Toktrapport/Havforskningsinstituttet/ISSN 15036294/Nr. 20-2021

CRUISE REPORT

North Sea Ecosystem Cruise

RV Dr Fridtjof Nansen 31 March – 26 April 2021

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Franzè, G, Falkenhaug, T, Albretsen J., Gundersen, K., Heldal, H.E., 2022. North Sea Ecosystem Cruise 2021, Cruise Report. Institute of Marine Research Cruise number DFN2021455. Toktrapport/ Havforskningsinstituttet/ ISSN XXXX

Contents

1. Summary

The North Sea Ecosystem cruise (NSEC) is a multi-purpose survey established to monitor distribution and interactions of several components that constitute the lower trophic levels of the pelagic food web including phytoplankton, zooplankton, fish eggs and fish larvae. The cruise is managed by the IMR projects Monitoring of climate and plankton in the North Sea Skagerrak (IMR 14920) and Early life history dynamics of North Sea Fishes (IMR 14917). The cruise provides horizontal and vertical distributions of physical and chemical oceanographic parameters and phytoplankton, zooplankton fish eggs and larvae community composition and structure in the northern North Sea and Skagerrak. Since 2020 the IMR plankton survey was expanded by adding the monitoring of an additional trophic level, microzooplankton. The survey area of the North Sea Ecosystem cruise 2021 covered the northern North Sea and the Skagerrak (57-60.8ºN, 2.2ºW- 8.6ºE). Sampling were made at pre-selected stations along the IMR standard hydrographic transects. In addition, higher temporal resolution sampling was undertaken at two 48-hour process stations east of Shetland (60ºN; 0.67ºW) and in Skagerrak (58.13ºN; 9.18ºE) to investigate the vertical and diel distribution of fish eggs and larvae and their potential predators and prey.

The 2021 NSEC also included the following additional assignments: a) monitoring of radioactive contamination (IMR project Monitoring of radioactivity in Norwegian waters IMR 15595), b) collection of herring larvae along the west coast of Denmark to support the Dutch Downs Recruitment Survey (DRS), c) collection of WP2 samples for metabarcoding analysis of the zooplankton component of the plankton community as part of a postdoctoral research project within the CoastRisk (IMR 15507-05).

Due to the ongoing Corona situation in spring 2021, extra precautions were taken in order to prevent the spread of coronavirus COVID-19 aboard the vessel and no scientific or crew personal was allowed to leave the vessel during the port call.

Cruise name:	DFN 2021455, North Sea Ecosystem Cruise
Cruise dates:	31.03.2021 – 26.04.2021
Vessel:	RV Dr Fridtjof Nansen
Master:	Tommy Steffensen
Area:	North Sea/Skagerrak (57-60.8ºN, 2.2ºW- 8.6ºE)
Ports of Call:	Lerwick, UK 04.04.21
	Kristiansand, Norway, 15.04.201 (crew change)
	Bergen, Norway, 26.04.21 (end of cruise)

Projects involved in the NSEC 2021:

- Climate and plankton in the North Sea and Skagerrak (IMR 14920),

- Early life history dynamics of North Sea fishes (IMR 14917).

- Monitoring of radioactivity in Norwegian waters (IMR 15595)

- CoastRisk (IMR 15507-05).

- Dutch Downs Recruitment Survey (DRS)

2. Introduction

The North Sea Ecosystem spring cruise (NSEC) has been run since 2010 by the Institute of Marine Research (IMR) as a multi-purpose survey. The cruise is usually performed in mid-April – mid-May to investigate the horizontal and vertical distributions of hydrography, chemistry, phytoplankton and zooplankton as well as fish eggs and fish larvae as part of several IMR projects. The 2021 NSEC delivered data and samples to the following projects: - Climate and plankton in the North Sea and Skagerrak (IMR 14920), Early life history dynamics of North Sea fishes (IMR 14917), Monitoring of radioactivity in Norwegian waters (IMR 15595), Monitoring of environment and plankton in coastal waters (IMR 15593) and the Dutch Downs Recruitment Survey (DRS).

The objectives of the North Sea Ecosystem Cruise 2021 were:

1) To sample pre-selected stations along standard transects for physical, chemical and biological parameters in the Northern North Sea and Skagerrak (IMR 14920, IMR 14917)
2) To map the abundance, distribution and species composition of phytoplankton, microzooplankton, mesozooplankton, and early life stages of fish (eggs and larvae). (IMR 14920, IMR 14917)
3) To undertake two process studies (northwestern North Sea and Skagerrak) to investigate the spatial, vertical and diel distribution of fish eggs and larvae and their potential predators and prey. (IMR 14920, IMR 14917)
4) To monitor radioactive contamination in Skagerrak (IMR 15595)
5) To acquire data on clupeida larvae in the water west of Denmark (DRS).
6) To acquire dry biomass samples for metabarcoding analysis (IMR 15593)

2.1 Monitoring of plankton, biogeochemistry and hydrography in the North Sea and Skagerrak (IMR 14920)

The aim of the IMR monitoring project ¨Climate and plankton in the North Sea and Skagerrak¨ is, 1) to collect and analyze biological, chemical, and physical data to characterize and understand the causes of variability in the North Sea and Skagerrak at the seasonal, and inter annual scales, and 2) to provide multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical variability. The monitoring activity includes one regional coverage per year (the spring survey in April/May) and additional sampling along three standard transects 4 (Utsira-StartPoint, Hanstholm-Aberdeen) or 12 times a year (Torungen-Hirtshals).

The spring survey on plankton and hydrography in the North Sea - Skagerrak has been carried out by the institute of Marine Research since 2006. From 2006 to 2014, the survey was undertaken as a combination of two cruises running in parallel: The Environmental cruise" (Miljøtoktet on RV G.M. Dannevig) in the Skagerrak, and ¨The North Sea plankton survey¨ (usually on RV/ Johan Hjort) in the northern North Sea. In 2010, sampling of fish eggs and fish larvae was included in the sampling program, and the survey was renamed to The North Sea Ecosystem Cruise (NSEC). Since 2015, the former two spring surveys in Skagerrak and the North Sea has been combined into one single cruise, covering both the northern North Sea and the Skagerrak.

2.2 Early life history dynamics of North Sea fishes (IMR 14917)

The IMR project Early life history dynamics of North Sea fishes aims to determine the distribution and abundance of fish eggs and larvae in the northeastern North Sea, and to link studies on the early life history of fish with zooplankton. The survey provides depth integrated distribution of fish eggs and larvae that can be related to the zooplankton and physical oceanographic data from the standard sections in the northern North Sea. In addition, studies are undertaken to investigate the vertical and diel distribution of fish eggs and larvae and their potential predators and prey.

2.3 Monitoring of radioactivity in Norwegian waters (IMR 15595)

Water samples are collected by IMR once a year from Skagerrak, for analyses of radioactive contamination (cesium-137). This project contributes to the national monitoring program "Radioactivity in the Marine Environment (RAME)" which is coordinated by the Norwegian Radiation Protection Authority.

2.4 Dutch Downs Recruitment Survey

The Downs recruitment survey since 2018 is carried out in the North Seas on an annual base. The Netherlands participates covering the relevant area in the North Sea in the. The continuity of the survey design is guaranteed by participation in the coordinating survey group (WGIPS). The aim of the DRS is to provide a recruitment index for the winter spawning herring population in the Southern North Sea and English Channel. In 2021 due to the Covid-19 restrictions, the Dutch colleagues were not able to carry out the survey and asked the North Sea Ecosystem project to help collect the necessary samples

3. Materials and Methods

3.1 Participation

A list of the personnel participating in the cruise, along with dates and their primary responsibilities, is presented in Table 1 while all the sampling equipment on board of the ship is presented in Table 2. A crew change was undertaken on the 28th April in Bergen.

Table 1. *Cruise participants*

Name	Role	Research group	Dates	Leg
Gayantonia Franzè	Cruise leader	Plankton 434	31.03 - 26.04.2021	1,2
Gaston Ezequiel Aguirre	Plankton	Plankton 434	31.03 - 15.04.2021	1
Mona Ring Kleiven	Plankton	Plankton 434	31.03 - 15.04.2021	1
Ann-Kristin Olsen	Fish larvae	Plankton 434	31.03 - 15.04.2021	1
Linda Fonnes Lunde	Plankton	Plankton 434	31.03 - 15.04.2021	1
Elizaveta Ershova-PostDoc	Plankton	Plankton 434	31.03 - 15.04.2021	1
Bahar Mozfar	Plankton	Plankton 434	15.04 – 26.04.2021	2
Astrid Fuglseth Rasmussen	Fish larvae	Plankton 434	15.04 – 26.04.2021	2
Eli Gustad	Instrument	Plankton 434	15.04 – 26.04.2021	2
Hilde Arnesen	Instrument	Plankton 434	15.04 – 26.04.2021	2
Hege Rognaldsen	Instrument	Elektr.instrument. 620	31.03 - 26.04.2021	1,2
Jan Frode Wilhelmsen	Instrument	Elektr.instrument. 620	31.03 - 26.04.2021	1,2

T***able 2.*** *Sampling equipment*

Instrument/Gear	**Data/samples**
SeaBird Electronics SBE911 CTD profiler	Temp, Salinity, Conductivity, Oxygen, light
Water bottle rosette (on CTD)	Nutrients (NO3, Si, PO4, TotN,TotP) Chlorophyll a Phytoplankton (cell counts) Microzooplankton (cell counts/species id)
Phytoplankton net (10µm)	Phytoplankton
WP2 (0.25 m^2, 180µm) ring net	Zooplankton biomass Zooplankton fixed samples (enumeration/species)
WP3 (1 m^2, 1000 µm) ring net	Gelatinous zooplankton
Gulf VII (280 µm)	Fish larvae and eggs
PUP (80µm) attached on Gulf	Prey items for fish larvae
MultiNet MAMMOTH (180µm)	Mesozooplankton (depth stratified samples)
MultiNet MAMMOTH (405 µm)	Fish larvae (depth stratified samples)
MIK without MikeyM	
Continuous measurements	
Echosounder	
ADCP	Water current velocities
Termosalinograph	Temp, Salinity, Fluorescence (surface)
Light sensor on deck	PAR (Photosynthetically active radiation)

3.2 Narrative

The cruise program was undertaken according to Table 3. Maps of the cruise track and stations are presented in Figure 1a, b. Sampling was undertaken on a 24h basis.

Leg 1 (31st March – 26th April): The vessel left Bergen at 10:00 UTC on March 31st 2021 in calm and sunny weather. The ship bunkered till 16:30. Before the start of the survey, we performed calibration for the flowmeter of both the GULF VII and the MultiNet Mammoth. The Gulf Calibration was performed between 16:40 and 17:10 while between 18:10 and 20:30 we calibrated the flowmeter of the MULTINET. The calibration of the Multinet did not give satisfactory results as the flowmeter did not work properly. A second deployment was necessary before the arrival at the first multinet station.

