Temporal changes of the benthic environmental conditions in a subarctic fjord with aquaculture activity

A geochemical and micropaleontological study

Hege Kristine Vågen

Fjords

Kaldfjorden, Troms

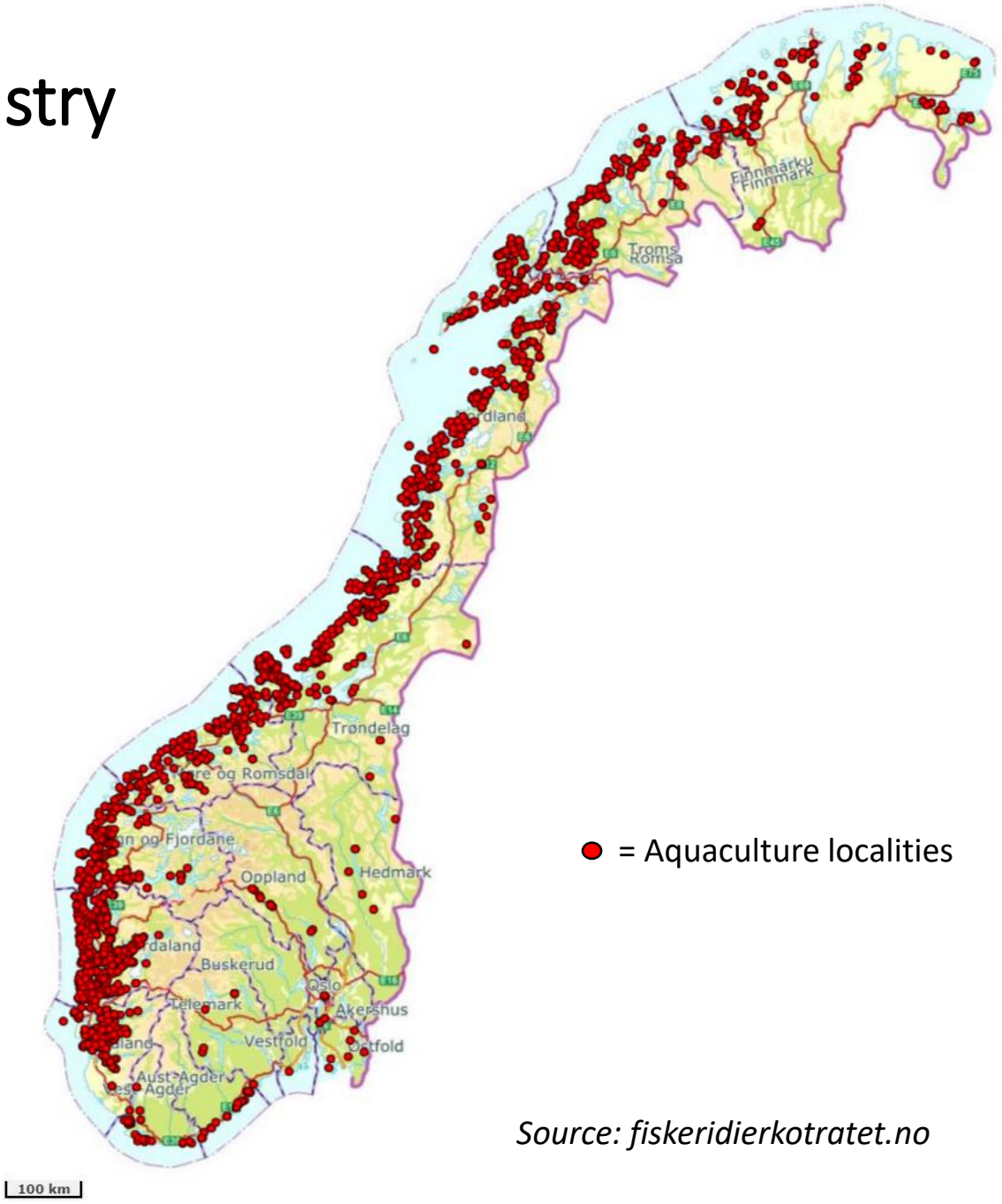
Norwegian aquaculture industry

Norwegian fjords:

- Sheltered, cold-temperate
- Become hot spots for aquaculture industry

Series of environmental concerns:

- Parasites
- Chemicals
- Escape of farmed fish
- **Organic waste**



Source: fiskeridierkotratet.no

Organic waste from aquaculture operations

Organic waste (excess fish food and fish waste)

Nutrient rich

Increase plankton blooms

Particulate organic matter

Sink and settle at various distances from fish farms

Decompose and consume oxygen

Biological systems are sensitive

Potentially alter the benthic environment

Ecological Quality Status (EcoQS)

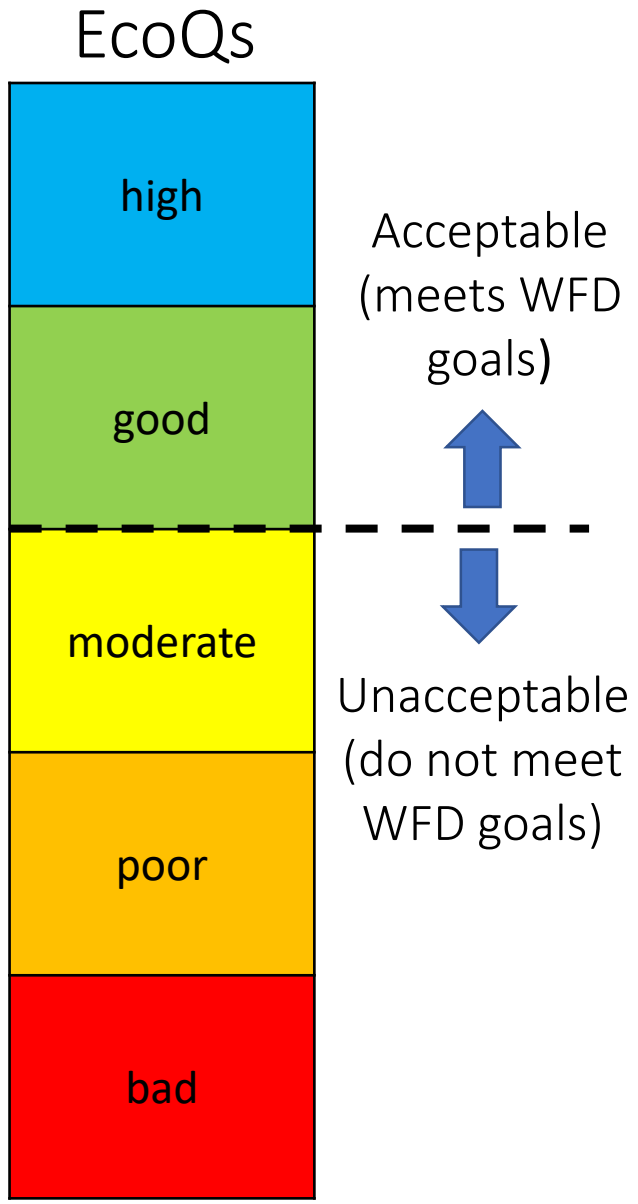
- EU's Water Frame Work Directive (WFD)

The purpose of environmental monitoring is to investigate the EcoQs or "health" of an area, and determine whether it has changed over time due to human impact.

