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*What impact has climate change had on the variability of the Baltic Sea ecosystem as evidenced by the presence or lack of marine plankton in Baltic Sea sediment cores?*

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Laidlaw research report



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*What impact has climate change had on the variability of the Baltic Sea ecosystem as evidenced by the presence or lack of marine plankton in Baltic Sea sediment cores?*

Abstract:

The Baltic Sea is the largest brackish sea in the world (ca. 393,000 km<sup>2</sup>) and relies upon inflows of saline water from the North Sea to maintain its hydrographic and environmental conditions (Binczewska *et al*, 2017). The inflows of saline sea waters from the North Sea impact the conditions of the Baltic Sea environment resulting in changing oxygenated and anoxic conditions. These changes are present in the form of laminations deposited on the Baltic Sea floor which are collected within Baltic Sea sediment cores for examination. The purpose of this research is to establish the entry point of the saline North Sea waters into the Baltic Sea by looking at the absence (anoxic conditions) or abundance (oxygenated conditions) of Benthic Foraminifera within the Baltic Sea cores from near the Aaland Sill.

Introduction:

This research paper aims to understand whether, due to isostatic uplift, the North Sea waters entered the Baltic Sea via the channel between Sweden and the Aland sill or whether the North Sea waters entered the Baltic Sea via crossing over mainland Sweden (and the Gotland Basin) before isostatic uplift had taken place. To understand this process, Benthic Foraminifera (marine plankton), an indicator of good connectivity to the North Sea due to anoxic and oxygenated living conditions for the forams, will be monitored in terms of abundance to see which is the more likely connection between the Baltic Sea and the North Sea. This paper specifically will focus on the abundances of forams present within Baltic Sea sediment cores taken from the channel in between the Aland sill and mainland Sweden. High abundance of forams will suggest good connectivity between the North Sea and the Baltic Sea which implies that the oxygenated North Sea waters entered the Baltic Sea from between mainland Sweden and the Aland sill and not over Sweden before isostatic uplift had taken place.

History of the Baltic Sea area:

The Baltic Sea is an old depression in the Fennoscandian bedrock which was covered by ice sheets during the ice ages and filled with water in the warmer periods (Leppäranta and Myrberg, 2009). The Baltic Sea, as seen in Figure 2, initially formed after the Weichselian glaciation (Ibid) and the slow removal of the Weichselian ice sheet resulted in isostatic uplift at a rate of up to 9mm per year in the north of the Fennoscandian bedrock. Due to this process of isostatic uplift, the Baltic Sea has undergone multiple alternating postglacial phases of brackish water and freshwater (Winterhalter *et al*, 1981) resulting in the multiple laminations we can see within the cores used for this research (Figure 1).

The history of the Baltic Sea started ca. 13,000 – 13,500 years BP when the ice sheet covering the area retreated to the southern edge of the Baltic basin (Tikkanen and Oksanen, 2002). This created a freshwater glacial lake called the Baltic Ice Lake in ca. 12,600 – 10,300 BP (Rosentau *et al*, 2009). After deglaciation, the Baltic Ice Lake proceeded to build up against the large margin of ice until ca. 10,300 BP when the Ice Lake discharged through several channels which had opened in central Sweden resulting in the Ice Lake reducing to ocean level (Tikkanen and Oksanen, 2002). When the Baltic Ice Lake had fallen to sea



Figure 1. Images of the Baltic Sea sediment core, section 4, taken from the XRF scanner. (Authors own)

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level, the connecting channels remained above sea level which isolated the Baltic Sea once more, resulting in the formation of the Anyclus Lake from 9500 – 8000 BP (Ibid). The Baltic Sea preceded to go through three more phases (The brief Mastogloia transitional phase, the Litorina Sea Stage – a greater influx of saline water entered the Baltic Sea through the straits of Denmark (7500 – 4000 BP) and the Limnea Sea stage – known as the less saline stage).

The changes in salinity of the Baltic Sea due to the progression through glaciation, deglaciation and isostatic uplift have caused laminations in the sediments preserved at the sea floor due to variations between oxygenated and deoxygenated (anoxic) conditions which are present within the Baltic Sea cores illustrating the changes in entry points of the Baltic Sea at different periods.



Figure 2. An image of the Baltic Sea and the location (in red) where the Baltic Sea cores were extracted (Political Map of the Baltic Sea, 2022).

