. Pinega	68.6*	-----	11.95	7.46	4.91	7.42	4.99
7. Voroncy	76.8*	74.7*	-----	7.02	6.05	10.26	4.04
8. Charijaga	65.4*	67.6*	63.5	-----	8.67	6.12	4.33
9. Kedvaran	72.9*	65.6	63.1	67.6*	-----	6.64	3.45
B/C. Iceland 4	74.2*	71.1*	71.3*	69.9*	69.3*	-----	6.14
D. Greenland 2	70.0*	73.1*	70.6	71.8*	68.1	68.1*	-----

* significance 99.9 %

Table 2. Correlation values (t-value: upper right part of tables and Sign test: lower left part of tables) between the chronologies from the White Sea region (sites 1 to 9 on Figure 7) and driftwood mean curves from Iceland (sites on Figure 1). a) *Pinus*, b) *Picea*. — *Töluleg gildi fyrir sambandið á milli árhringjalínurita frá Hvíta Hafs svæðinu og frá Íslandi og Grænlandi. a) Fura, b) Greni.*

MATERIAL

Driftwood samples were collected from three main areas in Iceland, (1) from the northwest coast at Strandir in 1988 (41 samples, Figure 1;B), (2) from the northeast coast, at Langanes, in 1989 (251 samples, Figures 1;C and 3) and (3) from the southwest coast, at Reykjanes peninsula in 1993 (51 samples, Figure 1;A). Additionally 25 samples were collected at Scoresby Sund in East Greenland in 1990 (Figure 1;D) by Christian Hjort (Dept. of Quaternary Geology, University of Lund). All sampled logs were resting on the recent shore and were collected with a chain saw, one disk from the thick end of each log (Figure 3b). The length of each log was measured in the field.

At the Dept. of Quaternary Geology, University of Lund, samples were prepared for dendrochronological study. The tree-rings of each sample were measured on an Aniol tree-ring measuring machine, connected to a PC-computer running the CATRAS programme (Aniol, 1983). Two to four radii were measured on each sample/log. If the tree-ring series of all the measured radii were synchronous they were averaged and one tree-ring curve made for each sample/log. The tree curves showing high t-values were visually checked by comparing the graphical plots of the curves. The best fitting ones were used to build up mean tree-ring curves from the driftwood samples (Table 3). All mean curves presented in this paper were then quality controlled by the COFECHA program (Holmes et al., 1986).

Samples with poorly developed tree-ring pattern, or missing tree rings between the different radii were not included in the analyses.

Figure 3. The site at Langanes, northeastern Iceland (C on Figure 1). a) Driftwood on the beach. b) Method of sampling. — *Frá Langanesi a) Reki á fjöru, b) Sýni tekin af rekavið til árhringjarannsókna.*

RESULTS

GENERAL NOTICE

The occurrence of recent driftwood on the Arctic shores and its islands is due two different processes; trees either began drifting because of natural processes, or because of human activity.

The first group includes trees with their root system preserved when they were washed ashore on an arctic beach, meaning that they were eroded from a river side. The second group includes trees that have obviously been cut with a saw before they began drifting, indicating that they came loose during timber floating to the forest industry. The driftwood is transported by rivers into the Arctic Ocean where the logs are caught in oceanic currents.

The driftwood deposited in Iceland today is - as will be seen below - dominated by wood that has come loose during timber floating on the Russian/Siberian rivers. All the driftwood that has been collected in Iceland originates from the boreal forest regions and has drifted with currents from the north.