What is the reference condition in one exact fjord?

Usually unknown

- Limited sediment data
- Limited biological time series



Aim:

Determine if there has been an environmental change from pre-aquaculture time to the present day

Find the reference condition of the fjord

How is this done?

Analysis of sediment cores

- Radiometrically dated

Reconstructed the depositional environment by analysis of:

- Grain size distribution
- Total Organic Carbon (TOC)
- Total Nitrogen (TN)
- Carbonate content
- Heavy metals

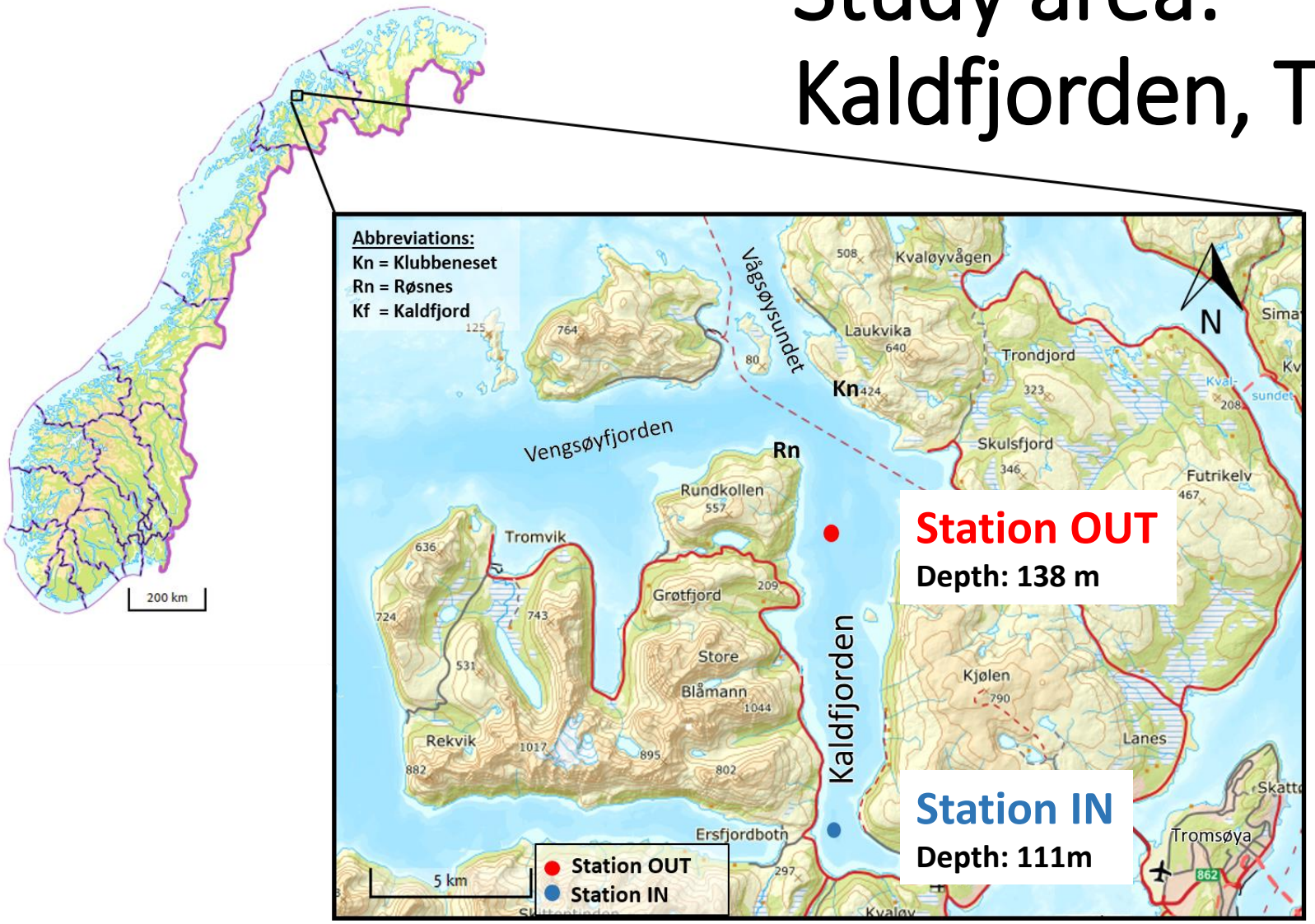
Ecological response through time:

- Study of benthic foraminifera

Picture of foraminifera, small (< 1mm) protist

Source: http://paleoaerie1.rssing.com

Study area: Kaldfjorden, Troms county



Source: kartverket.no

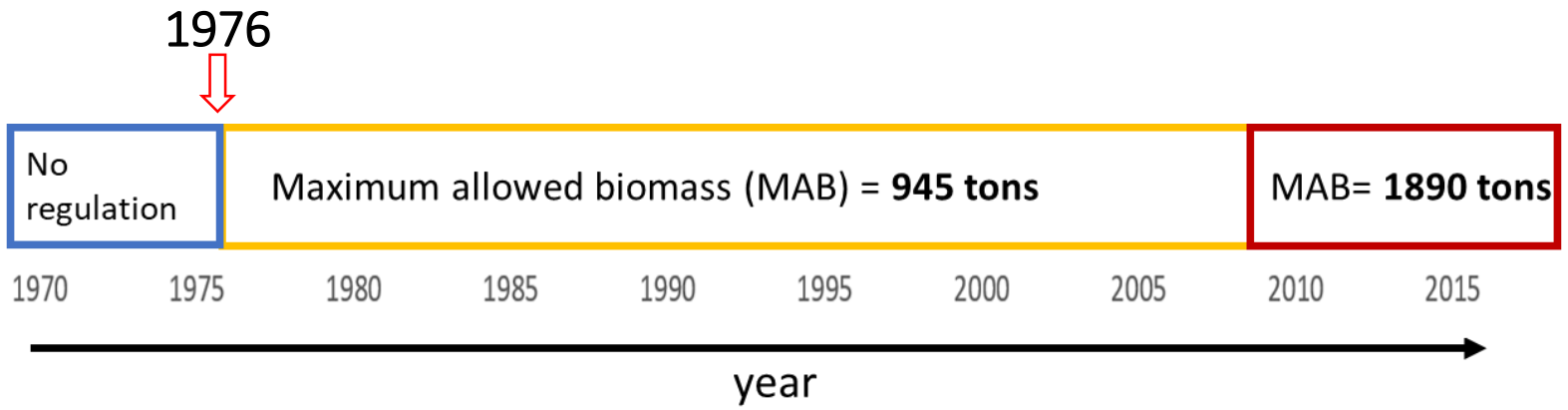
Two stations:

