

Alinlampi, a Late-Glacial site in the northern Karelian Republic

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A re-investigation of Alinlampi — known previously to have a complete stratigraphic succession from Younger Dryas (> 10 640 B.P.) to mid-Holocene (“Atlantic”) — was made using pollen, macrosubfossil and diatom analyses. The palynological and macrofossil analyses give a detailed picture of the vegetational succession consisting of three Late Weichselian and three Holocene stages. The first two phases represent pioneer vegetation before the development of forests. The NAP flora is very rich with many exotic elements, i.a. *Dryas octopetala*. Birches have been present from the beginning, first as solitary copses but by the end of the Late Weichselian as light forests. *Betula nana* characterizes the intermediate phase between open vegetation and forest. The Holocene forests have been dominated by pine and birches. The diatom succession reflects a development from cold, slightly alkaline conditions to warmer ones with increased alkalinity, and again to a colder and less alkaline state.

Key words: *Betula nana*, diatoms, *Dryas octopetala*, Holocene, Late Weichselian, macrofossils, paleoecology, pollen

Introduction

Since the discoveries of Late-Glacial *Dryas* vegetation in the southeastern foreland of the last glaciation in Fennoscandia by Lindberg (1900, 1916) and Markow and Poretzky (1935), knowledge concerning eastern periglacial vegetation increased considerably during the latter part of the 20th century. Especially noteworthy in this respect are the works by Repo and Tynni (1967, 1969), Hyvärinen (1971, 1972), Elina (1981),

Elina and Filimonova (1987), Bondestam *et al.* (1994), Demidov and Lavrova (2000), and Elina *et al.* (2000). Also valuable were the macrofossil analyses of Bondestam *et al.* (1994) as an addition to the more numerous pollen studies. Their results have recently verified the concept of a general occurrence of *Dryas* heaths in eastern Fennoscandia during the Late Glacial period as suggested by Kotilainen (1929) in the early 20th century (*see also* Vasari 1999).

There are five regions in eastern Fennoscandia

dia known for the recent occurrence of obvious relics of arctic-alpine biota, i.e. Ladoga and Onega Karelias, Finnish Northern Karelia, and the Kainuu and Kuusamo regions (Jalas 1961). Valuable information concerning Late Glacial vegetation in Russian Northern Karelia (*Karelia pomorica occidentalis*) has been provided by modern pollen diagrams from Shombashuo (65°05'N, 33°03'E; Elina 1981, Elina & Filimonova 1996) and Alinlampi (64°24'N, 34°22'E; Ekman *et al.* 1991).

A pollen diagram from Alinlampi, a little tarn immediately on the proximal side of the Rugozero (Rukajärvi) marginal moraine, was published in the guide book of the Field Conference on eastern Fennoscandian Younger Dryas end moraines (Ekman *et al.* 1991). It gives a detailed picture of the local pollen succession from Younger Dryas to the mid-Holocene as supported by three radiocarbon datings. The analyses of the botanical macroremains, however, gave only meagre results, revealing only the presence of the moss genera *Drepanocladus s. lato* and *Calliergon*. Because of this lack of information on macroscopic remains, the authors decided to make a renewed investigation with a special focus on them. The purpose was to get a more comprehensive picture of the conditions prevailing in front of the retreating glacier.

Material and methods

Alinlampi is a small, almost round, little lake, ca. 800 m in diameter. It lies on the proximal side of the high Rugozero (Rukajärvi) marginal moraine on top of which the village of Pushnoj is situated (Ekman *et al.* 1991: figs. 21 and 24). The big lake Shuezero (Suikujärvi), separated from Alinlampi by a low, narrow isthmus, lies at an altitude of 104 m a.s.l. The northern and eastern parts of the Alinlampi basin are very shallow, only 1–2 m deep with a sandy bottom. The southern part below the steep side of the marginal moraine is more than 10 m deep.

The bedrock consists of generally acid, Archaean rocks, migmatites and granitoids with some local amphibolites and greenstones (Luukkonen & Sorjonen-Ward 1998: fig. 4.2, Systra 2003: fig. 3). In the Russian landscape-geobo-

tical zonation of Karelia, Alinlampi is situated close to the boundary between two regions, the Pribelomorskaya lowland with the dominant vegetation consisting of *Pinetum cladinoso-hylocomiosum* and ombrotrophic bogs, and the Onega–White Sea watershed with *Pinetum sphagnosum* and aapa mires. According to the Russian geobotanical classification, the area is a part of the northern taiga forests (Elina *et al.* 2000), whereas in the western classification, this region belongs to the middle-boreal forest vegetation zone, the slightly oceanic-indifferent section of it (Ahti *et al.* 1968, Moen 1998). The relative mildness of the climate and the resulting character of the vegetation must be due to the close proximity of the White Sea and the rather low altitude of the landscape.

Sample collection

The material was collected on 18 April 2001. The sampling equipment used was a Russian peat sampler with a chamber 100 cm long and 7 cm in diameter. The sampling was done in the deepest part of the lake, close to the southern shore, at a place where the depth of the water was 770 cm and the thickness of the sediment 230 cm. The cores were taken with 10 cm overlap, cut in two and packed in plastic film as 50 cm pieces. Stratigraphical observations were somewhat superficial in the field and were checked later in the laboratory. The samples were brought to the Laboratory of Mire Ecosystems in Petrozavodsk, where they were kept in a cool store room until further treatment.