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Methods and materials:

Benthic Foraminifera

Benthic Foraminifera are microscopic marine organisms which are generally smaller than 1mm and live on the sea floor. The two types of Foraminifera (forams) we expected to find whilst conducting this research were the Elphidium species (which have calcium carbonate shell chambers with clear distinguished boundaries between the chambers) and the agglutinated species (they compose their shells by sticking grains and sediment together to form longer thinner shells). The Elphidium forams were more common and thus have a higher abundance than the agglutinated forams.

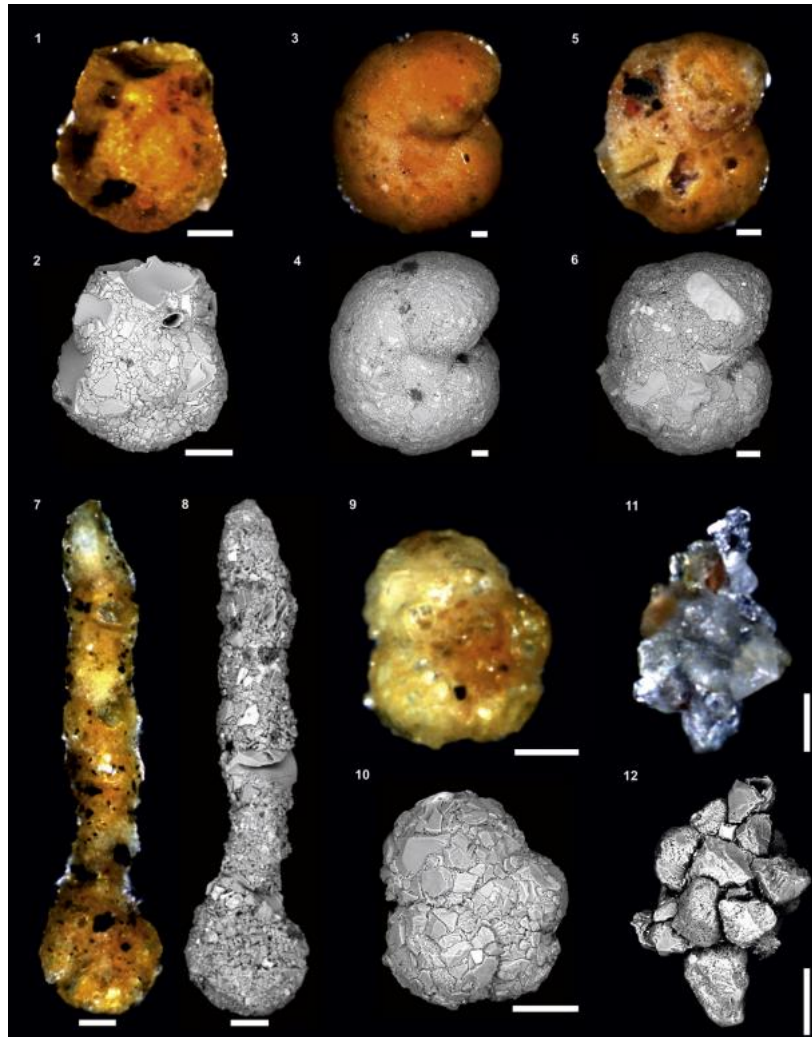


Figure 3. Diagrams of the varied species of forams (Stefanoudis et al., 2016). Type 4 are the Elphidium forams which were the focus of this research and type 7 are the agglutinated forams which appeared in core section 5.

Methods

The length of the entire core (all 8 sections) is 728cm with section 8 measuring 0-66cm, section 7 measuring 66-166cm, section 6 measuring 166-228cm, section 5 measuring 228-328cm, section 4 measuring 328-428cm, section 3 measuring 428-528cm, section 2 measuring 528-628cm and section 1 measuring 628-728cm. This research used core sections 5 and 4 which corresponded to the depth 228-428cm within the whole core.

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The cores used were split in half using geo tech equipment to cut through the outer plastic casing. A thin metal wire was then run in between the cut plastic case to cut the core in half. One side was labelled the working half of the core and the other was labelled the archive half of the core for XRF scanning and to be placed into storage.