- Inner/outer fjord → give a broader picture of the environmental condition in Kaldfjorden
- Allow for comparisons

Source: fiskeridierktoratet.no

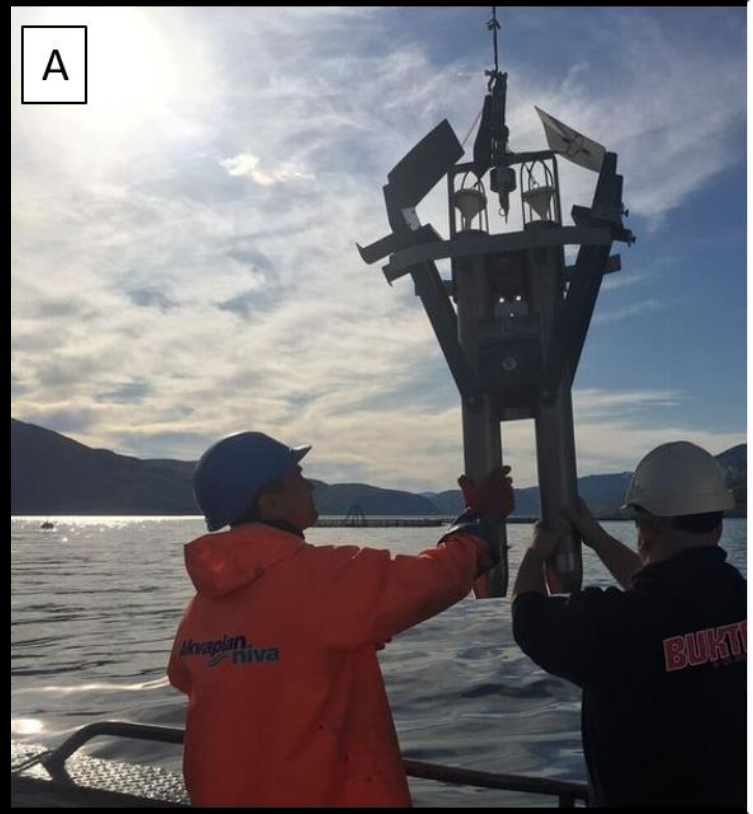
Pollution sources

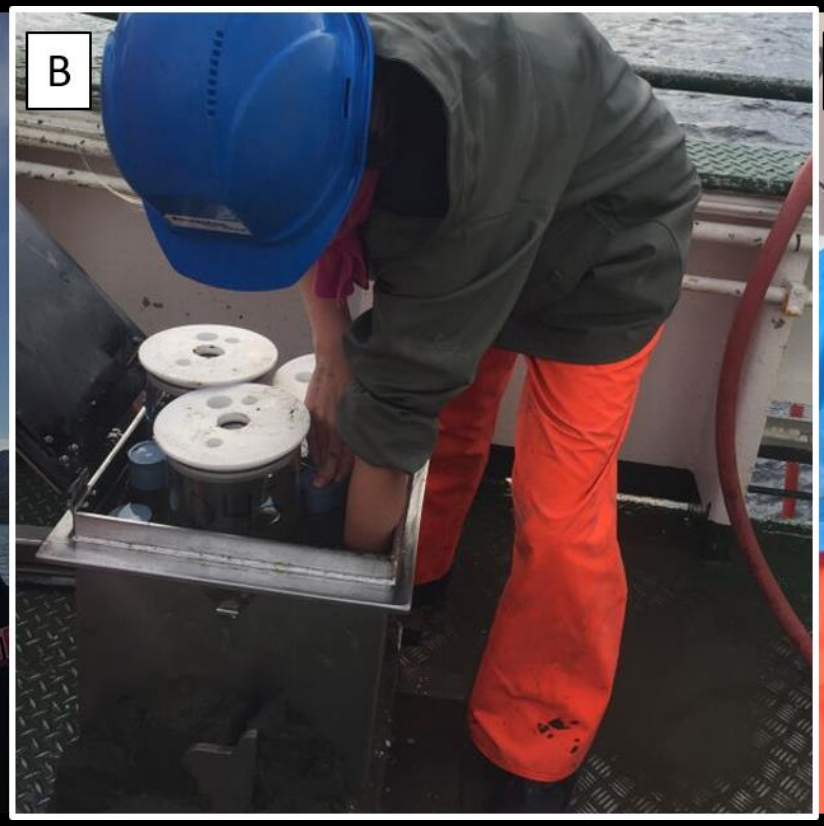
- Active aquaculture industry since early 1970s
- Some relocation of the fish farms