Laboratory analyses

The samples were dealt with in autumn (8–13 October) 2001. The original field observations were checked and the stratigraphy was described as follows:

- 1000–990 cm fine clay with remains of *Warnstorfia fluitans*,
- 990–980 cm clay with quartz grains,
- 980–970 cm clay with remains of *Warnstorfia fluitans*,

- 970–900 cm clay,
- 900–890 cm gyttja-clay,
- 890–870 cm clay-gyttja,
- 870–770 cm black loose gyttja.

Pollen and spores

For the pollen preparations, subsamples of 6 cm³ were taken between 1000–920 cm. Between 920–750 cm most of the samples were of 2 cm³ with the exception of 870–840 cm, where the volume could not be exactly measured because the consistency of the material was too soft.

Pollen preparations were made in the laboratory of Quaternary Geology and Palaeoecology, at the Institute of Geology. Minerogenic material was separated according to Grichuk's method using KJ + CdJ₂ heavy liquid (Grichuk & Zaklinskaya 1948). The organic fraction was then treated by the standard acetolysis technique (Fægri & Iversen 1964: p. 71).

The mounting medium was glycerol. Preparations were studied using a "Axiolab" microscope (Carl Zeiss, Jena). Pollen identifications were based on Moore *et al.* (1991), Kuprianova and Aleshina (1972, 1979) and Bobrov *et al.* (1983) in combination with a reference collection of modern material. The works of Kuprianova and Aleshina (1972, 1978) were relied upon in the identification of birch pollen. Special keys for Chenopodiaceae (Monoszon 1973 and consultation with E. I. Devyatova) as well as for *Urtica* and Polygonaceae (Punt *et al.* 1988) were also used. The identification of *Pediastrum* algae was based on Komarek and Jankovská (2001). Pollen diagrams were constructed using Tilia and Tilia Graph programs (Grimm 1991, 1992). The basic pollen sum (P) consists of the pollen taxa of trees, shrubs and dwarf shrubs as well as of non-arboreal pollen (NAP). Aquatics and spores were excluded from the pollen sum.

Macroscopic remains

After the subsamples for pollen and diatom analyses were taken, all the remaining material was used for the analysis of macroscopic remains. The cores were cut into 10-cm long pieces and

the overlapping parts of the cores were combined. Accordingly, the sizes of the individual samples are variable.

The samples were mixed with water and kept for about 24 hours before being washed through a sieve of 0.25 mm. The identification of the macroscopic plant remains was done with the help of handbooks such as Aalto (1970), Beijerinck (1947), Bertsch (1941), Dombrovskaya *et al.* (1959), Jessen (1955), Kats *et al.* (1977) and Schoch *et al.* (1988). Comparisons with recent material in the Herbarium of the University of Helsinki were also made. With regard to the subfossil fruitlets and catkin scales of birch, it is to be noticed that the two subspecies of *Betula pubescens*, ssp. *pubescens* and ssp. *czerepanovii*, were not separated.

The plant material is kept in a glycerol–alcohol mixture in the Botanical Museum, University of Helsinki.

Diatoms

Altogether 16 diatom samples from Alinlampi were taken at 10 cm intervals between 970–750 cm and analysed. At intervals 950–920 and 870–840 cm no samples could be taken.

Processing included treatment with Na₂P₃O₁₀, a water solution of CdJ₂ + KJ (specific gravity = 2.6) followed by washing with distilled water. Slides were mounted with anilin-formaldehyde tar, with a refraction index of 1.68. The number of diatoms was low at the depths of 970–900, 880–870 and 780–770 cm. Between 108 and 500 diatom frustules were counted from each sample. All diatoms in each subsample were identified with the "Jenaval" light microscope (Carl Zeiss, Jena) at 1000× magnification and under oil immersion. Diatom identification was done mainly according to Mölder and Tynni (1967–1973), Tynni (1975–1980), and Krammer and Lange-Bertalot (1986–1991). These reference books were also used as a source for ecological information. The diatoms were grouped in terms of their pH requirements and geographical distribution. The changes in pH during the course of the development of the lake were followed by means of the pH groups according to Meriläinen (1967) and Davydova (1985). The

sicaceae, *Thalictrum alpinum*, *Rumex*, *Oxyria*, *Cornus suecica*, *Urtica*, Polemoniaceae, *Pedicularis*, *Ranunculus*, *Caltha*, Asteraceae undiff. and *Serratula* type. The shrub and dwarf-shrub pollen groups included *Betula nana*, *Salix*, *Ephedra*, Ericales undiff. and *Empetrum*. The aquatic pollen flora was poor, consisting of occasional pollen grains of *Alisma*, *Typha latifolia* and *Myriophyllum spicatum*. Polypodiaceae (1.4%–2.7%) dominated among the spores of the pteridophytes. Also, spores of *Diphasiastrum complanatum*, *D. alpinum*, *Lycopodium annotinum* ssp. *alpestre* and *L. annotinum* ssp. *annotinum* as well as *Selaginella selaginoides* and *Equisetum* were found. *Isoetes* (undiff.) spores were found in small quantities.

Bryales and *Sphagnum* dominated the moss spore group. Hepaticae spores evidently indicate bare mineral soil.

Sub-unit 1B (980–930 cm), *Artemisia*–*Betula nana* PAZ

The relative proportions of AP decreased while those of shrubs (*Betula nana*) and NAP increased as compared with those in the previous sub-unit. The samples were still rather poor in palynomorphs although altogether 73 different taxa were found.