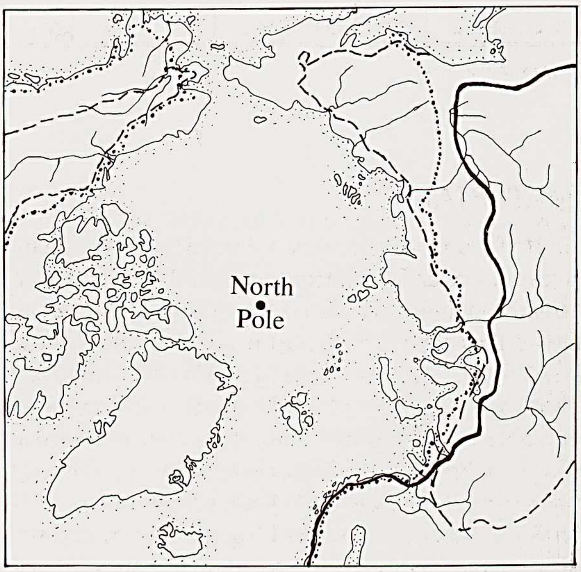

Figure 4. The Northern range of *Pinus silvestris*, *Larix* sp. and *Picea* sp. (modified from Hustich 1966). — *Útbreiðsla furu, lerkis og grenis.*

	Species/Genera	Sampling site (Fig. 1)	Time span	No. of trees	Internal correlation	Origin
Iceland 1	*Pinus silvestris*	C	1748-1973	15	0.673	Yenisey river
Iceland 2	*Pinus silvestris*	B and C	1820-1977	5	0.608	White Sea, Arkhangelsk
Iceland 3	*Pinus silvestris*	B and C	1777-1948	3	0.613	White Sea, Murmansk
Iceland 4	*Picea* sp.	B and C	1811-1982	7	0.567	White Sea, Arkhangelsk
Iceland 5	*Larix* sp.	B and C	1-224 Tree rings	7	0.520	East of Ural
Greenland 1	*Pinus silvestris*	D	1884-1961	2	0.680	White Sea, Arkhangelsk
Greenland 2	*Picea* sp.	D	1850-1930	3	0.503	White Sea, Arkhangelsk

Table 3. Dated and undated driftwood mean curves from this study. — *Samantekt á meðaltölum árhringja í rekaviði frá Íslandi og Grænlandi.*

	Iceland: Strandir (B)	Iceland: Langanes (C)	Iceland: Reykjanes (A)	Iceland total	Greenland: Scoresby Sund (D)
Pinus	29 (71 %)	171 (68 %)	32 (64 %)	232 (68 %)	9 (36 %)
Picea	3 (7 %)	42 (17 %)	8 (16 %)	53 (15 %)	10 (40 %)
Larix	7 (17 %)	33 (13 %)	11 (20 %)	51 (15 %)	4 (16 %)
broadleaf trees	2 (5 %)	5 (2%)	0	7 (2 %)	2 (8 %)
Total	41	251	51	343	25

Table 4. Distribution of the driftwood taxa collected in Iceland and Greenland. — *Tíðni mismunandi viðartegunda í reka á Íslandi og Grænlandi.*

SPECIES DISTRIBUTION AND ORIGIN

The distribution of the driftwood taxa from the sampling sites (A,B,C,D) are shown in Table 4 and summarised in the last column. The collections are all dominated by coniferous trees, indicating that they originate from boreal forest regions. If the species distribution is compared with the forest composition of the boreal forests of Russia (including Siberia) where *Picea* and *Pinus* dominate the western parts of the forests and *Larix* the eastern parts (Figure 4), it can be concluded that the *Larix* driftwood originates from the eastern boreal forests of Russia, while the *Pinus* and *Picea* samples originate from western Russia. As illustrated in Table 3 the collection from Greenland (D), although small, indicates that the tree species composition differs from that on Iceland, particularly in the amount of *Picea*. This might be due to input from the North American rivers (catchment area, Mackenzie, Canada and Yukon, Alaska is dominated by *Picea*) draining into the Arctic Ocean (Figure 4). Dendrochronological studies on driftwood from Baffin Island point in the same direction (Eggertsson and Laeyendecker, submitted).