Both coring stations located with some distance to the fish farms

Field work



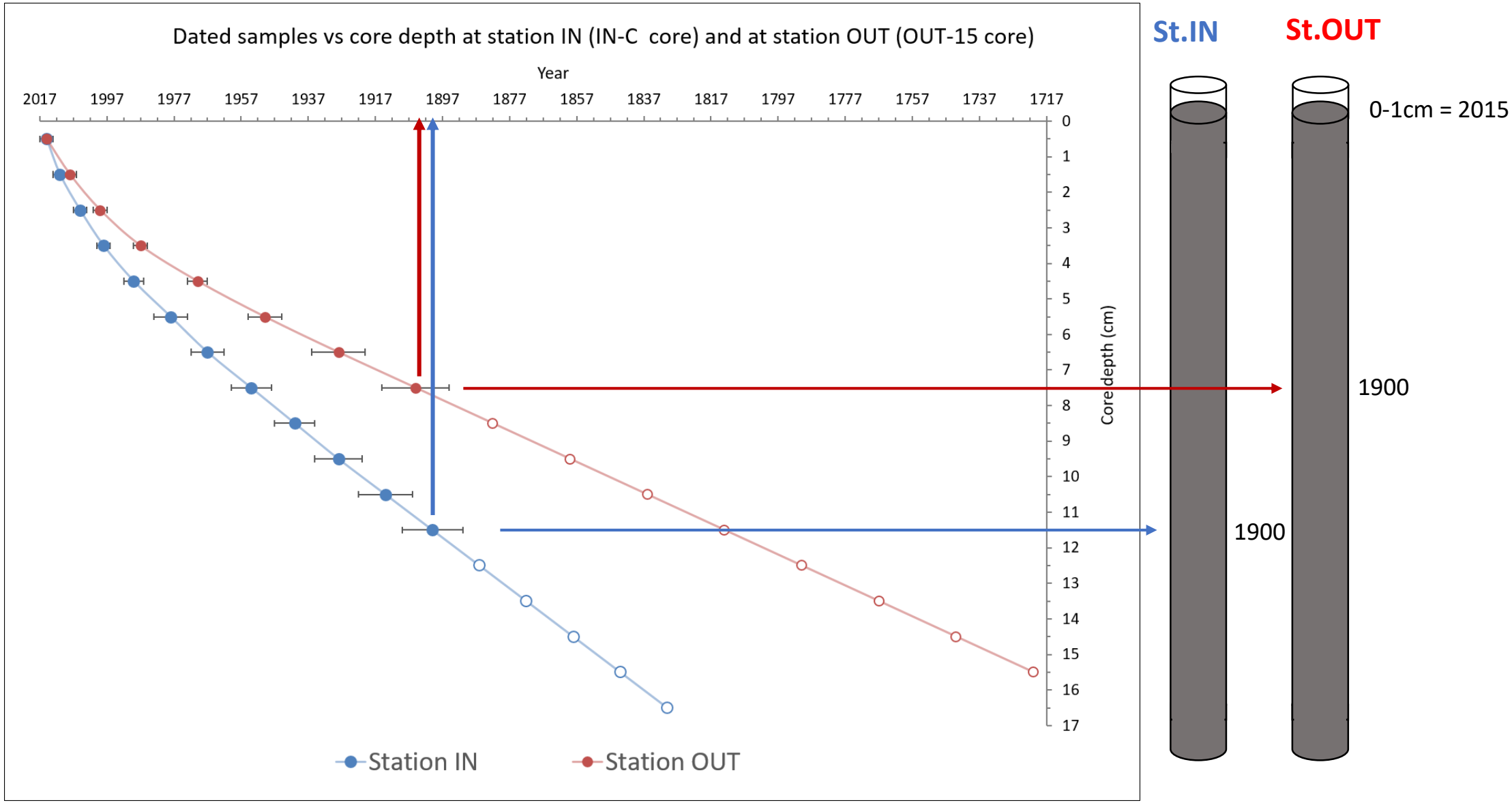


Collected sediment cores with a Gemini Corer (A) and Box Corer (B)

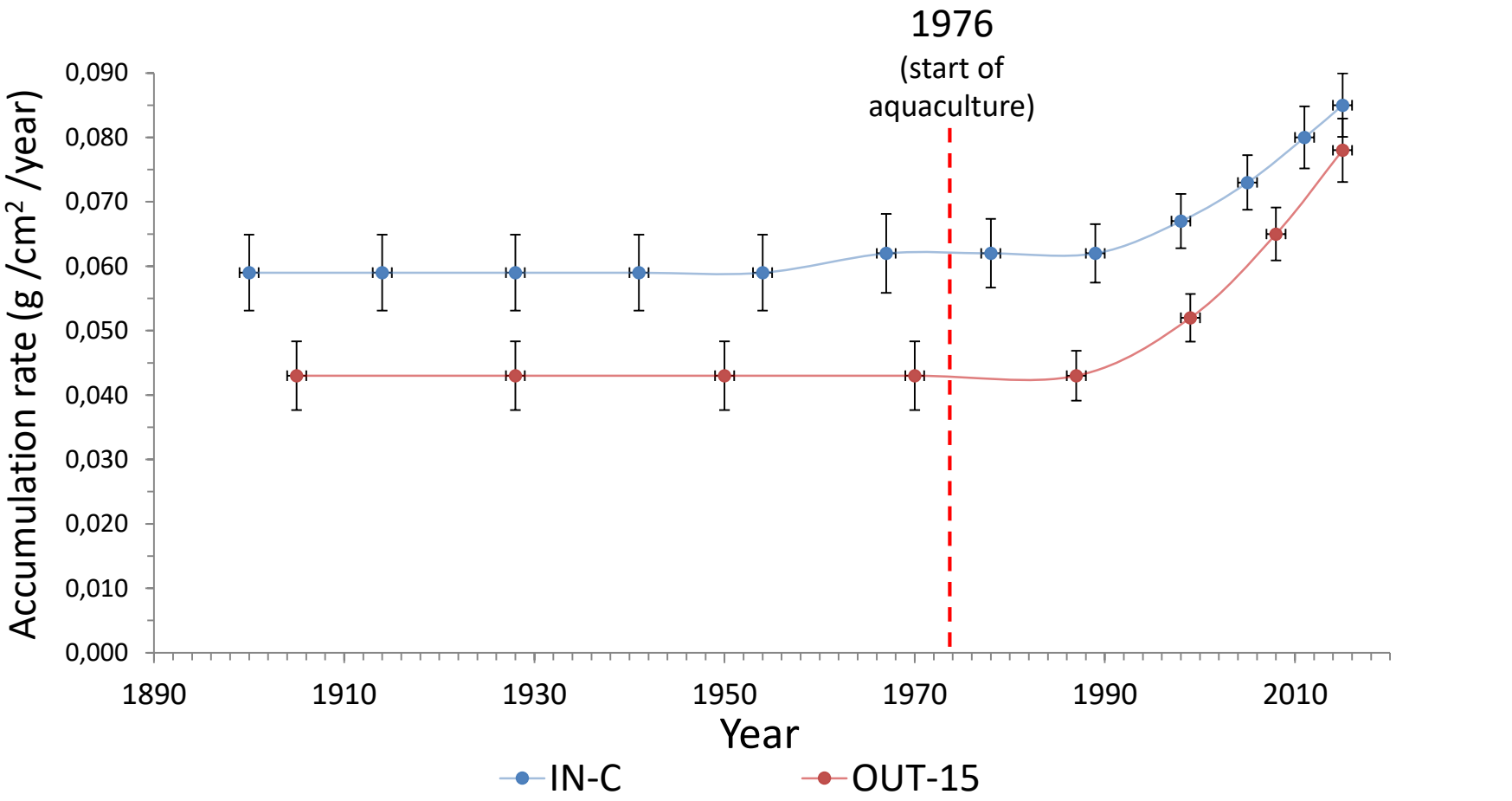
The cores were sliced in 1 cm slices (C)

