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FRESHWATER DISCHARGE AND THE DISTRIBUTION OF INTERTIDAL FORAMINIFERA, OUTER CHUPA INLET, WESTERN WHITE SEA

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ABSTRACT

Three species of calcareous foraminifera all belonging to the genus *Elphidium* were common on intertidal mud and sand beaches. Two species, *E. excavatum clavatum* and *E. albiumbilicatum*, dwelt proximally to freshwater outflows, whereas *E. williamsoni* occupied beaches bathed by waters with normal salinity.

Key words: Benthic foraminifera, cytoplasm color, distribution, Elphidiidae, intertidal, littoral, salinity, White Sea

ПРЕСНОВОДНЫЙ СТОК И РАСПРЕДЕЛЕНИЕ ЛИТОРАЛЬНЫХ ФОРАМИНИФЕР, ГУБА ЧУПА, ЗАПАДНОЕ БЕЛОЕ МОРЕ

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РЕЗЮМЕ

Массовыми представителями известковых фораминифер, обитающих на илистопесчаной литорали, оказались три вида, все из рода *Elphidium*. Два вида – *E. excavatum clavatum* и *E. albiumbilicatum* – встречались на распресненной литорали вблизи устьев рек, тогда как *E. williamsoni* населял участки побережья, омываемые водами с нормальной поверхностной соленостью.

Key words: бентосные фораминиферы, цвет цитоплазмы, распределение, Elphidiidae, литораль, соленость, Белое море

INTRODUCTION

The taxonomic composition of White Sea intertidal foraminifera has been addressed (Stschedrina 1948, 1955, 1962; Mayer 1962, 1980; Lukina 1985a, 1985b, 1988), but the distribution remains unstudied. In this paper, we semi-quantitatively compare foraminiferal assemblages inhabiting beaches distanced by kilometers.

Intertidal rotaliid foraminifera, including elphidiids, unlike the majority of foraminifera, all have brightly colored cytoplasm and are agile (Langer et al. 1989). Live specimens can be recognized confidently by the presence of cytoplasm and by particle-gathering activity. Taking this opportunity we did not perform cytoplasm staining, such as the rose Bengal technique, and treated unfixed samples. Accordingly precautions had to be taken to keep the foraminifera alive, and the samples had to be processed and counted within a few days. As we relied on natural cytoplasm

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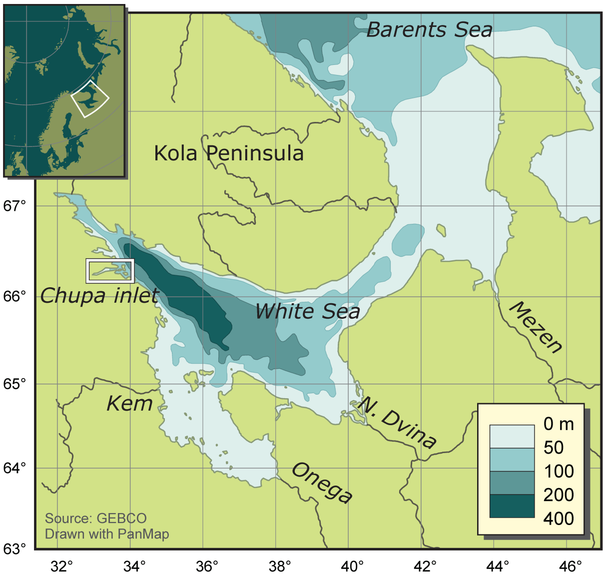

Fig. 1. Map of White Sea showing bathymetry and major rivers; Chupa inlet is boxed.

Рис. 1. Карта Белого моря. Район работ – губа Чупа – обведен рамкой.

coloration to distinguish live specimens, our reconnaissance encompasses the rotaliid fauna only.

