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Appearance of the Pacific diatom *Neodenticula seminae* in the northern Nordic Seas — An indication of changes in Arctic sea ice and ocean circulation

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ABSTRACT

The marine diatom *Neodenticula seminae* belongs to the present day planktonic assemblage of the subarctic North Pacific and its high-latitude marginal seas. In the middle and high-latitude North Atlantic, *N. seminae* occurred from the middle Pleistocene to the early–middle Pleistocene transition when it became locally extinct. After a long absence of 0.84 Ma, it was found again in the North Atlantic in the late 1990s (Reid et al. 2007).

Here we show from sediment samples taken in 2006, 2007 and 2008 that *N. seminae* now has appeared in the Nordic Seas for the first time in geologic history, and it already has a widespread modern distribution in the northern Nordic Seas. The appearance of *N. seminae* in the Nordic Seas coincides with an increased influence of Pacific water via the Arctic Ocean due to diminished sea ice and/or changed ocean circulation in the Arctic Ocean. Our results show that trans-Arctic exchanges, which were first observed in the North Atlantic in the late 1990's are still in motion, or possibly even accelerated during recent years. The appearance of *N. seminae* in the Nordic Seas might even suggest initiation of a unique climatic transition of the scale seen during the mid-Pleistocene transition. More trans-Arctic exchanges can be expected in the near future if the modern warming trend and reduction of sea ice continues in the Arctic.

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1. Introduction

The ongoing episode of climate warming has drastic consequences for marine conditions especially in the northern oceans (Fig. 1). The Arctic Ocean responds more rapidly to global warming than most areas of the planet; observations document accelerating retreat and thinning of the Arctic sea ice cover over recent decades (e.g. Comiso et al., 2008). These changes in sea ice cover substantially affect atmospheric, hydrographic and ecological conditions at high latitudes (Spreen et al., 2009; Leu et al., 2010; Overland and Wang, 2010; Polyak et al., 2010), e.g. freshwater export from the Arctic may modify global- to basin-scale ocean circulation patterns and climate (Greene et al., 2008; de Steur et al., 2009), or earlier phytoplankton blooms in the Arctic Ocean may have consequences to the Arctic food chain and carbon cycling (Kahru et al., 2011).

Neodenticula seminae (Simonsen & Kanaya) Akiba & Yanagisawa is a pennate marine planktonic diatom which belongs to the modern assemblage of the subarctic North Pacific and its high-latitude marginal seas, where it commonly accounts for >40% of the diatom assemblage (Kanaya and Koizumi, 1966; Sancetta, 1982; Sancetta and Silvestri, 1986; Takahashi, 1986; Shimada et al., 2006). The species appeared in the fossil record around 2.4 Ma in the North Pacific (Akiba and Yanagisawa, 1986: Yanagisawa and Akiba, 1990, 1998). During the Holocene, *N. seminae* was the dominant diatom assemblage in the Bering Sea from 6.5 cal ka BP to the present (Caissie et al., 2010). Primary productivity in the subarctic North Pacific is among the highest in the world's oceans with the phytoplankton serving as an efficient biological pump driving elemental cycles including the carbon content of the ocean (Honjo, 1997). The dominant diatoms (including *N. seminae*) in this highly productive region play an important role in ocean-scale ecosystem and biochemical dynamics (Shimada et al., 2006).

In the middle and high-latitude North Atlantic, *N. seminae* occurred from the Middle Pleistocene at 1.26 Ma to the early–middle Pleistocene transition at 0.84 Ma ago (Baldauf, 1986; Koç and Flower, 1998; Koç et al., 1999). Baldauf (1986) interpreted that the occurrence of *N. seminae* in the North Atlantic indicates the presence of cool and low-salinity surface waters originated from the Arctic Ocean in the early Pleistocene, and that this suggests that the Arctic Ocean was partially ice free allowing the transportation of the species between the Bering Sea and the North Atlantic. The time interval when *N. seminae* was present in the North Atlantic straddles the transition from the dominance of 41 ka cycles in the climate record to the dominance of 100 ka cycles. It is possible that the first occurrence of *N. seminae* in the North Atlantic is an indicator of the cooling, which started at 1.26 Ma, leading to the establishment of the 100 ka cycles

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and intensified Northern hemisphere glaciations. Conditions in the North Atlantic were too warm for subarctic *N. seminae* before 1.26 Ma, after which conditions cooled to subarctic environment favorable for the species. *N. seminae* thrived in the North Atlantic the next ca. 0.4 Ma until conditions turned too severe with perennial sea ice cover leading to the disappearance of the species at 0.84 Ma. A closure of the connection between the Pacific and the Bering land bridge due to the growth of ice and falling sea level (Head and Gibbard, 2005) could be another reason for the disappearance at this time, but more likely the colder conditions in the North Atlantic led to the extinction of *N. seminae* in this area (e.g. Reid et al., 2007). The presence of *N. seminae* in North Atlantic sediments may therefore be attributable to the unique conditions related to the mid-Pleistocene transition (Koç et al., 1999).