DENDROCHRONOLOGICAL INVESTIGATIONS

Of the *Pinus* samples from Langanes (Figure 1;C Table 4), 92 could be synchronised as one group, 54% of the total *Pinus* samples from that locality. They therefore originate from the "same" area. Out of those 15 were used to build a mean tree-ring curve for *Pi-*

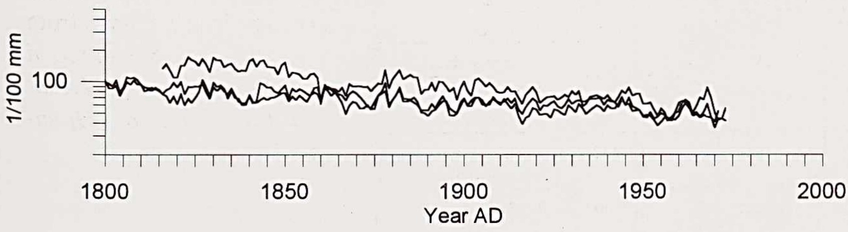

Figure 5. Plots of the three *Pinus* driftwood mean curves from Reykjanes, Strandir and Langanes. — *Meðaltal árhringja í rekavið frá Reykjanesi, Ströndum og Langanesi.*

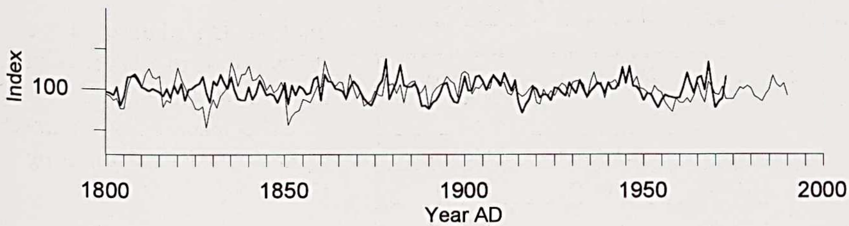

Figure 6. *Pinus* driftwood mean curve from Iceland (Iceland 1; thick line) and a master chronology curve from Yenisey in Siberia (thin line). — *Meðaltal árhringja í rekavið (furu) frá Íslandi (Iceland 1; þykk lína) og grunngildi frá Yenisey í Síberíu (mjó lína).*

nus (Iceland 1 in Table 3). For Strandir (Figure 1;B Table 4) 14 *Pinus* samples could be matched with the undated *Pinus* curve from site C, 38% of the total Strandir *Pinus* samples and for Reykjanes (Figure 1;A Table 4), 20 *Pinus* samples, 63% of the total Reykjanes *Pinus* samples. Figure 5 shows the plots of the *Pinus* driftwood mean curves from the different sampling localities in Iceland, indicating a high correlation between the curves.

To summarise, from a total of 126 *Pinus* samples collected on Iceland, 54% of the total *Pinus* samples could be matched, which allows the conclusion to be drawn that they originate from roughly the same area.

The attempt to date the driftwood tree-ring curve from site C (Iceland 1), with chronologies available from the boreal forests of western Russia, was not successful. This means that the logs making up this curve do not originate in the White Sea - Petchora region, from where there is a good network of chronologies available. However, a comparison with a *Pinus* master chronology from the middle reaches of the Yenisey river in Siberia (situated at 61°N, 90°E; Figure 2) (Eugene Vaganov, pers. comm. 1994) dated it, correlation values, t = 6.3; Sign test 65.1%, giving the end year of 1973 (Figure 6).

Only one of the *Pinus* samples from the Scoresby Sund collection in Greenland (Figure 1;D Table 4) could be matched with the dated curve from site C. However, the majority of *Pinus* samples from northern Svalbard (Eggertsson 1994b) and Jan Mayen (Stein Johansen, pers. comm. 1993) also fit the curve from site C.

Additionally, 9 other *Pinus* samples from collections B and C (Figure 1) could be matched, resulting in a mean curve where 5 trees were averaged. This mean curve (Iceland 2 in Table 3) could be dated through already established *Pinus* chronologies from the White Sea region in Russia, centred around Arkhangelsk (Table 2a; Figures 7 and 8) with 1977 as the last year. Another three *Pinus* samples from sites B and C could

Figure 7. Location of master tree-ring chronologies from the White Sea region. Numbers refer to Table 2. — *Staðsetning grunngilda frá svæðinu umhverfis Hvíta Haf. Númer vísa til töflu 2.*

be synchronised internally, giving a mean curve (Iceland 3 in Tables 2 and 3) which was dated to 1948 for the last tree ring via *Pinus* master chronologies from the White Sea region, this time centred around Murmansk (Table 2a; Figures 7 and 9).