STUDY AREA

The White Sea is a subarctic marine basin about 400 km across and >300 m deep (Fig. 1). This semi-isolated basin has decreased salinities. The surface water away from river mouths is 24–27‰; the deep water is 30–31‰ (Babkov and Lukanin 1985). From December through April, the inshore waters are covered with fast ice, the offshore with ice floes (Savoskin 1967). Snowmelt produces flood in April–May, and the inshore surface waters become nearly fresh (Rusanova and Khlebovich 1967; Babkov 1982; Babkov and Lukanin 1985).

The study area is located on the southwestern coast. Unlike the other coasts of the White Sea, which are mostly stretches of sand; this rocky coast is incised by fjord-type inlets, among which Chupa is a larger one (Fig. 1). There is little sand here; the intertidal zone is predominantly rock and boulders covered with kelp; mudflats are situated in sheltered embayments. The tide is semidiurnal with a 2-m range.

MATERIAL AND METHODS

Foraminifera

A total of 84 foraminiferal samples were collected on beaches in the outer Chupa Inlet and adjacent shores, within an 8-nautical-mile boat trip around the St. Petersburg University field station, which was the base of operation. A beach was defined arbitrary as a stretch of intertidal mud or sand 30–300 m in strandline and usually separated from another beach by rocky shore. We did not investigate thoroughly a single intertidal area; rather we took 1–5 samples on each beach (aiming to reveal presence/absence of taxa). The whole sampling set consisted of 39 such clusters, which are hereafter called stations. Samples at a station were taken 2–20 m apart, not randomly. We chose a sampling spot on a flat patch of mud or sand, avoiding *Arenicola* pit or mound, away from scattered boulders that sweep the surrounding sediment with their kelp overgrowth, and away from mussel beds.

The samples were sediment and seaweed. Surface sediment 0–1 cm was scooped out to a volume of 20 cm^3. On remote mudflats that were not easy to revisit and at stations where we anticipated few living specimens, we took larger volumes, 40, 60, or 80 cm^3. Beaches of coarse sand were avoided, as our previous observations (unpublished) showed that these sands were barren of live foraminifera. We sampled mud, sandy mud, or fine-to-medium sand. Unfixed sediment was sieved on 250-µm and 125-µm mesh screens with surface seawater within 3 hours after collection. The residues were stored at 10°C (the ambient air temperatures were 15–25 °C) and further processed within two days.

Intertidal kelp was not sampled because our earlier observations had indicated that the kelp had been devoid of foraminifera. Yet on certain mudflats densely grassed with *Zostera*, we took a few tufts together with the overgrowth of filamentous chlorophytes. The seaweed was rinsed vigorously in a bucket of ambient water and put aside. Repeated decanting yielded a heavy residue consisting essentially of mussel spat, small gastropods and foraminifera. We placed the residues into chilled beforehand water with normal surface salinity (27‰ locally), transported them in a cooler, and counted the samples within 3 hours upon delivery to the lab.

The samples were obtained during low tides 03–16 August 2011. The position of a station on the vertical scale was established visually, relative to the barnacle and kelp belts, and thus with an accuracy of ±20 cm. The majority of samples were collected in the lower intertidal (below the neap low tide). When this zone was flooded, samples were taken in the lower part of the middle intertidal. When large pools (>50 m across) were present in the middle and upper intertidal zones, those were sampled as a separate station.

After a sampling dart, each sieved residue was spread in a Ø 10-cm petri dish and stored in a temperature-stabilized room at 10°C. The petri dishes were left untouched for at least 30' giving the foraminifera the time to deploy pseudopodia and grab particles. Counting was performed under dissecting microscopes, with incident light, at magnifications ×16–52.

We chose to estimate foraminiferal population density semi-quantitatively on that basis that (1) density on branching substrates such as seaweed cannot be measured with accuracy sufficient for meaningful comparison with densities in sediment, and (2) our reconnaissance was aimed primarily on presence/absence of taxa, and a semi-quantitative approach saved time greatly. For each species we distinguished 3 grades of population density. Abundant – there were several live specimens in each field of vision (i.e. 20–80 specimens in fraction >250 μm per sediment volume 20 cm^3). Common – one specimen in each third field of vision (5–20 specimens per 20 cm^3). Rare – a few specimens per sample (1–4 individuals per 20 cm^3). For a station, at which more than one sample was taken, we produced a mean value for each species. In a situation, when all replicates were barren except one which yielded a few specimens, the species occurrence at this station was rated rare.

