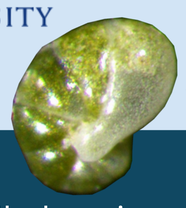
MASTER'S THESIS 2026

A Changing Foraminiferal Landscape in the Öresund: Cataloguing the potentially invasive *Nonionella* sp. T1 and Assessing Deep Learning for Species Identification

MALIN PÅLSSON[1], HELENA L. FILIPSSON[1], ALLISON Y. HSIANG[2]

[1]DEPT. OF EARTH AND ENVIRONMENTAL SCIENCES, LUND UNIVERSITY, SWEDEN, MA4233PA-S@STUDENT.LU.SE, HELENA.FILIPSSON@MGEO.LU.SE; [2]DEPT. OF ECOLOGY, ENVIRONMENT AND PLANT SCIENCES, STOCKHOLM UNIVERSITY, SWEDEN



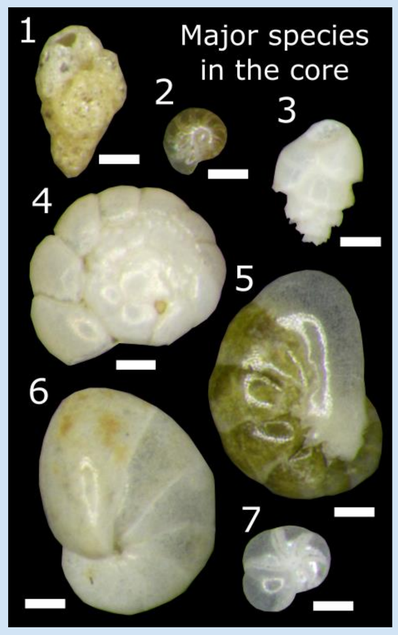
INTRODUCTION

Single-celled marine organisms such as foraminifera are valuable environmental indicators, as the assemblages of species vary depending on the surrounding marine conditions. Monitoring changes in species assemblages of benthic foraminifera can improve our understanding of past climatic events and give us insight into the potential future effects of anthropogenic climate change. Previous studies have identified changes in foraminiferal assemblages as well as the introduction of the potentially invasive species *Nonionella* sp. T1 in the Skagerrak-Kattegat[1], Oslo Fjord[2], Gullmar Fjord[1], and Öresund[3] regions. In this study, we quantify the presence of *Nonionella* sp. T1 in a sediment core collected off the south coast of the Island of Ven in the Öresund.

THE POTENTIALLY INVASIVE *NONIONELLA* SP. T1 IN THE ÖRESUND

Knowledge on the impact of denitrifying microorganisms is key for fully understanding the marine nitrogen cycle. *Nonionella* sp. T1 has been proven to act as a major denitrifying organism in the fjord environment[4], which raises the question on the impact in other marine ecosystems, like the Öresund. The presence of *Nonionella* sp. T1 can indicate changes in oxygen levels or nutrient supply in marine environments. By determining the historical prevalence of *Nonionella* sp. T1 alongside general foraminifera assemblages south of Ven, changes in marine conditions can be monitored. In this study, the first appearance of *Nonionella* sp. T1 happened at 11-12 cm sample depth and increased upward the sediment core, with a highest abundance at 26 % of the total amount.

Fig. 1. Species with ≥5 % of the total abundance in at least one sample.



1 *Eggerelloides medius/scabrum* 2 *Elphidium clavatum* 3 *Bulimina marginata* 4 *Ammonia batava* 5 *Nonionella* sp. T1 6 *Nonionella labradorica* 7 *Elphidium magellanicum*
Scale bar = 100 µm

STUDY SITE

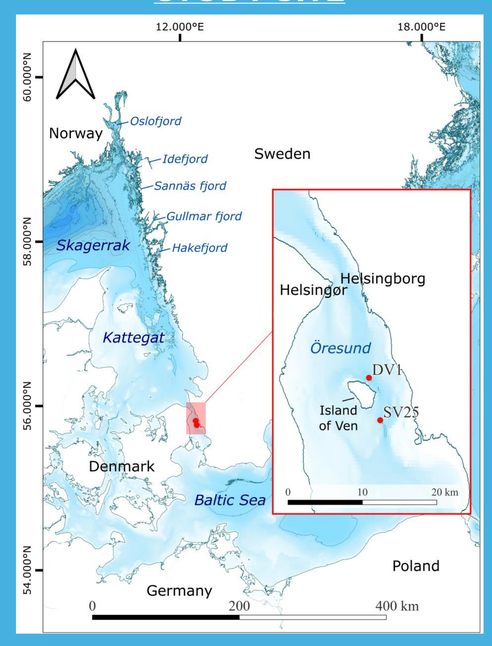


Fig. 2. The study site, south of Ven in the Öresund. The two sediment cores were collected with a GEMAX twin corer at a water depth of 46 m.