Thirteen *Picea* samples from sites B and C could also be synchronised and seven of them were used for a mean curve (Iceland 4 in Table 3). This *Picea* mean curve could be dated via *Picea* master chronologies from the White Sea region, with the end year of 1982 (Table 2b; Figure 7 and 10).

From Greenland, one mean curve made out of two *Pinus* samples (Greenland 1 in Table 3) and one made out of three *Picea* samples (Greenland 2) (Figure 1;D) could also be dated by chronologies from the White Sea region (Table 2; Figure 7).

Eggertsson (1994a) dated two *Picea* samples from Scoresby Sund via chronologies from the North America. One with chronologies from the Mackenzie delta in Canada, and one with chronologies from the Yukon river drainage area in Alaska. American driftwood has, however, not been detected so far in the recent driftwood collections from Iceland or Svalbard (Bartholin and Hjort, 1987; Eggertsson 1994b).

THE LARIX *DRIFTWOOD*

Dendrochronological analysis of the *Larix* driftwood samples is difficult due to problems with missing tree-rings and irregular tree-ring growth often caused by outbreaks of the larch bud moth (Schweingruber, 1988). Most of the *Larix* driftwood has the root system preserved (78%), indicating that it began its journey to Iceland via natural processes, probably eroded from a river bank.

Seven of the sampled logs gave relatively high internal correlations and could be used to form a mean curve (Iceland 5 in Table 3), yet, that curve was not datable with the available chronologies from Russia/Siberia. However, in the mountainous permafrost areas east of the Lena river (Figure 2) erosion by rivers is large and *Larix* is the dominating tree genus of the area (Hustich, 1966). Therefore it is assumed, as suggested by Samset (1991), that most of the *Larix* driftwood found on Iceland originates from these areas and possibly also from farther east, from the drainages of Indigirka and Kolyma (Figure 2). Unfortunately, no tree-ring chronologies are available for comparison.

DISCUSSION

Of the 53 *Picea* samples collected in Iceland 13 (24%) could be absolutely dated with *Picea* master chronologies from the White Sea region (Figure 2) and out of the 232 *Pinus* samples collected, 12 (5%) could be dated with *Pinus* chronologies from the same area. Figure 11 shows the distribution of the ages of the outermost tree-ring for each of the datable logs from the White Sea area and Table 3 lists the dated driftwood mean curves from this study. The youngest of the outermost tree-ring on a *Picea* log collected in Strandir (Figure 1;B) in August 1988 was 1982, indicating that it may take less than six years for a log to drift from the White Sea region to the coasts of Iceland.

The drift route of the samples originating in the White Sea region can be pictured as follows: rivers

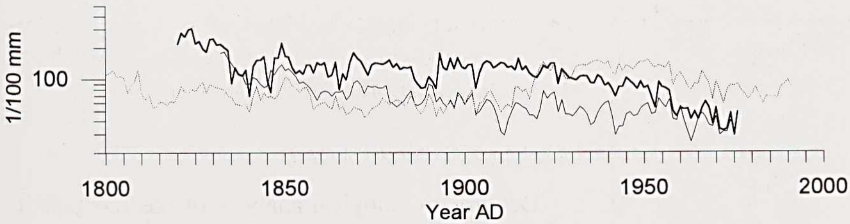

Figure 8. *Pinus* driftwood mean curve from Iceland (Iceland 2; thick line) and master chronologies from Arkhangelsk (thin line) and Voroncy (broken line). — *Meðaltal árhringja í rekavið (furu) frá Íslandi (Iceland 2; þykk lína) og grunngildi frá Arkhangelsk (mjó lína) og Voroncy (brotalína).*

