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NOEL BROADBENT

LICHENOMETRY AND ARCHAEOLOGY

Testing of lichen chronology on the Swedish North Bothnian Coast

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NOEL BROADBENT

LICHENOMETRY AND ARCHAEOLOGY

Testing of lichen chronology on the Swedish North Bothnian Coast

TABLE OF CONTENTS

1. PROJECT DESCRIPTION

The following report is based on fieldwork carried out within a research project at the Center for Arctic Cultural Research at the University of Umeå. This project focuses on the seal hunting cultures of the Bothnian region in Northern Sweden and Finland. In addition to ethnological, historical and linguistic data, numerous archaeological sites can be associated with sealing in this region from the Stone Age to the 19th century. Shore displacement has provided a useful chronological basis for indirectly dating these sites.

Archaeological research dealing with the Stone Age of this region has been previously undertaken (cf. Broadbent 1979), thus the main goal of the archaeological part of the Seal Hunting Cultures Project has been to identify and date sites from the Iron Age and Medieval periods. Radiocarbon dating of hearth coal from excavated sites is being carried out, but the greatest numbers of archaeological features on the coast found at levels corresponding to the Iron Age and later (less than 20 m.a.s.l.), consist solely of stone constructions (cairns, huts, mazes, ovens etc.) on exposed bedrock and wave-washed moraine beaches. Shore displacement can provide maximum datings for such features but very few can with certainty be interpreted as having been situated directly on contemporary beaches. This is why lichenometry, the use of lichen growth on stone surfaces, was tested within the archaeological project. Lichenometry can provide minimum ages for stone substrates and is thereby ideally combined with shore displacement chronology (Broadbent and Bergqvist 1986).

In connection with a field trip to the Haparanda archipelago in 1985 organized by Örn Taube of the Faculty of Mathematics and Sciences, Dr. Christer Nilsson (Dept. of Ecological Botany) suggested the possibility that lichen growth could

be used for dating coastal features in the Bothnian region; abundant growth of the crustose lichen Rhizocarpon geographicum was observed on stone mazes in the archipelago. This suggestion was passed on to the author and preliminary fieldwork was carried out by the author and Kathy Bergqvist in the Haparanda archipelago in July and August of 1985. This fieldwork was continued in 1986 on sites as far south as the island of Snöan off the southern Västerbotten coast.

In addition to the coastal sites, observations were carried out on stone monuments, headstones and bridges in Sweden and Finland.

This research has been made possible through funding from The Swedish Humanities and Social Science Research Council (HSFR) and the Natural Science Research Council (NFR).

2. RESEARCH GOALS AND METHODS

2.1 Lichenometry

The lichenometric method was developed in the 1950's by R. E. Beschel and has been mostly used in mountain environments for the dating of glacial moraine (cf. Locke et al. 1979, plus references; Innes 1983, 1984, 1985; Karlén 1975; Karlén and Denton 1976). Few studies have been previously attempted in coastal regions (cf. Donner et al. 1977; Birkenmajer 1981) or archaeology (cf. Follman 1961a, 1961b; Benedict 1967, 1985). No previous studies of lichenometry and archaeology have been carried out in the Bothnian region.

Over thirty-five species of lichen have been used for dating purposes but the most often used is the gray-green crustose group Rhizocarpon geographicum sensu lato. These lichens

prefer acidic rock surfaces and are common on Scandinavian granitic and gneiss rocks. Since lichen growth is very slow and crustose lichens tend to grow symmetrically, surface area or thallus diameter has been used to estimate age once a lichen growth rate has been determined. This can be calculated on the basis of direct measurements over long time periods or indirectly through previously dated surfaces, mine tips, headstones, bridges etc (Locke et al. 1979).

2.2 Lichen Growth on Uplifted Beaches

Vegetation rapidly colonizes the uplifted beaches of the northern Baltic and Bothnian regions and there are both long term and short term influences which affect plant composition (Ericson and Wallentinus 1979; Cramer 1986). In addition to uplift and eustatic effects over time, the influences of salinity and ice shaving are important. Salinity in the Bay of Bothnia is low, 2-3 o/oo as compared with 30 o/oo or more for sea water. This high fresh water dilution is the result of influx from numerous rivers, low evaporation and the absence of tides (Falkenmark and Mikulski 1975). Although water levels in the innermost parts of the Bay can rise 1 - 3 m with strong southerly storm winds, such conditions are temporary. For these reasons lichen colonization on rocky shores seems most comparable to that of lacustrine environments (cf. Santesson 1939). Lichens have been found to commonly colonize at about the 1 m elevation above mean sea level on protected shores where ice shaving effects are minimal (refer App. A).

In the present study an attempt has been made to correlate lichen growth on coastal bedrock and moraine beaches with uplifted beach levels. The main hypothesis of this approach is that lichen growth was continuous following initial colonization, thus lichen size should increase with elevation above sea level. If lichen growth follows a regular pattern

through time growth rates can be predicted. The earliest colonization of lichens on beaches was documented at different locales and maximum thalli of lichens were recorded at increasing elevations above mean sea level. Comparisons were then made between locales to determine any variability in lichen growth due to environmental conditions and/or differences in shore displacement.

3. THE STUDY REGION

The study region encompasses the Swedish Bothnian coastal zone between Haparanda and Hörnefors. Fieldwork was done primarily on coastal islands between 66 and 63 degrees latitude but also on the Bjuröklubb peninsula at latitude 64°28'N and longitude 21°35'E. Lichen growth on beaches was analyzed on two islands in the Haparanda archipelago, Östra Knivskär and Stora Hepokari, in the County of Norrbotten, and at Bjuröklubb, Stora Fjäderägg and Snöan, all in Västerbotten County. The sites are located along a ca 300 km stretch of Bothnian coast and thereby provide a good north-south cross section for comparitive purposes within this northern maritime upheaval zone. Sites were chosen on the basis of elevation and presence of archaeological features.

3.1 Climate

This a region of humid microthermal conditions with a continental D climate with a local maritime influence. The Gulf of Bothnia has a cooling effect (a negative temperature anomaly) in the summers and a warming effect in the winter. Average temperature in June is 12°C and in December ca -7°C. Mean lowland temperature in July varies little along the whole coastal Bothnian region, ranging between 15 - 17°C. Average Bothnian ice formation takes place in mid-November and break-up is in late May. Precipitation in the outer coast is low, 350 - 400 mm per year. The length of the growing season (+3°C) is ca 5,5 months.

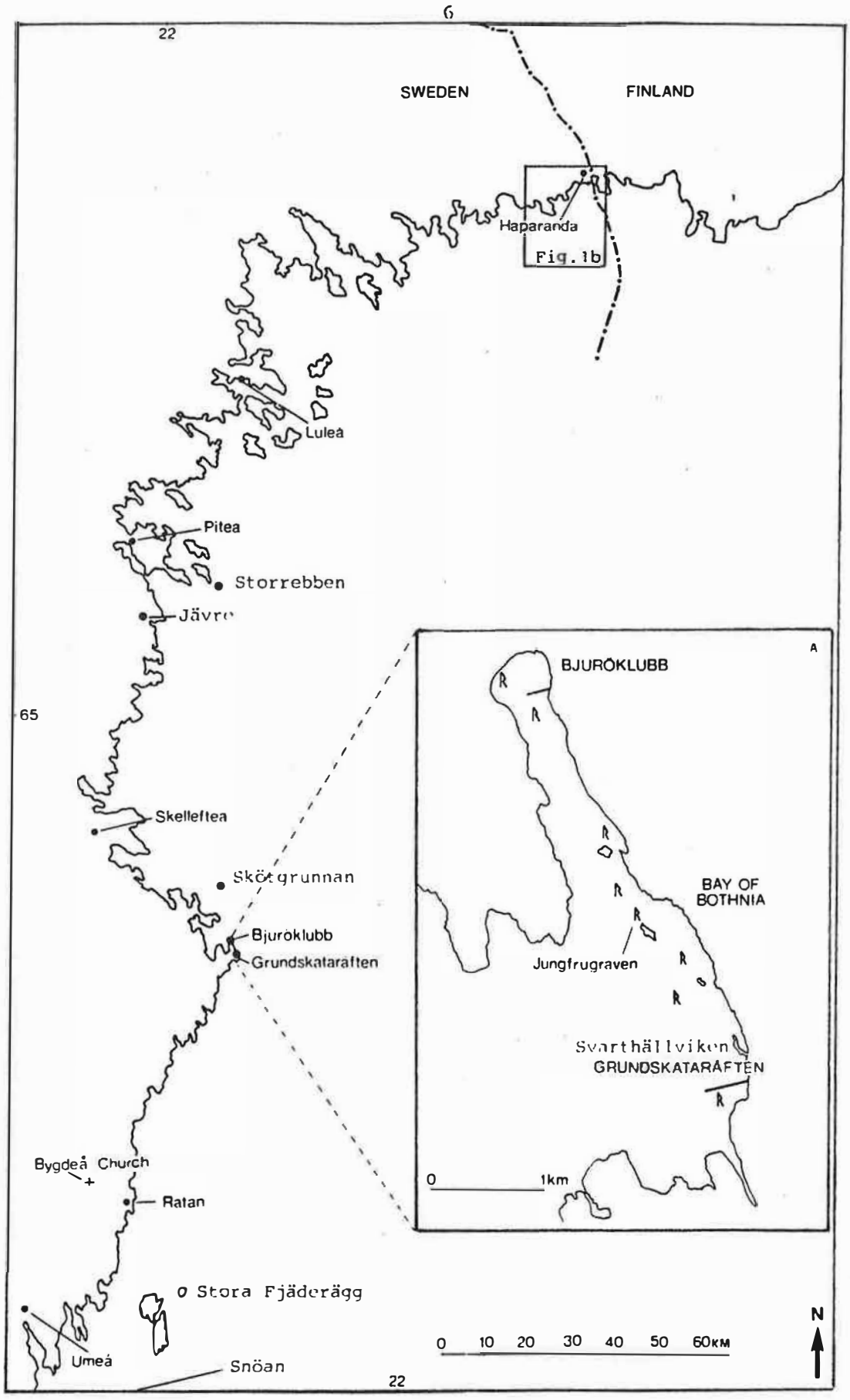


Fig.1a Map of study region with inset of Bjuröklubb.