Core lengths: 16-17 cm

Environmental Radioactivity Research Centre at University of Liverpool



Sediment accumulation rate (SAR) vs. year



Low compared to other fjords

average Sediment Accumulation Rate (SAR) in other Norwegian fjords

West Norway

Hordaland

Rogaland

Northern Norway

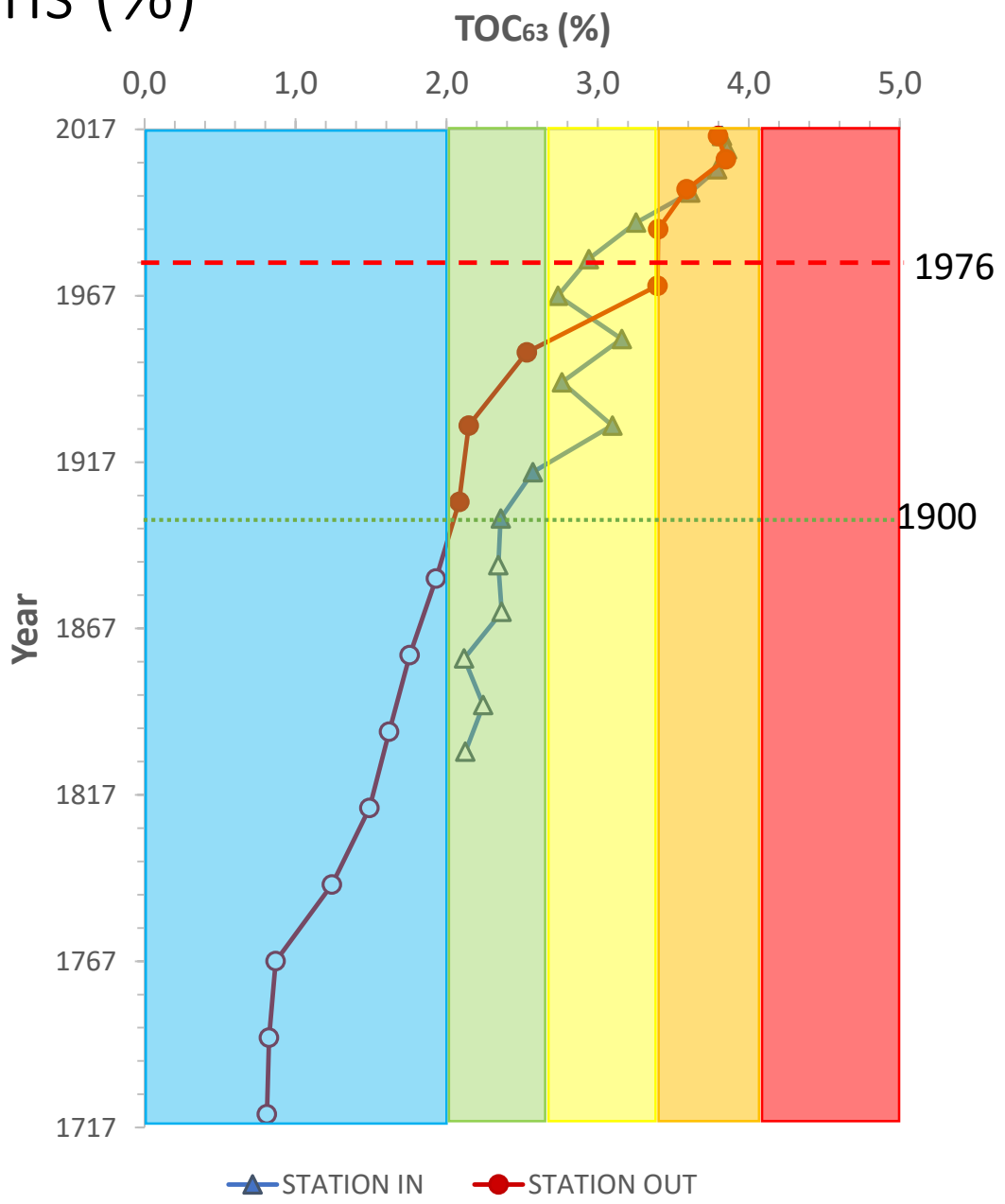
Troms

	Onarheimsfjorden (Sjetne, 2017)		**Lysefjord** (Duffield et at., 2017)	**Malangen** (Wassman et al., 1996)		**Kaldfjorden**	
SAR $g/cm^2/year$	0.18	0.10	0.11	0.18	0.27	**0.07**	**0.05**

Total organic carbon (TOC) concentrations (%)

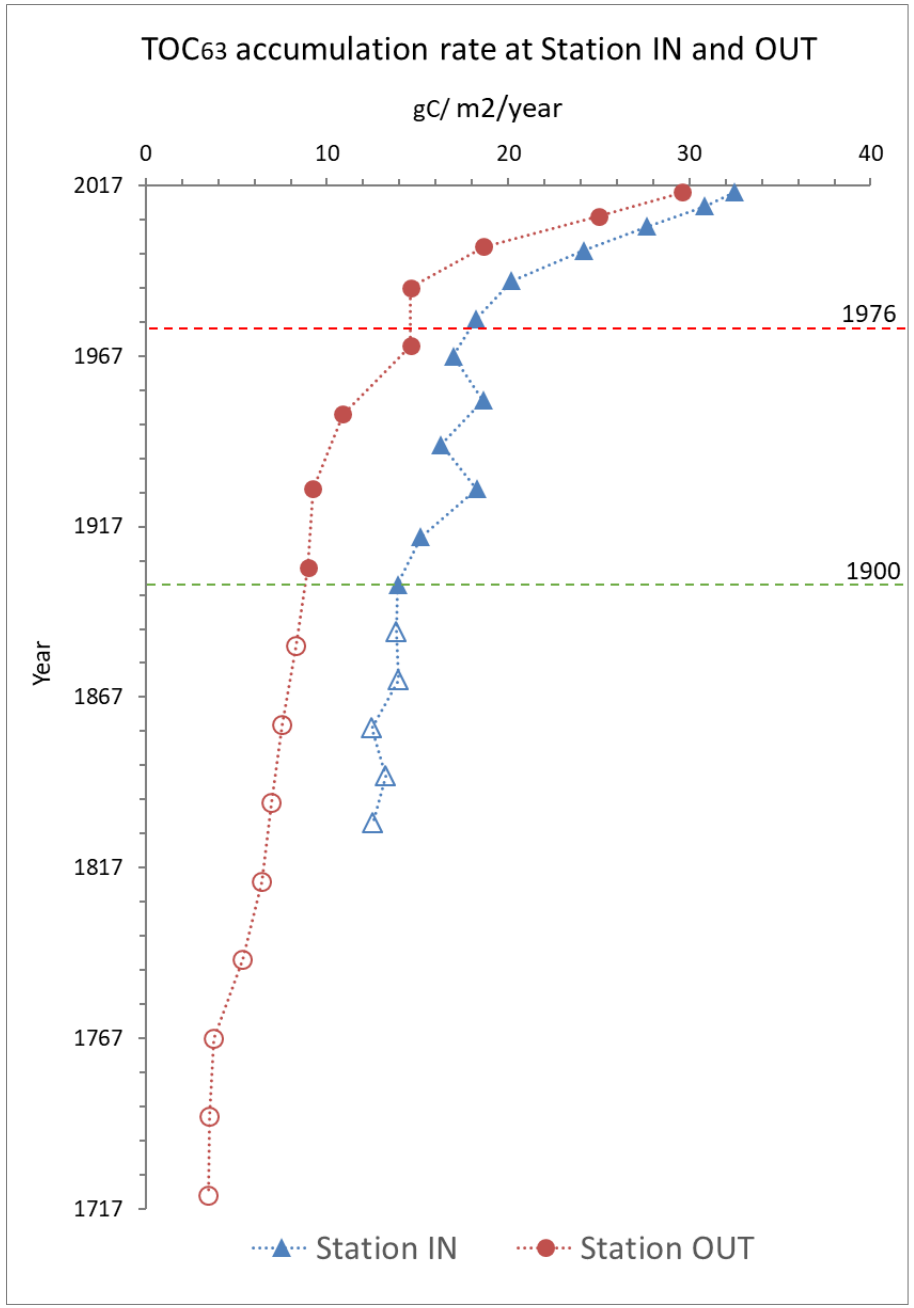
TOC_{63}: normalized to the sand content of the sample