Fig. 3. Relative abundances (%) of the seven major species of benthic foraminifera in the 17 analysed sediment samples. After its introduction, *Nonionella* sp. T1 contributed as one of the major species of the total foraminiferal assemblages. In SHE analysis[5], species richness, diversity, and evenness are statistically analysed. Slope changes (red arrow) in ln(E) vs ln(N) represent shifts between abundance structures, here ln(E) is plotted against depth to show the different slopes throughout the sediment levels.

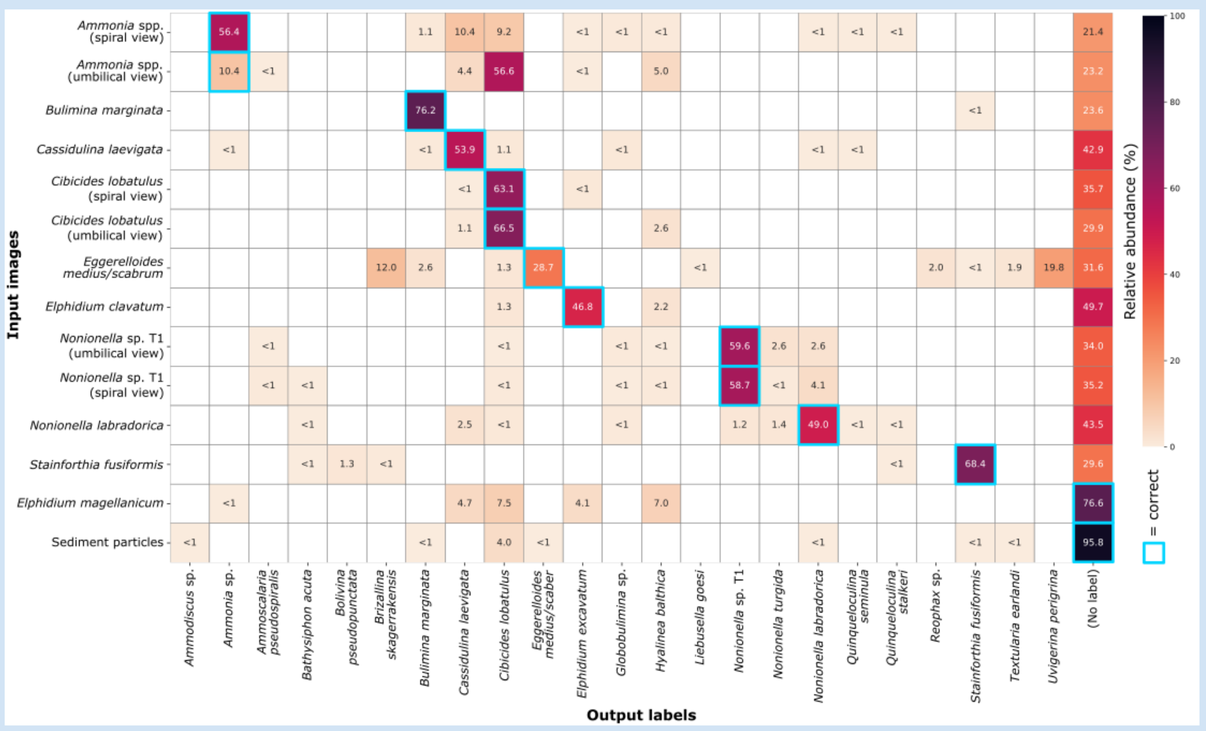
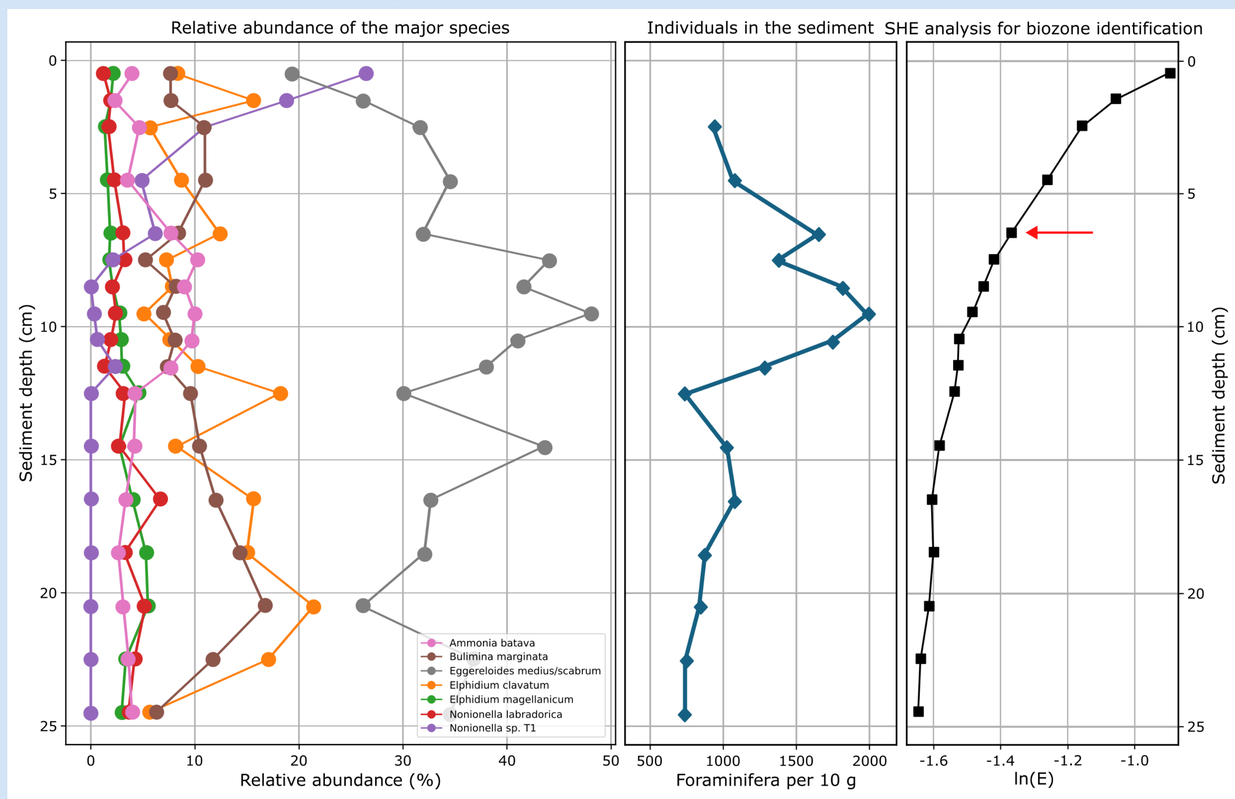