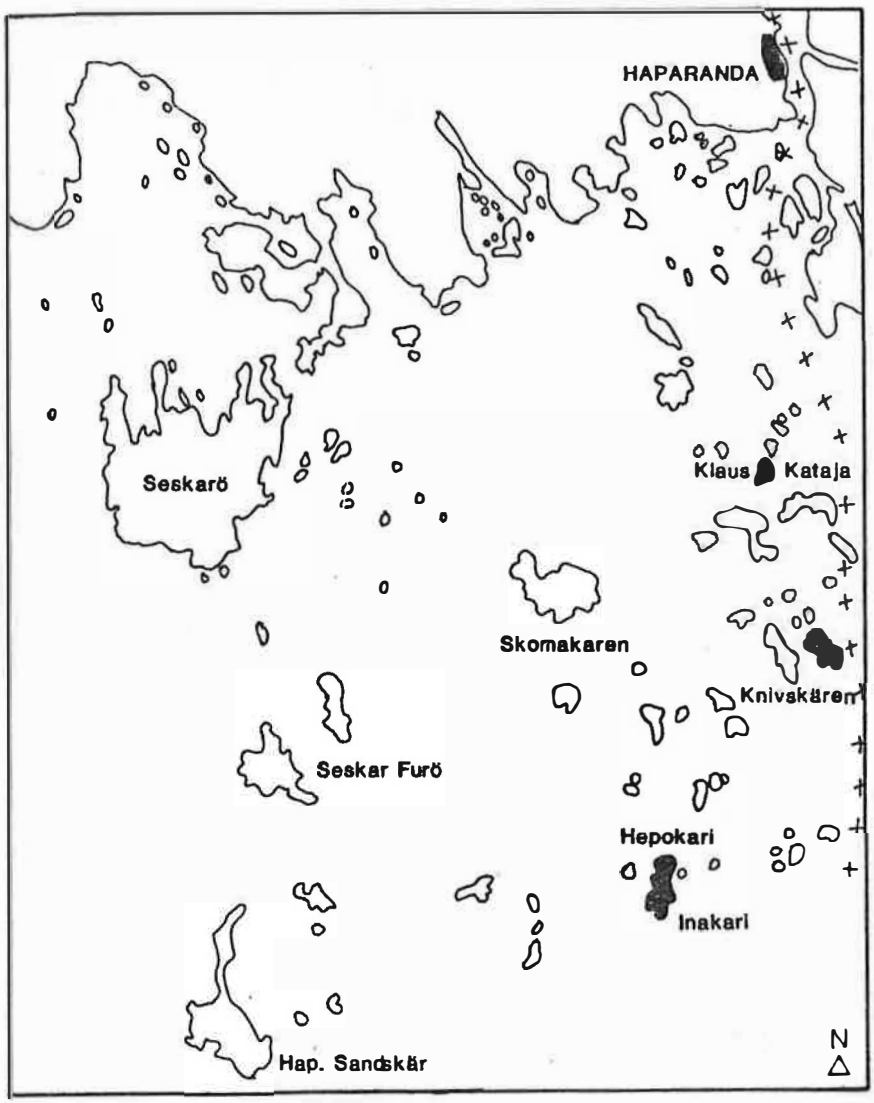


Fig.1b Map of islands studied in Haparanda archipelago

3.2 Shore Displacement

Watermarks from the 18th century and recent measurements indicate that present shore displacement along the North Bothnian coast is between 8.3 and 9.1 mm per year. Although eustatic fluctations have influenced displacement during the past 1500 years (cf. Mörner 1984), uplift rates are judged as having counteracted the effects of potential shore transgressions which might have disrupted lichen growth on beaches. In a previous study (Broadbent 1979), shore displacement rates for the region of maximum uplift on the coast were estimated using old watermarks and radiocarbon dates. An exponential equation pertaining to a damped elastic movement simulating crustal rebound was used to calculate displacement rates. Varve analysis of coastal lake basins has confirmed the trend of this model (Renberg and Segerström 1982). Thus, within this study estimated shore dates are calculated using Broadbent (1979:214). Since the purpose of developing lichenometry is to develop a chronology, conversion of specific shore levels to dates has been necessary. These calculations provide a basis for comparisons and testing with radiocarbon and historical dates in the region.

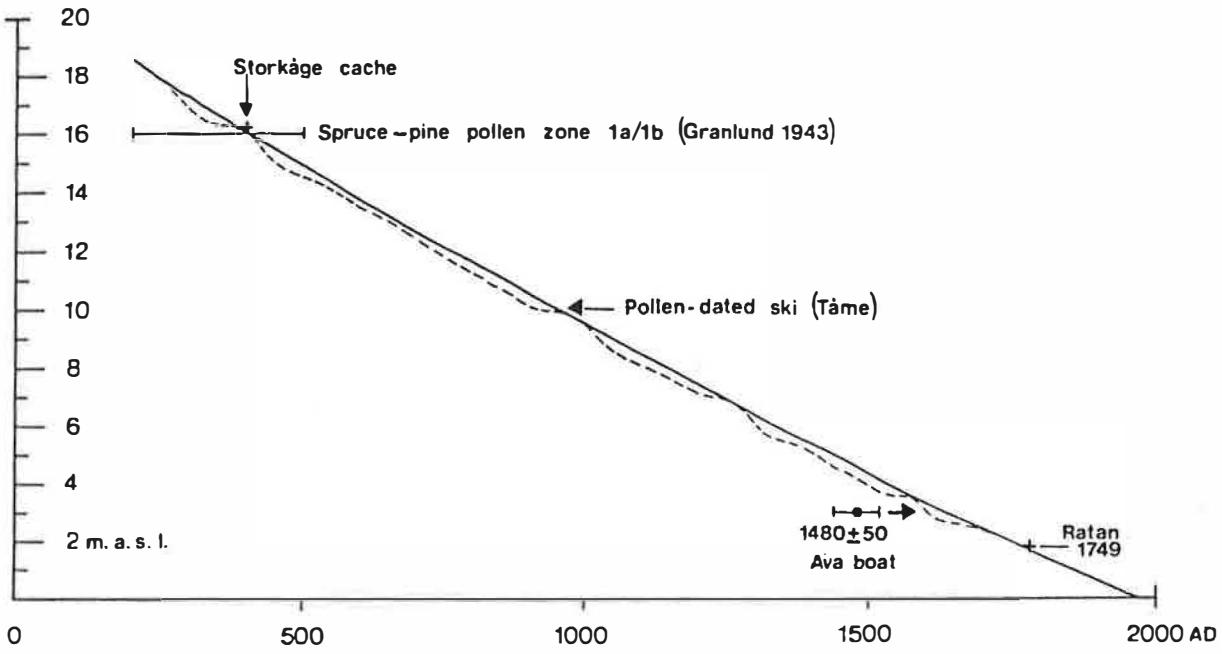


Fig. 2 Shore displacement for northern Västerbotten. Dashed line potential eustatic fluctuations.

observation for comparative purposes. In the case of ovoid or slightly irregular thalli both averages of length and width measurements and maximum lengths were recorded. At the Grundskatan site sample squares were analyzed to study lichen size frequencies at different elevations above mean sea level. Lichen samples were collected for species identification at the same site.

4.1 Analysis

The relationship between thallus diameter and elevation above sea level/age is best illustrated using bivariate graphs in which elevation is indicated on the y-axis and diameter on the x-axis. These are shown in figures 6 - 13.

Linear correlation coefficients (Pearson's product moment correlation) were calculated for each of the sites and in combined data.

Table 1. Correlation coefficients for maximum thallus diameters and elevations above mean sea level

Site	Correlation coefficient
Bjuröklubb	.99
Grundskatan	.98
Stora Hepokari	.97
Stora Fjäderägg	.98
Snöan	.94
Östra Knivskär	.95
Combined data	.96

The high correlations at these sites suggest the suitability of using a simple least squares linear regression equation for describing the data. These equations were calculated using the Minitab Statistical Computing System (Ryan et al. 1976). Several log transformations of x and y were tried, as

well as a second degree polynomial curve fitting equation, but these did not give better data fits. Any apparant curvilinear trends in this data seem better explained on the basis of field observations, e.g. irregularities of growth nearest the shore and extremely large lichens of R. alpicola type in very favorable locales. Specimens measuring up to 420 mm, observed at Snöan and near the Grundskatan locale, diverge from the overall growth trends at these sites and are viewed as aberrant, as are several other thallus individuals which totally diverged from overall beach growth trends. The correctness of this assumption can only be judged on the basis of the combined data and within standard deviation limits.

4.2 Species Identification

Twelve rock samples with gray-green crustose lichens were sent to Roland Moberg of the Uppsala University Herbarium for analysis. These samples were collected at the Bjuröklubb locale, latitude 64°21' N, longitude 21°35'E.
Ten specimens were identified as Rhizocarpon geographicum sensu latu, two as Rhizocarpon alpicola (Hepp.) Rabh. and two as Rhizocarpon inarense (Vain) Vain. R. alpicola is distinguished by large areoles as compared with R. geographicum (fig. 4) although the latter is a large and varied group (Runemark 1956). R. inarense can be recognized by bulbous

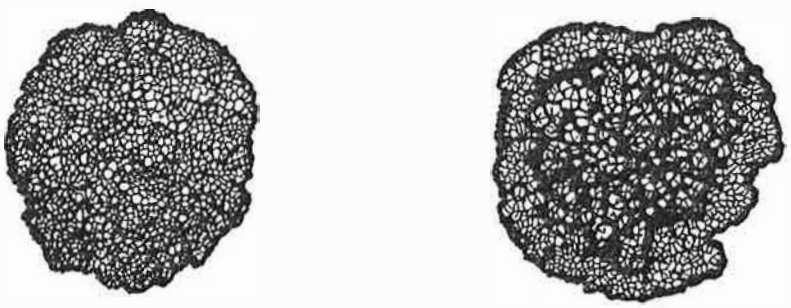


Fig. 4 Rhizocarpon geographicum (left) and Rhizocarpon alpicola (right).

apothecia and can be avoided. Only the two first species were used in this study. These voucher specimens were used for field identification purposes.