The criteria whether a specimen was alive were cytoplasm within the shell and a sheath of grabbed particles. Empty foraminiferal shells were noted but not quantified.

Salinity

We undertook salinity measurements because the foraminiferal data indicated (see the Results) that this could be a factor reflected in the foraminiferal distribution. We measured surface water salinity with a portable refractometer, Extech RF20, precision ±1‰. The low precision of this device was not a problem in our study area with its huge salinity gradient of >20‰.

All water samples were sucked with a pipette from a depth of 10 cm below the water surface. We took these samples from an outboard-engine boat or, when at the strandline, wading. There were 63 salinity stations. They were positioned and numbered independently of the foraminiferal stations (the numbering is not shown). At each salinity station, one measurement was performed immediately in the field, plus one 1.5-ml plastic tube filled up to the lid was delivered to the lab. Measuring was accomplished the same day. If the two replicates conflicted >1‰, a third and fourth measurements were performed on the same 1.5-ml sample.

One expects surface salinity in areas absorbing freshwater runoff to change promptly with tide and wind. Therefore we planned 27 salinity stations to map the area where we found a prominent shift in the foraminiferal fauna. There were 6 surveys, 3 for high tide and 3 for low tide (9–11 August 2011). Each survey commenced within one and a half hour after a high- or low-water astronomical standstill and lasted 2–2¼ hours. The 27 stations were sampled in the same succession. The isolines of surface salinity were drawn by hand, with no formal procedure applied, and, to a certain extent, reflected interpretation (see Fig. 4).

The other 36 salinity stations were visited once. Those samples were taken regardless of tide phase.

As we did not have contemporaneous support of vertical Conductivity-Temperature-Depth (CTD) data acquisition, we used a CTD profile obtained in the Keret estuary earlier, in 2003 (V.V. Kazaryan, St Petersburg Univ., pers. comm., 2003). The data were acquired in the Keret estuary off our foraminiferal station 32 with a “CTD-2002” unit manufactured and calibrated at the Arctic and Antarctic Research Institute.

RESULTS

Foraminifera

Three species of rotaliids occurred regularly on the studied beaches: *Elphidium williamsoni* Haynes, 1973, *Elphidium excavatum* (Terquem, 1875) *clavatum* Cushman, 1930, and *Elphidium albiumbilicatum* (Weiss, 1954). Most specimens had brightly colored cytoplasm, orange, yellow, light green, dark green,