The survey started with the sampling of the **Ferje-Shetland** transect (60.45N 4.37E) at 22:30 of the 31.03.2021. The sampling continued with the **Shetland Process Study Station.** The sampling of this station lasts for 48h in order to capture the dial migration of plankton and its variability. Samples are collected 4 times a day at dawn, midday, dusk, and midnight for two consecutive days using CTD, MultiNet MAMMOTH equipped with two sets of net (180µm, 405µm) and algae net. The first multinet was performed on 2nd of April at 13:00 in order to capture the midday plankton dynamics. During the last sampling of the process station (st. 96), the weather conditions stared to deteriorate thus, at 15:00 UTC of the 4th of April, after the end of the sampling we headed towards the port of Lerwick where we were forced to take shelter till the 7th of April when the weather conditions start to improve. At 9:20 of the 7th of April we resumed the sampling with the **Slotterøy mot W** transect. However, a new storm system hit the North Sea the night of the 8th and forced the DFN to seek shelter in the fjord till midday of the 9th. The sampling resumed with the **Utsira** transect on the 9th at 14:00. The weather conditions were still rough and forced the cancellation of the algae nets and WP3 sampling. However, the deployment of the CTD, WPII and GULF VII was managed. On station 129 (Utsira fix station #8) the crew noticed that the CTD cable was compromised and needed to be fixed in order to safely deploy the instrument. The operation took about 3 hours and 20m of the CTD cable were cut off. Standard sampling of the Utsira transect was resumed at 20:00 of the 9th and continued till the 11th afternoon. Due to the unfair weather condition and technical issues, the time schedule had to be modified and the sampling of the transect on the western part of the North Sea postponed. The Utsira transect was thus, followed by the sampling of the **Jærens Rev**, **Egerøya mot SW** and **Lista mot SW** transects before heading to Kristiansand port for the crew change on the 15th of April. The **Lindesnes** transect had to be cancelled due to time constrains.

Leg 2 (15th April-26th April) The Dr Fridtjof Nansen left Kristiansand at 18:00 UTC. The first part of the second leg of the survey was characterized by calm sunny weather that allowed a smooth sampling of the Skagerrak Sea. In the following order the sampling of the **Oksøy-Hanstholm, Torungen-Hirtshals, Jomfuland Skagen, Jomfuland Koster, Vaderø, Måseskjær and Gøteborg-Fredrikshavn** was performed between the 15th and the 18th of April. On the 19th we reached the ***Deep Skagerrak Process Study Station*** (58.8N, 9.11E) where we planned to conduct our second process study following the sampling method described earlier. After a successful first day of sampling, due to changing weather conditions we had to leave our position in the Skagerrak and move on to sample the transects in the water west of Denmark. The three transects in this area (**Harboør, Huseby Klit and Knude dyb)** are all characterize by very shallow waters, which makes it challenging to sample in rough seas. However, we managed to perform the sampling programmed as well as the MIK sampling requested for the DRS. On the morning of the 22nd the sampling of the **Hanstholm-Aberdeen** transect (57.00N, 8.11E-1.00W) began. The first 5 stations of Hanstholm-Aberdeen transect are characterized by a max depth of 55m. The deployment of some instrument in such shallow water is quite challenging thus, the Algaehåv, the WPIII and one multinet were cancelled on this first section. After this first rough patch the sampling of the transect went smooth. While sampling the transect on the **East Coast of Scotland we received new of** a medical emergency suffered by a close relative of one of the crew members thus, the sampling plan of the Scotland East Coast transect was reduced allowing us to perform the last transect, the **Fair Isle – Pentland** before heading to Bergen two days ahead of schedule. Despite the somehow unfair sea conditions and some other challenges, the cruise was successful and most of the planned sampling was performed.

Table 3. *Time schedule of the North Sea Ecosystem Cruise 2020205*

Start		**Stop**		
Date	**Time UTC**	**Date**	**Time UTC**	**Activity**
Leg 1				
31.03	12:00			**Departure Bergen**
31.03	12:30	31.03	16:30	bunkering
31.03	16:40	31.03.	20:30	Calibration of Gulf and Multinett flow meters
31.03	22:30	02.04.	02:45	Transect “Feie – Shetland”
02.04.	13:00	04.04.	15:00	Process Station “Shetland”
04.04.	17:30	07.04.	08:00	**Port call Lerwick**
07.04.	09:20	09.04.	02:00	Transect “Slotterøy mot W”
09.04.	14:10	11.04.	12:00	Transect “Utsira-StartPoint”
11.04.	22:00	13.04.	15:00	Transect “Jærens Rev mot SW”
13.04	18:00	14.04	10:00	Transect “Egerøya mot SW”
14.04	14:00	15.04	02:00	Transect “Lista mot SW”
15.04	08:00			**Port call Kristiansand**
Leg 2				
15.00	18:00			**Departure Kristiansand**
15.04	18:30	16.04	06:00	Transect “Oksøy-Hanstholm”
16.04	10:20	17.04	01:30	Transect “Hirtshals-Torungen”
17.04	05:12	18.04	08:34	Transect “Jomfruland-Skagen”
17.04	09:30	17.04	17:00	Transect “Koster-Jomfruland”
17.04	19:00	18.04	03:00	Transect “Väderö”
18.04	06:14	18.05	14:00	Transect “Måseskjær”
18.04	18:00	18.04	19:30	Transect “Fredrikshavn-Gøteborg”
19.04	05:00	20.04	02:00	Process Station Skaggerek
20.04	14:00	20.04	20:00	Transect Harboer
20.04	22:00	21.04	03:00	Transect Huseby Klit
21.04	07:30	21.04	14:30	Transect Knude dyb
22.04	09:12	24.04	08:30	Transect Aberdeen-Hanstholm
24.04	10:00	24.04	23:30	Transect Scotland East Coast
25.04	00:30	25.04	17:30	Transect “Fair Isle – Pentland”
26.04	10:00			**Arrival Bergen**

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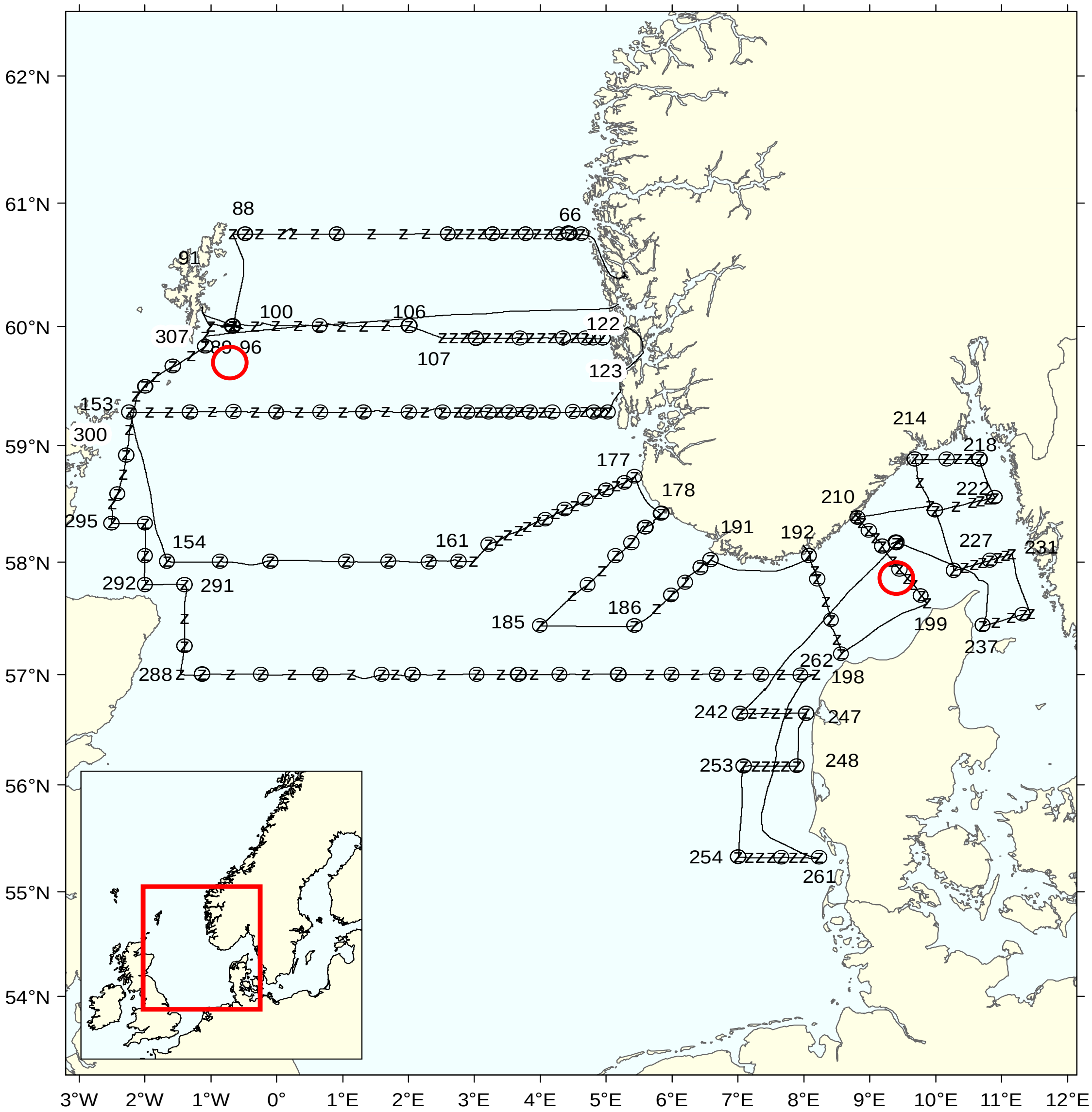


Cruise no 2021455 "Dr. Fridtjof Nansen" (Chart I)
30 March- 26 April2021

z CTD st.no 66-307
○ Plankton st. (WP-II net)

Figure 1a. *RV Dr Fridtjof Nansen 31.03-26.04.2021. Cruise track with stations for CTD casts and plankton sampling. Process stations are indicated with red circles*