Pollen of *Betula* increased, *B. pubescens* being the dominant type (22.1%–33%) also including *B. pubescens* ssp. *czerepanovii* (1.0%–2.8%). *Alnus incana* had a continuous curve; one pollen grain of *Alnus* cf. *viridis* ssp. *fruticosa* was also found. Single pollen grains of *Ulmus* and *Tilia* were regularly present; pre-Quaternary pollen grains had a low but continuous curve.

Betula nana (4.5%–7.8%) and *Salix* (1.1%–2.8%) were the most common shrubs. *Ephedra* (1–2 pollen grains) and *Hippophaë rhamnoides* (1 pollen grain) were also found.

Artemisia was the most common taxon among the NAP, its proportion rising to 23.5% before gradually decreasing to 9.5%. Values of Chenopodiaceae (2.1%–4.4%) and Poaceae (2.4%–3.8%) remained at about the same level as before. Cyperaceae pollen percentages increased gradually and reached up to 11.2%. Asteraceae, Caryophyllaceae, *Helianthemum*,

Dryas and Ranunculaceae all had continuous but low curves. The NAP flora as a whole was very rich, including *Armeria*, Brassicaceae, *Cornus suecica*, *Thalictrum alpinum*, *Potentilla* type, *Pedicularis*, *Urtica*, *Rumex/Oxyria* type, *Gentiana*, *Viola palustris* type, *Plantago media/major* type, Papaveraceae, *Serratula* type, *Bidens* type, *Aster* type, Apiaceae, *Epilobium* (possibly also *E. angustifolium*), *Rubus chamaemorus*, *Saxifraga*, *Valeriana*, *Polygonum* type (incl. *P. amphibium* and *Bistorta major*). The Chenopodiaceae group included at least *Chenopodium album*, *C. rubrum*, *C. polyspermum*, *C. foliosum*, *Bassia scoparia*, *Kochia laniflora*, *Ceratoides latens*, *Atriplex nudicaulis*, *Salsola kali* and *Salicornia herbacea*.

Pollen of aquatic plants (besides *Polygonum amphibium*, also *Alisma*, *Potamogeton*, *Sparganium*) was rare.

Polypodiaceae formed the most common group among the pteridophyte spores; other taxa were *Equisetum*, *Isoetes*, *Botrychium boreale*, *Diphasiastrum complanatum* (low, discontinuous curve), *Huperzia* cf. *selago* and *Lycopodium annotinum*, both ssp. *annotinum* and ssp. *alpestre*. Bryales spores increased in the upper part of this sub-zone while those of *Sphagnum* decreased. Only one Hepaticae spore was found.

Pediastrum colonies had a maximum. Pre-Quaternary pollen grains did not occur.

Sub-unit 1C (930–910 cm), *Betula nana*–Ericales PAZ

The pollen composition of this sub-unit reflected an intermediary stage between treeless pioneer vegetation and developing forests. Pollen of *Betula pubescens* ssp. *pubescens* was rather abundant whereas *B. pubescens* ssp. *czerepanovii* pollen decreased. *Betula pendula* pollen increased at the boundary of this sub-unit. *Populus* pollen appeared for the first time and formed a continuous curve. Also *Pinus* rose markedly at the upper boundary of this sub-unit. Pollen of two typical indicators of bare mineral soil, *Artemisia* and Chenopodiaceae decreased markedly at the upper limit of this sub-zone. The dwarf-shrubs, *Betula nana*, Vacciniaceae (i.e. Ericaceae) and *Empetrum*, together with *Junipe-*

rus, had rather short-lived maxima. *Salix* pollen increased again after a minimum at the end of the previous zone.

The aquatic flora was quite variable, including *Isoëtes*, *Typha latifolia*, *Myriophyllum*, *Alisma*, *Sparganium*, *Potamogeton* and *Nuphar*.

Fern spores appeared here. *Equisetum* spores had a clear maximum, as did also *Diphasiastrum complanatum*. *Lycopodium annotinum* ssp. *annotinum* and ssp. *alpestre* were characteristic spore types. *Lycopodium clavatum* made its first appearance here.

Bryales spores were still numerous, as they were during the previous phase. *Pediastrum* colonies were also common, *P. boryanum* var. *boryanum* being the main type.

Palynomorph unit 2 (910–750 cm)

This unit was characterised by a clear dominance of tree pollen, an indication of the existence of forests. In the stratigraphy, the until now almost purely minerogenic clay became richer in organic content before changing to pure black gyttja.

Sub-unit 2A (910–855 cm), Betula–Pinus PAZ

Fifty-one pollen and spore types. Pollen spectra showed a marked increase of tree pollen values (94.9%). *Betula pubescens* ssp. *pubescens* dominated (23.5%–54.3%). The *Pinus* curve began with a peak (57.9%) in the lowermost part of the zone and then fell to a value of 28.5% in the upper part. Pollen of *Betula pendula* (1.9%–3.8%), *B. pubescens* ssp. *czerepanovii* and *Picea* (2.8%–4.9%) was present in some samples. Pollen of *Alnus incana* occurred constantly, having had a minimum in the previous PAZ. Pollen of *Alnus glutinosa* appeared. *Salix* pollen increased again after a minimum at the end of the previous zone. A drastic decrease occurred in the representation of *Artemisia*, Chenopodiaceae and Ericales pollen.