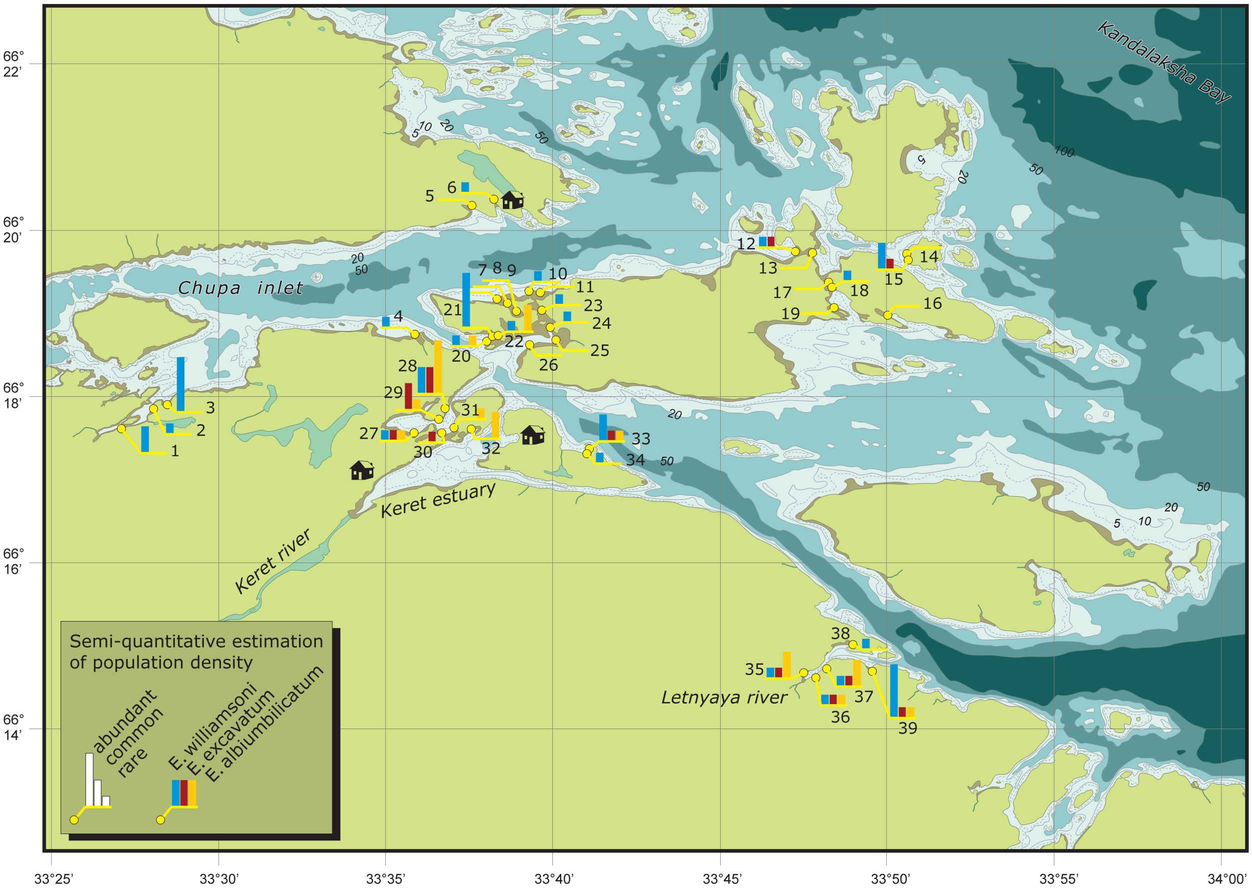

Fig. 2. Map of outer Chupa inlet and adjacent water area showing position and labels of foraminiferal sampling stations.

Рис. 2. Карта внешней части губы Чупа и прилежащей акватории. Показаны станции отбора проб на фораминиферовый анализ.

dirty green, or brown. After a few hours in petri dish they accumulated at the sediment surface and remained there afterwards, each partly concealed by a cocoon of silt grains. Specimens with brightly colored cytoplasm but lacking grabbed particles were rare, <5%; we registered those dubious specimens as live. White empty shells of *E. williamsoni* were common but less frequent than live individuals. There were few empty shells of *E. excavatum clavatum* (hereafter shortened to *E. excavatum*) and *E. albiumbilicatum*. Other rotallids were *Aubignyna* sp. occurring at two stations and a single juvenile individual of *Haynesina orbiculare* (Brady, 1881) (tabulated data not shown).

The others were non-rotaliid foraminifera with colorless cytoplasm, which was often difficult to distinguish. We did not make quantitative observations.

Semi-quantitative data on distribution were acquired on cytoplasm-colored rotallids, the vast majority of which were the 3 species of *Elphidium* (Fig. 2). Thirteen of the 39 foraminiferal stations yielded no *Elphidium*. We revisited certain beaches, and some stations that had appeared barren yielded *Elphidium* after all (stn. 20, 21, 27, 29). Thus it remained unclear whether the 13 stations with zero counts were true barren or lacked replicates. The population density varied greatly between beaches (Fig. 2). When *E. williamsoni* or *E. excavatum* ranked 'abundant' or 'common' in a sediment sample, they were represented by specimens of nearly identical size, indicating that these were offspring of a single reproduction pulse. The same species when clinging to seaweed were diverse in size. There was no other discernible pattern in population density.