Classification for TOC content in marine sediment according to STF Veileder 97:03					
	1	2	3	4	5
	High	Good	Moderate	Poor	Very poor
TOC content (mg/g):	0 - 20	20 - 27	27 - 34	34 - 41	41 - 200
TOC content (%):	0 - 2.0	2.0 - 2.7	2.7 - 3.4	3.4 - 4.1	4.1 - 20.0



Total Organic Carbon accumulation rate

- Using the SAR and analysed TOC concentrations
- Post-aquaculture time: Continuously increasing



TOC accumulation rate in other fjords

Min – max values

West Norway

Hordaland

Rogaland

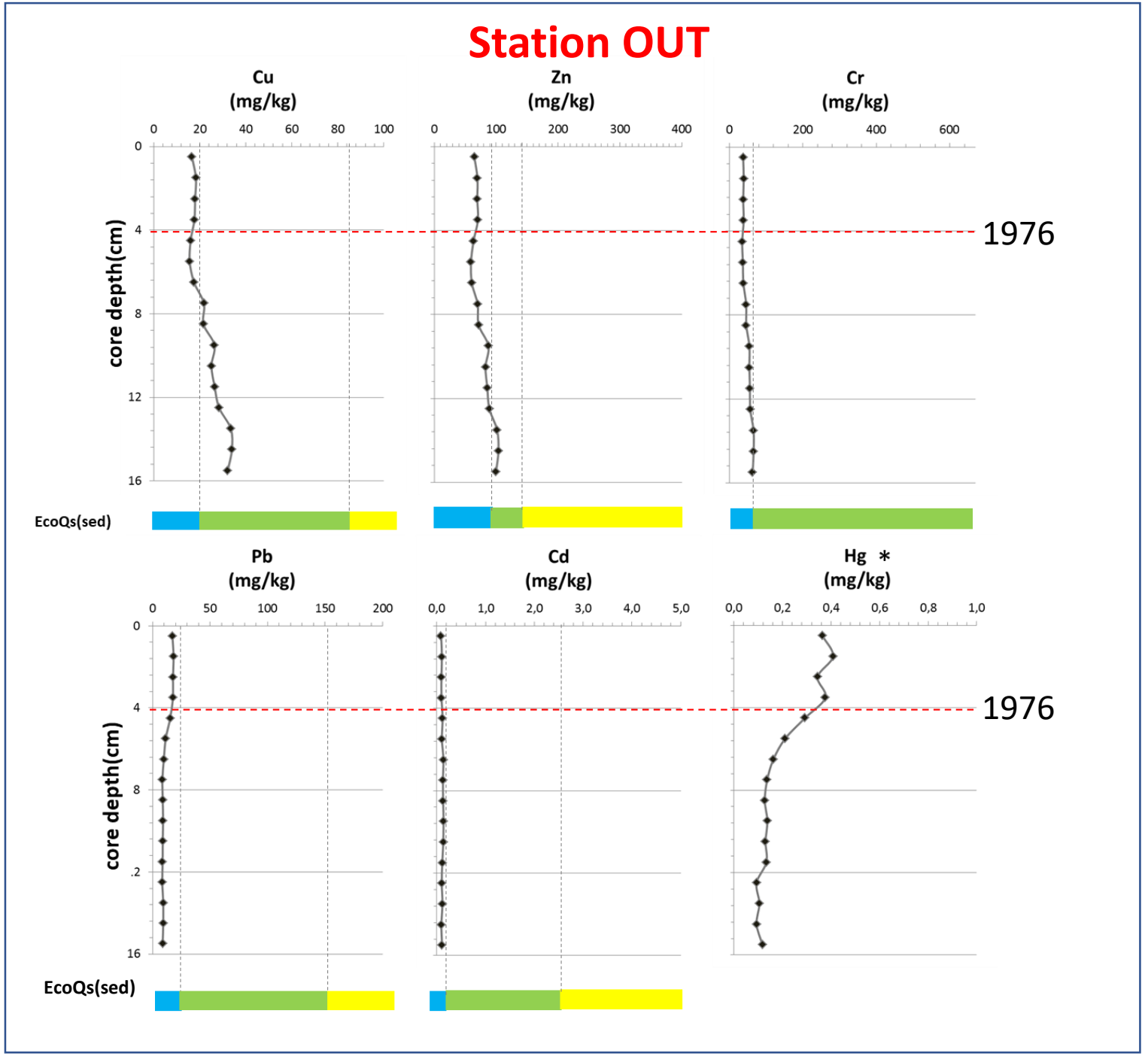
Northern Norway

Troms

	Onarheimsfjorden (Sjetne, 2017)	**Lysefjord** (Duffield et at al., 2017)	**Malangen** (Wassman et al., 1996 and Husum and Hald, 2004)	**Kaldfjorden**
TOC accumulation rate (g C/ m^2/ year)	14 - 42	14 - 60	18 - 36	**6 - 32**

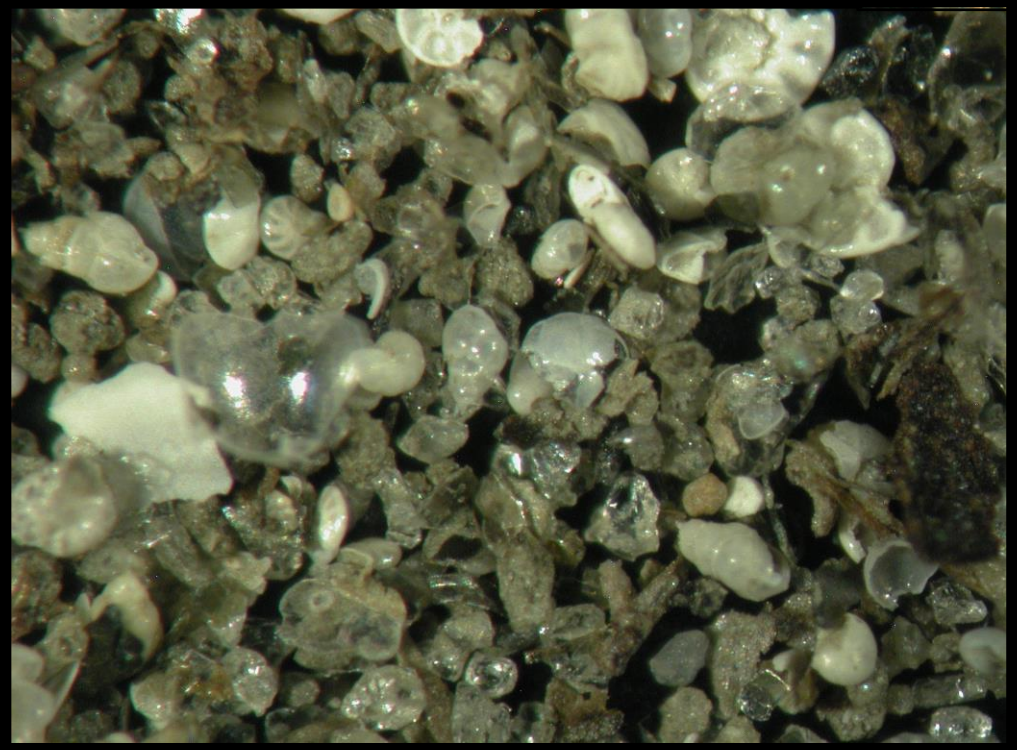
Heavy metal concentrations (mg/kg) in Kaldfjorden

