3D foraminifera unravel environmental changes in the Baltic Sea entrance over the last 200 years

Constance Choquel[1], Dirk Müter[3], Sha Ni[1], Laurie Charrieau[1,2],Behnaz Pirzamanbein[4], Gerhard Schmiedl[5], Helena L. Filipsson[1]

1) Department of Geology, Lund University, Sweden, 2) AWI, Bremerhaven, Germany, 3) FORCE Technology, Brøndby, Denmark 4) Department of Statistics, Lund University, Sweden, 5) Department of Geology, Hamburg University, Germany

Contacts: constance.choquel@geol.lu.se and helena.filipsson@geol.lu.se

Fig. 1. Map of the study area.

Context of the study

- ❑ We analyzed a **3D set of 124 calcite microfossils** recording the period from early industrial to present-day conditions at the entrance of the Baltic Sea (Öresund, Fig.1).
- ❑ The **foraminiferal fauna** has changed profoundly in this vulnerable region subject to combined hydrographic changes and increasing anthropogenic pressures.
- ❑ We extended the analyses on *Elphidium clavatum* specimens to explore potential changes in test morphology through **synchrotron-based µCT**.

We hypothesize that potential changes in the morphological patterns are leaded by environmental changes and should be detectable by the 3D reconstructions.
What do we learn from morphological variations compared to faunal fluctuations? Do they tell us the same story?

3D analyses

Specimens were mounted on Gecko tape and analyzed on Beamline 47XU SPring-8 with a **resolution of 500 nm**

Innovative post-data analysis with free software

Thickness, calcite surface, calcite volume, number of pores, SV ratio, pore density

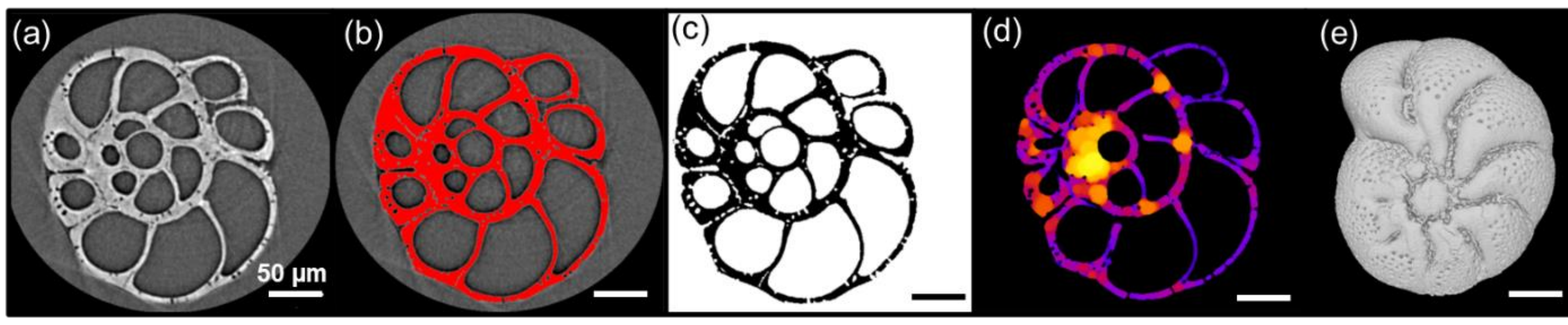

Fig 2. Illustration of the stepwise image processing. (a) Visualization step in Fiji. (b) Segmentation step in Fiji. (c) Binary image from the segmentation. (d) Thickness with arbitrary color scale using BoneJ plugin in Fiji. (e) 3D reconstruction of the test in MeshLab.

Morphometrics relationships

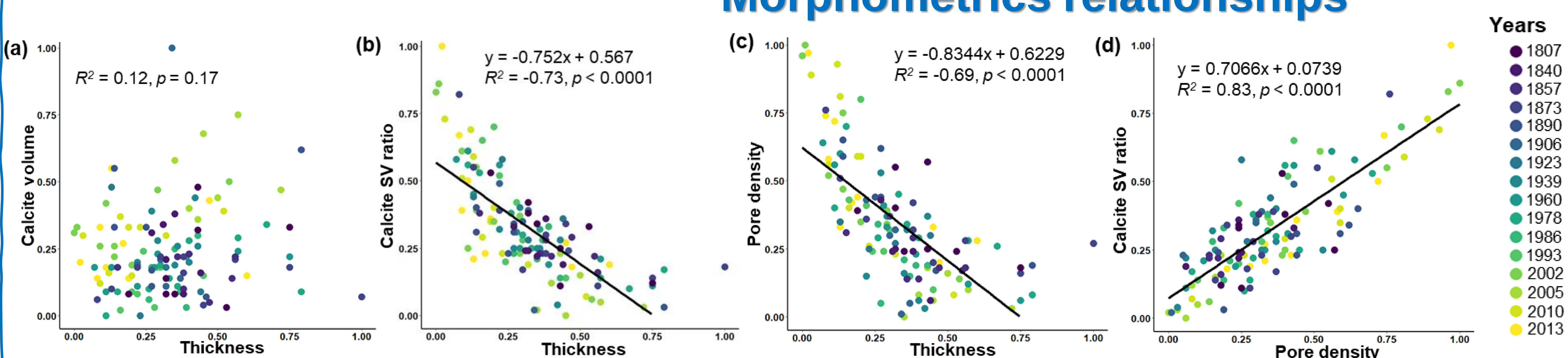

Fig. 3. Morphometrics relationships with linear correlations. The color range corresponds to the estimated years (~1.5 years for the recent layers and up to ~10 years for the deepest layers).

- ❑ Wide range of morphological patterns: thinner tests have a higher calcite SV ratio and a higher pore density, conversely, thicker tests have a lower calcite SV ratio and a lower pore density.
- ❑ **Morphological traits** previously associated with environmental stressors can be used for palaeoecological interpretations.