The main effort was to reveal presence or absence of a species on a beach. *Elphidium williamsoni* occurred on most beaches. There were only 4 stations

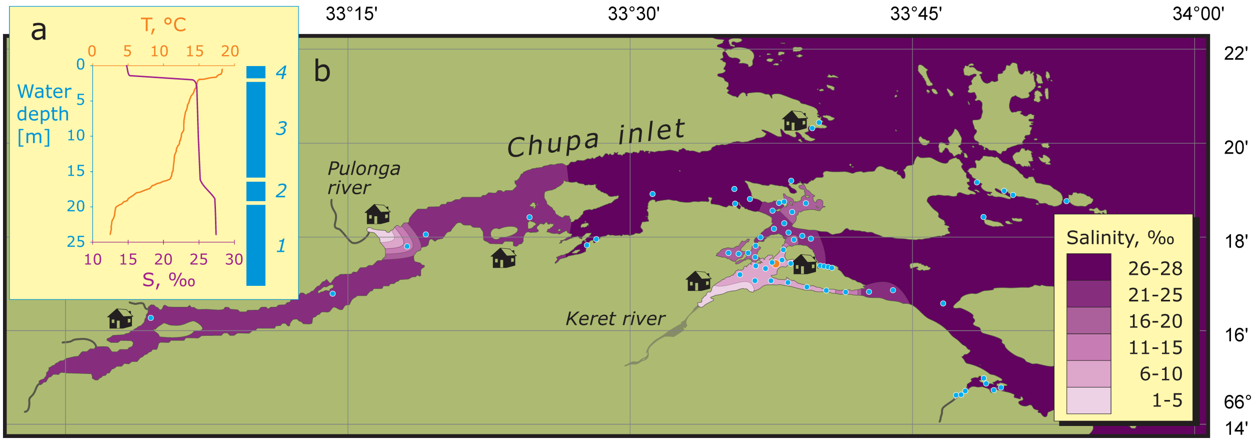

Fig. 3. a. CTD profile acquired in July 2003, located in distal part of Keret estuary (marked by filled circle in b). Stacked bars denote interpreted layers of water column: 1 winter chilled water; 2 seasonal pycnocline; 3 mixed layer; 4 river influx. **b**. Nonrecurrent survey of surface salinity, 9–17 August 2011. Filled circles denote salinity stations.

Рис. 3. а. CTD профиль получен в 2003 г., расположен во внешней части Керетской губы (станция пробоотбора отмечена черным кругом на рис. 3b). Нумерованные прямоугольники справа от графиков означают интерпретированные слои водного столба: 1 – зимняя охлажденная вода, 2 – сезонный пикноклин, 3 – верхний перемещанный слой, 4 – речной сток. **b**. Однократная съемка поверхностной солёности, 9–17 августа 2011 г. Серыми кругами обозначены станции отбора проб на соленость.