The methods used to conduct the Baltic Sea research include sampling, sieving and microscopy. The core was initially cleaned using knives and microscope slides to even out the surface for sampling. The sampling was conducted by measuring out core section 4 (1m in length) and marking every 1cm interval on the side of the core. Samples were taken in the amount of 20g and were taken in 1cm samples from 424cm to 420cm for the first batch of samples – this batch was taken in 1cm samples up to the boundary where the core changed from clay to laminated layers which was at 418cm. These samples were placed into glass beakers filled with deionised water and labelled with their depth (424-423cm i.e.). The remaining batches of samples which were collected from the core were collected in 2cm 20g samples and placed into beakers (also containing deionised water) from the following depths in core section 4: 418-328cm. For core section 5, the samples were all collected in 20g 2cm samples from 328-228cm (328-326cm, 326-324cm...).

For sieving we used a 63-micron sieve to collect the fine materials and forams if present. The 20g 1cm samples (only section 4) were washed using deionised water, after being weighed, until the clay and organic material had been removed (to make the microscopy easier). Once sieved, the excess water in each beaker was removed and then the washed finer materials were transported and placed into a drying cupboard overnight so that the sample could be viewed dry under a microscope the following morning. The same process of measurement and sieving was used for the 2cm samples (both core sections), but some samples remained wet and were not placed into the drying cupboard overnight but were taken straight to the microscope to be viewed wet, the rest were dried out overnight to be viewed dry under the microscopes the following day.

When the samples were brought to the microscope there were two methods to observe them depending on whether the sample was dry or wet. If the sample was dry, it was lightly loosened within the beaker and spread in a thin layer over a small black tray which was placed under the microscope to examine the sample. Wet samples were swirled within the beaker to mix up the sample into the deionised water and to move any organic material to the sides and was then collected using a pipette. The sample was then evenly spread across the black tray using the pipette, like the dry sample, to be viewed under the microscope.

To collect the forams, a small paint brush was used to lightly pick the forams up and place them onto a separate microscope slide to be collected and for easier examination later.

Once the samples were fully examined for forams, they followed one of two processes: wet samples were then taken to the drying room to dry out before being collected and placed into a small glass vial to be stored for later examinations if needed. These glass vials were labelled with the ship code and the depth which the sample was taken from (MSM 99 – 320-318cm i.e.). Dry samples were put straight into the glass vials after examination and labelled in the same format.

Due to time restraints, radiocarbon dating of the forams was not possible.

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#### Results:

##### Core section 4

The abundances of forams were recorded in terms of the number of specimen per gram (Figure 4).

The archived half of the core was put through an X-Ray fluorescence scanner to understand the composition of the core in terms of different elements such as manganese, calcium, and iron (Figure 4). These results were then compared with the amount of specimen per gram to see the relationship between the element concentrations and foram abundances.

As seen in figure 4, the layers containing higher concentrations of manganese yielded higher abundances of forams per gram than the laminations which had lower concentrations of manganese. The abundances of forams for core section 4 spiked between 398-404cm (0.25, 2.35 and 0.15 forams per gram were found within these samples) in a direct relation with the manganese spike between laminations 398.8-405.1cm which had concentrations of 7,000-10,366 counts per second (cps). Two other spikes on the specimen per gram scatter graph also correspond to spikes of manganese within the core section: 390cm – 0.8 forams per gram (12,098 cps) and 412cm – 0.7 forams per gram (7,834 cps). In contrast, at 370cm when we see 0.35 forams per gram and 420cm where we see 0.2 forams per gram, we do not see a major spike in the manganese concentrations like with the higher foram per gram readings because we get 202 cps at 370cm in core depth and 216 cps at 420cm in core depth.

In stark contrast to the manganese, the iron concentrations have an indirectly proportionate relationship to the forams per gram because the iron concentrations are higher in the laminations with little to no forams. From 372-342cm in the core there is a higher concentration of iron (7,529 – 10,117 cps) but a complete absence of forams. The higher concentrations of iron within the core correlate to the more clay-based sections to the lower end of the core section (408cm to 428cm – 4,680< cps) and the higher end of the core section (365cm to 341cm – 9,745< cps) both of which yielded minimal to no forams per gram (the largest amount being 0.15 forams per gram at 418cm).

The calcium concentrations remain steady throughout the core section, with low level concentrations of less than 2,000 cps from 328-374cm, the calcium counts per second then varyingly increase over 2,000 cps throughout the rest of the core section with its highest concentration of 4,499 cps at a depth of 417cm.

##### Core section 5

Section 5 had higher abundances than section 4 with the maximum of forams per gram being 23.25g at 299cm (465 forams within the 20g sample). As seen in figure 5, between 259-245cm and between 315-311cm there were complete absences of forams. The depths where there were no forams are surrounded by depths above and below where there are forams present.