After a long absence, re-occurrence of *N. seminae* was reported in the Labrador Sea (Fig. 1) during the late 1990s as the first record in the North Atlantic for more than 0.8 Ma (Reid et al., 2007). They suggested that *N. seminae* was carried in a pulse of Pacific water in 1998/early 1999 via the Canadian Arctic Archipelago and/or Fram Strait, and that the event coincided with modifications in Arctic hydrography and circulation, the increased flows of Pacific water into the Northwest Atlantic and the exceptional occurrence of extensive ice-free water to the North of Canada in the previous year 1998. It appears therefore that the appearance of *N. seminae* is an indicator of the speed of the change that is taking place in the Arctic and North Atlantic Oceans as a consequence of regional climate warming and marks a change in the circulation between the North Pacific and North Atlantic Oceans via the Arctic (Reid et al., 2007, 2008).

Although *N. seminae* was found at one site north of Iceland in 2002 (Reid et al., 2007), this species has never been found elsewhere in the Nordic Seas (the Greenland, Iceland and Norwegian Seas). In this paper, we report the appearance of the Pacific diatom *N. seminae* in surface sediment samples recovered in 2006–2008 from the northern Nordic Seas. This discovery represents a considerable expansion of its subarctic range since its appearance in the plankton of the northern North Atlantic in 1999. We also discuss the causes of this appearance and the significance of the findings as evidence of the trans-Arctic migration of planktonic organisms from the North Pacific to the North Atlantic.

2. Material and methods

During the International Polar Year 2007–2008 (IPY), 36 stations were sampled for surface sediments from the East Greenland and West Spitsbergen margins, Greenland Basin and Fram Strait during cruises by the R/V *Jan Mayen* in October 2006, September 2007, and August 2008.

Undisturbed surface sediment samples were taken by multi corer and/or box corer. As an original aim, a total of 25 surface sediment samples were studied for diatoms in order to extend the existing training data set of Andersen et al. (2004b) for diatom transfer functions for quantitative sea surface temperature (SST) reconstructions (Miettinen and Koç, in preparation).

The diatom samples were prepared using the method described by Koç et al. (1993), which consists of HCl and H_2O_2 treatment to remove calcium carbonate and organic matter, clay separation and preparation of quantitative slides. A Leica Orthoplan microscope with 1000× magnification was used to identify and count the diatoms. The counting procedure described by Schrader and Gersonde (1978) was followed. A minimum of 300 diatom frustules (in addition to *Chaetoceros* resting spores) were identified for each sample.

3. Results

N. seminae was found in most of the surface sediment samples (21/25 = 84%) taken from the northern Nordic Seas in 2006, 2007

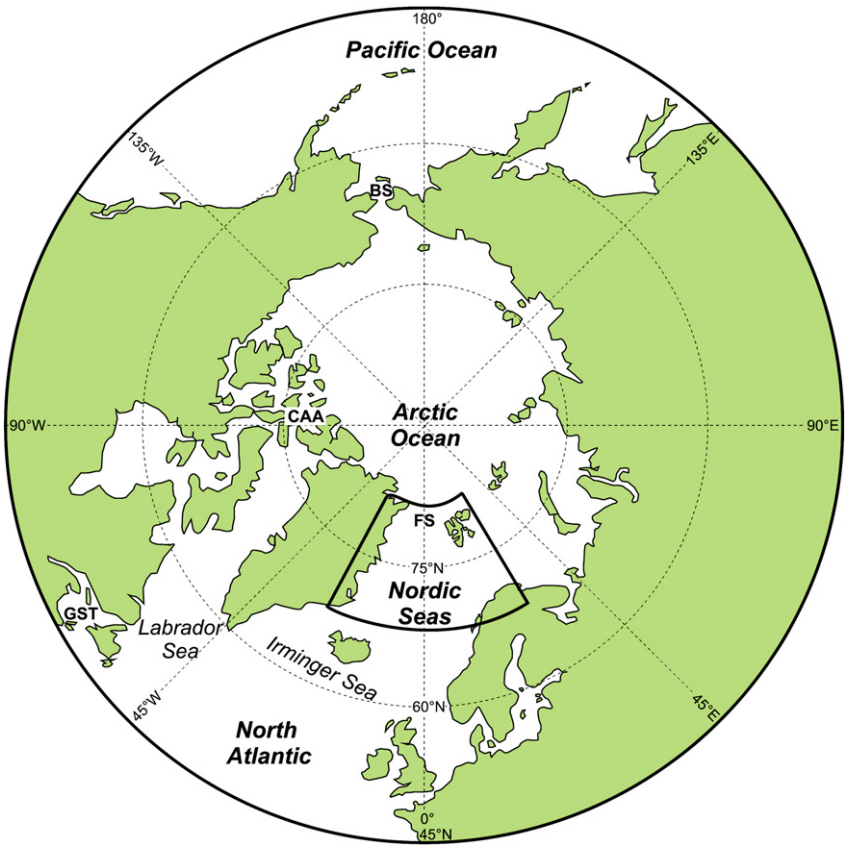

Fig. 1. The northern oceans. FS = Fram Strait, BS = Bering Strait, CAA = Canadian Arctic Archipelago, GST = Gulf of St. Lawrence. The study area is outlined.

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