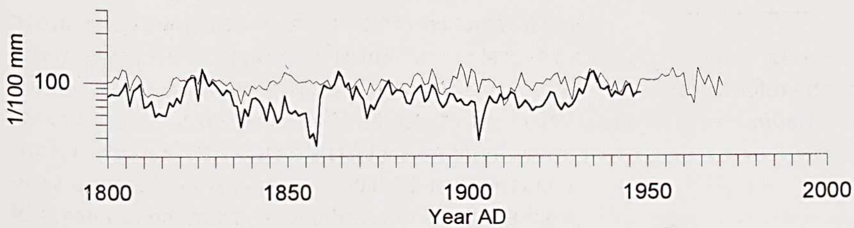

Figure 9. *Pinus* driftwood mean curve from Iceland (Iceland 3; thick line) and a master chronology from Murmansk (thin line). — *Meðaltal árhringja í rekavið (furu) frá Íslandi (Iceland 3; þykk lína) og grunngildi frá Murmansk (mjó lína).*

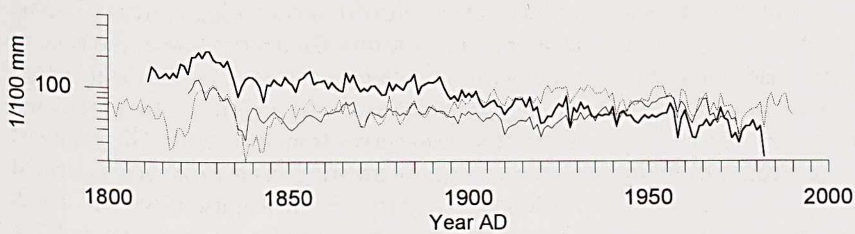

Figure 10. *Picea* driftwood mean curve from Iceland (Iceland 4; thick line) and master chronologies from Arkhangelsk (thin line) and Voroncy (broken line). — *Meðaltal árhringja í rekavið (greni) frá Íslandi (Iceland 4; þykk lína) og grunngildi frá Arkhangelsk (mjó lína) og Voroncy (brotalína).*

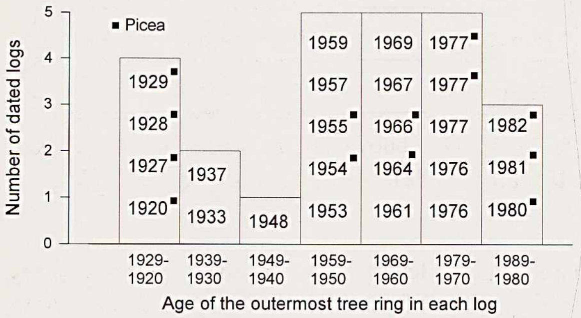

Figure 11. Age distribution of driftwood collected in Iceland and originating in *Picea* samples are marked by black square, otherwise *Pinus*. — *Aldursdreifing rekaviðasýna frá Íslandi, sem borist hafa frá svæðinu umhverfis Hvíta Hafið. Greni er merkt með svörtum hringjum. Annað er fura.*

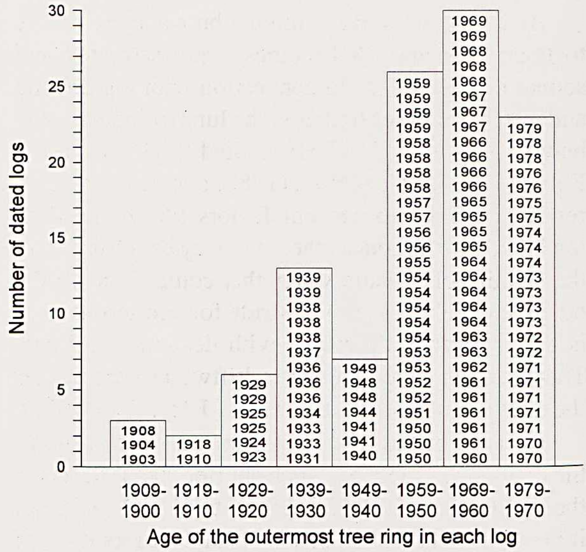

Figure 12. Age distribution of *Pinus* driftwood collected in Iceland and originating in the middle reaches of the Yenisey river in Siberia. — *Aldursdreifing furu í rekavið frá Íslandi, sem borist hafa frá Yenisey í Síberíu.*