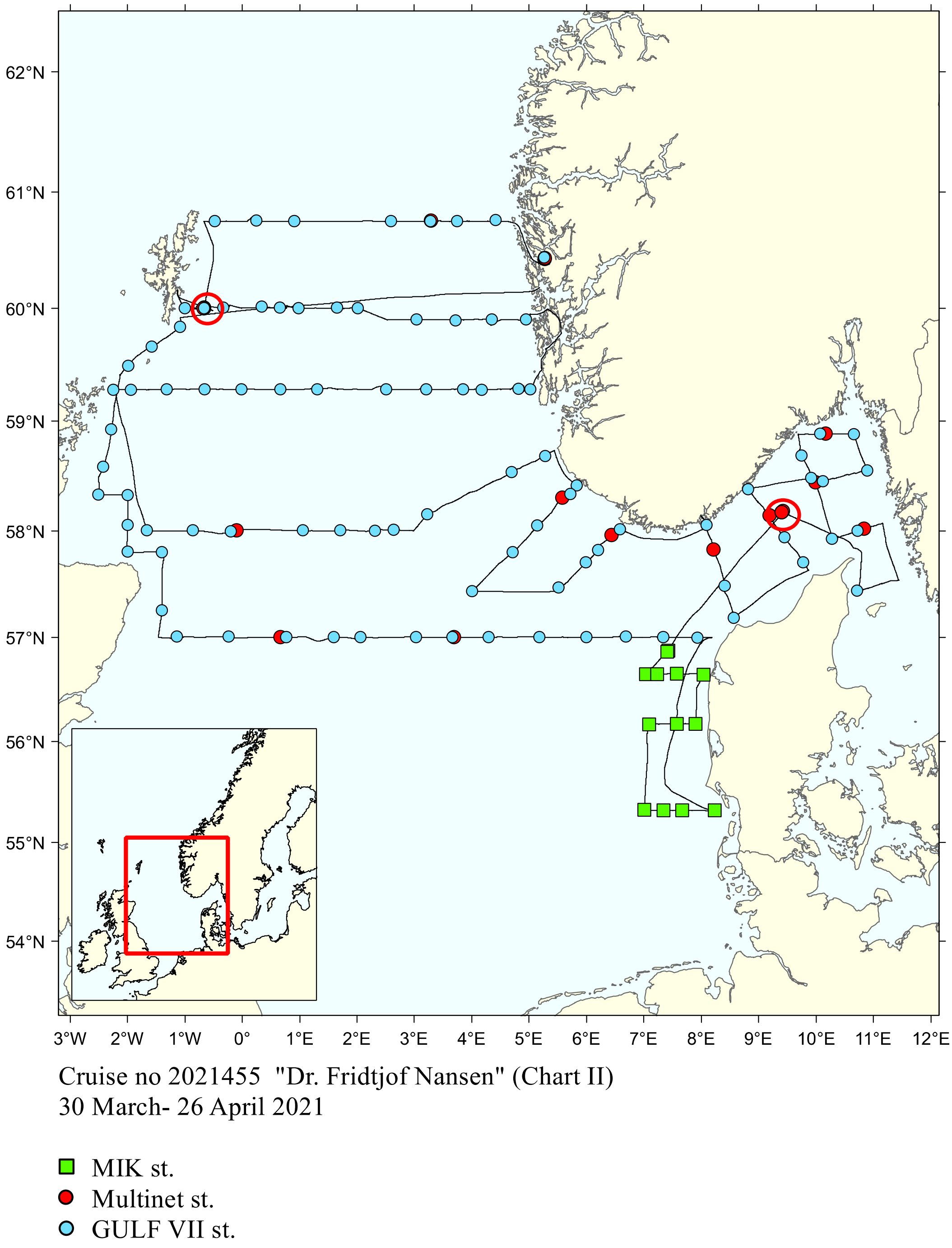


Figure 1b. *RV Dr Fridtjof Nansen 31.03-26.04.2021. Cruise track with stations for WP2, Multinet, Gulf VII, and MIK. Process stations are indicated with red circles.*

3.3 Hydrography

Seawater temperature and salinity were measured at all stations with a SeaBird Electronics SBE911 CTD profiler fitted with a water bottle rosette.

3.4 Biogeochemistry

Water samples for nutrient analysis (nitrate, nitrite, phosphate, silicate) were sampled from all CTD stations at all depths. From each depth 20 mL aliquots of sample water were collected in clean polyethylene bottles and added 0.2 mL chloroform, before storage at +4 ºC until further analysis at the *Plankton Chemistry Laboratory* at the Institute of Marine Research (IMR) in Bergen. Chlorophyll pigment samples (268 mL) were taken from eight depths between the surface and 100 m and collected on GF/F fiber glass filters. The filters were stored at -20 ºC to be analyzed for Chlorophyll-*a* and Phaeopigments (Chl-*a*, Phaeo) at the *Plankton Chemistry Laboratory* in Bergen.

Samples for Total Nitrogen and Phosphorous (Tot-N and Tot-P) were collected at selected stations in the Skagerrak and along the Danish west coast (Table 4). Samples were obtained from CTD water bottles at 5, 10, 20, 30 and 100 m (or deepest possible if bottom depth < 100 m). Collection and handling of samples were carried out in accordance with the *Handbook for Plankton Collections and Analysis* (Hassel et al., 2019). Analyses of Tot NP was performed by the *Plankton Chemistry Laboratory* (IMR) in Flødevigen

Oxygen was sampled along the Torungen-Hirtshals transect at six pre-selected stations (229-234) while CDOM was sampled at two coastal stations in Skagerrak, Langesund and Oslofjord 1, for the coastal monitoring program (IMR 15593).

Table 4. ***Transect, number of stations and number of samples collected for the specific chemistry analysis***

Transect	Station Nr	Nutrients	Chlorophyll a	TOT NP
Fedje-Shetland	66-88	225	181	-
Prosess stasjon 48 t, P1	89-96	10	50	-
Slotterøy mot W	97-122	240	206	-
Utsira mot W	123-153	272	245	-
Jærens rev mot SW og W	154-177	201	183	-
Egerøya mot SW	178-185	66	60	-
Lista mot SW	186-191	58	47	-
Oksø Hanstholm	192-198	54	45	30
Torungen Hirtshals	199-212	98	83	56
Jomfuland Koster	213-218	51	45	30
Vaderø	219-224	55	45	29
Måseskjær	225-232	67	64	40
Gøteborg-Fredrikshavn	233-237	23	28	23
P4 Skagerrak døgnstasjon	238-241	12	32	0
Harboør	242-247	23	29	23
Huseby klit	248-253	18	24	18
Knude dyp	254-261	23	31	23
Hanstholm Aberdeen	262-288	147	172	21
Scotland East Coast	289-294	45	47	-
Fair Isle - Pentland	295-307	85	96	-

3.5 Phytoplankton

Samples for phytoplankton species composition and abundance were obtained from preselected stations along the transects (Figure 1a). Samples for algal cell counts (100 ml) were collected from 10 m depth water bottle of the CTD sampler and fixed in Neutral Lugol. Qualitative phytoplankton samples at some of the stations were obtained from vertical net tows with the Algae-net (10 µm mesh; 0.1 m^2 opening; 30-0 m) and fixed with 2ml of 20% formalin. Samples were stored in the dark and cool room till return to the laboratory. Post analysis of phytoplankton samples were conducted using a Leica microscope at the *Flødevigen Plankton Laboratory*.

3.6 Microplankton

Microzooplankton were collected at 23 selected stations along the standard North Sea transects. Samples were collected in parallel with phytoplankton and zooplankton samples to acquire a better understanding of whole North Sea plankton community structure. Additional 52 samples were collected for a highly temporal and spatial coverage at the two process study stations: the Deep Skagerrak and the Shetland station. Water samples from microzooplankton enumeration and identification (1000-500ml) were collected from the 10m CTD sampler bottle, fixed in 2% (fin. Conc.) Acidic Lugol and stored in a dark refrigerated room (4°C). Post cruise analyses were performed at the *Flødevigen Plankton Laboratory*. Selected sampled were analyzed using a Flowcam VS-1 quipped with a 4x magnification and 600 µm flowcell.

3.7 Mesozooplankton

Mesozooplankton were collected by vertical tows with WP-2 plankton nets (0.25 m^2 opening; 180 µm mesh size) from the bottom to the surface, and from 200-0 m, bottom depth permitting. Additional stratified sampling of zooplankton was carried out by Multinet MAMMOTH (Hydrobios, 180µm, soft cod-ends). Oblique tows were made from 5 m above bottom while releasing nets at standard depths (Table 5).

Table 5. *MultiNet standard depth of the IMR zooplankton monitoring in the North Sea-Skagerrak*

Depth strata	MultNet number
0-bottom	0
bottom-400	1
400-300	2
300-200	3
200-150	4
150-100	5
100-50	6
50-25	7
25-0	8

Large medusae and ctenophores were removed from whole samples, and the displacement volume of each species was recorded. The remaining zooplankton sample was split in two parts by a Motoda plankton splitter: one part was fixed in 4% borax buffered formaldehyde for species identification and enumeration. The other half was used for estimation of biomass (dry weight): samples were fractionated into three fractions (180-1000µm, 1000-2000µm and >2000µm) and placed on pre-weighted aluminum trays, dried at 60°C for 24 hours and kept in a freezer until return to Bergen. From the >2000 µm size fraction euphausiids, shrimps, amphipods, fish and fish larvae were counted, and their lengths measured separately before drying. In addition, Chaetognaths, *Pareuchaeta* sp. and *Calanus hyperboreus* from the >2000 µm size fraction were counted and dried separately (but sizes not measured).

Samples were not split on the transect Hanstholm-Aberdeen, due to shallow depths and small sampling volumes. Instead, two WP2-tows were taken: 1/1 sample was fixed in 4% formaldehyde, and 1/1 sample was fractionated and dried for later biomass measurements. All dry weights were determined at the IMR plankton laboratory in Bergen after the cruise. Details on the sampling procedures are found in the IMR Plankton Manual (Hassel et al., 2019).

3.8 Fish eggs and larvae

Sampling for fish eggs and larvae was undertaken at selected stations along each of the standard North Sea transects (Figure 1b) using a Gulf VII high-speed sampler (Nash *et al.* 1998) (76 cm frame). The sampler was fitted with a 40 cm diameter nose cone, a General Oceanics flow meter was fitted slightly off center in the nose cone (for quantities of water filtered) and a 280 µm mesh net. The sampler was towed at 5 knots in a double oblique haul to 100m depth or to within 10m of the bottom. All fish eggs and larvae were sorted from the samples at sea, sub-sampling being undertaken where necessary, and preserved in 4% seawater and Borax buffered formalin.

In addition, a PUP sampler (5 cm diameter nosecone with a General Oceanics flowmeter to determine the water volume sampled and a 80 µm mesh net) was fitted to the Gulf VII to provide samples of prey items for fish larvae. These samples were also preserved in 4% seawater and Borax buffered formalin.

3.9 Process stations

The process studies were performed at two stations: the Deep Skagerrak Process Study Station (58.8N, 9.11E), and the Shetland Process Station (60ºN; 0.67ºW). The Shetland Stations was sampled over a 48-hour period following a schedule of 4 sampling a day: sunrise, mid-day, sunset and mid-night. The Deep Skagerrak Station during this campaign was sampled over only 24 hours due to inclement weather. Details of parameters sampled and the timeline for both process stations are shown in Table 6. Briefly, due to the wide size range that characterize plankton, and to be able to collect several components of the food web, we combined water samples from CTD, algae net (10µm mesh) and Multinet MAMMOTH (Hydro-Bios) equipped with two sets of mesh sizes: 180 µm and 405 µm. Water samples from the CTD sampler were used for nutrient analysis, Chl-a, phytoplankton and microzooplankton characterization. A small size mesh net tow served for a better specie-specific characterization of rare plankton species. The samples collected by Multinet MAMMOTH were intended for biomass and identification of mesozooplankton (180µm mesh) and fish egg and larvae (408µm mesh). All the samples were collected, preserved, and analyzed as described in section 3.5 to 3.8. The target depths for the MultiNet MAMMOTH and water samples are given in Table 6 together with the physical-chemical parameters collected. Nutrients were collected once a day from the first CTD cast while acoustic signals were continuously recorded during the 48 hours.