In figure 5, the forams per gram graph shows that from 309-277cm there were constant abundances of forams from 0.2 to 23.25g per sample and at the core depth 275cm and 235cm there were two complete absences of forams suggesting a short but sharp change in climatic conditions resulting in their temporary absence from the Baltic Sea floor.

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Ostracods (a class of the Crustacea species, also known as seed shrimp) were present within section 5 unlike section 4. In figure 5, they appeared in layers 263cm, 231cm and 327cm but do not appear anywhere else within the entire core. Also, agglutinated forams (which differ from Elphidium forams due to their shells being made from the adhesion of sand and sediment) appeared at 233cm. There have been no other agglutinated forams present throughout both sections 4 and 5. Similarly, at 305cm orange-stained forams were present suggesting an iron concentration which has caused them to be stained. Also, the same organic calcium carbonate organic shells were also found throughout core section 5 – suggesting a consistent calcium concentration throughout the section, as shown in figure 5.

In comparison to core section 4, there is a much lower manganese concentration throughout core section 5 with one major peak at a depth of 318cm (3,703 cps) which corresponds to the dark lamination present in the core and a spike in the forams present (7.55g per sample). The other minor spikes of manganese also correspond to the dark laminations within the core. These darker laminations have a greater spike in terms of forams. In addition, there are two periods where there is no manganese concentration present at all, these depths are 299cm and 249cm. The rest of the core section's manganese concentration is relatively low in comparison to core section 4 as it only crosses over 100 cps two times, one of which being the major peak.

The calcium concentration remains constant throughout the core mirroring that of the iron concentration. The calcium concentration only reduces at two depths, 263cm (572 cps) and 245cm (616 cps) otherwise remaining between 788 cps and 1,974 cps throughout the rest of the core. Its highest concentration is 1,974 cps at 307cm.

The iron concentration is the highest concentration of the three observed elements within core section 5 with the concentration remaining between 3,405 cps (264cm) and 14,985 cps (308cm). The iron concentration does share the same trend as the calcium concentration (as seen in figure 4) and again features most prominently in the clay rich areas of the core which, for section 5, is the whole core.

Unlike the manganese concentration in the core, both the iron and calcium concentrations within the core have no relationship with the foram abundances.