Psittacanthid and lycopod spores were fairly abundant. *Diphasiastrum* spores were more abundant during this phase than at any other time. The *Equisetum* curve fell.

The aquatic flora was fairly rich, including *Isoëtes*, *Alisma*, *Sparganium*, *Typha latifolia*, *Potamogeton*, *Myriophyllum* and *Nuphar*. *Pediastrum boryanum* var. *boryanum* was the most common *Pediastrum* type.

Sub-unit 2B (855–820 cm), Pinus–Betula PAZ

Forty-two pollen and spore types. The pollen spectra were characterised by maximal dominance of AP (93.9%–97.4%). *Pinus* was the dominant pollen type, while pollen of *Betula pubescens* ssp. *pubescens* decreased gradually. *Betula pendula* had a weak maximum, and the *B. pubescens* ssp. *czerepanovii* pollen curve decreased clearly after a weak rise at the beginning of this sub-phase. The curve of *Alnus incana* rose. The amounts of *Salix* and all other shrubs decreased as did all the NAP types.

The aquatic flora was quite poor, consisting of only *Isoëtes*, *Batrachium* and *Polygonum amphibium*.

Sub-unit 2C (820–750 cm), Pinus–Betula–Alnus–Picea PAZ

Fifty-nine pollen and spore types. The dominant AP type was *Pinus*. Both *Betula pubescens* ssp. *pubescens* and *B. pendula* were also important constituents whereas *B. pubescens* ssp. *czerepanovii* did not occur. *Picea* pollen increased after a transient minimum in the previous sub-zones. Pollen of *Alnus incana*, *A. glutinosa* and broad-leaved deciduous trees (*Quercus*, *Ulmus*, *Corylus*, *Tilia*) all had maxima in this zone. *Betula nana* was still present, being the commonest member of the poor shrub pollen flora. *Rhamnus frangula* and *Viburnum opulus* were other shrubs.

The proportion of NAP was low. Among the pollen types present, *Urtica* and *Humulus* (three pollen grains) as well as Liliaceae deserve mention.

The aquatic flora contained *Isoëtes*, *Typha latifolia*, *Batrachium*, *Polygonum amphibium*, *Myriophyllum spicatum* and *M. alterniflorum*.

Pediastrum boryanum ssp. *boryanum* colonies were the most numerous algal remains.

Polypodiaceae spores were the most numerous of the pteridophyte spores. The occurrence of *Pteridium aquilinum* deserves special mention. *Sphagnum* spores were again common.

Macroscopic plant remains

A characteristic feature of the Alinlampi succession was the exceptional poverty of the samples. This may be due to the great depth of the sampling site, close to the steep side of the adjoining moraine ridge.

The macroscopic remains found did not allow distinguishing of any natural units, being thus best surveyed against the background of the palynomorph units (Table 1).

Palynomorph unit 1

Sub-unit 1A (1000–980 cm), NAP PAZ

Five taxa. One seed of *Najas flexilis*, oospores of *Nitella* and numerous fragments of *Warnstorfia fluitans* were the only remains of aquatic plants. Terrestrial material consisted of one fragment of *Salix herbacea/polaris* leaf and two fruitlets of *Betula pubescens* type.

Sub-unit 1B (980–930 cm), Artemisia-Betula nana PAZ

Nine taxa. Most of the macroremains found were, as before, fragments of *Warnstorfia fluitans*. Several oospores of *Nitella* and one oospore of *Chara* were found. Fragments of *Salix herba-*

Table 1. Diaspores and other macrofossils found in the sediment samples. Abbreviations: b = bark, c = catkin scales, f = fragments, lf = leaf fragments, n = needles. Symbols: + = very sparse, ++ = sparse, +++ = rather sparse, xx = abundant.

	1000–990	990–980	980–970	970–960	960–950	950–940	940–930	930–920	920–910	910–900	900–890	890–880	880–870	870–860	860–850	850–840	840–830	830–820	820–810	810–750
<i>Chara</i> , oospores			1																	
<i>Nitella</i> , oospores	1	1	1			6			1											
<i>Warnstorfia fluitans</i>	+	xx	xx	xx	++									+						
<i>Calliergon</i> sp.																				++
<i>Najas flexilis</i>	1																			
<i>Potamogeton perfoliatus</i> , f																				+
<i>Stratiotes aloides</i> , spine										1										
<i>Typha</i> sp., f											++									
<i>Schoenoplectus lacustris</i>																				1
<i>Phragmites australis</i> , f											+	++	+		++					
<i>Dryas octopetala</i>						1		2												
<i>Dryas octopetala</i> , lf						++	++	1	1											
<i>Salix herbacea/polaris</i> , lf	1		++		++	+	+				+		++							
<i>Salix reticulata</i> , lf			+	++	++	+														
<i>Juniperus communis</i> , n												2								
<i>Betula nana</i> , c			2							1										
<i>Vaccinium microcarpum</i>												1								
<i>Eriophorum</i> , f											+		+							
<i>Juncus</i> sp.			1																	
cf. <i>Puccinellia</i>			1																	
<i>Betula</i> cf. <i>pubescens</i>		2	5		1		1		1	3	1	7	6	1	1					
<i>Betula</i> cf. <i>pubescens</i> , c												1	3	1	1					2
<i>Pinus silvestris</i>																1				
<i>Pinus silvestris</i> , n																	1			1
<i>Pinus silvestris</i> , bf													++	++	++					++
<i>Picea</i> sp., bf														++	++					

cea/polaris continued to occur in this sub-zone, similarly as also *Dryas* (leaf fragment and one fruit) and *Betula pubescens* (fruitlets). The new taxa found were *Betula nana*, *Salix reticulata* (leaf fragments), *Juncus* and Poaceae (cf. *Puccinellia?*).