3D time-series

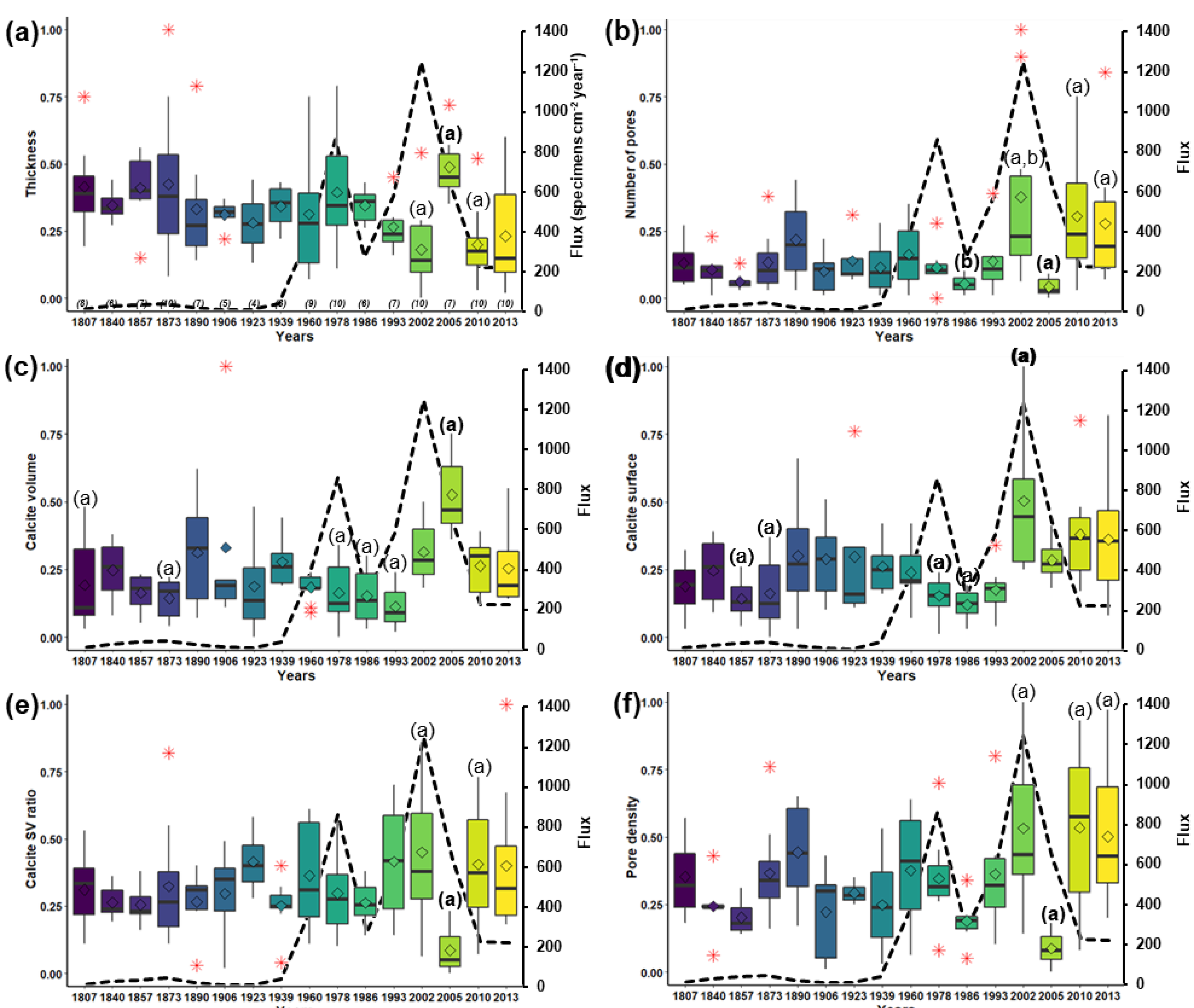

Fig. 4. 3D time-series. Number of scanned specimens in italics above the (a) x-axis. The diamonds indicate the average. The red stars are outliers. The morphological values are adjusted (0-1). The bold letters (a, b) indicate significant differences. The dotted line is the E. clavatum *flux (specimens cm^{-2} year^{-1}) from Charrieau et al., (2019).*

- ❑ **Long-term trends** (200 years): thickness loss by ~20% and number of pores increase by ~74%, resulting from continuous environmental changes in the region.
- ❑ **Short-term variabilities** (decennial): major changes associated with large morphological variability reveal contrasting environmental conditions, whereas minor changes with lower morphological variability indicate stabilizing environmental conditions.
- ❑ **Flux *versus* morphology**

- Before the 1940s: no change in flux but morphological variations especially pore density → natural variability of bottom water [O_2].
- Industrial Revolution (the 1940s-2000s): both flux peaks are related to the increase in morphological variability → anthropogenic effects
- The 2010s: flux stable and low but the morphological variability remained very large → multiple stressor effects e.g., low [O_2] events, lower/more variable pH, and warmer temperatures.

Conclusions

3D time-series provide a valuable baseline to reconstruct the Baltic Sea entrance evaluation over the last 200 years and could be an alternative to faunal description to unravel environmental changes.

Acknowledgement: We thank the captain and crew of r/v Skagerak, and the staff at the SPring-8 synchrotron facility (BL 47XU) as well as funding from the Swedish Research Council Formas, the Interreg project "MAX4ESSFUN Cross Border Network and Researcher Programme", Lund University Center for studies of Carbon Cycle and Climate Interactions (LUCCI). We thank the Carl Tryggers Foundation for funding Constance Choquel's post doctoral fellowship.