Table 6. *MultiNet depth and mesh size used during the sampling of the process stations in the North Sea and Skagerrak.*

Net Nr	**Mesh**	**Deep Skaggerrak Process Station**	**Shetland Process Station**
1	180µm	bottom-250m	75m-bottom
2	180µm	250-100m	40-75m
3	180µm	100-50m	20-40m
4	180µm	50-0m	0-20m
5	use to relocate at depth		
6	405µm	bottom-250m	75m-bottom
7	405µm	250-100m	40-75m
8	405µm	100-50m	20-40m
9	405µm	50-0m	0-20m

Table 7. *Timeline and parameters collected at the two process study stations.*

Station	Date	Time	Depth	Continous recording: Acustic	Continous recording: Oxigen	Continous recording: PAR	Nuts	Chl-a	Algae Net 0-30m	Microzoo/ Phytoplankton	Multinet-Mammuth 180µm	Multinet-Mammuth 405 µm
Shetland Process Station (60º0'N 0º40'E)	2-3.4.21	20:50	10	x	x	x	x	x	x	x	0-20	0-20
			20				x	x				
			30				x	x		x	20-40	20-40
			50				x	x		x	40-75	40-75
			100				x	x		x	75-bottom	75-bottom
	3-4.4.21	02:00	10	x	x	x		x	x	x	0-20	0-20
			20					x				
			30					x		x	20-40	20-40
			50					x		x	40-75	40-75
			100					x		x	75-bottom	75-bottom
	3-4.4.21	07:30	10	x	x	x		x	x	x	0-20	0-20
			20					x				
			30					x		x	20-40	20-40
			50					x		x	40-75	40-75
			100					x		x	75-bottom	75-bottom
	3-4.4.21	14:00	10	x	x	x		x	x	x	0-20	0-20
			20					x				
			30					x		x	20-40	20-40
			50					x		x	40-75	40-75
			100					x		x	75-bottom	75-bottom
Deep Skaggerrak Process Station (58º8'N 9º11'E)	19.04.21	05:00	10	x	x	x	x	x	x	x	50-0	50-0
			30				x	x		x		
			50				x	x		x	50-100	50-100
			100				x	x		x		
			200				x	x			100-250	100-250
			400				x	x				
			600				x	x		x	250-bottom	250-bottom
	19.04.21	12:00	10	x	x	x		x	x	x	50-0	50-0
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x			100-250	100-250
			400					x				
			600					x		x	250-bottom	250-bottom
	19.04.21	22:00	10	x	x	x		x	x	x	50-0	50-0
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x			100-250	100-250
			400					x				
			600					x		x	250-bottom	250-bottom
	20.04.21	00:00	10	x	x	x		x	x	x	50-0	50-0
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x			100-250	100-250
			400					x				
			600					x		x	250-bottom	250-bottom

3.10 Radioactivity

Water samples are collected yearly from 10 preselected stations in the Skagerrak (Table 8, Figure 2) for analyses of the radionuclide cesium-137 (Cs-137) (project number 15595). In 2021, samples were collected from 9 of these stations (indicated in Table 8). At each station, 50 liters of seawater are collected from the ship's seawater intake and filled directly into 25 L plastic cans. The samples are later analyzed for Cs-137 at the Laboratory for inorganic chemistry at IMR, Bergen, according to the internal method "460 - Bestemmelse av Cs-137 i sjøvann" (MET.UORG.01-17). This is a modified version of the analytical procedure described by Roos et al. (1994).

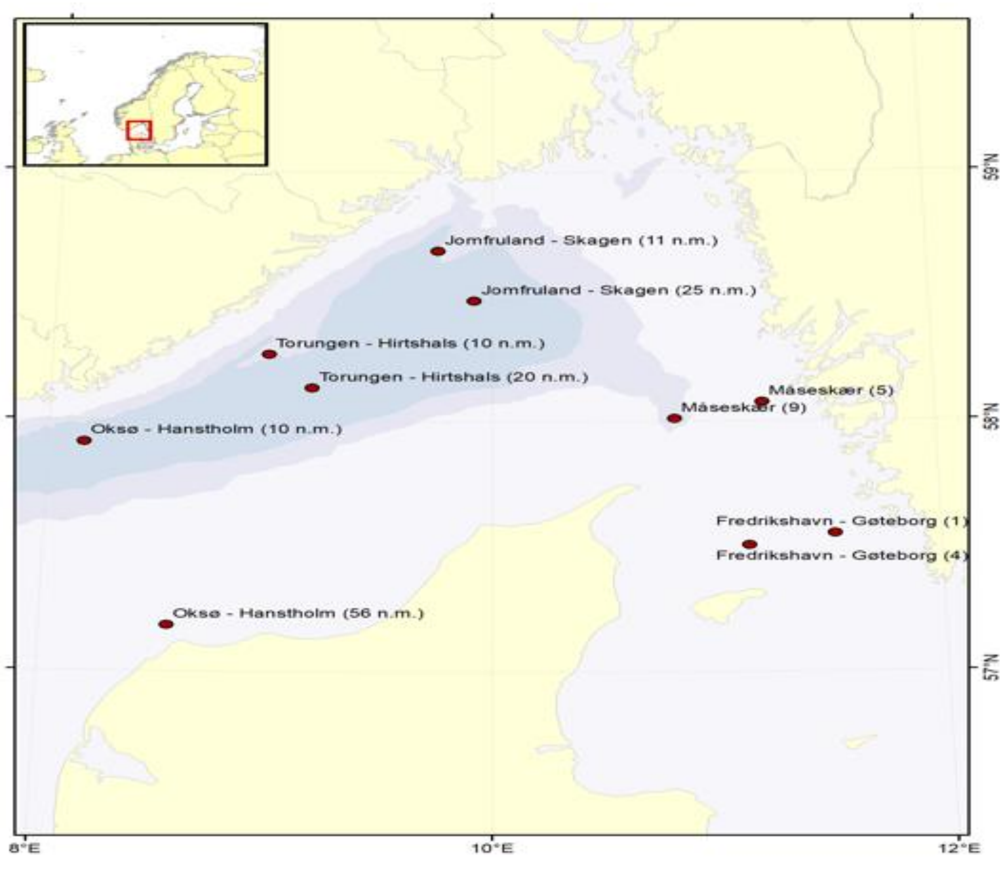


Figure 2. *Stations where seawater has been collected yearly since 2008 for analyses of Cs-137*

Monitoring of radioactive contamination in the Skagerrak is part of the national monitoring program Radioactivity in the Marine Environment (RAME), which is coordinated by the Norwegian Radiation and Nuclear Safety Authority (DSA) (e.g. Skjerdal et al., 2017; Skjerdal et al., 2020).

Table 8. *Station list where samples for monitoring of cesium-137 were collected in April 2021.*

St. no.		LatD	LatM	Lat Dec		LongD	LongM	Long Dec		Collecte
1	Fredrikshavn - Gøteborg (1)	57	33	57.55	E	11	32	11.53	N	-
4	Fredrikshavn - Gøteborg (4)	57	30	57.51	E	11	9	11.14	N	x (CTD 2
5	Måseskær (5)	58	2	58.03	E	10	57	10.94	N	x (CTD 2
9	Måseskær (9)	57	57	57.95	E	10	26	10.43	N	x (CTD 2
3	Jomfruland - Skagen (11 n.m.)	58	41	58.68	E	9	45	9.75	N	x (CTD 2
5	Jomfruland - Skagen (25 n.m.)	58	29	58.48	E	9	55	9.92	N	x (CTD 2
4	Torungen - Hirtshals (10 n.m.)	58	16	58.27	E	8	59	8.98	N	x (CTD 2
6	Torungen - Hirtshals (20 n.m.)	58	8	58.13	E	9	11	9.18	N	x (CTD 2
3	Oksø - Hanstholm (10 n.m.)	57	55	57.92	E	8	10	8.17	N	x (CTD 1
12	Oksø - Hanstholm (56 n.m.)	57	11	57.18	E	8	34	8.57	N	x (CTD 1

3.11 Dutch Downs Recruitment Survey

In 2021 the Downs Recruitment Survey (DRS) was carried out following the IBTS-MIK protocol as much as possible, but the sampling was carried out both day and night, instead of only at night. Both Netherlands and Norway participated in the survey. Norway sampled 11 station between April 20 and 21st along three transects, Harborø, Huseby Klit, and Knude Dyb on the west coast of Danmark. MIk-Samples, pre-screened on board to sort out the clupeid, were preserve in 4% formaldehyde. Once on land, to prevent issues with custom, the scintillation tubes were drain of the formaldehyde and stuffed with wadding to prevent the larvae from drying-out. Samples were then shipped to the Wageningen Marine Research in Netherlands for identification and measurements.