Sub-unit 1 C (930–910 cm), Ericales–Betula PAZ

Three taxa. The only taxa within this section were *Nitella* (one oospore), *Dryas octopetala* (two fruits and fragments of leaves) and *Betula* cf. *pubescens* (one fruitlet).

Palynomorph unit 2

Sub-unit 2A (910–850 cm), Betula–Pinus PAZ

Twelve taxa. The occurrence of *Nitella* oospores ceased in this section. Fragments of *Warnstorfia fluitans* occurred but sparsely; tissue fragments of *Eriophorum*, *Phragmites*, *Salix* sp. and *Typha* were found. Fruitlets and fruit scales of *Betula pubescens* occurred fairly abundantly in several samples. Also, pieces of *Pinus* bark and one seed were found. Two seeds of *Juniperus* indicated its presence.

One fruitlet of *Betula nana* and a seed of *Vaccinium microcarpum* were also found. A new taxon was *Stratiotes aloides*, represented by a spine.

Sub-unit 2B (850–820 cm), Pinus–Betula PAZ

One taxon. A very sterile section, in which only *Pinus* was found.

Sub-unit 2C (820–750 cm), Pinus–Betula–Alnus–Picea PAZ

Eight taxa. A needle plus some tissue of *Pinus* and fruitlets of *Betula pubescens* were the remains of trees. Besides these, also a fruitlet

of *Schoenoplectus lacustris* and tissue of *Typha*, *Potamogeton perfoliatus*, *Carex chordorrhiza*, *C. lasiocarpa* and *Calliergon* were found.

Diatom succession

Unit DAL-1 (970–950 cm)

Twenty-five taxa with the planktonic *Aulacoseira* species dominating (80.8%; Fig. 2). The remainder consisted of the epiphytic forms of *Fragilaria* spp., *Tabellaria flocculosa*, *Gomphonema* spp., benthic *Anomoeoneis* spp., and *Pinnularia* spp. Arcto-alpine and boreal forms together comprised 50% of all diatoms. The water level of the lake seems to have been moderately high, the water rather cold and the pH about 6.4 (Fig. 3).

Unit DAL-2 (950–880 cm)

A drastic change took place in the diatom community (Fig. 2). The dominant taxa were planktonic ones: *Aulacoseira granulata*, *A. granulata* var. *angustissima*, *A. italica*, *A. italica* var. *valida* and *A. distans*. Subdominant taxa were epiphytic species of *Fragilaria*, *Gomphonema*, *Achnanthes* and *Tabellaria flocculosa*, together with benthic species of *Anomoeoneis*, *Frustulia*, *Pinnularia*, *Amphora* and *Navicula*. Cosmopolitan species dominated; arcto-alpine and boreal taxa decreased to 15%–38%. The pH was neutral-slightly alkaline (6.4–7.2). Alkaliphilous and indifferent species dominated the diatom community. The water of the lake became deeper and warmer than before (Fig. 3).

Unit DAL-3 (880–850 cm)

Sixty-two taxa (Fig. 2). Planktonic taxa such as *Aulacoseira granulata*, *A. angustissima*, *A. italica* (plus var. *valida* & ssp. *subarctica*), *Cyclotella stelligera* and *C. kuetzingiana* were still dominant even if their share in relation to epiphytic *Fragilaria*, *Tabellaria flocculosa*, *Epithemia* and *Cymbella* as well as to benthic *Anomoeoneis*, *Frustulia* and *Navicula* decreased. Arcto-alpine and boreal forms increased up to