Results for section 4

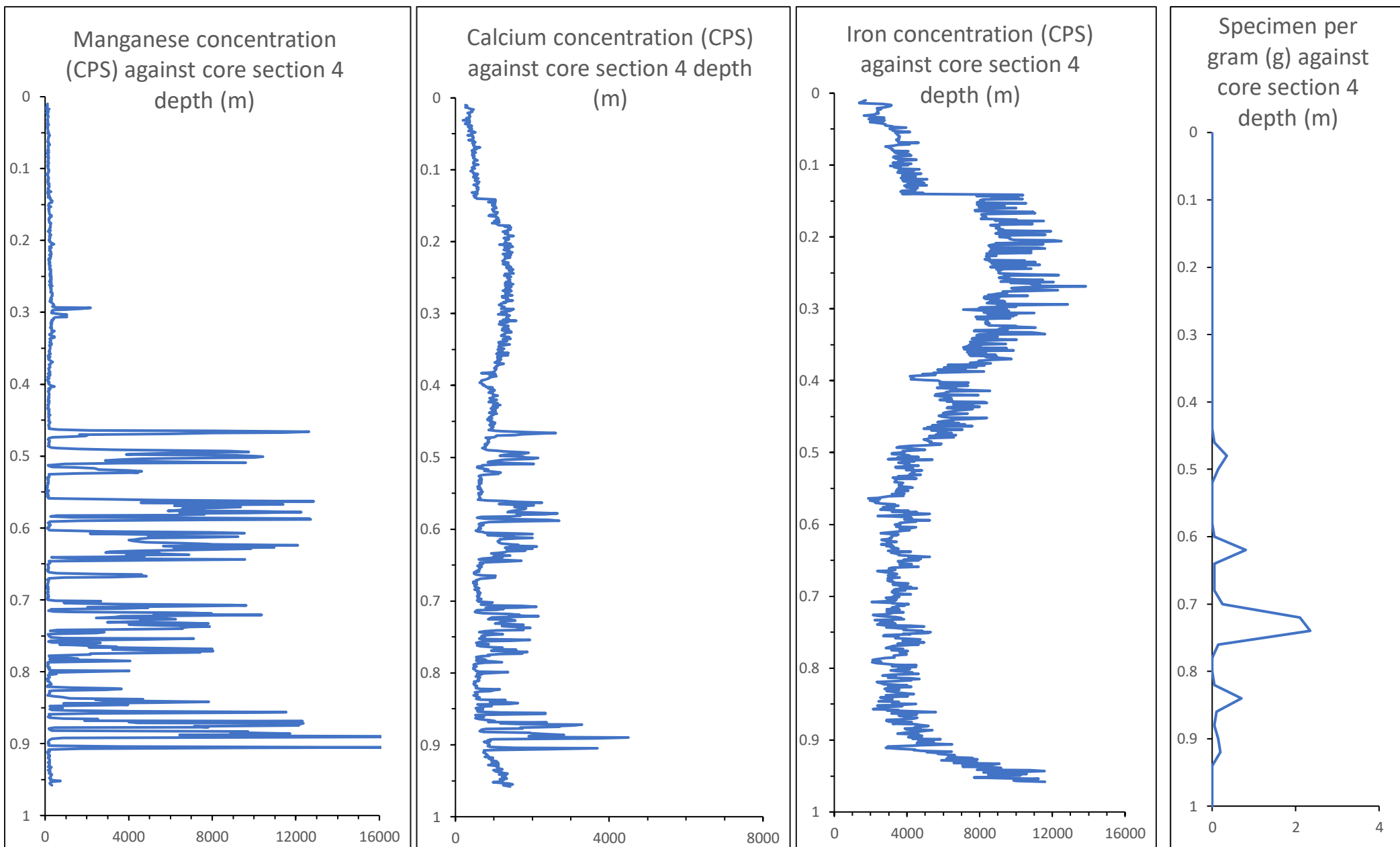


Figure 4. A graph of the manganese, iron, and calcium concentrations within core section 4 (Authors own) compared to the core's laminations and the number of forams (specimen) per gram of sample