- No apparent change throughout the two cores



Foraminifera

Station IN



Station OUT

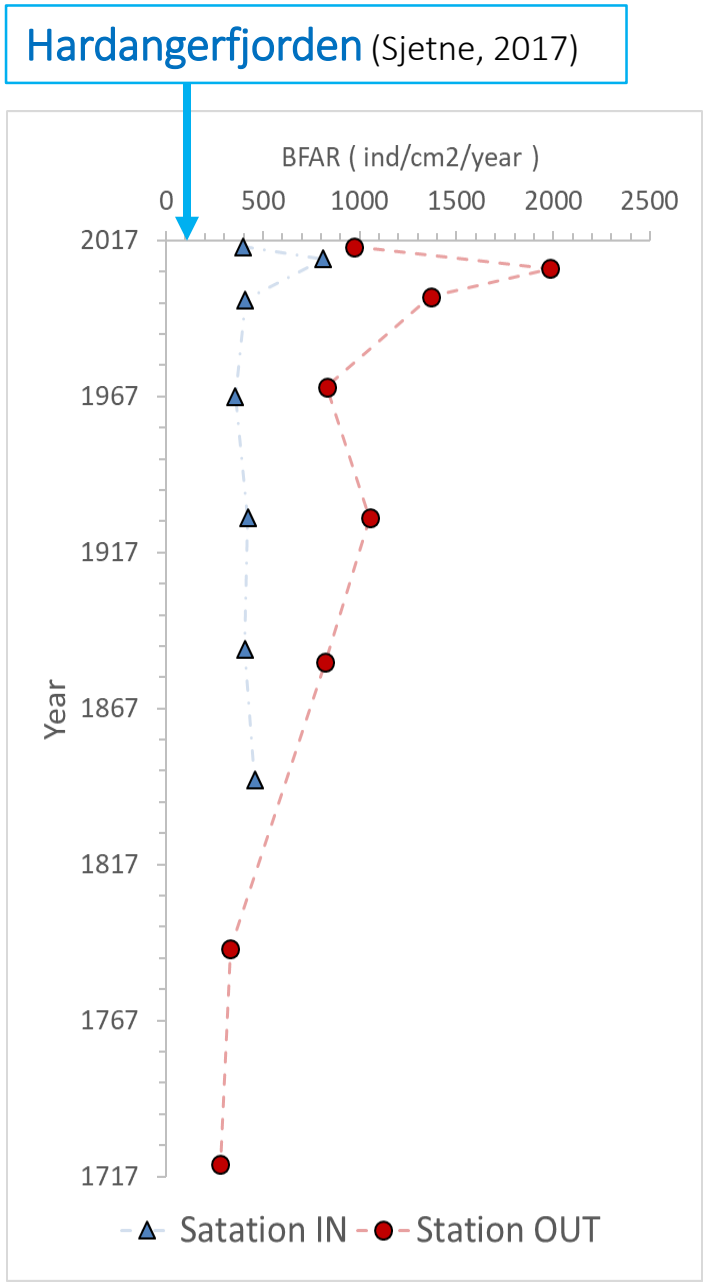
Pictures of the typical sediment composition of the 63-500 µm sample fraction from each station
(Each picture show a 2.5 mm x 2 mm section of the sediment sample)

Method:

- >300 individuals were picked, identified to species level and counted from each analysed sample

Benthic Foraminifera Accumulation Rate (BFAR) (individuals/cm²/year)

- Unusually high
- High productive area
- Could also be related to the low SAR



Diversity indices

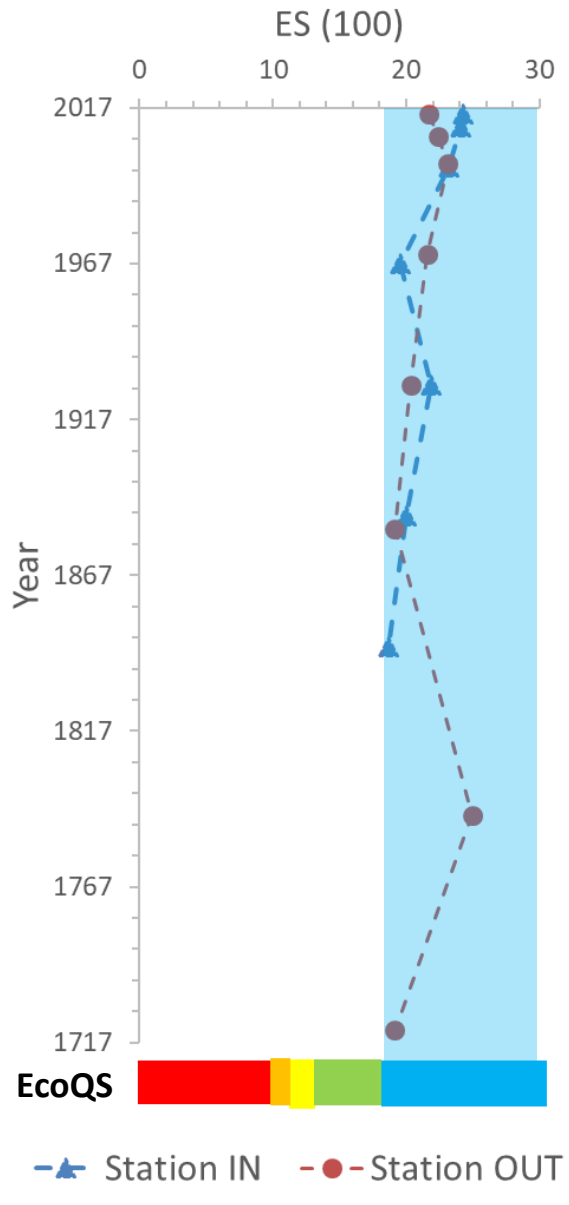
Station IN: 53 benthic foraminiferal species