5. INVESTIGATED SITES

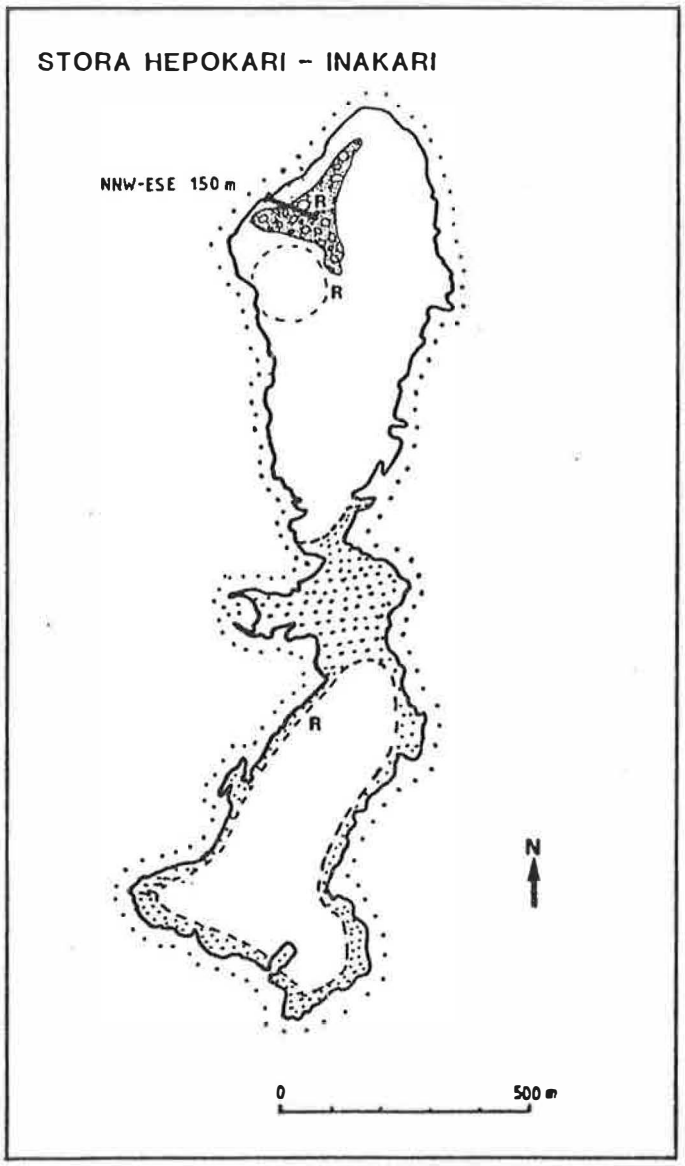
5.1 Haparanda Archipelago, Norrbotten County

The first site to be investigated was Östra Knivskär in the middle Haparanda archipelago. Fieldwork was carried out in 1985. This island has a maximum elevation of ca 13 m.a.s.l. and there are numbers of stone features, in particular small cairns for supporting net drying posts (Hederyd 1982). On the southwest side of the island there is an isolated basin with associated stone features, including hut walls and ovens, and the island could have been used by man since Viking or early Medieval times.

A series of parallel wave-washed moraine beaches with exposure towards the northeast were chosen for study. Following exact elevation determinations of the beach levels, maximum thallus diameters were recorded up to an elevation of 7.68 m.

The first colonization of R.geographicum on the beach was observed at an elevation of 0.76 m above mean sea level. The first thalli were measured at an elevation of 1.16 m and thereafter at 10 intervals up to the maximum elevation (App. A1). Lichens were also measured on the cairns found on this beach (refer 9:1).

The second site to be studied was the Island of Stora Hepokari situated some 4 kilometers farther out in the archipelago. A ca 150 m long elevation transect was extended in a NNW-ESE direction up to an elevation of 7.52 m. First colonization



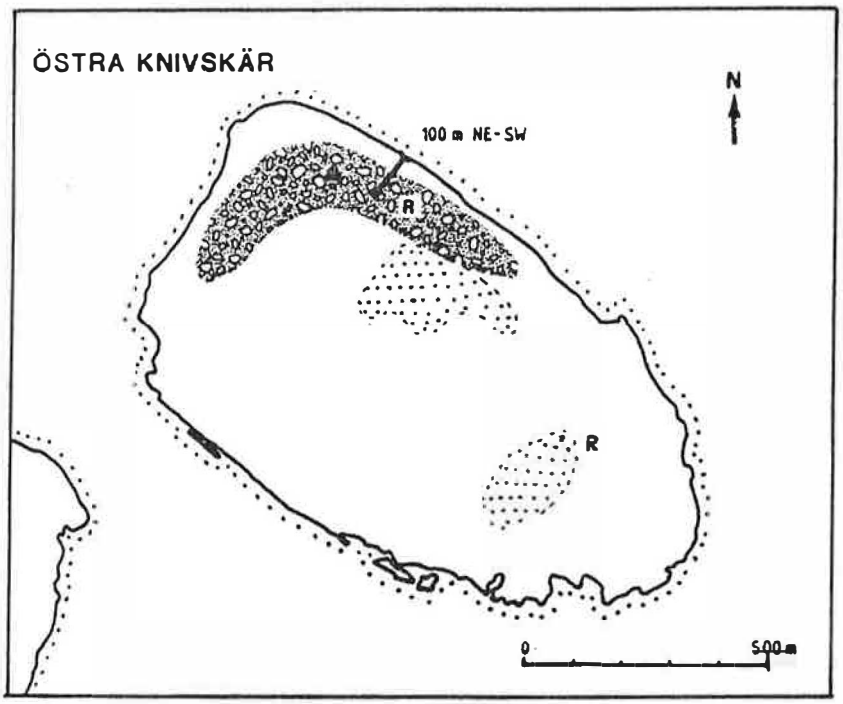


Fig. 5 Lichen growth curve sites on Östra Knivskär and Stora Hepokari in the Haparanda archipelago.

(Eq. 6) $$Y = 0.657 + 0.0389\ X,$$

where X equals thallus diameter in millimeters. The standard deviation is $\pm$0.51 m.

These individual and combined data suggest a high correlation between maximum lichen thallus diameter and elevation above sea level. The accuracy of these calculations can best be judged through comparisons with other locales both locally and on a greater regional basis. A local comparison, made on the island of Klaus, situated some 2,5 km nearer the mainland shows some regional consistency. The maximum lichen diameter observed at 5 m.a.s.l. was 110 mm. According to equation 5, the predicted maximum lichen size for this elevation is precisely 11 cm.

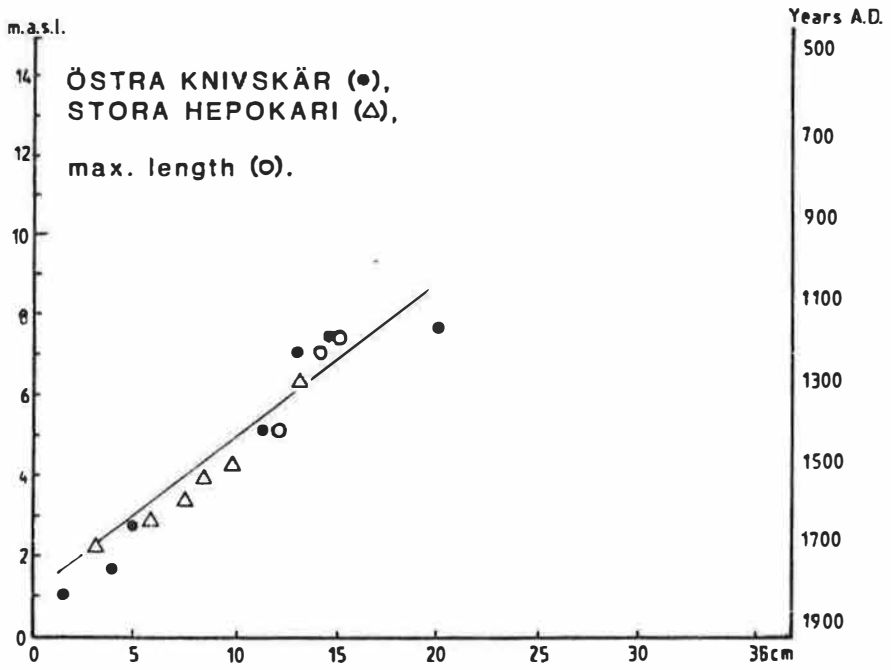


Fig. 6 Maximum thallus diameters and elevations above sea level, Ö. Knivskär and St. Hepokari, Haparanda. r = .95, p < .001.

5.2 Bjuröklubb and Grundskataräften, Västerbotten County

The next sites to be investigated were Bjuröklubb and Grundskataräften (Grundskatan), Lövånger parish, located on a hook of land extending out into the Gulf of Bothnia from the Västerbotten coast. Bjuröklubb is well known as an important fishing area during the early 1500s as described by Olaus Magnus.

Grundskatan is not mentioned in any historical sources but there are large numbers of archaeological remains (Hallström 1942). This area is a prime focus of the archaeological part of the Seal Hunting Cultures Project.

Both locales had exposures of E-NE. Bjuröklubb is characterized by 8 fairly straight terraces extending for 150 m up to ca 15 m.a.s.l. Lichens were measured at 14 levels up to 14.29 m (App. A3). Colonization was observed at 1.28 m. The lower part of this rocky beach was fairly ice scored and clear of vegetation. At the highest level, the beaches had been disturbed by vehicles.

Individual and combined data were used for calculating regression lines. At Bjuröklubb the correlation between maximum thallus diameter and elevation is .99.

The equation describing thallus diameter by elevation at Bjuröklubb is:

(Eq. 7) $$Y = -32.5 + 28.3 X,$$

where X is elevation above sea level. The standard deviation of Y is $\pm$12.86 mm.

Conversely, the equation for elevation above sea level on the basis of thallus diameter is:

(Eq. 8) $Y = 1.21 + 0.0349\ X,$

where X equals thallus size in millimeters. The standard deviation is $\pm$0.45 m.

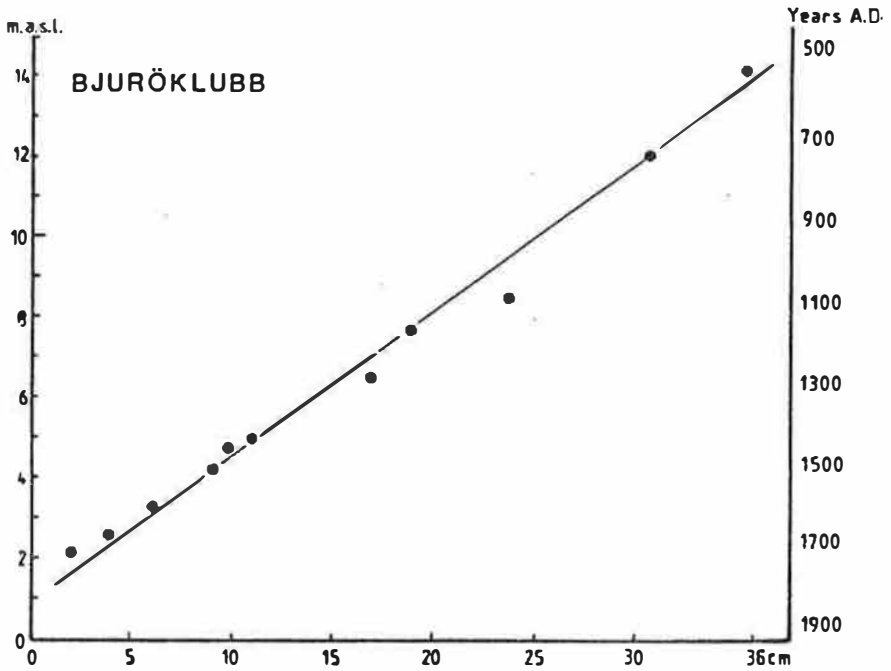


Fig 7 Maximum lichen diameters and elevations above sea level, Bjuröklubb, Västerbotten. r = .99, p < .001.

