DRASTIC

Diatoms and **R**hizari**A**n**S** in**T**erplay in the polar s**i**lica **C**ycle

Cruise report

Photo: The LUN II (captain U. Buquen) chartered by UBO/ISblue, for the Drastic expedition in a fjord north of the Arctic Circle (credit O. Chuberre)

1. Project objective

1.1. Context

Silicifiers are among the most important living organisms on planet Earth. They are able to take advantage of the presence of silicon (Si), the second-most-abundant element in the Earth's crust, and a major nutrient in the ocean to build silicified structures, which gives them an ecological advantage against predators, for motility, or to facilite the penetration of light and nutrients into cells.

Among silicifiers, **diatoms** play a key role in the trophic networks of the most productive coastal or open-ocean ecosystems, as well as in the biology-mediated transfer of CO_2 from the surface to the ocean interior (the so-called biological pump of carbon). Pelagic diatoms have been extensively studied, but these photosynthetic organisms are not the only ones that use dissolved mineral silica (dSi) to form a skeleton or a siliceous carapace. Recently, the combination of genomic and biogeochemical data has revealed that **another group of silicifiers, the Rhizaria,** has been largely underestimated and correlates with carbon export fluxes at 150 m depth, highlighting an **unexpected role of this taxa in the carbon**

biological pump, and also in the silica cycle (Llopis Monferrer et al. 2020, 2022 ; Biard et al., Guidi et al., 2016).

Rhizaria constitute a diverse super-group of marine protists, globally distributed, dwelling from the surface down to bathypelagic depths. Most Rhizaria elaborate a silica skeletal ballast that allows them to sediment to the bottom of the oceans where they are well preserved due to their resistance to dissolution. Rhizaria are therefore commonly used as biostratigraphic markers and in reconstructions of paleoenvironments.

Rhizaria were among the first protists inhabiting the ocean, and **their evolution have shaped the global marine Si cycle over geological time**. In the Cambrian (~500 Ma), rhizarians were assumed to control the silica output of the oceans together with sponges. In the Mesozoic (~186 Ma), diatoms arose in the planktonic realm and became an important competitor to rhizarians regarding the access to dissolved silica (dSi). Because of their superior affinity to dSi, diatoms decreased dSi concentrations down to the relatively low levels observed in today's oceans. A recent study suggests that diatoms came to dominate the ocean's Si cycle in part because of the evolution of a diverse repertoire of silicon transporter (SIT) genes.

In today's ocean, new alterations are observed linked to the rapid increase of CO_2 in the atmosphere due to anthropogenic activities. High latitudes climate and ecosystems are particularly impacted by increasing sea temperature and melting ice, altered circulation of water masses, etc., leading to changes in the entire food web. Some of these effects are already visible, diatoms in the ice are disappearing and the rhizaria diversity is decreasing at high latitudes (Trubovitz et al., *Nature* 2020)

This begs the question: How will the community structure of siliceous planktonic organisms evolve in response to these alterations? Will diatoms or rhizarians take over? Are we going to experience a drastic evolution as in the past? What impact will this have on the silica and carbon cycle?

1.2. Objectifs

The objective of this project is to better understand marine environmental changes in high latitudes, and their consequences on the fate of planktonic siliceous organisms. For this, it is essential to better constrain the distribution, the biodiversity and the ecophysiology of diatoms and siliceous rhizarians simultaneously.

To reach this goal, we propose a cruise along a north-south transect in the North Atlantic, from Tromsø to Bergen (Norway). The originality of the project is to develop a transdisciplinary approach (including ecology, physiology, biogeochemistry, and genomics) to quantify the role of Rhizaria and Diatoms in the silica cycle from the Arctic Ocean to the North Atlantic, in a spirit of low-carbon research mission using a sailboat as a scientific base.

2. Campaign operations

The expedition departed from Brest (France) by truck on the 29th of May 2024 to reach the boat in Tromsø (north of Norway) on the 1st of June 2023. The cruise finished in Bergen (south of Norway) on the 21st of June 2023 and the team was back in Brest on the 23rd of June.

All Scientific objectives met.

A total of 16 sampling stations were performed along the Norwegian coastline (Figure 1): 4 stations at 1000 m depth, 2 at 750 m, 7 at more than 400 m depth and 3 shallow stations.
We sailed along a latitudinal gradient from 69°46N – 60°59N.