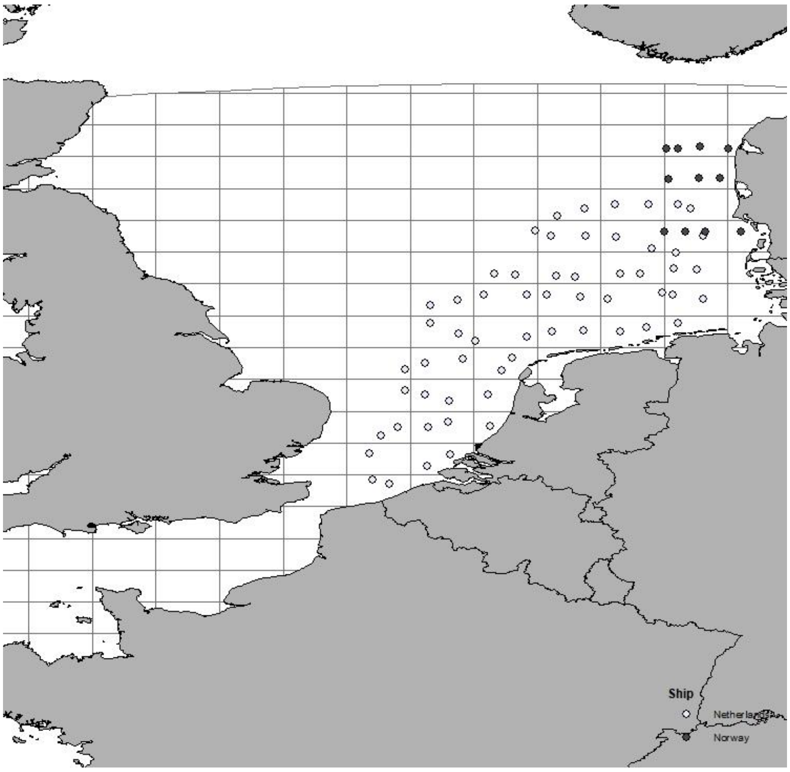


Figure 3 *Sampled stations by country during the 2021 DRS (○ Netherlands; ● Norway).*

Table 8. *Summary of sampling (number of stations) on transects and process stations*

Station Nr	Transect	Nutrients	Chlorophyll	TOT NP	Radio-activity	Phytopl. Abund.	Phytopl. Net 30-0m	Microzoopl.	WP2 bottom-0m	WP2 200-0m	WP3	Gulf	Multinet Mammoth	MIK
66-88	Fedje-Shetland	225	181	0	0	2	6	4	7	3	3	7	1	0
89-96	Prosess stasjon 48 t, P1	10	50	0	0	0	7	32	0	0	0	0	8	0
97-122	Slotterøy mot W	240	206	0	0	5	2	3	8	3	0	12	0	0
123-153	Utsira mot W	272	245	0	0	4	4	5	15	6	0	13	0	0
154-177	Jærens rev mot SW og W	201	183	0	0	4	2	4	13	3	3	10	1	0
178-185	Egerøya mot SW	66	60	0	0	0	1	1	5	1	3	5	1	0
186-191	Lista mot SW	58	47	0	0	2	3	1	4	2	3	4	1	0
192-198	Oksø Hanstholm	54	45	30	2	3	2	1	3	1	0	3	1	0
199-212	Torungen Hirtshals	98	83	56	4	10	3	1	5	2	0	5	1	0
213-218	Jomfuland Koster	51	45	30	0	4	3	0	3	0	0	2	0	0
219-224	Vaderø	55	45	29	0	3	2	0	2	0	0	2	1	0
225-232	Måseskjær	67	64	40	2	4	1	0	2	0	0	1	0	0
233-237	Gøteborg-Fredrikshavn	23	28	23	1	2	1	0	2	0	0	1	0	0
238-241	P4 Skagerrak døgnstasjon	12	32	0	0	0	4	20	0	0	0	0	4	0
242-247	Harboør	23	29	23	0	3	2	0	4	0	0	0	0	4
248-253	Huseby klit	18	24	18	0	3	2	0	4	0	0	0	0	3
254-261	Knude dyp	23	31	23	0	3	2	0	4	0	0	0	0	3
262-288	Hanstholm Aberdeen	147	172	21	0	8	5	3	19	0	0	13	2	0
289-294	Scotland East Coast	45	47	0	0	0	5	0	5	0	0	5	0	0
295-307	Fair Isle - Pentland	85	96	0	0	6	6	0	6	0	0	6	0	0
Sum		1773	1713	293	9	66	63	75	111	21	12	89	21	10

4. Results and Discussion

4.1 Hydrography

The hydrographic coverage of the survey area provides information on the main characteristics of the water masses in the northern North Sea and in the Skagerrak. The lowest surface salinities are typically found in the Skagerrak due to the Baltic outflow of low-saline waters through the Kattegat and the supplement of fresh water from local rivers along the Skagerrak coast. The resulting low-saline surface waters then follow the Norwegian coast westward out of the Skagerrak and northward along the coast, as the Norwegian Coastal Current (NCC). The shelf area in the northern North Sea is typically dominated by inflow of Atlantic water from the north (from the Tampen area) and from the west between the Orkneys and Scotland as the Fair Isle Current.

Based on the hydrographic measurements from the Ecosystem Cruise from March 31 to April 26, 2021, the NCC can be identified in the resulting surface salinity map in the areas with the minimum values (Figure 4, left panel, blue and yellow colors). Although we see normal salinity values along the Norwegian coast in the Skagerrak, the near-shore salinities along the Norwegian west coast are relatively high. The weather during and prior to the cruise was dominated by low pressure systems from the west with winds introducing heavy mixing of the water masses in the northern North Sea both laterally and vertically, attenuating the low-salinity pattern of the NCC in this area. Also, the temperatures along the Norwegian west coast are quite similar to what is found in the northern North Sea shelf area (Figure 4, right panel).

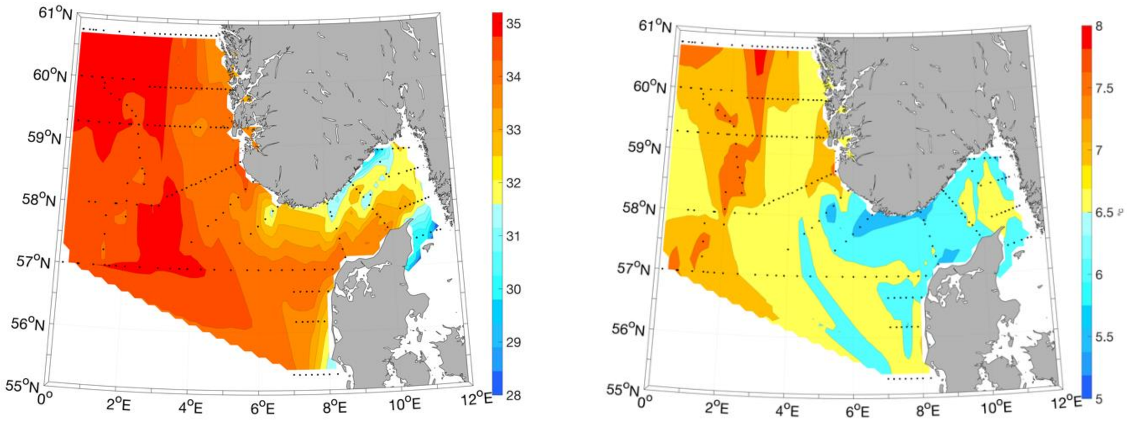


Figure 4 *Salinity (left panel) and temperature (right panel) distribution during the North Sea ecosystem cruise 2021.*

The surface temperatures (10m depth) varied between 5.5-6.5^{O}C in the Skagerrak to 6.5-8 ^{O}C along the Norwegian west coast and the northern North Sea. We can identify relatively warm and saline water with North Atlantic origin flowing southward east of the Orkneys. We see typical spring conditions were the local waters resulting in the NCC are slightly colder than the Atlantic waters dominating the northern North Sea.

In relation to the long-term average, both the surface salinities and temperatures were slightly above normal.

4.2 Satellite image

Figure 5 shows the evolution of Chlorophyll a concentration in the studied area during the period March 30 to April 26. The images are mean values over 8-day period. The satellites images show lower concentration of Chlorophyll a during the first half of the survey (Figure 5 a-b) compared to the second half (Figure 5 c-d). Chlorophyll start accumulate along the Norwegian coast (Figure 5c) however, during the last 8 days higher concentrations (red color) were detected all over the Norths Sea Shelf area.

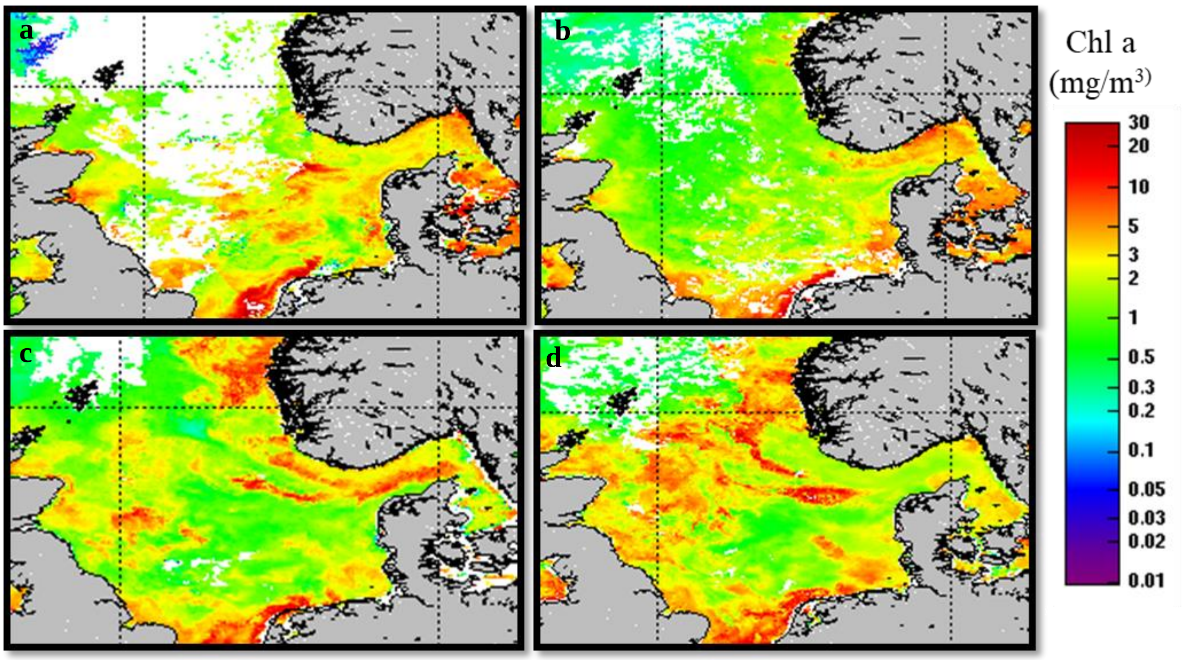


Figure 5. *Evolution of the 8 days mean surface chlorophyll-a concentrations from MODIS satellite imagery over the period 30.03.2021 to 26.04.2021. a) 30/03-06/04; b) 07/04-14/04; c) 15/04-22/04; d) 23/04-30/04.*

4.3 Biogeochemistry

During the 2021 spring survey higher nutrients concentrations were measured in the Northern sector of the North Sea (Figure 6 a-c). These concentrations are most likely connected to the strong mixing events that occurred during the first half of the survey and that re supply the surface water with new nutrients. Lower concentrations were observed in the southern section and along the Danish coast where the higher Chlorophyll a concentration (Figure 6d) suggest a higher usage of the resources by phytoplankton.