Grundskatan is situated ca 4 km SSW of the Bjuröklubb locale. This exposed wave-washed moraine beach extends for 300 m up to an elevation of ca 14 m.a.s.l. There are nine large curving terrace formations with stone constructions between 5 and 14 m.a.s.l. Numerous additional features (cairns and hut foundations) lie between 14 and 16 m.a.s.l. in a largely overgrown area at the top of the beach ridge. Twenty-nine levels were examined at this site,but because of overgrowth and beach gravel deposits, maximum lichen increments were only found up to 8.94 m.a.s.l. (App. A4).

The equation describing lichen diameter with elevation is:

(Eq. 9) $$Y = -27.5 + 28.7\ X,$$

where X equals elevation. The standard deviation of Y about the regression line is ±12 mm.

For calculating elevation from lichen diameter at this site the equation is.

(Eq. 10) $$Y = 1.06 + 0.0340\ X,$$

where X equals lichen diameter. The standard deviation of Y is ±0.41 m.

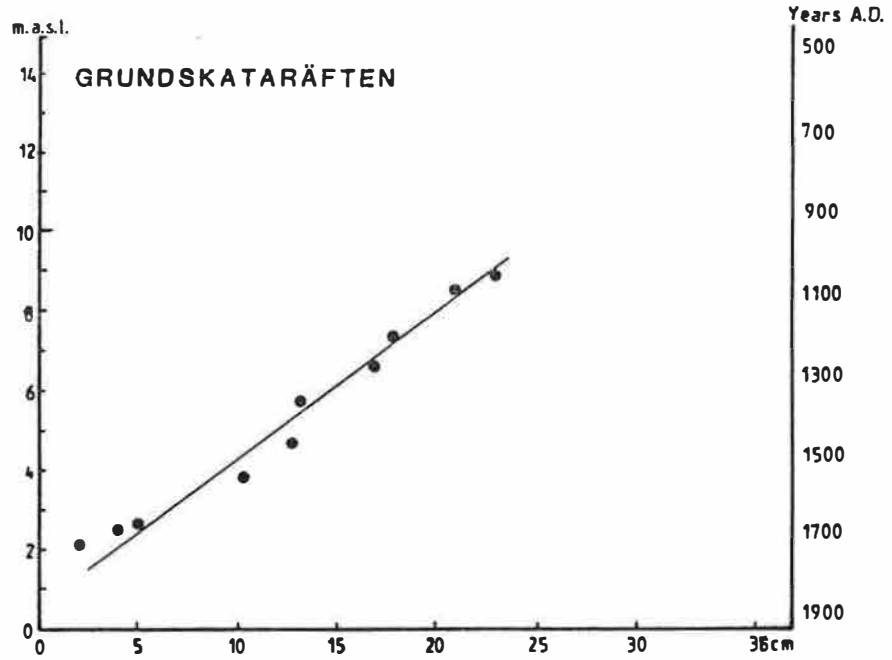


Fig. 8 Maximum thallus diameters and elevations above sea level, Grundskatan, Västerbotten. r = .98, p < .001.

The data from Grundskatan and Bjuröklubb were combined and new regressions calculated. The correlation coefficient for the combined data is .99.

The equation for thallus size on the basis of elevation is:

(Eq. 11) $Y = -28.3 + 28.2 X,$

where X equals elevation above sea level. The standard deviation of Y is $\pm$12.26 mm.

For calculating elevation from thallus diameter the equation is:

(Eq. 12) $Y = 1.08 + 0.0349 X,$

where X equals thallus diameter in millimeters. The standard deviation of Y about the regression line is $\pm$0.43 m.

5.3 Stora Fjäderägg, Västerbotten

This island is situated to the north of the Holmöarna islands and is the outermost island of the Västerbotten coast, located 15 km from the mainland. Numerous archaeological and historical features are registered on the island. A silver ring dating to the 13th century, human bones, and other items, were found in a cairn in the early 1900s (Serning 1960:150).

A wave-washed moraine beach on the east side of the island was chosen for analysis. A 340 m long transect was extended from 1.18 to 15.58 m.a.s.l. providing 22 sampling levels (App. A5). The correlation coefficient between maximum thallus diameter and elevation is 0.98.

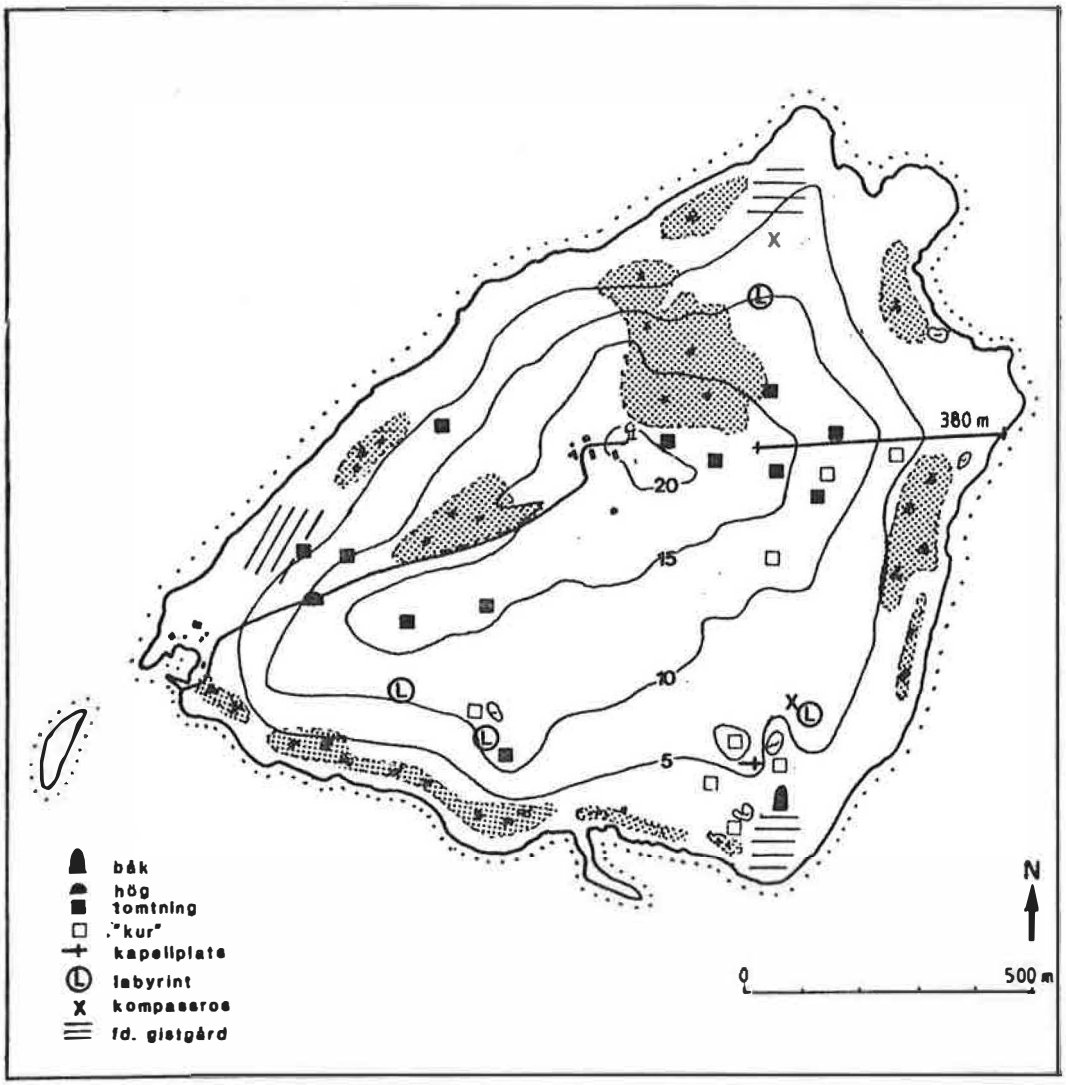


Fig. 9 Stora Fjäderägg, lichen growth curve and cultural features. båk = sea marker, hög = cairn, tomtning = hut, kur = shooting blind, kapellplats = chapel site, labyrint = maze, kompassros = compass rose, gistgård = post supports.

For calculating size from elevation the following regression equation was determined:

(Eq. 13) $$Y = - 0.0868 + 22.2 X,$$

Where X equals elevation above sea level. The standard deviation of Y is $\pm$15 mm.

For calculating elevation from thallus diameter the equation

is:

(Eq. 14) $$Y = 0.130 + 0.0442\ X,$$

where X in this case equals thallus diameter. The standard deviation of Y is ± 0.67 m.

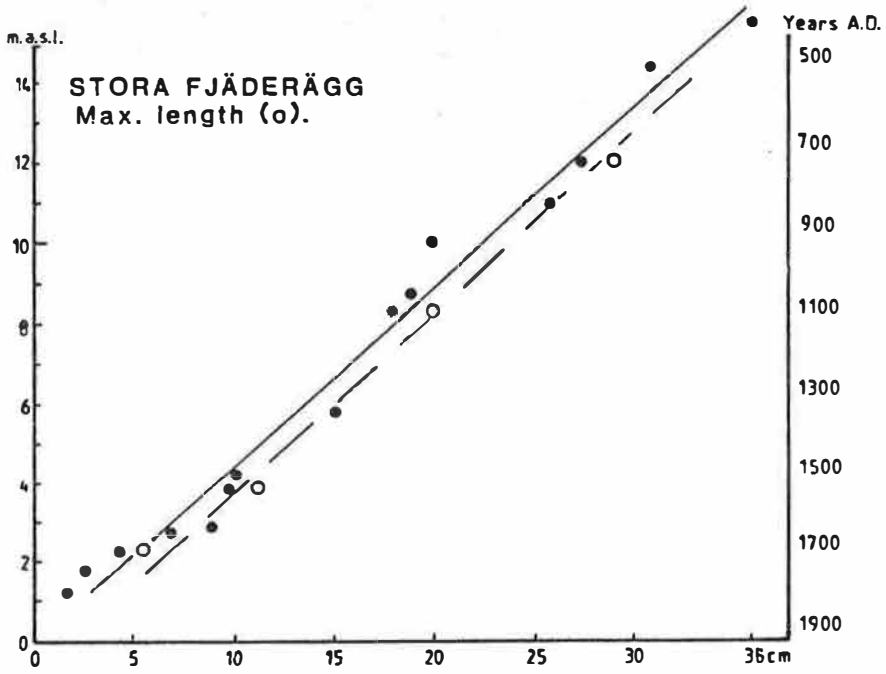


Fig. 10 Maximum thallus diameters and elevations above sea level, Stora Fjäderägg, Västerbotten. r = .98, p < .001.

This island lies to the east of a faultline which also separates the Holmöarna from the mainland. Although the trend of lichen growth is linear, the rate is slower than for the other studied sites. This could reflect the local geological conditions or perhaps a somewhat harsher climate. It can be noted, however, that the maximum lengths of irregular thalli better correspond to the data from other sites, which speaks against environmental causes. Thus, the presence of the faultline and the overburden of water on the sea bottom seem more likely explanations.