Results for section 5

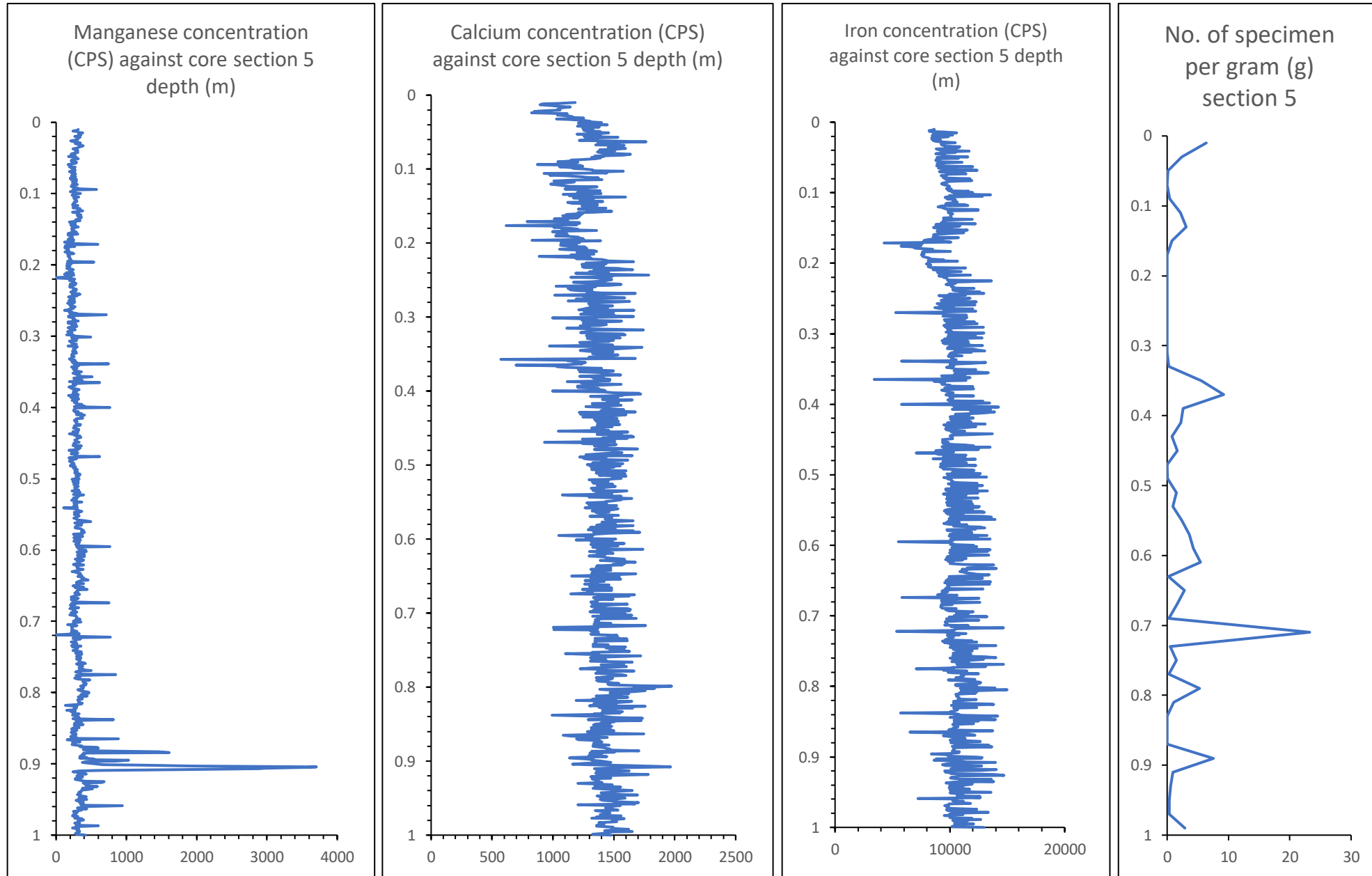


Figure 5. A graph of the manganese, iron, and calcium concentrations within core section 5 (Author's own) compared to the core's depth and number of forams (specimen) per gram.

### Discussion:

As seen in figure 6, core section 5 had much higher abundances of forams in comparison to section 4 which it sat above. Where foram abundances rise, the environment is likely to be marine dominated with oxygenated waters supporting the forams and where forams are absent, conditions are either freshwater or anoxic which do not support the forams.

### Core section 4

The results from the XRF scanner, shown in Figure 4, show higher concentrations of manganese in the 'gold' coloured laminations of the core. The higher levels of manganese suggest that the gold laminations date to periods with anoxic conditions because manganese is far better preserved in oxygen sparse conditions (when manganese is in oxygenated conditions it is oxygenated and thus less well preserved so there will be much smaller concentrations present in oxygenated laminations). In addition, the forams collected from these laminations are also smaller in size and abundance in comparison to the forams collected from the oxygenated laminations (section 5) because they have focused primarily on survival not growth and have thus tried to reproduce a lot quicker, similarly, the conditions in core section 4 were less hospitable so not as many forams survived. As a result, where conditions are good for forams to survive (as in section 5), they grown larger whereas, when conditions are harsh (like in section 4), the forams struggle to survive and are smaller because they reproduce more quickly. It is likely that the higher abundances of forams (390cm, 412cm, 398-404cm) are supported by the higher manganese concentrations and could reproduce more resulting in higher abundances per gram than in the laminations where there is a significantly smaller concentration of manganese. These higher abundances in section 4 are still much smaller than the abundances from core section 5, however.

In core section 4, the abundances of forams are found in the lower concentrations of iron within the core. The indirect relationship between the concentration of iron in cps and the limited number of forams per gram show that forams are not primarily found in clay, iron rich conditions. It is likely that they struggle to survive and thus cannot reproduce to sustain their population meaning that the iron resides in the depths of the core which are inhospitable for the forams. In addition, the calcium readings could have corresponded to the calcium carbonate of the Elphidium foram shells, however, upon examination of the samples, it was confirmed that the calcium concentration does not correspond to foram abundances as it remains constant throughout the core, even in laminations where there are no forams present. The concentration could also be related to the biotic material found within multiple layers of the core which has a calcium carbonate shell, like the Elphidium