At each stations we deployed a set of sensors, including :
- PAR + fluo down to 300 m,
- the CTD + Suna nitrate sensor and the new Clearwater silicates sensor down to the bottom
- Plankton closing net (80 µm) from the bottom to 200 m, and from 200 m to the surface
- Niskin bottles to sample at the bottom, at the surface and at the depth of the chloro maximum
- Surface plankton net (20 µm) at the surface for phytoplankton biodiversity

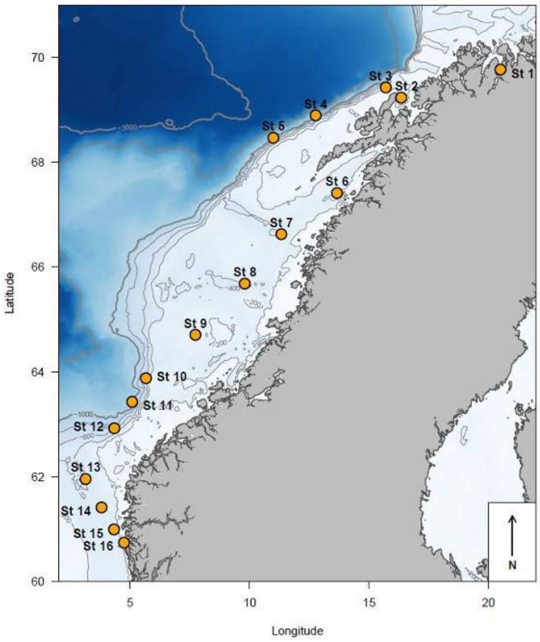


Figure 1: Location of sampling stations in the Norwegian Sea, overlaid on bathymetry data obtained from EMODnet (processed using R software).Copy from H. Le Gac M1 report)

3. Results

3.1. General scientific results:

The data readily available are the sensor data and CTD (Conductivity, Temperature, Density) profiles (Figure 1). These data already illustrate that we cross several water masses, with surface water temperature ranging from below 7°C in the north, to waters above 12 °C southward, around 60°N.

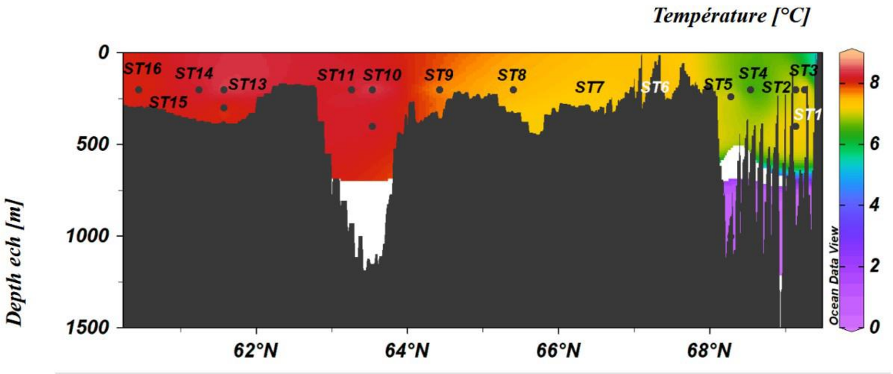


Figure 2 *Vertical representation of temperature as a function of depth and latitude (copy from J. Dagorn M1 report)*

This coincides with preliminary results of chlorophyll concentrations (Figure 3) and zooplankton microscopic observations (Table 4).

Chlorophyll concentration peaks at station ST6 (1.4 µg/L, Figure 3), while surrounding stations show significantly lower values: 0 (ST7), 0.31 (ST5), 0.24 (ST4), 0.14 (ST3), and 0.4 µg/L (ST2). Southern stations exhibit generally higher concentrations (0.56–1.5 µg/L, ST14–ST16), except for ST15 (0.02 µg/L). Despite the northern peak at ST6, chlorophyll levels are higher in the south.

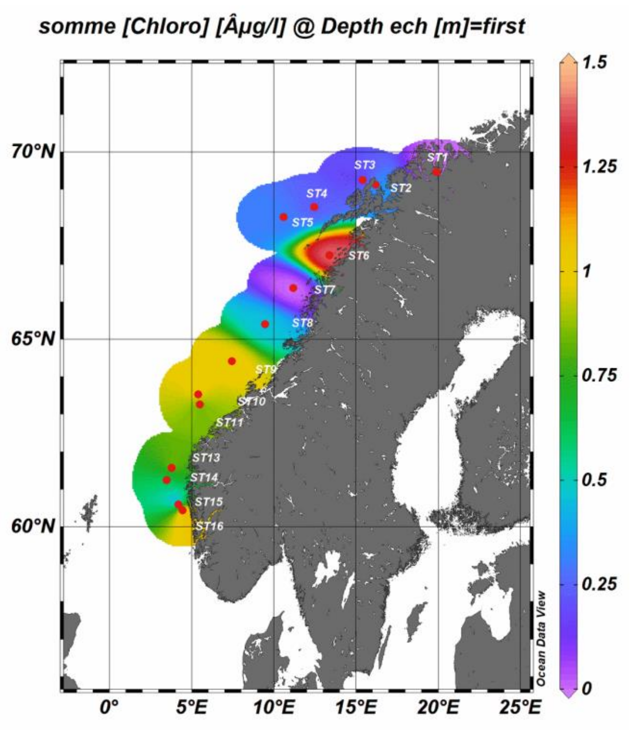


Figure 3 Variation of surface chlorophyll concentrations (µg/L) across sampling stations (copy from J. Dagorn M1 report)