Some archaeological features were examined for lichen growth, including stones which were part of the steps of a chapel set up in 1729. These stones were measured using the Schmidt Test Hammer (Sjöberg 1987:38) and found to be much harder than the surrounding stones, having rebound values equivalent to that of the 2 m level on the island. This suggests a date to the mid-1700s.

The weathering of the steps shows that the stones had been overturned when they were put into place. Lichen diameters on the sides and back portion of the steps measure 18-25 mm, with one specimen measuring 31 mm. Using equation 20 for estimating age, 25 mm equals a date of 1751 ±35 and 31 mm a date of 1730 ±35.

Although shore displacement appears somewhat slower on this island, these calculations do not deviate very much from expected shoreline and historical dates.

5.4 Snöan, Västerbotten

The island of Snöan, located some 40 km to the south of Stora Fjäderägg, is also ca 10 km closer to the mainland. Like Stora Fjäderägg, the island was used intensively by fisherman and seal hunters in the past. There are numbers of registered hut sites, mazes and cairns etc. (Löfgren and Olsson 1983).
An extended wave-washed moraine beach facing NNE was sampled at 15 elevations along a 222 m transect from 1.41 to 14.38 m.a.s.l. (App. A6). The correlation between thallus diameter and elevation is .94. All incremental points were used for calculating a growth curve including an exceptionally large R. alpicola which was found in a protected area behind the uppermost beach ridge (thallus diameter 420 mm).

to shore topography and overgrowth, notably between 8 - 12 m.a.s.l; nevertheless the regression lines describing this material do not deviate from the other locales except for Stora Fjäderägg. As the southernmost site to be analyzed, where both shore displacement and environmental differences could be expected, this data was found instead to be in good overall agreement.

Three huts located at about the 17 m level had very large thalli in association, measuring 170 - 280 mm. Using equation 16 and converting elevation to age (Eq. 20) this suggests dates of ca A.D. 864 -1250. Radiocarbon dates from huts of the same type and high elevations at Grundskatan, plus the archaeologically dated find from Stora Fjäderägg (Serning 1960) coincide with this date range.

5.5 Svarthällviken, Västerbotten

Svarthällviken is a small, now uplifted and isolated, bay located just to the north of Grundskatan and below the 5 m elevation contour. This site is particularly interesting within the Seal Hunting Cultures Project because numerous engravings with names of seal hunters and dates between 1791 and 1915 are found on the black rocks by the bay. On its north side, on what was once an island, are some stone features including a partially completed maze.

This low lying locale is very damp and humid as compared with the steep moraine beaches at Grundskatan and Bjuröklubb. Lichen growth on the beach and on features is, consequently, rapid. A growth curve from the beach up to the maze, which lay at ca 3 m.a.s.l., was constructed using five points.

Table 2. Maximum lichen diameters and elevations above mean sea level at Svarthällviken, Västerbotten

Elevation (m)	Max. Thallus Diameter (mm)
1.96	34
2.58	54
2.83	69
3.00	80
2.92	95 (in depression)

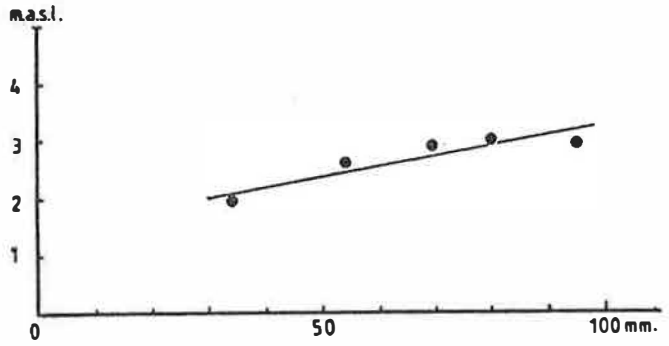


Fig. 13 Maximum thallus diameter and elevations above sea level, Svarthällviken, Västerbotten. $r = .91$, $p < .001$.

The correlation coefficient for these data is .91 and the regression equation is as follows:

(Eq. 17) $$Y = -69.3 + 51.5\ X,$$

where X equals elevation above sea level. The standard deviation of Y is $\pm$11 mm.

A comparison with the nearby Grundskatan equation (Eq. 9).

shows a steady increase with sizes 4 -72 mm larger at Svarthällviken from the 2 m elevation. The humidity of the site is much greater than any of the other locales which could be quantified in a future study.

Table 3. Comparison between calculated lichen growth rates at Svarthällviken and Grundskatan, Västerbotten

Elevation (m)	Eq. 17 (mm)	Eq. 9 (mm)	Diff.
2	34	30	+ 4
3	85	59	+26
4	137	87	+50
5	188	116	+72

The accuracy of Equation 17 for Svarthällviken could be checked using two engravings at the site. Both, from 1797, were overgrown by relatively large thalli of Rhizocarpon geographicum. Thallus sizes were,respectively, 15 and 16 mm which using equation 21, the conversion of elevation to age using general shore displacement rates, rendered 1776 ±20 and 1773 ±20. These results are considered satisfactory in view of all the potential sources of error involved.

Lichen thalli on the maze at the 3 m elevation measured up to 95 mm with the average of the 5 largest thalli equalling 92 mm. The 3 m elevation is estimated as dating to ca 1650 and the calculated age of mean thallus diameter on the maze is 1648 ±20. This means that either the maze was built almost at the water's edge or that the largest lichens were transported with beach stones. According to Benedict (1967) lichens generally do not survive transport but this assumption is hard to prove. Thus, the only way to determine which hypothesis is correct is on the basis of weathering rates for the site, i.e.whether or not these stones were overturned. Both the maze stones and the beach have been examined using the

Schmidt Test Hammer (Sjöberg 1987:45) but unfortunately it was not noted at that time which stones had the largest lichens. According to these calculations about 35% of the stones have with certainty been overturned. It will be an easy matter to correlate lichen sizes with these stones when the site is revisited in 1987.

Lichen growth undergoes two phases, a very rapid initial growth for 100 - 300 years, termed the "great period" by Beschel (1950), followed by a slower linear growth rate for up to 1000s of years (Armstrong 1976; Topham 1977). Although the Svarthällviken material is suggestive of rapid initial growth, this can be entirely due to favorable microenvironmental conditions. On more exposed beaches lichen growth appears, in fact, to be initially retarded nearest the shore due to ice shaving etc. More analysis of favorable locales of this type would help to define the problem but Svarthällviken was the only low lying site of this type thus far studied within the project.

5.6 Bygdeå Church, Västerbotten

The shore growth of lichens in this study has been described using linear equations and, as such, apply primarily to the second phase of growth following colonization which begins after 100 - 300 years (see above). This means that most of the curves apply to lichen growth from ca 2 m.a.s.l. and higher, or from ca A.D. 1750.

In order to analyze growth during its earliest phase following colonization, headstones in the Bygdeå Church cemetery, located about 40 km north of Umeå and about 10 km from the coast, were studied. Rhizocarpon geographicum thalli could be measured on forty-five headstones dating from 1953 to 1864. A source critical presentation of this material is published in Broadbent (1987).

One of the first questions to be addressed applies to the degree of weathering necessary on freshly worked stone surfaces before lichens can colonize. At this site the first headstones to display lichen growth date to 1953 suggesting that ca 35 years of weathering precedes colonization.

Maximum thallus sizes and headstone ages are indicated in figure 14. To describe this material a least squares curve-fitting analysis using a second degree polynomial equation was used since growth is assumed to be exponential rather than linear. The correlation coefficient is .69.
The resulting equation for age from thallus diameter is:

(Eq. 18) $$Y = 16.1 + 3.06\ X + 0.0682\ X^2$$

The standard deviation of Y is $\pm$18 years.

This equation can be tested using undated family headstones, datable through church records, as well as other stone monuments. For example, two family headstones at Bygdeå with maximum thalli measuring 15 mm were estimated, using equation 18, as dating to 1907. Parish records indicate about 1903 for the death of the stones' owners. A Royal momument from Lövånger, located ca 50 km farther north, dates to 1921 and is estimated from lichen size, 13 mm, as dating to ca 1916. In both instances the error is only 4 - 5 years.

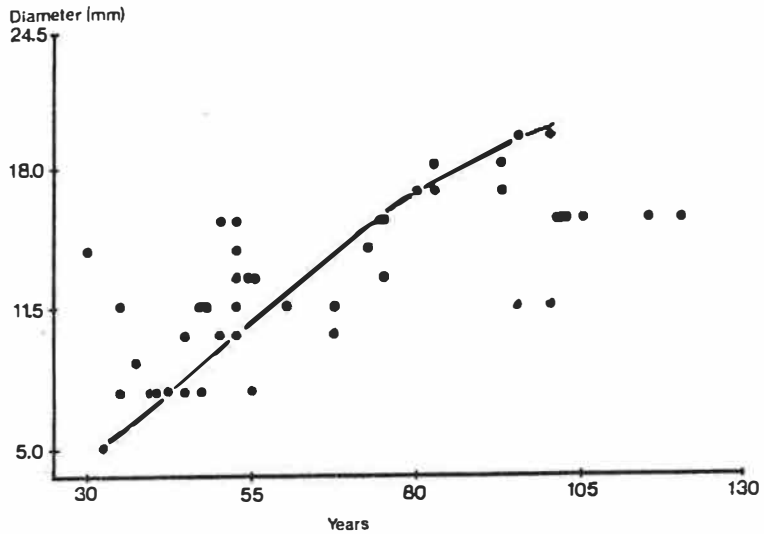


Fig. 14 Thallus diameters on headstones at Bygdeå Church Cemetery, Västerbotten. r = .69

Headstones have been examined at Lövånger, Backen and Holmön churches in Västerbotten and Grundsunda church in Västernorrland. In Finland the Korsnäs church cemetery in Österbotten was studied. Considerable differences can be observed in the relative presence or absence of lichens on the stones due to previous cleaning and/or air pollution. Many of the stones are family-owned and lack dates. At this writing, all church records have not yet been examined. For comparitive purposes, however, the Korsnäs cemetery, which occupies a position similar to Bygdeå church, and had 23 dated stones with Rhizocarpon geographicum growth, can be mentioned. These stones date between 1943 and 1907, a shorter time period than the Bygdeå stones, thus comparisons can only be made within this time range. The correlation coefficient of thallus diameter and age is about the same as at Bygdeå, .71.

On the basis of a second degree polynomial equation to describe the Korsnäs data, it is estimated that a stone with thalli measuring 10 mm will date to 1937 $\pm$6, and 15 mm will date to 1919 $\pm$6. Using the Bygdeå equation, 10 mm will date to 1931 and 15 mm to 1907. These results therefore suggest some consistency in spite of the geographical distance between the Swedish and Finnish Bothnian coasts. In any case, much more data is necessary before any firm conclusions can be drawn. There are many sources of error involved and micro-environmental differences can have considerable influences on local growth.