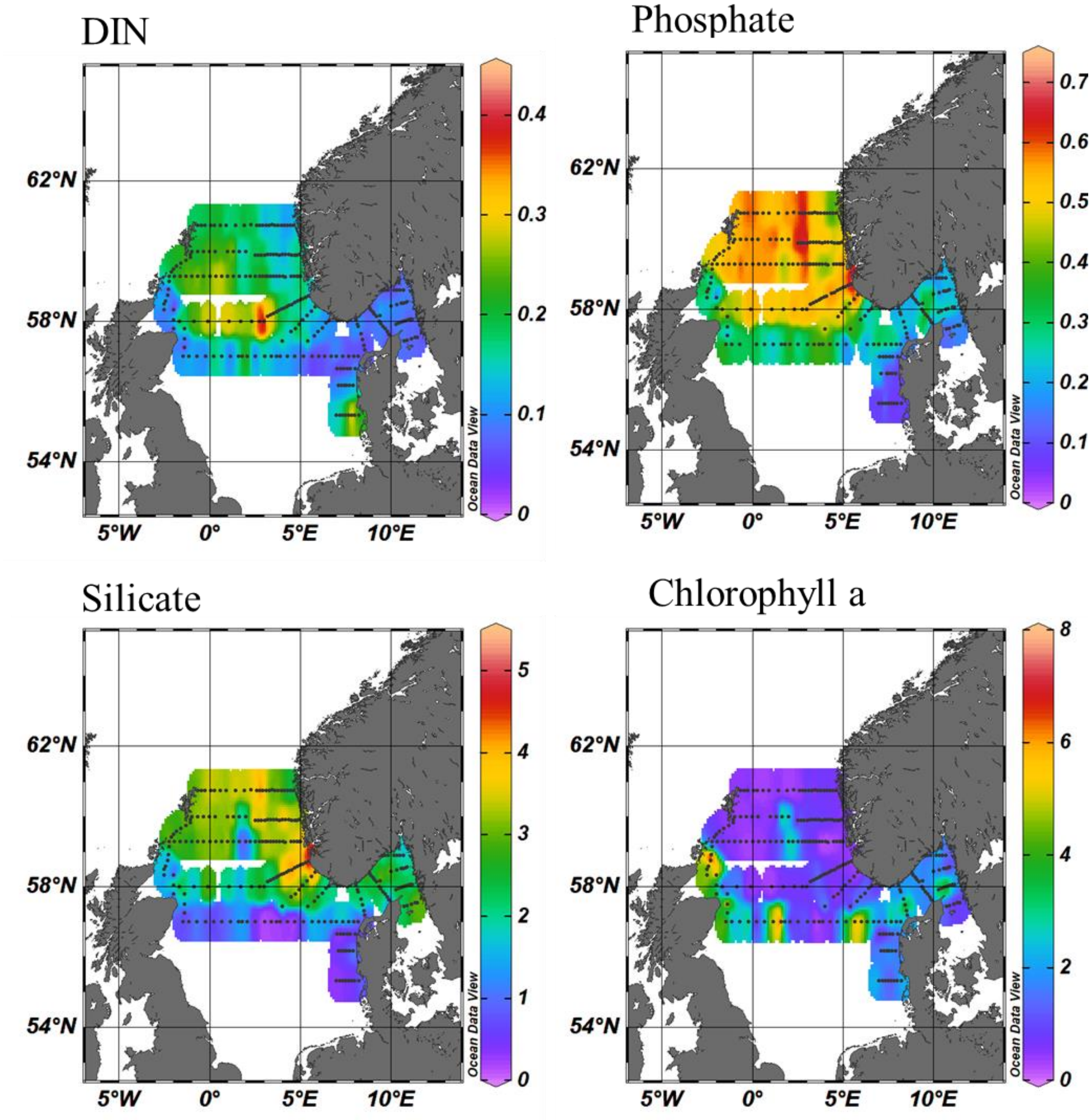
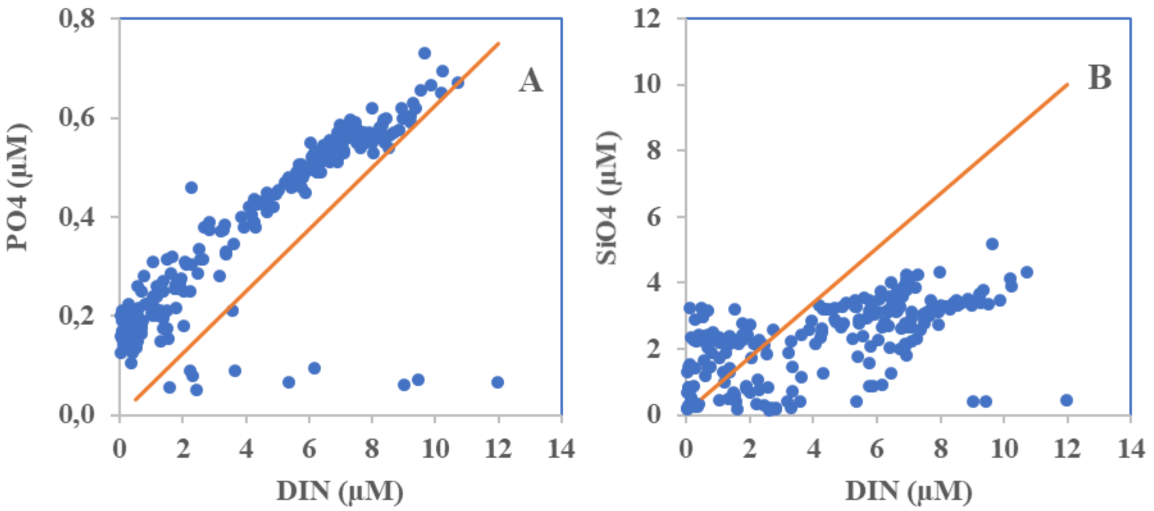


Figure 6 *Nutrient concentrations during the North Sea spring survey 2021: a) dissolved inorganic nitrogen (DIN, nitrite + nitrate), b) Phosphate, c) silicate and d) Chlorophyll a.*

Calculated dissolved inorganic nutrient ratios showed an N:P-relationship lower than 16 for most parts of the North Sea (Figure 7) suggesting that phosphate was in abundance relative to DIN (nitrite + nitrate). Phytoplankton had less access to silicate than DIN, which may suggest that the primary producers were both silicate and nitrogen-limited (P>N>Si) in these areas. Diatoms, the single users of silicate, appeared more limited of silicate than of phosphate (Figure 7c). One area west of Jutland, Denmark, exhibited a unique combination of high DIN and extremely low phosphate concentrations (Figure6a-b; 7a). The high DIN at these stations appeared to be caused by elevated nitrite concentrations in this region, compared to all other regions of the North Sea.



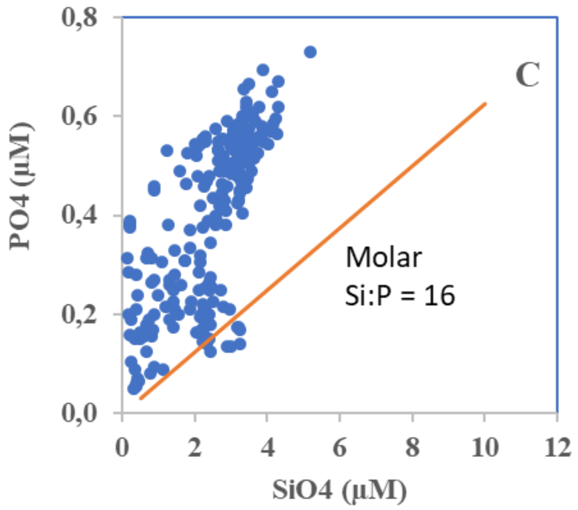


Figure 7 *Dissolved inorganic nutrients measured in surface waters (0-10 m depth) from the Ecosystem cruise (March 31 – April 25, 2021) in the North Sea and the Skagerrak region. Phosphate (A) and silicate (B) was plotted as a function of dissolved, combined nitrogen (DIN= NO2+NO3), and phosphate (C) was plotted as a function of silicate. Whole line shows the Redfield N:P relationship and other molar relationships (N:Si, Si:P), that are assumed necessary for a balanced cellular synthesis and growth in phytoplankton.*

As expected, nutrient concentrations were low in areas with high Chl-*a* concentrations (Figure 8). At 40% of the stations visited, silicate concentrations were <2 µM (Figure 8b). Stations with surface silicate concentrations <2 µM where found in the southern North Sea along the Aberdeen-Hanstholm transect (57 °N latitude) and at the southernmost stations off the western coast of Denmark (Figure 1a). Such low silicate concentrations might be the results of diatoms growth event occurred before the survey sampling time.

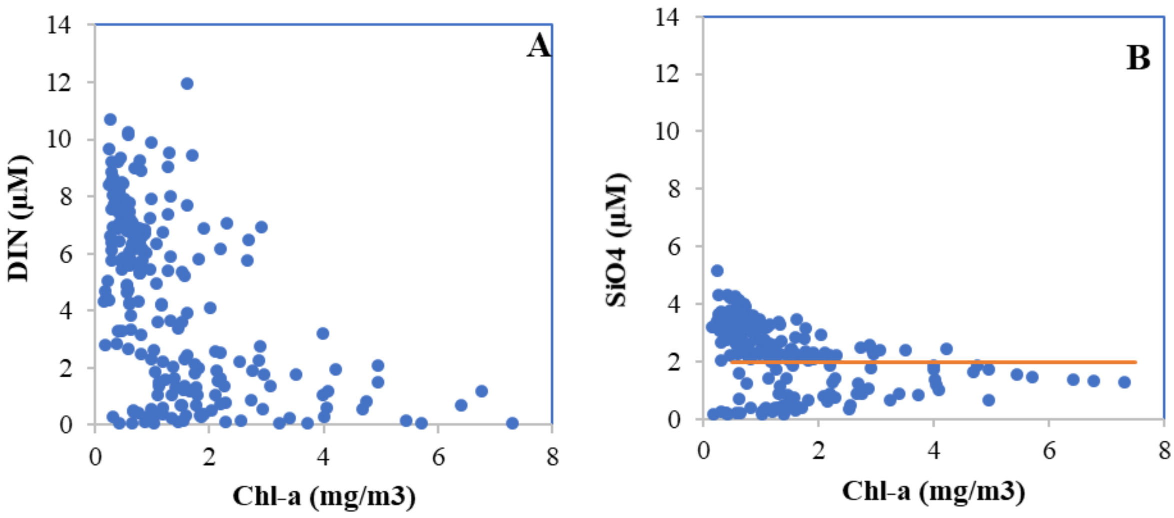


Figure 8: *Concentrations of dissolved inorganic nitrogen (DIN), dissolved silicate (SiO4), and cellular pigment content (Chl-a) measured in surface waters (0-10 m depth) from the Ecosystem cruise (March 31 – April 25, 2021) in the North Sea and the Skagerrak region. DIN (A) and SiO4 (B) was plotted as a function of Chl-a concentrations. Silicate concentrations <2 µM (whole red line) shows where diatoms are no longer competitive with other phytoplankton.*

4.4 Phytoplankton taxa

Phytoplankton was identified through microscopic analysis following the Utermöhl (1958) method that enables better resolution of individual species abundance.
Microscopy results show that the highest abundance measured in the North Sea in spring 2021 was recorded along the Danish west coast on the Huseby klit transect. Station 250 accounted for the most abundant phytoplankton population with 3,3 million cells/liter, while most of the other stations registered numbers below the 1 million cells/l (Figure 9)