Preliminary results (Table 1) revealed key insights about zooplankton communities in the Norwegian Sea across depth layers. Surface samples exhibited greater diversity with 18 taxonomic groups distributed across 13 stations, compared to 15 groups at 11 deeper stations. Four dominant taxa - Calanoida, Tintinnida, Appendicularia, and Nauplii - prevailed at both depths, though their relative abundances shifted markedly. Tintinnida showed extreme abundance variations, ranging from 18 to 49716 ind/m³ in surface waters, while Calanoida populations demonstrated more moderate fluctuations between 229-2643 ind/m³ at the surface and 8.5-264 ind/m³ at depth. Rare taxa maintained consistently low densities (3-120 ind/m³ surface, 0-4.8 ind/m³ depth). Community structure differed substantially by depth, with surface waters dominated by Calanoida (33%) and Tintinnida (60%), whereas deeper layers showed stronger Tintinnida dominance (82%) alongside reduced Calanoida presence (16%). Three taxa disappeared completely in deep samples. Environmental analyses revealed Tintinnida correlated with chlorophyll-a and pheophytin in surface waters, while Calanoida distributions tracked latitudinal gradients and temperature. The findings highlight depth stratification as the primary community structuring factor, with Tintinnida abundance potentially signaling post-bloom conditions and Calanoida distributions reflecting thermal growth responses. Methodological constraints, particularly the 80µm mesh size, may have underestimated smaller Tintinnida populations.

	Calanoida	Tintinnida	Appendicularia	Nauplius	Taxons rares
ST1-2	758 (±51)	84(±26)	56(±6)	61(±6)	11
ST2-2	229 (±33)	711(±72)	33(±10)	0	7
ST3-2	836(±201)	2187(±544)	37(±19)	40(±1)	3
ST4-2	396(±19)	18(±6)	14(±3)	54(±11)	27
ST5-2	497(±37)	532(±31)	8(±1)	115(±7)	14
ST6-2	1000(±99)	25487(±2185)	8(±3)	107(±22)	7
ST8-2	1186(±137)	4240(±291)	48(±9)	192(±10)	15
ST9-2	940(±81)	10222(±508)	65(±13)	111(±15)	5
ST10-2	2201(±174)	49716(±5523)	72(±10)	431(±22)	27
ST11-2	1273(±64)	11806(±786)	45(±5)	211(±30)	32
ST13-2	2643(±168)	15065(±1384)	98(±7)	321(±28)	48
ST14-2	2176(±82)	742(±284)	100(±13)	165(±30)	120
ST16-2	1065(±139)	638(±160)	37(±5)	61(±2)	28

	Calanoida	Tintinnida	Appendicularia	Nauplius	Taxons rares
ST2-3	525,8 (±63,9)	6062,4(±783,0)	1,6(±1,3)	4,8(±2,2)	3,2
ST3-3	53,2(±4,7)	452,4(±31,3)	2,4(±0,9)	3,0(±0,8)	0,5
ST4-3	11,3(±0,7)	56,1(±9,5)	0,1(±0,1)	0,8(±0,2)	0,5
ST5-3	24,2(±1,5)	25,8(±3,2)	0,3(±0,2)	2,0(±0,4)	3,2
ST6-3	113,9(±9,7)	890,1(±83,2)	0	2,5(±2,0)	1,9
ST7-3	20,4(±6,7)	6213,8(±261,5)	0,9(±1,5)	5,8(±4,3)	0
ST8-3	264,1(±24,8)	17860,4(±1527,0)	3,3(±0,7)	3,3(±1,4)	1,7
ST10-3	58,8(±9,6)	3749,4(±214,4)	6,5(±0,3)	0,6(±0,6)	4,8
ST13-3	144,5(±17,1)	7253,1(±664,8)	0,9(±1,6)	1,2(±1,0)	2,4
ST15-3	8,5(±5,0)	131,2(±21,4)	0	1,2(±0,4)	1
ST16-3	141,3(±5,8)	45,6(±6,7)	0	1,2(±0,4)	1,5

Table 4 : Abundance (ind/m³) of the main zooplankton groups observed in surface (left) and deep (right) water samples at each stations, with standard deviation given in brackets (table copy from H. Le Gac report)

Results for silicified organisms (specifically diatoms and radiolarians) are still under analysis.
Two Master's thesis reports have been published:
- Julie DAGORN, Étude de la diversité et de la répartition du zooplancton le long des côtes norvégiennes - Analyse de l'influence des paramètres environnementaux. M1 Ecologie Marine et Halieutique, Université du Littoral Côte d'Opale ULCO (2023-2024)
- Hugo Le Gac, Etude de la répartition du zooplancton en mer de Norvège en fonction des conditions environnementales et du gradient latitudinal. M1 Science de la Mer et du Littoral, Université de Bretagne Occidentale (2023-2024).

and two manuscripts for international peer-reviewed journals are in preparation:
1- The first is a paper describing the distribution of phytoplankton and zooplankton communities along with environmental data from the sensors
2- The second presents and describes the use of the new Si sensor(see below) during profile deployment and the comparison with traditional chemical method.