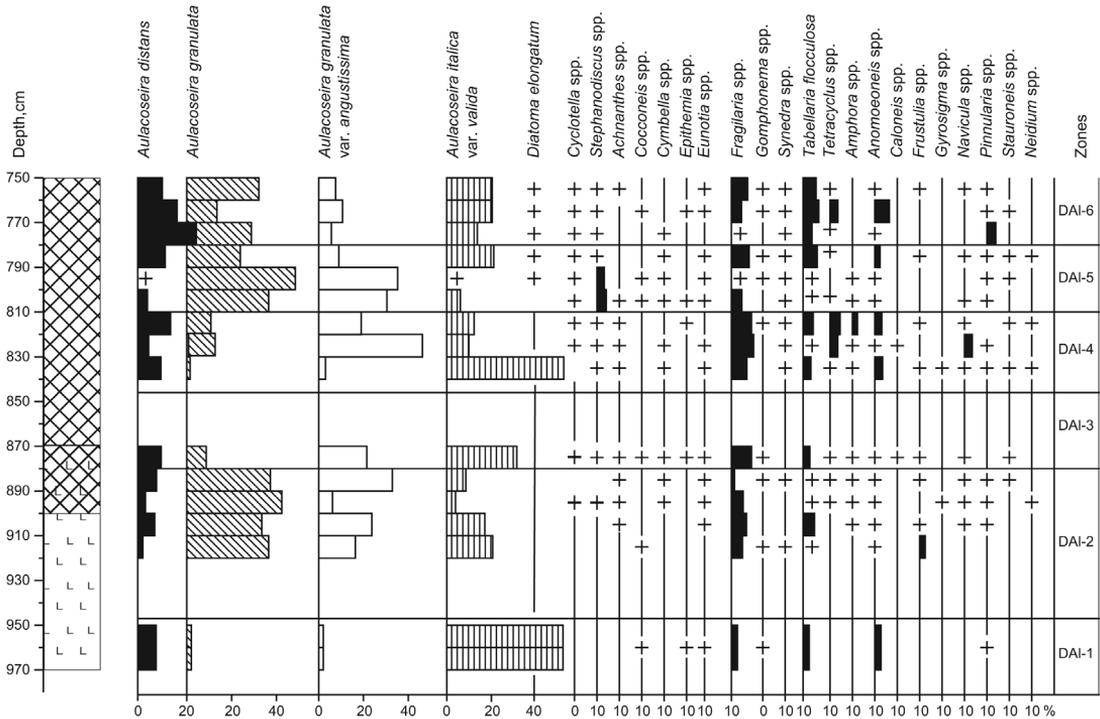


Fig. 2. Simplified diatom diagram.

60% of the total diatom assemblage. The pH was about 6.7. Alkaliphilous taxa declined while acidophilous and indifferent ones increased. The water level became somewhat lower (Fig. 3).

Unit DAL-4 (850–810 cm)

In this section the share of epiphytic taxa like *Eunotia*, *Cymbella*, *Tabellaria flocculosa*, *Fragilaria construens*, *F. brevistriata* and *Achnanthes* was somewhat higher than before (Fig. 2), probably an indication of an extension of the littoral zone. An increase of cosmopolitan taxa in connection with a decrease of the arcto-alpine and boreal ones suggests a warmer climate than before and an increase in the surface runoff. The pH was 6.4–7.0 (Fig. 3).

Unit DAL-5 (810–790 cm)

This assemblage was characterised by a marked maximum of the planktonic taxa *Aulacoseira distans*, *A. granulata*, *A. angustissima*, *A. italica*

var. *valida* and *Stephanodiscus* spp. (Fig. 2). The benthic and epiphytic species had a minimum. The alkaliphilous taxa increased, indicating slightly alkaline conditions with a pH of 7.2–7.4 (Fig. 3).

Unit DAL-6 (790–750 cm)

In this section the planktonic taxa decreased slightly, while the epiphytic and benthic ones increased (Fig. 2). The share of the arcto-alpine and boreal diatoms grew at the expense of the cosmopolitan ones. The water was somewhat colder and more acid than before; the pH is 6.4–6.5 (Fig. 3).

Discussion

As was to be expected on the basis of the location of Alinlampi and of the previously published pollen diagram by A. Kolkanen (Ekman et al. 1991), the sediment succession studied obviously covers the Late-glacial and Holocene