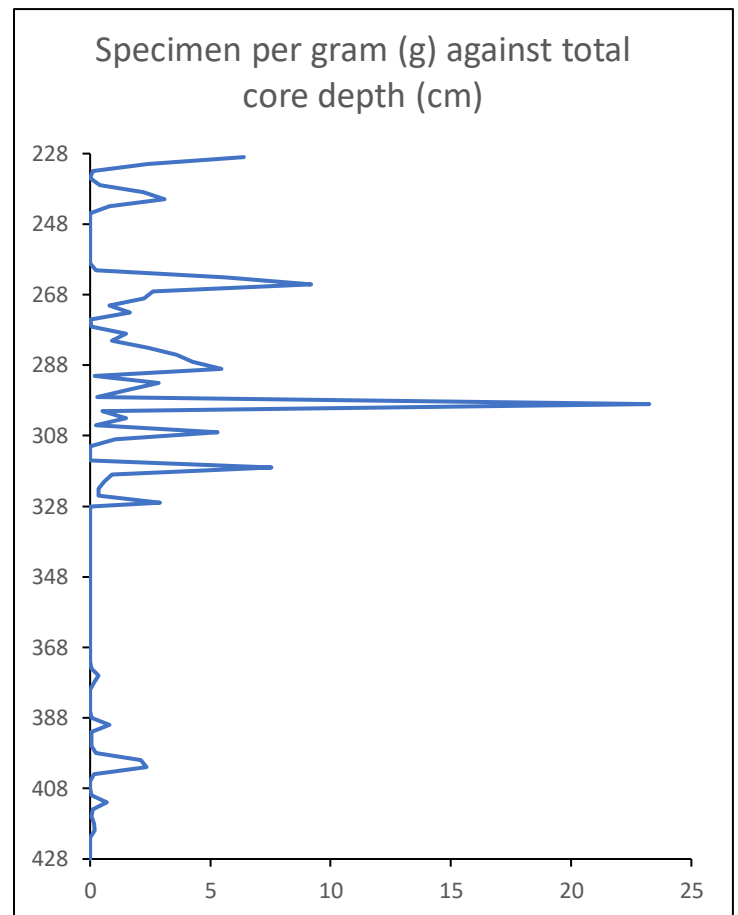


Figure 6. A graph of the total number of forams per gram in sections 4 and 5 of the core.

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shells. Their presence within the core could have contributed towards the consistent concentration of calcium carbonate found on the XRF scans. The Iron concentrations correlate with the calcium suggesting both elements can easily survive in the redox conditions which are anoxic. Between 342cm – 368cm, the calcium and iron graphs show the same trend and are in direct correlation with each other matching each other's peaks and troughs.

Section 4's small abundances could be explained by hypoxia caused by algal blooms which have dissolved the available oxygen in the Baltic Sea near the sea floor resulting in less oxygen for the forams and thus smaller to minimal abundance sizes. The depths of 374-330cm could correspond to a dead zone where there was no oxygen left near the sea floor for the forams to survive, resulting in their complete absence for a considerable period until the oxygen returns from the depth 328cm to 228cm.

The forams appear to be able to survive within the anoxic conditions due to the correlation with the manganese concentrations, however, when the conditions become hypoxic, they struggle to attain the oxygen needed for survival and reproduction. The smaller abundances of forams could link to adult forams being able to survive in oxygen limited conditions but not for extended periods – explaining their smaller size and the lack of forams in general – there was enough oxygen for them to survive for a limited time, but not long term like in section 5. There was a high turnover of forams due to the lack of oxygen resulting in smaller populations and their smaller sizes due to the prioritization of survival and reproduction over development.

Core section 5

The stark contrast of foram abundances between section 4 and section 5 suggest that section 5 formed under more oxygenated conditions which were able to support the development of larger abundances of forams per gram. The contrast between the amount of foram abundances at the top of section 4 and the bottom of section 5 could illustrate a major change in environmental conditions, such as the transition between a glacial and interglacial period or the transition from hypoxic to oxygenated conditions, which caused a shift in the survivability of the Baltic Sea ecosystem meaning forams were much more able to develop and survive. The composition of section 5 does not differ far from section 4 in terms of the clay and silt found in the samples however, section 5 did not have clear laminations which were observed in section 4, again suggesting different oxygenated conditions in which section 5 formed under.

The size of the forams from section 5 were larger than section 4 however, in comparison to standard sized forams, they are still smaller.

The North Sea's higher oxygenation levels (and slower reduction of oxygen concentrations – 9% per year as compared to 11% for the Baltic Sea) could have restored the harsh environmental conditions in core section 4 back to a level of oxygenation within section 5 where the forams were able to survive and reproduce resulting in the higher abundances of forams throughout core section 5. The change in sections could correspond to the move between the Litorina sea stage (saline waters from the North Sea causing oxygenated conditions) and the later Limnea sea stage (the reduction of saline waters from the North Sea resulting in the decrease of oxygenated waters) due to the entry and exit of the marine North Sea water into the Baltic Sea.