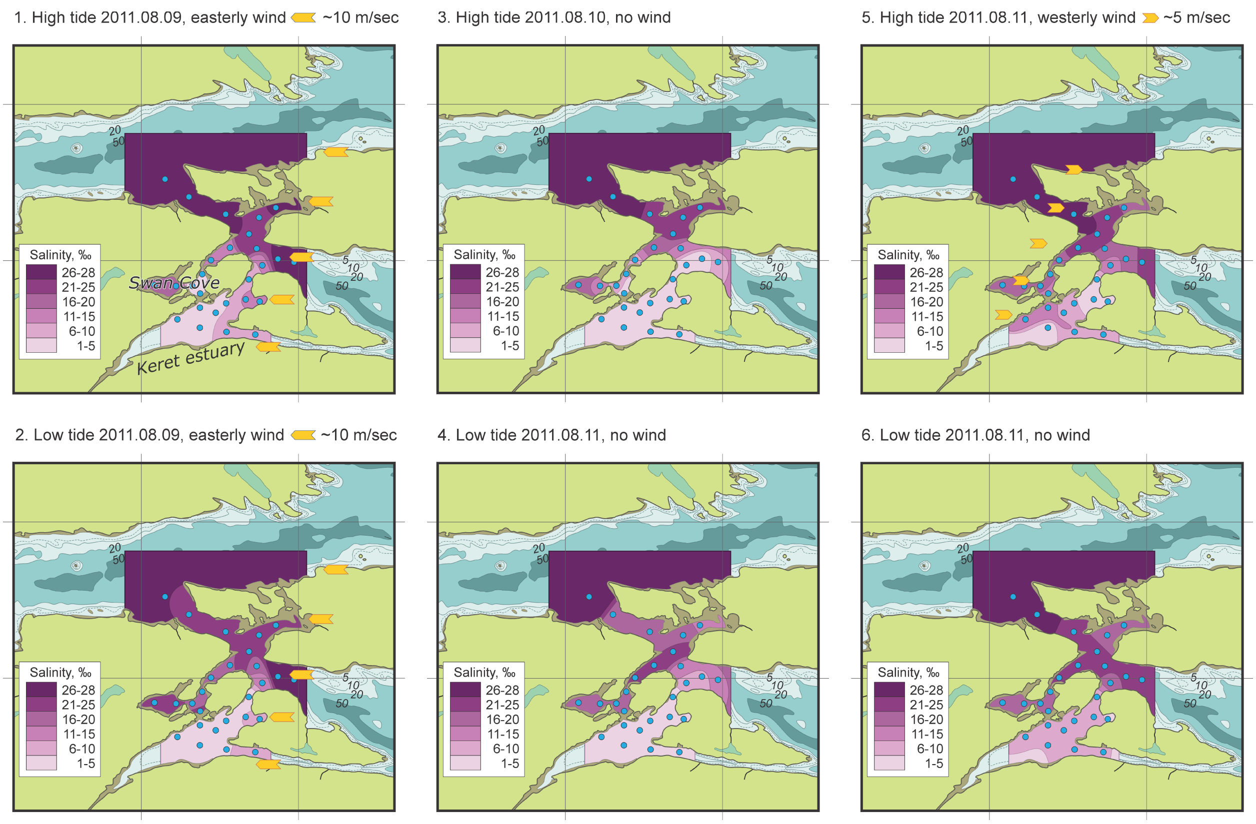

Fig. 4. Recurrent surface salinity 9–11 August 2011. Filled circles denote salinity stations.

Рис. 4. Шестикратная съемка поверхностной солёности 9–11 августа 2011 г. Светло-серыми кругами обозначены станции отбора проб на соленость.