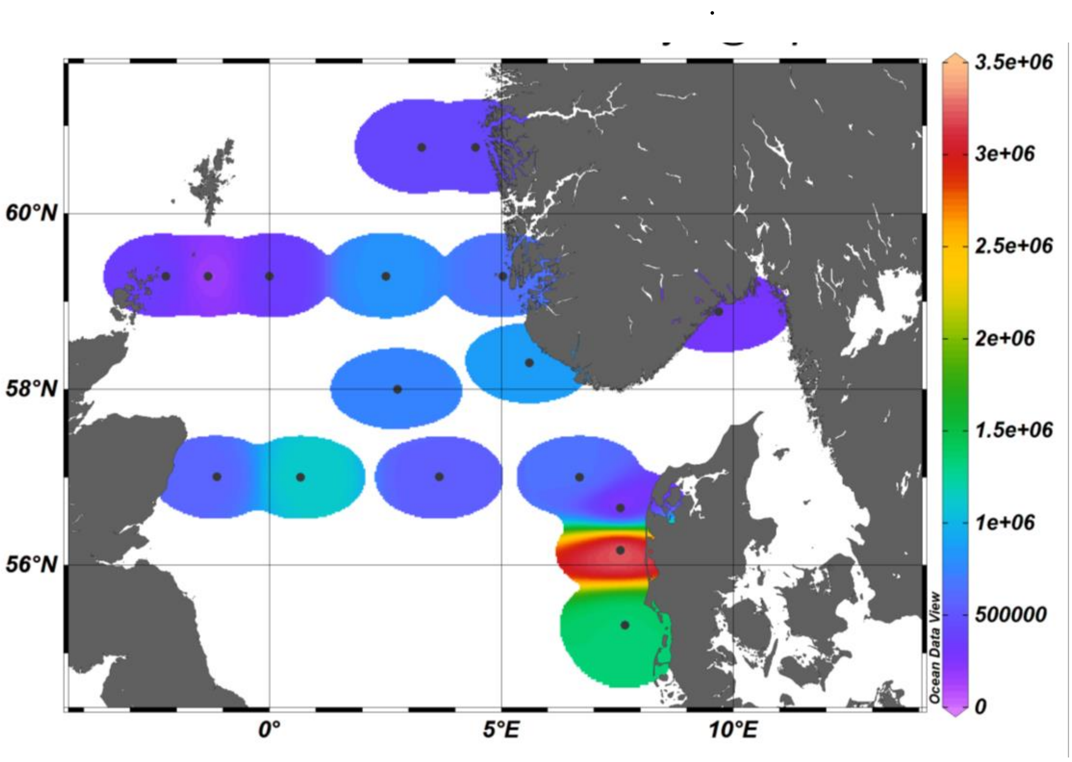


Figure 9. *Total phytoplankton abundance in cell/liter as measured through microscopy analysis*

The Phytoplankton population of the North Sea was largely dominated by cell smaller than 10µm reflecting the advantage of small cells in low nutrient environments. The most abundant phytoplankton were small unidentified flagellates which represented usually between 41 and 94% of total population (Figure 10a). At station 250 small flagellates accounted for 71% of the total abundance while diatoms represented less than 2%. Cryptophyceae <10µm were also important contributors to phytoplankton abundance at many stations throughout the region. Despite a widespread dominance of small phytoplankton, the coastal areas of the North Sea, along both the Norwegian and the Scottish coast were often characterized by a higher contribution of diatoms. However, only in one station within the Norwegian trench, station #179, diatoms represented more than 50% of the phytoplankton abundance.

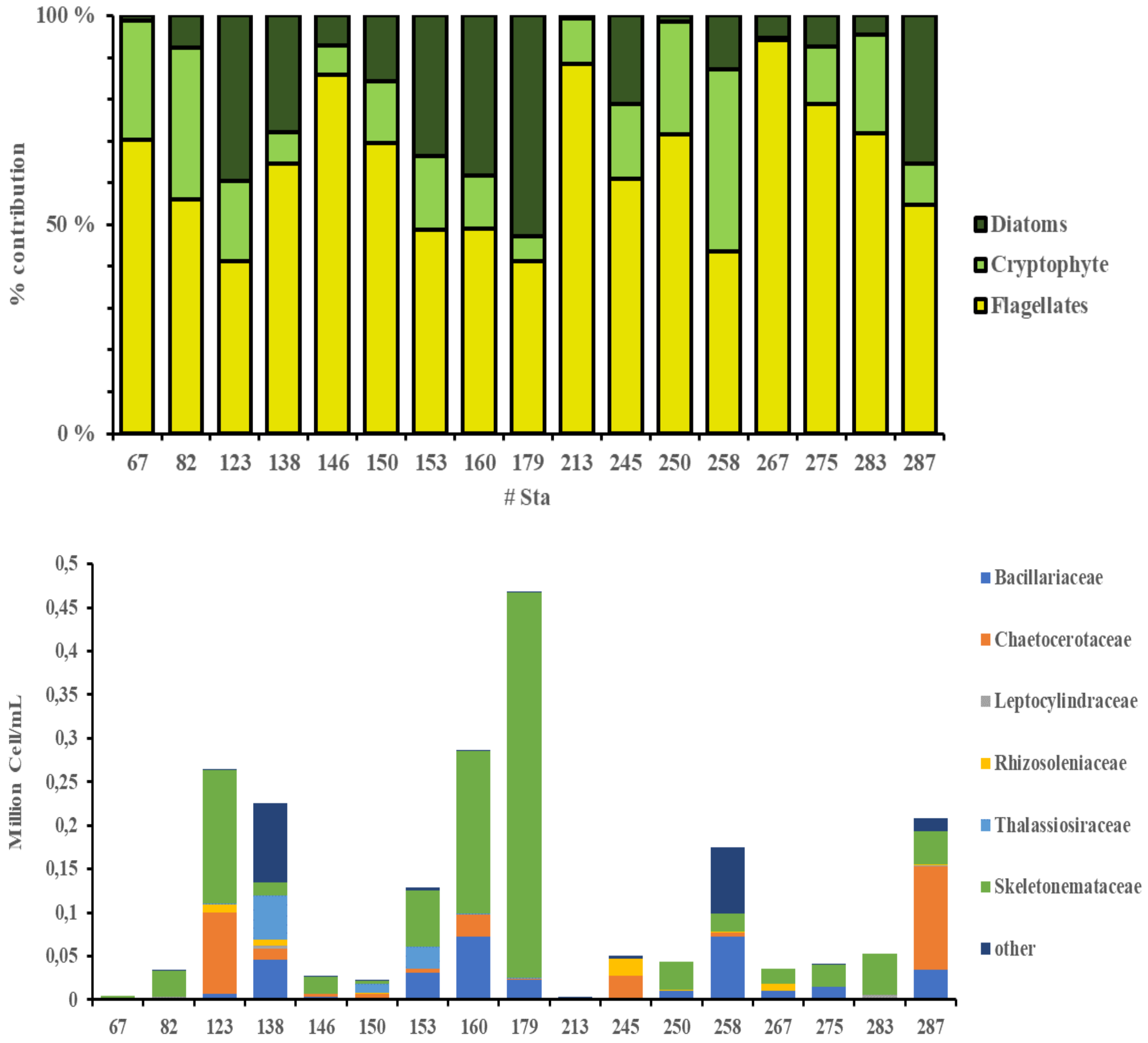


Figure 10. *Phytoplankton relative contributions (a) and diatoms concentration (b) at few selected stations part of the standard NSEC transects).*

Despite the lower abundance that characterized the diatom component compared to the other phytoplankton, diatom population was quite diverse. The most abundant species were smaller chain forming diatoms belonging to the Skeletonemataceae and Bacillariaceae family (Figure 10b). *Chaetocheros* spp. also contributed significantly at several stations.

4.5 Microplankton

Microzooplankton samples from selected stations of fix transects have been analyzed though a flow imaging system (FlowCam). Taxonomic and functional determination were assigned though a machine learning approach. This analysis includes organisms in the size range 30-200µm. we were able to subdivide the plankton community in 3 groups: Phaeocystis colonies, Diatoms chains and heterotrophic/mixotrophic microzooplankton.

Phaeocystis colonies were detected in few samples mostly in the southwestern part of the North Sea. The highest Phaeocystis colonies abundance was recorded along the Scotland coast at station 292, where also diatom chains and microzooplankton were the most abundant (Figure 11). The higher abundances observed in this area are most likely linked to the inflow of the Fair Isle Current bringing on the North Sea shelf nutrients rich water.

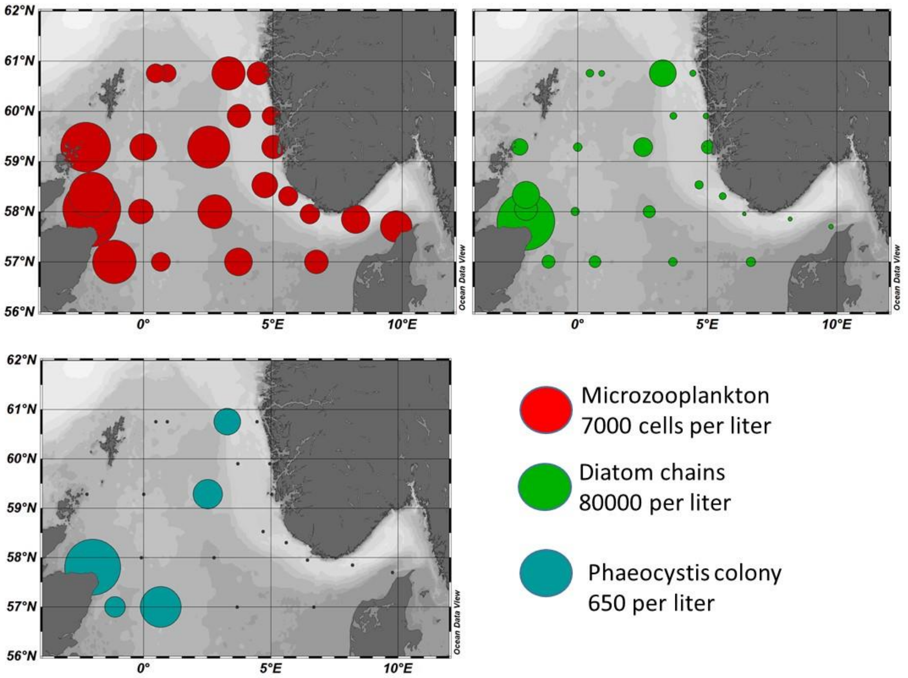


Figure 11. *Areal distribution of microzooplankton (red), diatoms chains (Green) and Phaeocystis colonies (turquoise) based on FlowCam imaging system.*

The size spectra analysis revealed that the organisms measuring 30µm in Area Besed Diameter (ABD), the smallest size class within the instrument detection limit, dominated the North Sea plankton community (Figure 12). The steepness of the slope of the curves revels the higher or lower contribution of smaller cells to the plankton assemblage.