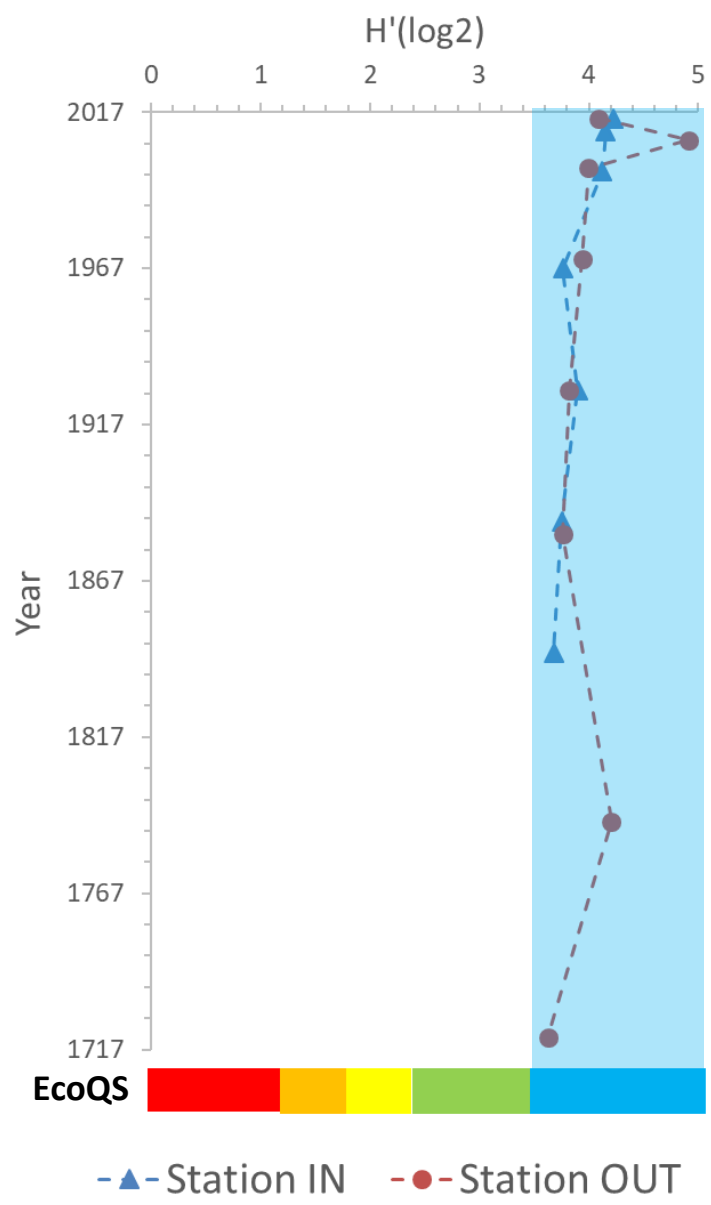
Station OUT: 54 benthic foraminiferal species

ES_{100} (Hulbert, 1971)

$H_{(log2)}$ (Shannon and Waver, 1967)

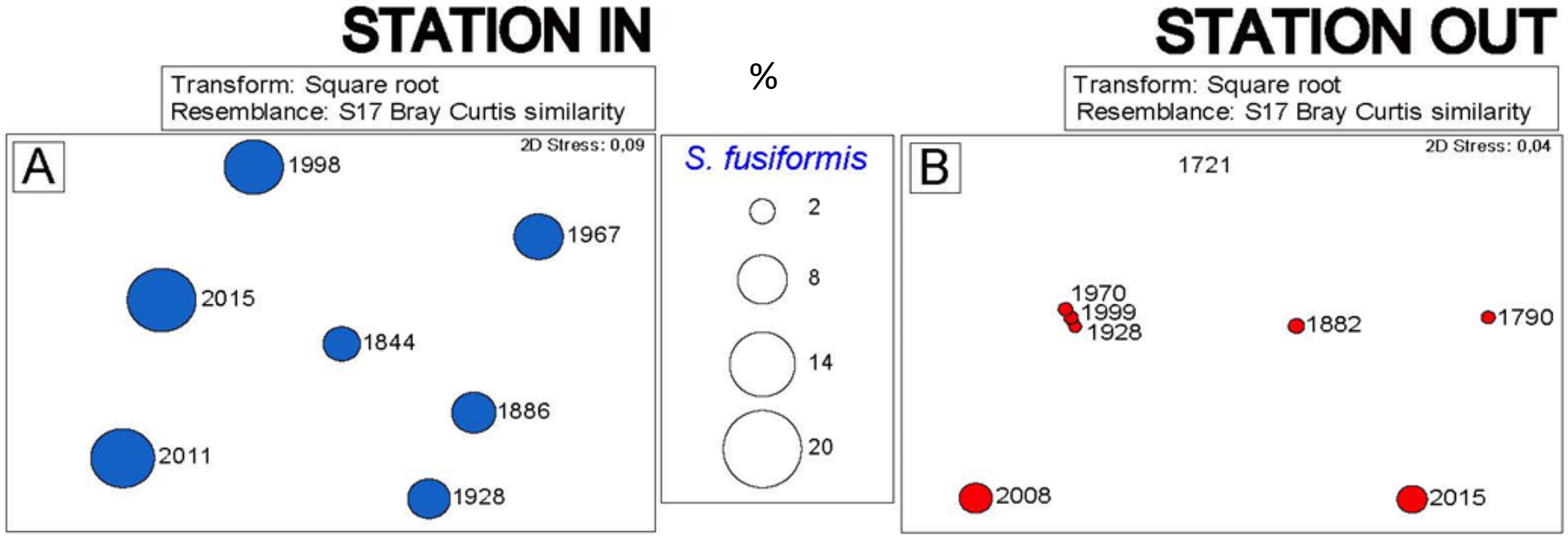
«High» status in all samples investigated at both stations





Species

Station IN	Station OUT
Cassidulina reniforme (19%)	*Cassidulina reniforme* (22%)
Bulimina marginata (14%)	*Cassidulina laevigata* (10%)
Elphidium excavatum (10%)	*Cassidulina neoteretis* (9%)
Stainforthia fusiformis (9%)	*Cibicides lobatulus* (6%)
Hyalinea balthica (8%)	*Pullenia osloensis* (6%)
Pullenia osloensis (6%)	



Summerize

- Unusually low SAR
  - No river input
  - Surrounding topography
- High TOC concentration and foraminifera concentration
  - Partly explained by low SAR
- Post-aquculture increase in TOC accumulation rate:
  - Same time at both stations
  - High compared to «reference conditions»
  - Not high when compared with other fjords
- BFAR still high compared to other fjords
  - Combination of high production + low SAR?
  - Transport from high productive area?
- No evidence of increased heavy metal concentrations
- Difference in depositional environment and species assemblage between inner vs. outer Kaldfjorden
  - Difference in hydrography
  - More TOC available at Station IN

Conclusion

- Clear increase in TOC accumulation rate from reference conditions to post-aquaculture time at both stations
- It has not effected the diversity of benthic foraminifera «High»
- Some change in species assemblage up-core
- For example increase in relative abundance of *Stainforthia fusiformis*
- Could be viewed as an important early warning sign

☺ Thank you for your attention! ☺

Kaldfjorden, the most beautiful fjord in Troms, keep it healthy!