6. BEACH SAMPLE PLOTS AND SIZE FREQUENCIES

The main prerequisite for using shore elevations to determine growth rates is that there will be remnants of original colonizing populations surviving from the lowest to the highest levels on a shore. Although this hypothesis has proven to be correct, there are gaps in the shore data at the individual sites. These have been primarily related to local shore topography, rock sizes and overgrowth. There is not enough data to relate variations to potential eustatic influences and this seems to have been of minimal importance with regard to the long term lichen growth patterns discussed here. Of considerable interest, nevertheless, is an apparent gap in the shore data between 9-12 m.a.s.l. (fig. 16) which would correspond to a period of transgression in southern Sweden during the Viking Age (cf. Mörner 1984).

Another important question must be considered and relates, instead, to the nature of the lichen populations at each level and the processes of ongoing colonization, competition and succession.

Lichen size frequencies at different elevations were studied at Grundskatan using random 1 m^2 plots. Three plots were made at each level and an additional sample was made of a side beach at the 13 m level at Grundskatan.

Table 4. Sample plots, Grundskatan

Elevation	Mean diameters			Max. diameters			Calc. max
(m.a.s.l.)	I	II	III	I	II	III	
5	24	25	37	90	70	110	116
10	24	33	28	85	155	90	260
11	30	32	25	170	145	90	288
13	25	22	25	170	70	85	345
13	33	29	33	120	190	400	345

The means for thallus sizes within the plots ranged between 22-33 mm for all levels. Maximum observed thallus sizes were more variable but only at the 5 m level did they approach the calculated maximum thallus sizes on the basis of the Grundskatan growth curve (fig. 17). An extremely large thallus from the side beach at the 13 m level was larger than that expected for the Grundskatan beach. This specimen, and other exceptionally large thalli from the same spot, are hard to explain except in microenvironmental or local genetic terms since they so totally diverge from the growth trends seen at this and the other studied sites. Means sizes on these beach plots are, otherwise, within the range of the other samples at Grundskatan.

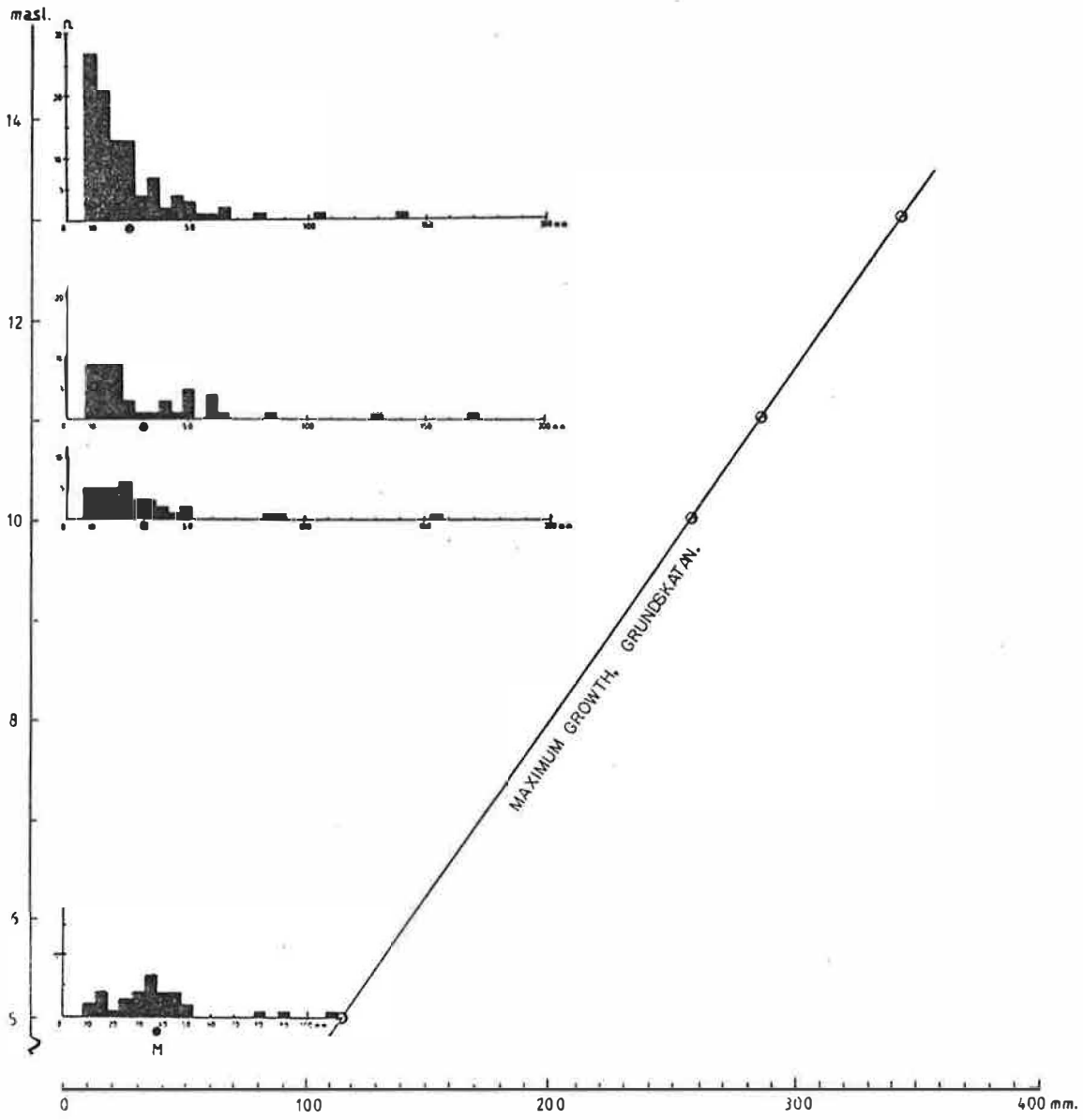


Fig. 17 Size frequencies of thalli in sample plots and maximum growth curve at Grundskatan, Västerbotten

four sites between lichen diameter and R-values (at Bjurö-klubb, Grundskatan, Snöan and Stora Fjäderägg) showed close correspondence with increasing elevations above sea level (Sjöberg 1987:33-63).

Since degrees of weathering can be related to elevation, it is possible to determine whether or not a stone has been overturned at any given level: the undersides of the stones will display a greater degree of hardness and less weathering than the upper, exposed, side of the stones. On this basis it can be possible to accept or reject a large lichen thallus for dating purposes. This was the major reason for testing the Schmidt Test Hammer within this project and may well prove to be one of the most important supplementary methods in lichenometric dating.

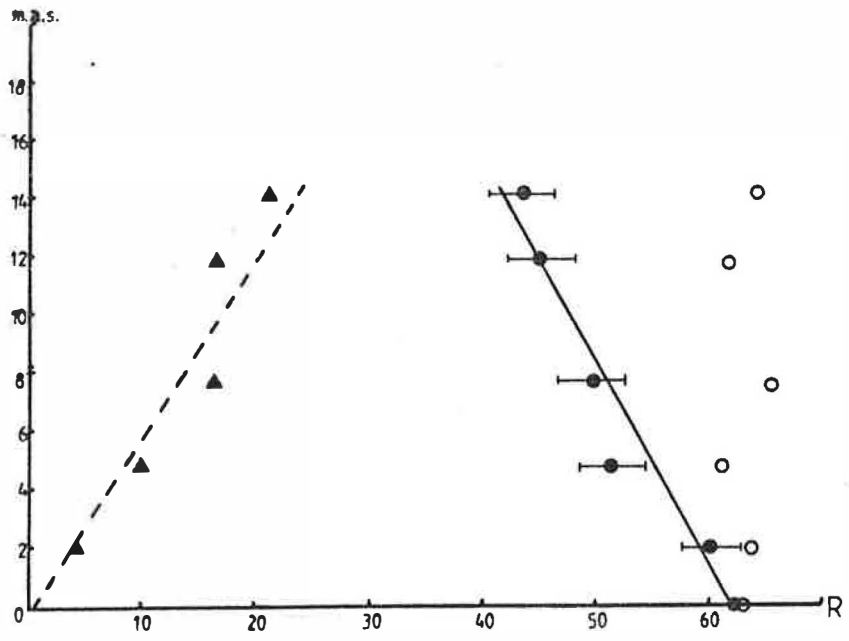


Fig. 19 Right: weathering (R-values) on upper- and under-sides of moraine stones at Bjuröklubb, Västerbotten. Left: differences between these R-values by elevation (Sjöberg 1987).

8. LICHEN GROWTH AND CHRONOLOGY

Thus far the main focus for discussion has been the correlation between elevation above mean sea level and maximum thallus diameter. The goal of lichenometry is to determine not only the rate of growth of a lichen species but to be able to apply this information to chronological problems, that is, to date stone substrates of unknown age.

Present shore displacement on the north Bothnian coast is ca 0.91 cm per year. This rate applies to the northern Västerbotten coast and should also apply to islands of the eastern coast farther to the south. A described previously, a physical model for shore displacement in this region has been used to calculate rates of displacement in the past and to assign elevations approximate ages. The mathematical model is described in Broadbent (1979). For purposes of this study, only elevations below 20 m. a.s.l. are relevant. Some additional shore data and potential eustatic influences (cf. Mörner 1984) are shown in fig. 2.

Table 5. Shore displacement for Västerbotten coast (present rate 0.91 cm/yr).

Year	M.a.s.l.	Rate(cm/yr)
0 BC/AD	21.19	1.26
100	19.94	1.24
200	18.71	1.22
300	17.51	1.20
400	16.32	1.18
500	15.15	1.16
600	14.00	1.14
700	12.87	1.12
800	11.76	1.10
900	10.67	1.09
1000	9.59	1.07
1100	8.53	1.05
1200	7.49	1.03
1300	6.46	1.02
1400	5.46	1.00
1500	4.47	0.98
1600	3.50	0.97
1700	2.54	0.95
1800	1.60	0.94
1900	0.67	0.92
2000	- 0.25	0.90

It has been assumed that land upheaval has dominated shore displacement during the past 2000 years and that eustatic influences this far north were not great enough to disrupt the long term lichen colonization of north Bothnian beaches. It might be possible, however, to study eustatic fluctuations on the basis of lichen growth, if not in this region then farther to the south where transgressions have been documented. As described earlier, the only suggestion of eustatic influence in the present material is a possible gap in lichen shore data at levels corresponding to the Viking period (refer 6). In spite of this,the linearity of the shore growth data is apparant and consistent along the whole north Bothnian shore between Haparanda and Hörnefors.
On this basis, the shore elevations were converted to specific dates using the data in Table 5. The table values were used directly for Bjuröklubband Grundskatan as well as Svarthällviken. Rates were reduced somewhat for the Haparanda elevations. These calculations are given in Appendix B.