draining the forested areas carry the logs into the White Sea, and then currents transport them to the Barents Sea where the wood probably gets frozen in sea ice. The ice is driven by wind and oceanic currents, probably in an anticlockwise direction to the southernmost part of Svalbard where it is caught by the branch of the Norwegian Current that flows north along the west coast of Spitsbergen (Figure 2). When the log reaches the Fram Strait - and if it has by then been displaced far enough westward - the East Greenland Current takes over and transports it in the eastern part of the current (south off the east coast of Greenland), until it is maybe washed ashore on the north coast of Iceland.

Figure 12 shows the distribution of the ages of the outermost tree-ring for each of the datable driftwood logs from Iceland, which can be correlated with the mean curve from Langanes. The Langanes curve (Iceland 1 in Table 3) covers the time span from 1748 to 1973. Most of the trees fitting the mean curve give a similar date of the last tree-ring in each sample (Figure 12) indicating that the trees began drifting from the Yenisey during the period from circa 1940 to 1980. During the end of the 1960's drift ice was common on the northern coasts of Iceland (e.g. Stefánsson, 1981) and during the same time the amount of driftwood increased. Some of this material might be present as an increased concentration of some end years in Figure 12. After the second world war the logging industry in Russia has been concentrated in the areas of the upper and middle reaches of the Yenisey river in Siberia (Eugene Vaganov, pers. comm. 1994), the area where most of the recent *Pinus* driftwood in Iceland originates. The logs fitting the mean curve from site C are probably transported by the Transpolar Current and then south along the east coast of Greenland by the East Greenland Current to Iceland (Figure 2).

BUOYANCY OF DRIFTWOOD IN CONNECTION WITH THE ORIGIN OF THE DRIFT ICE

As noted, wood has a limited buoyancy or ability to float on water. It becomes water saturated and sooner or later sinks. In connection with log drifting and water storage of timber in the lumber industry, the buoyancy of wood has been studied (Nylinder, 1961; Edlund, 1966). Häggblom (1982) summarized these results, taking into account factors like removal of the bark, which reduces the buoyancy of a trunk, and the salinity of oceanic water that could improve the buoyancy (Table 5). A major rule for coniferous trees is that buoyancy decreases with decreased volume. This means that the smaller the driftwood is the shorter the time it can stay afloat in water (Häggblom, 1982).

Because of the relatively short buoyancy time of the driftwood (Table 5), much shorter than it takes for the wood to reach the islands in the North Atlantic, it is obvious, as mentioned by many authors that the drift ice of the Arctic Ocean is the main factor in transporting the wood. When the driftwood reaches the ocean, normally during river breakups, it floats on open water for probably a couple of months until it becomes frozen into the pack ice.

Vowinckel (1963) estimated that the drift ice of the East Greenland Current had its main origin in the Arctic Ocean, and that only a small amount of ice is formed south of 80°N.

From the origin of the driftwood it must be concluded that some of the drift ice reaching the coasts of Iceland has the "same" origin as the driftwood, i.e. Siberian coast and the Barents Sea.

Type of wood	Maximum period of buoyancy
Picea	17 months
Pinus	10 months
Larix	10 months
Betula	6 months
Populus	10 months
Salix	10 months

Table 5. The buoyancy of wood (modified from Häggblom 1982). — *Áætlaður flottími rekaviðar.*

CONCLUSION

The driftwood deposited on today's coasts of Iceland mainly consists of coniferous trees of Russian/Siberian origin. *Pinus* and *Picea* components dominate the logs that have come loose during timber floating on the Russian/Siberian rivers draining into the Arctic Ocean, while the majority of the *Larix* wood has a natural origin (root system intact).

The wood has been transported with currents from the Arctic Ocean through the Fram Strait between Greenland and Svalbard, south along the east cost of Greenland to Iceland. The relatively short buoyancy time of the driftwood indicates that the wood must have been frozen in and transported by the drift ice. This implies further that driftwood and drift ice have the same origin, the Barents and Siberian seas. When the ice approaches the coasts of Iceland it melts and the imbedded wood is released and floats in open water. Some of the wood is then transported by currents clockwise around Iceland until it is washed ashore.