The consistent abundances of forams in section 5 could suggest steady and comparatively unaffected environmental conditions which allowed the forams to reproduce at a consistent rate resulting in prolonged periods of their presence. The two unusual bland periods where there were

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no forams in section 5 could illustrate a short but sharp change in environmental conditions within the Baltic which resulted in their absence for that period.

The presence of laminations within both cores (mainly section 4) indicates more stratified conditions in the water column which resulted in poor oxygenation of the deeper waters in the Baltic Sea due to less mixing between surface waters with higher oxygen concentrations leading to less hospitable conditions for the forams. Core section 5 which has the least laminations is likely characterised by well mixed conditions in the water column and thus has more oxygenated bottom water conditions which supports the forams far more than the anoxic bottom water conditions of core section 4.

There are still periods in section 5 however that do not have forams which suggests core section 5 does also have anoxic periods caused by the reduction of oxygen in the bottom waters in the Baltic Sea due to climatic changes like the Litorina and Limnea sea stages.

### Conclusion:

For a definitive conclusion, the remaining core sections 1-3 and 6-8 would also need to be sampled and their foram abundances counted to determine whether the location between the Aaland sill and mainland Sweden was the main entry point of the North Sea into the Baltic Sea, however, from the data collected from core sections 4 and 5 we can state that the forams are evidence of marine water from the North Sea entering the Baltic Sea because the North Sea provides more oxygenated water to the Baltic sea which supports the forams. The lack of forams within both core sections provides evidence for anoxia and stratification of the cores due to changing oxygenation levels in the bottom waters of the Baltic Sea by the reduction of the marine North Sea waters and its higher concentration of oxygen. Core section 4 provides convincing evidence for a period where the North Sea was not entering the Baltic Sea between mainland Sweden and the Aaland sill because of its clearly stratified, anoxic conditions. The forams die out in lengthy periods of anoxia because they cannot survive, thus, core section 4 likely corresponds to a period in which the North Sea was not present within the Baltic Sea, and the Baltic's bottom sea waters were inhospitable. On the other hand, core section 5 provides compelling evidence for the North Sea entering the Baltic Sea via the Aaland sill and mainland Sweden due to the well mixed conditions the core section formed under, providing a suitable environment for the larger foram abundances in which they could both survive and reproduce. Their continual presence throughout the core suggests that this period where the North Sea was entering the Baltic Sea increasing oxygenation, continued for a lengthy period which oxygenated the bottom waters of the Baltic Sea so substantially that it increased the hospitality of the Baltic Sea floor environment for the forams allowing for larger populations and continual survival.

### Bibliography:

Binczewska, A., Moros, M., Polovodova Asteman, I., Sławińska, J. and Bąk, M., (2017). "Changes in the inflow of saline water into the Bornholm Basin (SW Baltic Sea) during the past 7100 years - evidence from benthic foraminifera record". *Boreas*, Vol 47(1), pp.297-310.

Leppäranta, M., and Myrberg, K., (2009), "*Physical oceanography of the Baltic Sea*". Berlin: Springer/Praxis Pub., pg.2.

*What impact has climate change had on the variability of the Baltic Sea ecosystem as evidenced by the presence or lack of marine plankton in Baltic Sea sediment cores?*

(2022), *Political Map of the Baltic Sea*. [image] Available at:

<<https://www.nationsonline.org/oneworld/map/Baltic-Sea-map.htm>> [Accessed 21 July 2022].

Rosentau, A., Vassiljev, J., Hang, T., Saarse, L. and Kalm, V., (2009), "Development of the Baltic Ice Lake in the eastern Baltic". *Quaternary International*, Vol 206 (1-2), pp.16-23.

Stefanoudis, P., Schiebel, R., Mallet, R., Durden, J., Bett, B. and Gooday, A., (2016), "Agglutination of benthic foraminifera in relation to mesoscale bathymetric features in the abyssal NE Atlantic (Porcupine Abyssal Plain)". *Marine Micropaleontology*, Vol 123, pp.15-28.

Tikkanen, M. and Oksanen, J., (2002). "Late Weichselian and Holocene shore displacement history of the Baltic Sea in Finland." [online] *Fennia*.journal.fi. Available at:

<<https://fennia.journal.fi/article/view/3760>> [Accessed 19 July 2022].

Winterhalter, B., Flodén, T., Ignatius, H., Axberg, S. and Niemistö, L., (1981). "Chapter 1 Geology of the Baltic Sea". *Elsevier Oceanography Series*, Vol 30, pp.1-121.