The correlation coefficients for thallus diameter and estimated age before present were high: .94 for Haparanda, .99 for Bjuröklubb and Grundskatan and .91 for Svarthällviken.
Linear regression equations for estimating age from thallus diameter were calculated for these locales and are as follows:
For the middle Haparanda archipelago,

(Eq. 19) $Y\ (age) = 84.8 + 3.95\ X$

standard deviation $\pm$ 55 years

for Bjuröklubb and Grundskatan:

(Eq. 20) $Y(age) = 147 + 3.48\ X$
standard deviation $\pm$35 yrs

and Svarthällviken:

(Eq. 21) $Y(age\ AD) = 1802 - 1.73\ X$
standard deviation $\pm$21 yrs

These equations will be used for dating and discussion purposes. The Svarthällviken locale has already been discussed and has been confimed within the standard deviation limits by rock engravings at the site.

Although these equations render absolute dates, they should only be seen as relevant within their standard deviation limits and are intended for use in this coastal zone. The lichen dates should furthermore be viewed as minimal age determinations since colonization of a substrate can never be exactly known, although assumed to be within 5 - 10 yrs. Several source critical problems must be taken into account when dating a feature using lichenometry. Besides the uncertainty of knowing when lichens first colonized a given substrate, there is always some doubt as to whether or not the largest lichens on a feature represent its age. Large lichens can be aberrant or transported from the surrounding area. Benedict (1967, 1985) therefore recommends the use of size frequencies to define feature populations enabling the rejection of very large thalli. As noted earlier it seems unlikely however, that any more than a few individuals ever survive among old populations on these beaches, thus the assumption of a continuous log-normal population can only be expected for relatively young populations (less than 500 yrs).

This leaves the use of single individual sizes or the mean of the five largest individuals as the only alternative for dating features greater than 500 years of age. The only way to be sure of the accuracy of this method is on the basis of weathering, i.e. identifying over-turned stones in a feature using the Schmidt Test Hammer or by comparation with other similar features.

9. LICHENOMETRY AND ARCHAEOLOGICAL FEATURES

9.1 Small Cairns on Östra Knivskär, Haparanda

Parallel rows of small cairns which once supported net drying posts are found on the same beach used for constructing the growth curve (cf. Hederyd 1982). Thallus diameters of R. geographicum were measured on 45 cairns in 4 cairn rows between 3.8 to 7.5 m.a.s.l. The means and medians of thallus sizes for the cairn rows showed consistency independent of elevations above sea level. This suggests a single normally distributed lichen population. Frequencies were converted to a log 10 scale according to Benedict (1967) (Broadbent and Bergqvist 1986). The largest lichen thallus measured 65 mm and an average of the 5 largest lichens, 61 mm. Thus, according to equation 19 , these cairns should date to A.D. 1643 ±55. The lowest lying carins of these rows lay at 3.8 m.a.s.l. which gives a maximum possible date of ca A.D. 1545. This suggests that the cairns were built about 1 m above mean sea level. These results are historically consistent with what is known about the region.

9.2. Grundskatan

Lichen size frequencies were determined for a maze, five cairns and a so-called Russian oven att this site. The maze and cairns lie near the top of a moraine ridge between 13-16 m.a.s.l., and the oven is situated at the 10 meter elevation.

9.2.1 Stone Mazes (Labyrinths)

A stone maze situated at 13.5 m.a.s.l. at Grundskatan was analyzed and the lichen size frequencies indicate a log-normal distribution (fig.21). Maximum lichen diameter for this feature is 95 mm. Using equation 21 the age of this feature on the basis of the largest lichen (95 mm) is estimated as being 1507 ±35 yrs. There is no way to verify this date although the feature overlies a hut which, judging by a radiocarbon date for another hut at the same level, dates to A.D. 780 ±70 (St. 10787). Four lichen dated cairns at the same site coincide with the dating of the maze.

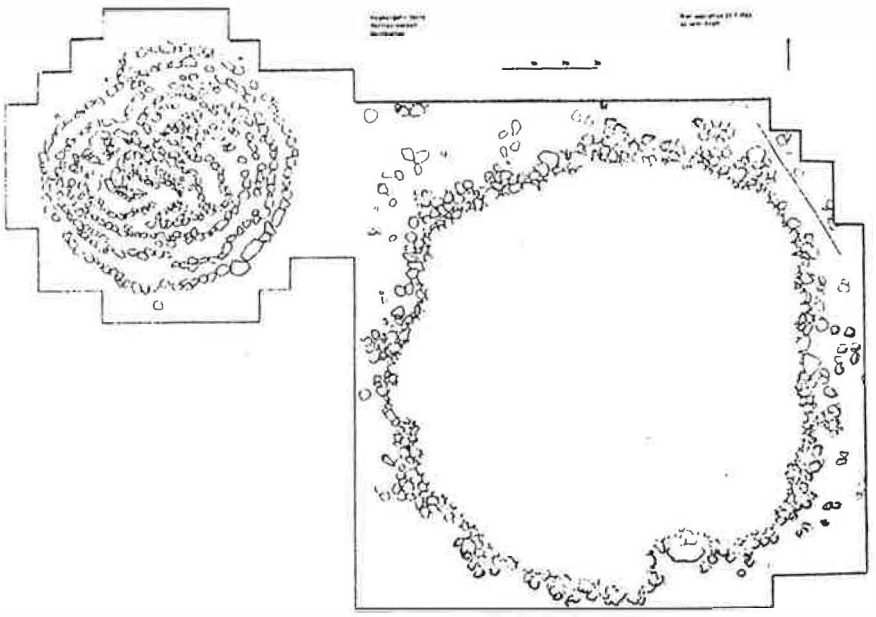


Fig 20 Maze (labyrinth) and outline of cairn at Jävre, Norrbotten. Cairn dates to Bronze Age, labyrinth to A.D. 1455.

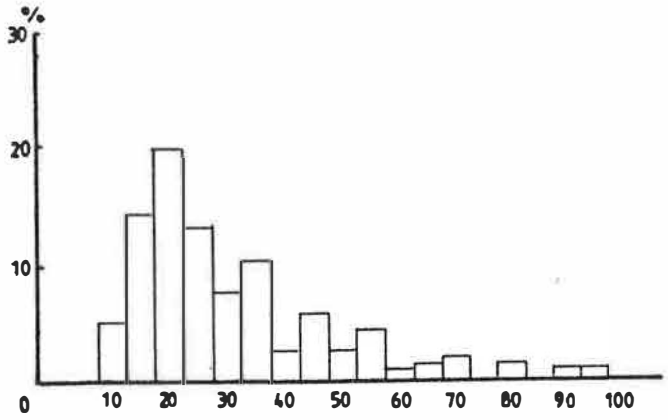


Fig 21 Size frequencies of thalli on maze at Grundskatan, Västerbotten. Sum 183. Estimated age A.D. 1507-1525.

Mazes of this type are very common on the north Bothnian coast but have been almost impossible to date except on the basis of elevation above sea level.

Some preliminary lichen dates based on maximum thalli and averages of the five largest thalli have been determined in addition to Grundskatan, at Ratan, the islands of Skötgrunnan and Snöan in Västerbotten and at Jävre in southern Norrbotten.

Table 6. Lichen datings of mazes (labyrinths)

Site	Elev. (m)	Max. dia.	Mean dia.	Calc. age
Jävre	85	155	104	1299-1476 (1455)
Ratan 1	20	85	67	1542-1604
Ratan 2	20	46	31	1678-1730
Grundskatan	13.5	95	90	1507-1525
Snöan	10	30	25	1816-1850
Skötgrunnan	5	46	38	1677-1706
Svarthällviken	3	95	92	1638-1648

The maze at Snöan was clearly of more recent date than the other features. Overturned rock surfaces can be visually distinguished and the lichen measurements are taken from these faces. Larger thalli transported from the surrounding beach measure up to 50 x 70 mm and many of these were dying or already dead.

The Jävre maze is interesting because it is situated on a mountain top and by a Bronze Age Cairn. The Schmidt Test Hammer was used to measure hardness of the maze stones, hardness beneath the stones (bedrock), and stones in the cairn (refer Sjöberg 1987:47). These results suggest that the maze stones were taken from the heavily weathered surface of the cairn. Lichen growth suggests a medieval date for the maze which, by virtue of its elevation and proximity, could otherwise be interpreted as contemporary with the cairn. The largest thallus on an overturned stone in the maze measures 115 mm which renders a date of A.D. 1455 making this the oldest dated maze thus far analyzed.

The Ratan mazes date to periods in which mercantile activity was particularly intense at this natural harbour ("Norrlands-hamn"). In 1640 a request was made to establish a market there and in 1695 an inn was built on the island (Fahlgren 1963). The younger maze is most probably a copy of the first feature.

The Skötgrunnan maze lies at an elevation of 5 m and is undoubtedly connected with the herring fisheries which operated from the island. This island was granted to the Pite fishermen by Queen Kristina at the end of the 17th century (Fahlgren 1953:278) and the lichen dates coincide with this period.

The datings of these stone mazes all fall within a 400 year period between 1450 and 1850 which is consistent with the idea that they were built by fishermen during medieval and historical times. Their elevations are misleading since they occur as high as 85 m.a.s.l. Even associations with other stone features can be misleading judging by the Jävre maze which lies close to a Bronze Age cairn and the Grundskatan maze which lies among, and on, huts which have now been radiocarbon dated to the early Viking period (unpublished).

9.2.2 Cairns

Lichen size frequencies on five cairns situated between 13 and 16 m.a.s.l. were studied at this site. The size distributions on four of the cairns are very similar and terminate at 90 - 110 mm. The fifth cairn was largely overgrown. If one accepts the hypothesis that these populations reflect age then the cairns should date to between A.D. 1455 - 1525. Nevertheless, three lichens on three of the cairns, measuring repectively 135, 166 and 175 mm, would render dates of A.D. 1229 - 1368.
Three of the cairns were excavated but did not provide any organic remains which could be radiocarbon dated. This leaves testing using the Schmidt Test Hammer as the only way to know which values are most accurate, although the lichen dates are all within the medieval period and thereby not contemporary with the radiocarbon dated huts found at the same elevations. The fact that the cairns and the maze at Grundskatan all date to this time period speaks in favor of them belonging together archaeologically. Further testing of this site is planned.

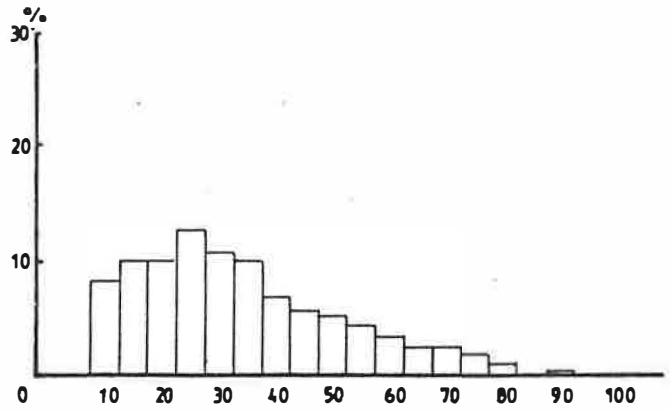


Fig 22 Size frequencies of thalli on cairn at Grundskatan, Västerbotten. Sum 199. Estimated age A.D. 1455-1525.