3.2. New Sensor deployment

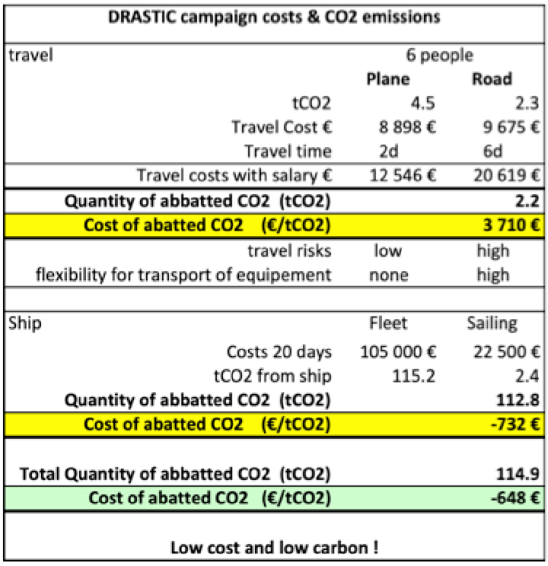
Drastic has been also the opportunity to test with success a new in situ sensor of silicate concentration in seawater. This innovative sensor, developed to monitor nutrient concentrations and to be later integrated on a modular and transportable multi-sensor cabled observation. We deploy the sensor during Drastic expedition to make profiles in the water column, which has never been done to date.

To our knowledge, the deployment of autonomous silicic acid concentration sensors is non-existent in polar waters. This sensor with high frequency data transmission is unique and offer a great observation and research tool that will strongly contribute to the excellence of French scientists.

Water samples have been taken in parallel to check by traditional analyses, the accuracy of the sensor's measurement in the temperature range (between 7° and 15°C) and silicate concentrations encountered.

3.3. Environmental impact: 100 tCO2 abated, with a negative abatment cost!

The expedition also aimed at being low carbon, hence the use of a traditional sailboat, the Lun II (Fig. 2), built in 1914 and commanded by captain Ulysse Buquen.



DRASTIC campaign costs & CO2 emissions		
travel	6 people	
	Plane	Road
tCO2	4.5	2.3
Travel Cost €	8 898 €	9 675 €
Travel time	2d	6d
Travel costs with salary €	12 546 €	20 619 €
Quantity of abbatted CO2 (tCO2)		**2.2**
Cost of abatted CO2 (€/tCO2)		**3 710 €**
travel risks	low	high
flexibility for transport of equipement	none	high
Ship	Fleet	Sailing
Costs 20 days	105 000 €	22 500 €
tCO2 from ship	115.2	2.4
Quantity of abbatted CO2 (tCO2)		**112.8**
Cost of abatted CO2 (€/tCO2)		**-732 €**
Total Quantity of abbatted CO2 (tCO2)		**114.9**
Cost of abatted CO2 (€/tCO2)		**-648 €**
Low cost and low carbon !		

In 20 days of sailing, the DRASTIC mission consumed 951 liters of fuel (equivalent to 2.4 tons of CO_2), to be compared with oceanographic vessel (i.e. the RV "Côtes de la Manche") burning on average 3 tons of fuel (i.e 7,6 tons of CO_2) .... per day!

Given the assumptions, one can keep in mind the order of magnitude: the sailboat saved around 100 tons of CO2.

The cost per day of the sailboat is also much lower than that of an oceanographic vessel. The saving is around 5,000€ per day. Over 15 days, the saving is 75k€, or, in economic jargon, -750 € is abated per tCO2 saved. This negative abatement cost shows that we are making financial savings at the same time as reducing CO2 emissions.
This is the key message, because moving to a low-carbon society often involves major investment, and therefore a positive abatement cost.
Switching from big ship to sailing boats also saves money! Consequently, it is possible to change our research practices.

As shown in the table above, travel costs and emissions have little impact compared to the choice of the vessels.

4. Project Follow-up

Although the campaign at sea is over, there is still work to be done to analyse the samples and exploit the results.
However, the initial results are very promising, the team is enthusiastic and the contacts we have made with our Norwegian colleagues are very positive. We are already thinking about another campaign (in the same spirit) to sample the start of the plankton bloom, earlier in the season.