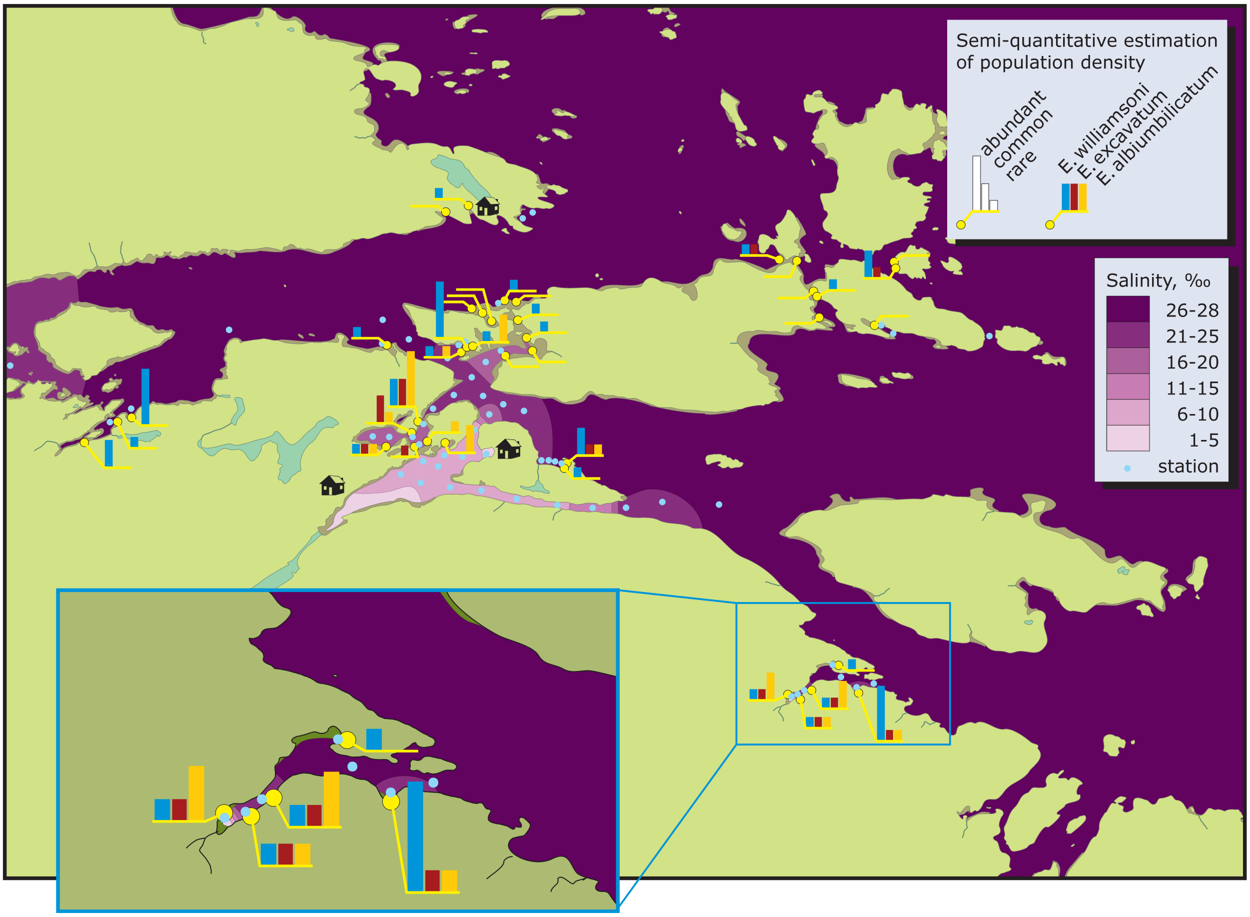

Fig. 5. Foraminiferal distribution and surface salinity.

Рис. 5. Распределение фораминифер и поверхностная солёность.

where this species was absent, whereas the other two *Elphidium* (either or both) were present, stn. 29, 30, 31, 32 (Fig. 2). These 4 stations were situated close to each other and were most proximal to the Keret river mouth. This suggested a possible effect of salinity on the distribution.

Salinity

The nonrecurrent surface-salinity survey showed that that the Keret river was the major source of fresh water in the Chupa fjord and its surroundings (Fig. 3b). The surface brackish layer formed by river influx however was only 1 m thick. In the Keret estuary, it capped the typical high-latitude water column: the seasonally warmed mixed layer (15 m thick in this case) underlain by a winter-chilled water (Fig. 3a).

The foraminiferal stations of interest (stn. 29, 30, 31, 32) were located in or near the outer Swan Cove (see Fig. 4 for location), a small basin connected by an intertidal channel to the Keret estuary and by a shallow subtidal channel to the outer straits. The recurrent surface salinity survey had a station grid aimed to trace short-term variability in the Swan Cove and the adjacent water bodies. The surface salinity was changing perceptibly with tide and wind (Fig. 4). 1. During high tide, brackish water poured from the Keret estuary to the outer Swan Cove. The easterly wind upwelled saltier water at the eastern shore of the Keret estuary. 2. Retarded by the wind, low-salinity water (<20‰) was not released from the estuary at low tide (in support, we observed little ebb in the estuary). The wind upwelled saltier water again at the eastern shoreline. 3. The brackish water poured from the estuary to the Swan Cove at high tide again. The 5‰ isoline had the broadest spread. The wind had died, and the brackish water flushed out of the estuary overcoming the high tide. 4. This survey showed the broadest spread of low-salinity water (<20‰) in the adjacent straits. The water that had accumulated in the estuary during the wind was dissipating in the straits. 5. The westerly wind upwelled saltier water at the north-western shoreline of the estuary. 6. The weakest gradients were observed after calm weather. Overall during the recurrent survey, foraminiferal stations 29, 30, 31, 32, where *E. williamsoni* was lacking (see Fig. 2 for location), had lowest surface salinities.