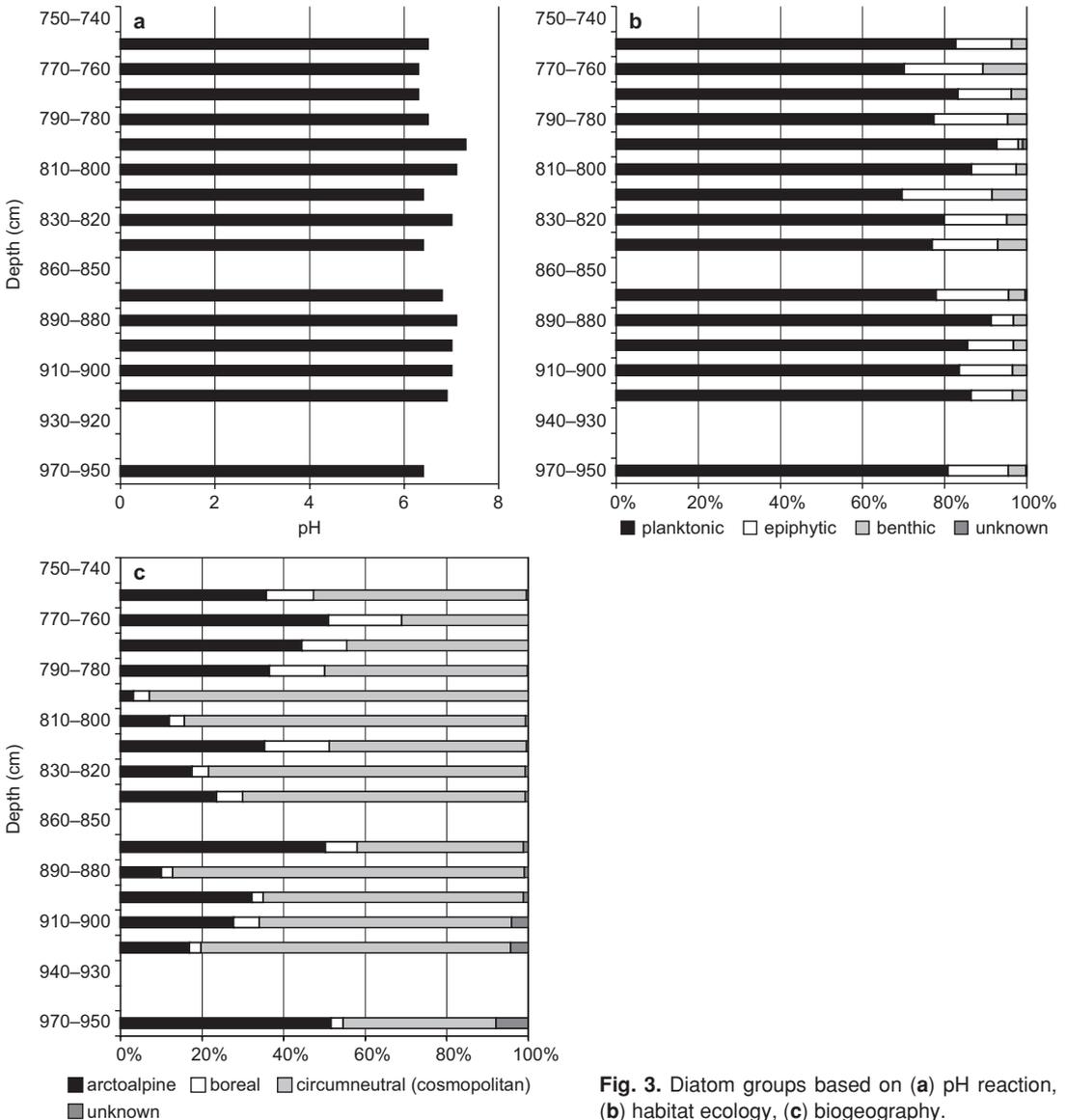


Fig. 3. Diatom groups based on (a) pH reaction, (b) habitat ecology, (c) biogeography.

from the Younger Dryas chronozone to the mid-Holocene. The macrofossil record turned out to be surprisingly meagre. The renewed study, however, succeeded in considerably augmenting the pollen study, and the diatom analyses help to elucidate the ecological history of the lake.

In the 1991 pollen profile the Younger Dryas was divided into three subzones. According to Ekman *et al.* (1991), the ice margin retreated from the moraine ridge on the southern side of Shuezero (Suikujärvi) 10 850–10 900 years ago, during the Younger Dryas chronozone. The dating 9800 ± 150 B.P. (TA-1488) was from just the

beginning of the subsequent Preboreal. According to Ekman *et al.* (1991), the three pollen subzones of Younger Dryas reflect three different climatic periods during about one millennium, the middle one representing warmer climatic conditions.

Similarly to the earlier published pollen diagram, the present one reflects three phases before the development of forests at the level of 910 cm. This event is evidently contemporaneous with the level of approximately 412.5 cm in the diagram of Ekman *et al.* (1991). The three-fold pollen succession is essentially similar to the vegetational succession found in Finnish

Northern Karelia by Hyvärinen (1971, 1972) and Bondestam *et al.* (1994).

There is first an evidently short phase reflecting open pioneer vegetation with an abundance of *Artemisia*, Chenopodiaceae and other heliophilous plants, all indicative of bare mineral ground (Palynomorph sub-unit 1A, 1000–980 cm).

The next phase corresponds with the palynomorph sub-unit 1B (980–930 cm). This is a phase of a very rich and varied pollen flora, which still includes considerable proportions of mineral soil indicators. According to the evidence of the macroremains not only *Betula nana* but also *B. pubescens* belonged to the vegetation of this period. The maximal occurrence of dwarf-willows (*Salix* cf. *herbacea* and *S. reticulata*) and the presence of *Dryas octopetala* are characteristic features of this phase. Also, *Ephedra* and *Hippophaë rhamnoides*, both absent from the present Karelian flora, are likely to have grown in the region at that time.

The third phase before the development of forests is represented by the palynomorph sub-unit 1C (930–910 cm). It was evidently a forest-tundra period with an increasing occurrence of tree birches, mainly *Betula pubescens* ssp. *pubescens* and *B. pubescens* ssp. *czerepanovii* but, for the first time, also some *B. pendula*. *Betula nana* now had a pollen maximum; this is also true for ericaceous dwarf-shrubs Ericaceae and *Empetrum*. *Juniperus* pollen had here a weak peak. Both *Artemisia* and Chenopodiaceae decreased decisively during that period. Macroscopic finds prove the continued existence of *Dryas*.

This vegetational succession before the real advance of forests follows in principle the same pattern as was found earlier in Finnish Karelia (Hyvärinen 1971, 1972, Bondestam *et al.* 1994). There are, however, certain special characteristic features here. One is the occurrence of *Najas flexilis* already during the initial pioneer phase. This finding is, however, in harmony with several others indicating the early immigration of *N. flexilis* into eastern Fennoscandia. It has been found in the Late-Glacial in southern Finland (Mölder *et al.* 1957: pp. 11–13), Late Glacial/Early Holocene in southeastern Finland (Lappalainen & Vasari 1962), Preboreal in Northern Finnish Karelia (Tolonen 1963) and the Kainuu province, NE Finland (Kanerva 1956). Somewhat further north in Finland, in the Kuusamo

province, the earliest record of *N. flexilis* is likely to be from the boundary Preboreal/Boreal, i.e. about 9000 B.P. (Vasari 1962). The somewhat climatically as well as edaphically less exacting *Alisma plantago-aquatica* should also be noted in this connection. Kotilainen (1954) and Kalela (1961) already paid attention to the early immigration of several thermocratic, edaphically more or less exacting water-plants into eastern and northern Fennoscandia.

The intermediary phase between heath-like vegetation and proper forests, the palynomorph sub-unit 1C (930–910 cm) deviates clearly from the corresponding phase in Finnish Karelia and further south, as here it was a question of a typical forest tundra instead of heaths dominated by either *Betula nana* as in Finnish Karelia or *Empetrum* and/or *Juniperus* as further west (see e.g. Iversen 1973, Vasari 1977, Bondestam *et al.* 1994). The presence of *Dryas* indicates rather favourable edaphic conditions, which is not often the case with regard to this transitory period.