Fig. 4. Confusion matrix of input images and output labels from the YOLOv7 model, summarising the results from all different imaging conditions (1 680 input images). The correct output labels shown in blue.



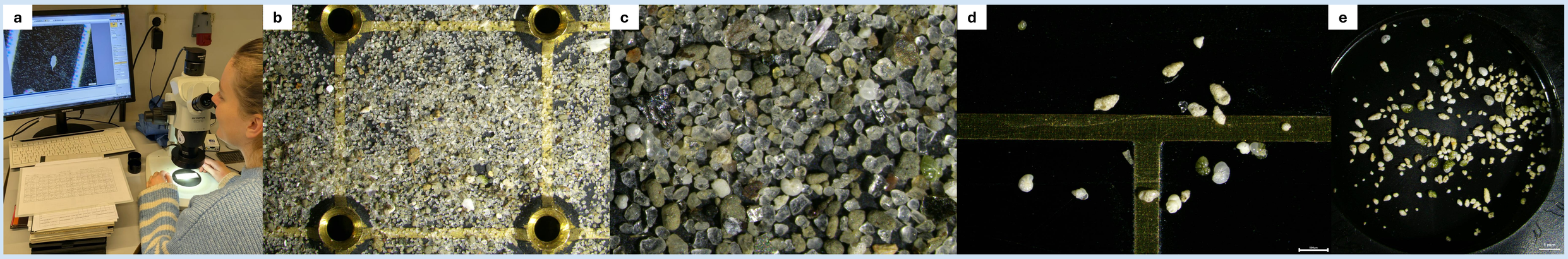


Fig. 5. The different steps of species identification. a) Looking at samples in the light microscope. b) Looking for foraminifera in material from fraction >100 to <500 µm. c) Close-up on how the foraminifera can look in the sand. d) Picked foraminifera ready for identification. e) Identified foraminifera in a sample.