9.2.3 A Russian Oven

All lichens on a Russian oven at Grundskatan were measured and the size-frequency distribution appears log-normal.[1]

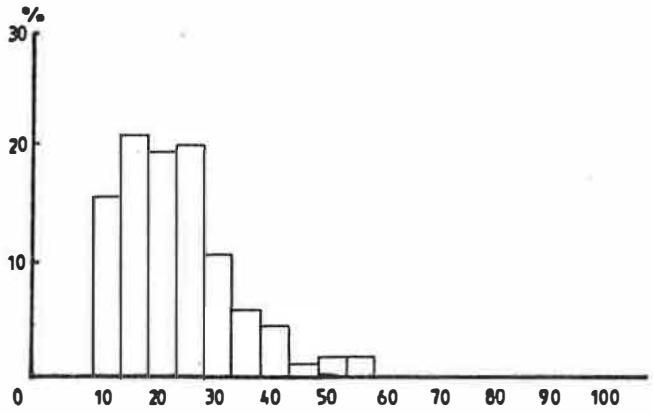


Fig 23 **Size frequencies of thalli on Russian oven at Grundskatan, Västerbotten. Sum 138. Estimated age A.D. 1706.**

Maximum lichen diameter in the distribution is 55 mm. Using the growth curve for Grundskatan a date of 1659 ±35 is obtained. Features of this type are considered as having been built during the Russian invasions of the coast in the early 1700s (cf. Flink 1985; Dahlström 1937). This suggests that the nearby Svarthällviken growth curve is more suitable for such a young feature and, indeed, according to Eq. 21 it would date to 1706 ± 21. Carbon from the oven was subsequently radiocarbon dated to ca 1700 (St. 10784), which is fully consistent with the interpretation of the feature as a relic of the Russian invasions. The elevation, 10 m, would date it to the Viking period.

1. Note. Frequencies somewhat truncated on left since thalli less than 10 mm were not measured.

10. FINAL CONCLUSIONS

The study has provided evidence that lichen growth on displaced beaches in the North Bothnian region follows linear trends between ca A.D. 600 and 1750.

This, conversely, suggests that environmental differences and irregularities in shore displacement have not been great enough to disturb long term lichen growth on these shores.

On this basis, growth rates for Rhizocarpon geographicum sensu latu and Rhizocarpon alpicola can be predicted and ages (±35-55 years) can be assigned thalli on archaeological and historical features.

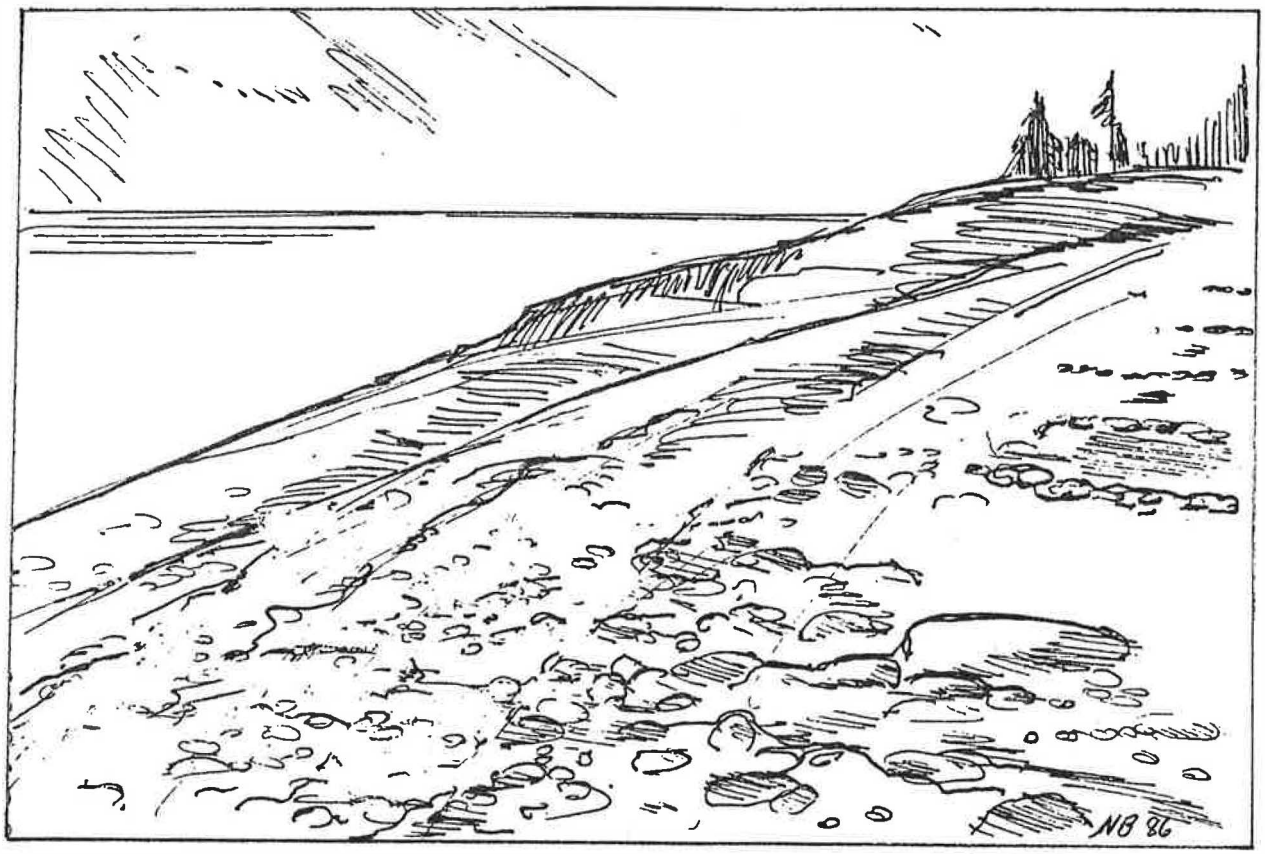
Lichen size frequencies were found to be of limited use for describing and dating successively higher-lying beach levels and/or features more than 500 years of age. The Schmidt Test Hammer can be used instead to accept or reject large thalli for dating purposes.

Various archaeological features including cairns, mazes (labyrinths), huts, a Russian oven and chapel steps were dated using associated lichen growth. These results were compared with shore level and radiocarbon datings as well as historical facts. Church headstones were used to define rapid initial lichen growth during the past 150 years.

This study has indicated that lichenometry can be developed on the basis of shore displacement and can function as a useful chronological tool in this northern coastal region.

The main focus of this project has been archaeological and more detailed analyses of beach topography on the basis of lichen growth, i.e. indications of eustatic variations, storminess and climate changes, were not attempted. This, however, could be a productive theme for future research.

In general, the potentials for studying lichen growth and developing lichenometry are probably better in this region than anywhere else in the world. There are more opportunities for establishing local chronologies using shore displacement, archaeological and historical dates, and for making comparisons between locales. The archaeological project will be continued for one more year but hopefully these results will lead to other projects within other disciplines.



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A 4 GRUNDSKATAN

	Elevation (m)	Diameter (mm)	Comments
	1.10	colonization	
1	2.09	19	
2	2.62	39	
3	2.68	49	
4	3.92	105	partially overgrown
5	4.18	105	
6	4.36	170	Rh alpicola (hanging)
7	4.82	128	
8	5.31	114	shooting blinds
9	5.87	133	
10	6.33	-	overgrown
11	6.41	-	"
12	6.67	170	
13	7.40	181	
14	7.86	153	hut, small cairns
15	8.21	-	" "
16	8.63	211	
17	8.94	230	overgrown
18	9.22	-	"
19	10.08	-	shooting blinds
20	10.58	-	
21	10.67	-	above Russian oven
22	11.07	-	
23	11.53	-	
24	11.79	250	
25	11.95	-	cairn, huts
26	12.15	-	"
27	12.94	-	"
28	13.30	-	"
29	13.52	-	labyrinth, huts

A 5 STORA FJÄDERÄGG

	Elevation (m)	Diameter (mm)	Comments
1	1.18	16	
2	1.85	26	
3	2.27	41 (53)	Rh alpicola
4	2.74	67 (69)	" "
5	2.91	87	
6	3.38	72	
7	3.90	95 (110)	Rh alpicola
8	4.27	100	
9	4.36	100	numerous of same size
10	4.94	100	
11	5.97	150	Rh alpicola
12	6.24	150	depression
13	7.63	-	overgrown base of ridge
14	8.46	180 $\bar{x}$	(20x16)
15	8.85	190	
16	10.13	200	
17	11.04	260	
18	11.36	260	
19	12.10	275 $\bar{x}$	(290x260)
20	13.49	260	
21	14.53	310	
22	15.58	360	

APPENDIX B

B 1 Elevation, dates and maximum thallus diameters of *R. geographicum* at Ö. Knivskär and St. Hepokari, Haparanda archipelago.

Elevation	Displ.(cm/yr)	Date A.D.	Years(B.P.)	Max.Dia.
1.16	0.92	1848	137	16
1.70	0.93	1791	194	39
2.88	0.94	1667	319	48
2.95	0.94	1660	325	57
3.41	0.96	1613	372	75
3.97	0.96	1556	428	85
4.17	0.97	1535	449	98
5 05	0.98	1446	538	112
5.85	0.99	1367	618	131
7.44	1.02	1212	772	145
7.68	1.02	1189	796	200

B 2 Elevations, dates and maximum thallus size of *R. geographicum* and *R. alpicola* at the Grundskatan site

Elevation	Displ.(cm/yr)	Date A.D.	Years(B.P.)	Max.Dia.
2.09	0.94	1748	237	19
2.62	0.95	1692	293	39
2.68	0.96	1685	300	49
3.92	0.96	1556	429	105
4.36	0.97	1511	473	170*
4.82	0.98	1464	521	128
5.87	1.01	1359	626	133
6.67	1.01	1280	705	170
7.40	1.02	1209	776	181
8.63	1.05	1090	895	211
8.94	1.06	1071	914	230

* *R. alpicola*

B 3 Elevations, dates and maximum thallus size of *R. geographicum* and *R. alpicola* at the Bjuröklubb site

Elevation	Displ.(cm/yr)	Date A.D.	Years(B.P.)	Max.Dia.
2.13	0.94	1743	242	19
2.67	0.95	1686	299	39
3.33	0.96	1618	367	60
4.21	0.97	1527	458	93
4.82	0.98	1465	520	97
5.16	0.99	1430	555	116
6.51	1.01	1305	680	140
7.76	1.03	1174	811	190
8.57	1.05	1095	890	240*
10.24	1.07	940	1045	245
12.19	1.11	761	1224	310
14.29	1.15	575	1410	358

* *R. alpicola*