From the level of 910 cm upwards the pollen record reflects the dominance of forests in the surrounding landscape. The forests were at first (Palynomorph sub-unit 2A, 910–855 cm) likely to have been dominated by birches (mainly *Betula pubescens* ssp. *pubescens*, but also *B. pendula* and probably *B. pubescens* ssp. *czerepanovii*, too). In addition to these, it seems evident that also *Picea*, *Alnus incana*, *A. glutinosa* and *Populus tremula* grew in the local forests. It is somewhat surprising that also *Salix herbacea* continued to be present. It seems evident that juniper also still grew here, despite its meagre representation in the pollen record.

The aquatic flora was quite rich, including taxa such as *Isoëtes*, *Stratiotes aloides*, *Potamogeton*, *Alisma*, *Typha latifolia*, *Myriophyllum* and *Nuphar*. At present *Stratiotes* is known to grow quite close to Alinlampi, near Sosnovets (Ramenskaya & Andreeva 1982: p. 58).

According to the diatom analyses the lake water was slightly alkaline at the beginning of this phase. During the course of the Palynomorph unit 2A there were, however, the first indications of the onset of acidification in the diatom community.

The maximum density of the forests evidently characterises the period represented by

the Palynomorph unit 2B (855–820 cm). *Pinus* was clearly the dominant tree. *Betula pendula* was more common than either earlier or later. *Betula pubescens* ssp. *czerepanovii* pollen disappeared from the record. The pollen curve of *Alnus incana* began to rise.

The diatom community was indicative of a relatively warm climate and a slight rise in the pH of the water. The aquatic macrophyte flora was, however, rather poor.

The last period (Palynomorph unit 2C) visible in the sediment succession was further dominated by pine forests. The share of *Picea* has, however, increased, as did both *Alnus incana* and *A. glutinosa*. The pollen of broad-leaved deciduous trees (QM) also increased. It would be tempting to assume that *A. glutinosa* was eventually able to spread into the region, although no direct evidence of it exists. After a short rise in alkalinity, the lake water became more acid.

Among other known Karelian pollen profiles suited for comparison with that of Alinlampi the closest is from Rugozero (Rukajärvi), only about 70 km away (64°02'N, 32°48'E) (Elina *et al.* 2000). There are strong similarities between these two profiles. The Rugozero profile begins with the *Betula nana*–Ericales maximum characteristic for the intermediary phase between the early periglacial treeless vegetation and the advancing birch forests. The end of this period was dated in the Alinlampi profile to 9800 ± 150 B.P. (Ekman *et al.* 1991); in the Rugozero profile the same horizon is considerably younger, 9230 ± 80 B.P. (Elina *et al.* 2000), which is similar to Finnish Northern Karelia, about 9200 B.P. (Koi-vusilta) and later than 9550 B.P. (Mustalampi) (Bondestam *et al.* 1994). Reasons for the earlier advance of trees at Alinlampi may possibly have been the greater distance from the retreating glacier (e.g. Hyvärinen & Eronen 1979) and the ameliorating influence on winter conditions of the waters in the White Sea basin.

The estimated radiocarbon age for the boundary BO2/AT1 in the Rugozero profile is about 8000 B.P. The Atlantic zone is then mainly understood in the traditional way on biostratigraphical grounds, on the basis of the maximal occurrence of thermophilous trees (cf. Mangerud *et al.* 1974). The concept is in accordance with that of Tolonen and Ruuhijärvi (1976: p. 186), namely that the

beginning of the postglacial climatic optimum represented by the sharp rise in the *Alnus* curve and the associated QM peak “proves in practice to be indeed the most nearly synchronous of all the pollen zones so far recognized”.

The corresponding horizon in the present Alinlampi series is not quite so clear. It could, perhaps, be best placed at the boundary between the *Pinus–Betula* and *Pinus–Betula–Alnus* sub-units (820 cm). The occurrence of many thermophilous plants in the pollen record supports such a concept. Thus, besides the relatively numerous pollen grains of *Alnus glutinosa* and broad-leaved deciduous trees, there were also those of such southerly plants as *Viburnum opulus*, *Humulus*, *Pteridium aquilinum*, *Typha latifolia* and *Polygonum amphibium*.

Neither of the Alinlampi profiles seems to extend to the usually clear rise of the *Picea* pollen curve. It is to be noted, however, that neither the Rugozero profile representing the Onega–White Sea watershed region nor the Shombashuo profile from the Pribelomorskaya lowland show any clear increase in the spruce pollen curve (Elina *et al.* 2000: figs. 42d and 43). In all three cases the *Picea* pollen curve remained constantly low. This is thus a feature common to quite a large area.

The beginning of the Atlantic chronozone (AT1), evidently reflected as the *Pinus–Betula–Alnus* palynomorph sub-unit (2C), is according to Elina and Filimonova (1996) interpreted at Shombashuo as the replacement of north-taiga forests by middle taiga forests, i.e. clearly more southern forests. In Finnish terminology this would mean a change from middle boreal to south boreal forests. Pine and birch must have dominated in these forests while spruce had only a subordinate role.

The change to the present situation — the dominance of forests of more northerly character — was not visible in our diagram.

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