METHODS

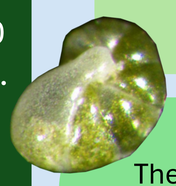
The sediment core was collected south of Ven on 2nd of October 2025, onboard r/v *Sabella*, at 46 m water depth. The core was sectioned into one centimeter-slices and freeze-dried. After wet-sieving and oven-drying, material in the fraction >100 and <500 µm was studied under light microscope. For each sediment sample, a minimum of 300 foraminifera were picked and identified, resulting in 17 samples and 5 540 foraminifera.

IMPLEMENTING MACHINE LEARNING FOR SPECIES IDENTIFICATION

Traditional manual methods for studying foraminifera tend to be time-consuming and labor-intensive. As part of the project, a YOLOv7 deep learning model was assessed on species identification, trained to identify 29 species of benthic foraminifera based on a total amount of 22 138 individuals from >70 sediment cores from the Skagerrak fjords.[6] In 14 experimental setups, testing both known and unknown foraminifera to the model, as well as sediment particles, different imaging conditions were studied. The accuracy of the model's output data varied depending on magnification, brightness, focus, and pixel resolution. There was no universal optimal imaging setup, which made direct application on species identification of unpicked samples difficult. However, the YOLOv7 model showed great potential as a first step in automated identification.

CHALLENGES

- Distinguishing between morphologically similar species; could lead to a larger error in species data than genus data
- Some species are easier to find in the sand, giving certain risk of overrepresentation compared to more camouflaged species
- Preservation bias: Are the foraminifera in the sediment core showing the true signal of past benthic foraminifera fauna?



ACKNOWLEDGEMENTS

The authors thank the captain and crew onboard r/v *Sabella* for the fieldwork during sediment core collection, as well as Marko Plavetić for assistance with the machine learning analysis. Project funding is provided by Stiftelsen Oscar och Lili Lamms minne and Stiftelsen Längmanska kulturfonden.

REFERENCES

- 1 Polovodova Asteman, I., Schönfeld, J. (2016). Recent invasion of the foraminifer Nonionella stella Cushman & Moyer, 1930 in northern European waters: evidence from the Skagerrak and its fjords. J. *Micropalaeontology*., 35(1), 20–25. https://doi.org/10.1144/jmpaleo2015-007
- 2 Deldicq, N., Alve, E., Schweizer, M., Polovodova Asteman, I., Hess, S., Darling, K., & Bouchet, V. M. P. (2019). History of the introduction of a species resembling the benthic foraminifera Nonionella stella in the Oslofjord (Norway): morphological, molecular and paleo-ecological evidences. *Aquatic Invasions*. 14(2). 182-205. https://doi.org/10.3391/ai.2019.14.2.03
- 3 Charrieau, L. M., Ljung, K., Schenk, F., Daewel, U., Kritzberg, E., Filipsson, H. L. (2019). Rapid environmental responses to climate-induced hydrographic changes in the Baltic Sea entrance. *Biogeosciences*, 16(19), 3835-3852. https://doi.org/10.5194/bg-16-3835-2019
- 4 Choquel, C., Geslin, E., Metzger E., Filipsson, H. L., Risgaard-Petersen, N., Launeau, P., Giraud, M., Jauffrais, T., Jesus, B. & Mouret, A. (2021). Denitrification by benthic foraminifera and their contribution to N-loss from a fjord environment. *Biogeosciences*(18), 327-341. https://doi.org/10.5194/bg-18-327-2021
- 5 Wilson, B., Orchard, K., & Phillip, J. (2012). SHE Analysis for Biozone Identification among foraminiferal sediment assemblages on reefs and in associated sediment around St. Kitts, Eastern Caribbean Sea, and its environmental significance. Marine Micropaleontology, 82-83, 38-45. http://dx.doi.org/10.1016/j.marmicro.2011.10.001
- 6 Plavetić, M., Hsiang, A. Y., Josefsson, M., Hulthe, G. & Polovodova Asteman, I. (2025). Deep learning accurately identifies fjord benthic foraminifera. *Journal of Micropaleontology*(44), 693-711. https://doi.org/10.5194/jm-44-693-2025