DISCUSSION

Within the variability revealed by the recurrent salinity survey, there was a consistent pattern: brackish water (<10‰) capping the estuary dissipated in the adjacent straits (Fig. 4). This consistency suggested that the broader picture based on nonrecurrent data (Fig. 3b) also was rather stable despite the effect of tide and wind and thus could be compared to the foraminiferal distribution. The four stations where *E. excavatum* and/or *E. albiumbilicatum* occurred but *E. williamsoni* was lacking indeed had lowest surface salinity (Fig. 5). The only station situated within the Keret estuary (stn. 32) and characterized by lowest salinity values, yielded only *E. albiumbilicatum*.

The presence of elphidiids in areas mapped for constant presence of brackish water (<10‰), such as stn. 32, does not mean the foraminifera withstand such low salinities. The surface brackish layer is thin (Fig. 3a), and therefore the intertidal zone is flooded with much saltier subsurface water every high tide, or nearly every high tide. When the tide ebbs and the capping brackish layer subsides, the littoral foraminifera may dig into the sediment where the pore water retains high salinity (Langer et al. 1989).

The *Elphidium* distribution (Fig. 5) supports the notion that *E. excavatum* and *E. albiumbilicatum* tolerate decreased salinities (Conradsen 1993; Austin and Sejrup 1994; Hald et al. 1994; Alve 1995; Polyak et al. 2002). Besides, *E. albiumbilicatum* has been repeatedly mentioned as a brackish- and shallow-water species (e.g., Lutze 1965; Gehrels and Plassche 2004). One would seek confirmation of the pattern at other river mouths. We did not find such in our study area. The Pulonga river mouth had no soft-sediment beaches in its vicinity. The discharge of the Letnyaya river was weak; the brackish water even at low tide spread only a 100 m from the mouth (Fig. 5). The pattern however seems to be confirmed in other seas. On the Barents-Sea coast of Kola Peninsula, *E. williamsoni* occurs on beaches with normal marine salinity, whereas *E. albiumbilicatum* is found at river mouths (Korsun et al. 1994). At the Tana delta of northern Norway, *E. albiumbilicatum* is characteristic of the brackish setting (Corner et al. 1996). In the North Sea and Baltic Sea, all the three *Elphidium* in different combinations have been reported from the intertidal zone (Murray and Alve 1999; Horton and Edwards 2006; Gehrels and Newman, 2004), with *E. albiumbilicatum* reported from low-salinity environments (Nikulina et al. 2007; Polovodova et al. 2009). Further south, *E. albiumbilicatum* does not occur (Murray and Alve 1999), whereas the *E. excavatum* taxonomy becomes complicated (Wilkinson 1979).

Though the distribution of the three *Elphidium* species in the intertidal zone appears coupled to the salinity distribution (Fig. 5), neither our study nor those cited above have demonstrated that salinity controls the foraminiferal distribution directly in a physiological way. In fact, a survey across the profound salinity gradient along the coast of the Skagerrak (Murray and Alve 1999) has not revealed that *E. williamsoni* is any less frequent at low salinities than *E. excavatum* or *E. albiumbilicatum*. This may indicate that salinity preferences of the three species differ in certain regions only. Then the effect of salinity is indirect. It may be mediated by another factor, e.g. the availability of preferred fresh- or brackish-water food diatoms (cf. Alexander and Banner, 1984; Knight and Mantoura, 1985; Bernhard and Bowser, 1999) or the longevity of the ice cover period.

To conclude, the distribution of the intertidal *Elphidium* appears coupled to salinity. Yet the physiological nature of the link is not understood.

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