Dendrochronological analyses on the youngest dated driftwood show that it may take less than six years for the Arctic driftwood to reach Iceland and, correspondingly drift ice takes the same time.

American driftwood has so far not been identified in the Icelandic driftwood collections although it is present in collections from East Greenland. This suggests that the western part of the East Greenland Current carries driftwood and drift ice of a partly different origin than the eastern part of the same current.

A further conclusion of the present study is that, if a pollution accident should occur in the Arctic Basin the waste will be transported in the same direction as the driftwood. This is especially relevant to the possible initiation of oil prospecting in the Barents sea. Some driftwood on the coasts of Iceland has been transported from the White Sea region via the Barents Sea. An accident in the Barents Sea could possibly affect the Icelandic waters.

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ÁGRIP

UPPRUNI REKAVIÐAR Á ÍSLANDI KANNAÐUR MEÐ ÁRHRINGJAALDURSGREININGU

Við frá fjarlægum löndum rekur sífellt að ströndum landsins. Útbreiðsla hans er breytileg en segja má að finna megi rekavið meðfram allri strandlengju landsins. Viðurinn á uppruna að rekja til skógarsvæða Rússlands og Síberíu. Árnar, sem renna frá skógarsvæðum Rússlands, Síberíu, Kanada og Alaska bera með sér mikið magn viðar út í Norður-Íshafið. Fljótin rjúfa árbakka sína þannig að viðurinn fellur í fljótin og einnig tapast mikið magn timburs við fleytingar. Fleytingar eiga sér aðeins stað í Rússlandi og Síberíu. Þegar viðurinn nær hafinu frýs hann í hafís og berst með ísnum til fjarlægra stranda. Stór hluti alls hafíss í Norður-Íshafi berst með hafstraumum inn í Norður-Atlantshaf í gegnum Fram-Sund á milli Grænlands og Svalbarða.

Samtals voru rannsökuð 343 sýni af rekavið sem safnað var á þremur mismunandi stöðum á Íslandi; Ströndum, Langanesi og Reykjanesi. Einnig voru 25 sýni frá Scoresbysundi á Grænlandi könnuð. Sýnin voru viðar- og árhringjaaldursgreind til þess að kanna uppruna þeirra.

Grundvöllur árhringjaaldursfræði er sá að breidd árhringja í trjám er breytileg frá ári til árs og ræður þar mestu um veðurfar og frjósemi jarðvegs. Tré af sömu tegund og frá sama svæði mynda svipað árhringjamynstur fyrir sama vaxtartímabil. Aðferðin byggist á að bera saman árhringjagildi sýnis s.s. rekaviðar saman við árhringjagrunngildi frá skógarsvæðum sem umlykja t.d. Norður-Íshaf.

Samtals voru 25% af greni og 5% af furu í rekviðnum aldursgreind með hjálp árhringjagrunngilda frá Hvítahafs svæðinu í norður Rússlandi. Af furunni voru 54% sýnanna nothæf í meðalárhringjalínurit sem síðan var aldursgreint með hjálp grunngilda frá Yenisey í Síberíu, sem er skammt frá einu stærsta skógarhöggssvæði Rússa.

Nú á dögum er mestur hluti furu og grenis reka sagað timbur frá skógarhöggssvæðum Rússlands og Síberíu sem tapast hefur út í Norður-Íshaf af völdum fleytinga, en stór hluti lerkis í rekanum er af "náttúrulegum" uppruna og hefur rofist úr bökkum fljótanna í austur Síberíu.

Rekaviður af Norður-Amerískum uppruna hefur greinst í reka frá Grænlandi en ekki á Íslandi þrátt fyrir að margfalt fleiri sýni hafi verið könnuð þaðan. Þetta leiðir líkum að því að ísinn sem berst suður með Austur Grænlandsstraumnum, frá Fram-Sundi og inn í Norður-Atlantshaf, sé að einhverju leyti af ólíkum uppruna.