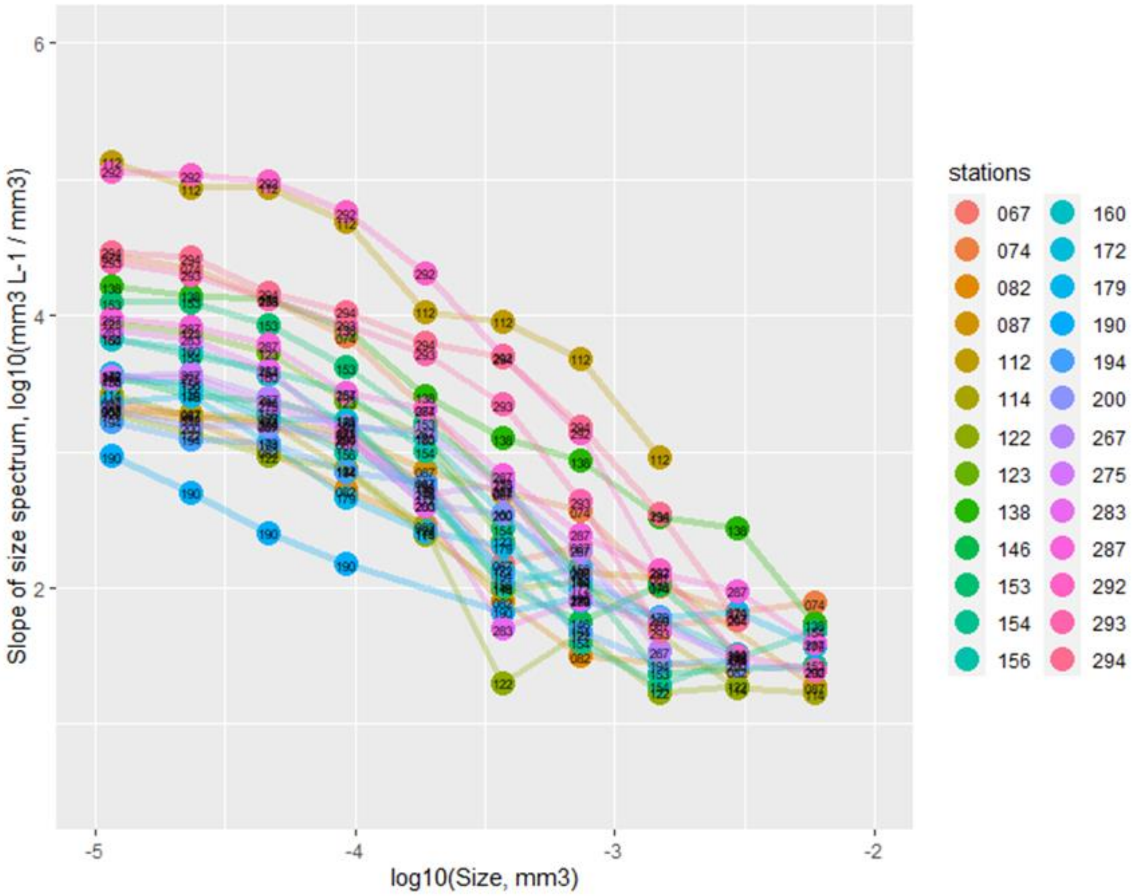


Figure 12. *Plankton size distribution in the size range 30-200µm showing that the larger contribution to plankton abundance is due to smaller cells at all the station analyzed.*

Thus, station 292 which presents the steepest size distribution curve, was characterized by a much larger contribution of small microplankton compared to station 190 which curve was less steep.

4.6 Mesozooplankton

Horizontal distribution

Depth integrated zooplankton biomass (g dry weight/m^2) in April 2021 is presented as total biomass (>180µm, Figure 13a) and as three different size fractions (Figure 13b-d). The highest biomass values were registered along the Hanstholm-Aberdeen transect, and above the Norwegian Trench (14 g/m^2). The 180-1000 µm size fraction (Figure 13b) contains small sized copepods (*Oithona* sp, *Pseudocalanus* spp), juvenile stages of large copepods (*Calanus*) and benthic larvae. However, this fraction may also contain phytoplankton. The highest biomass values of this smallest fraction were observed in Skagerrak and along the Hanstholm-Aberdeen transect. The 1000-2000 µm size fraction, which is dominated by *Calanus* spp, showed similar distributions, with highest values in the Norwegian Trench in Skagerrak (Figure 13c). The biomass of the size fraction >2000 µm was generally low, and mainly found in the Skagerrak and the southern part of the investigated area (Figure 13d).

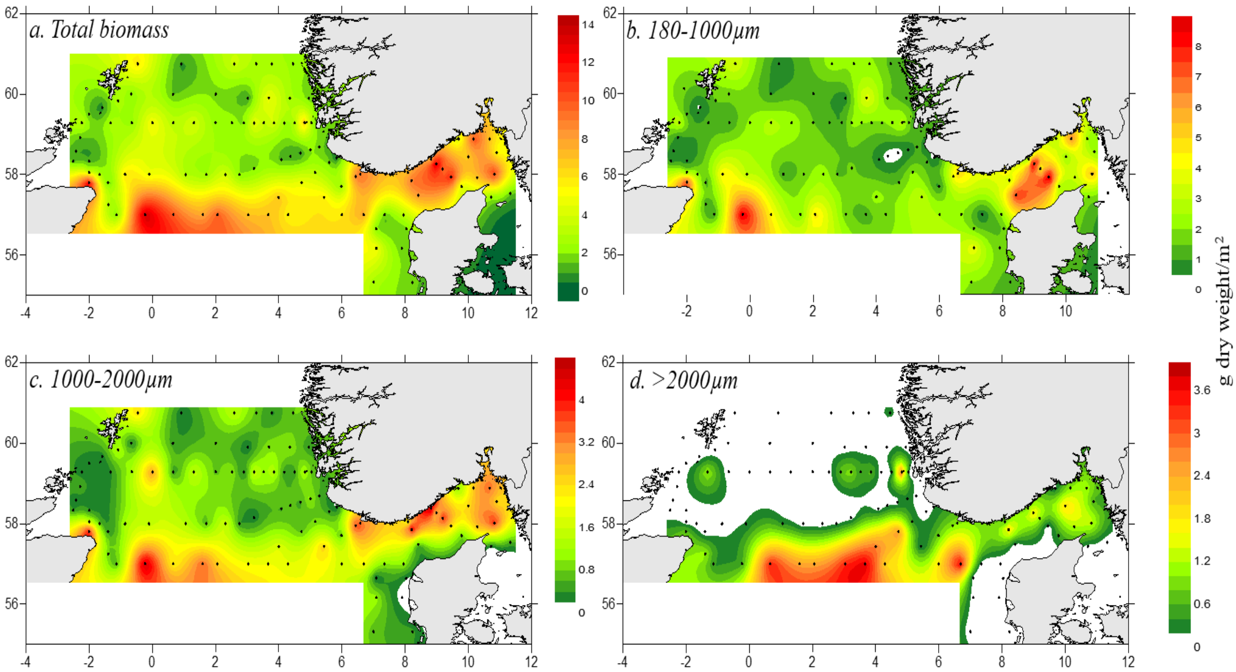
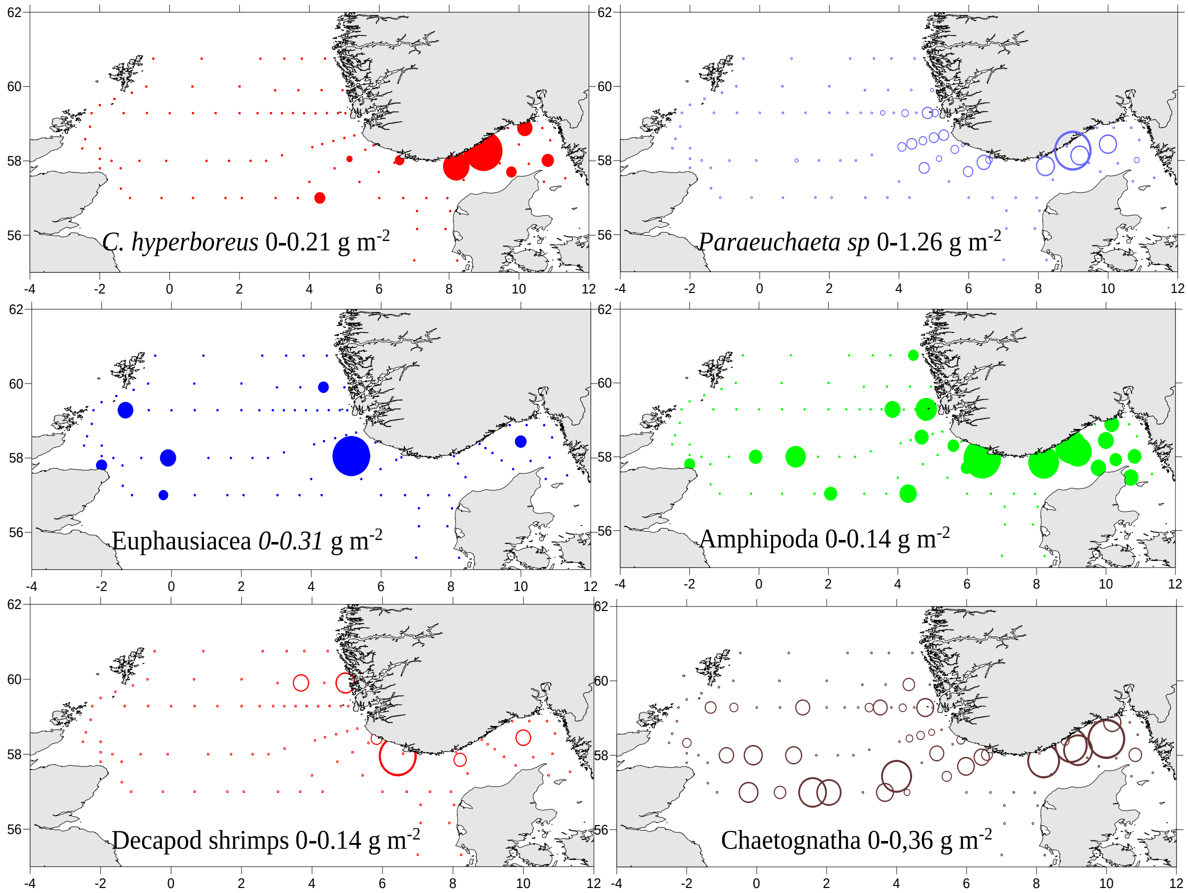


Figure 13. *Zooplankton biomass (g dry weight m^{-2}) in depth integrated net tows (bottom surface, WP2) as total biomass >180µm (a), size fraction 180-1000 µm (b), size fraction 1000-2000 µm (c) and size fraction >2000 µm (d).*

The >2000µm size fraction contains a large variety of planktonic organisms from large sized copepods (*Calanus hyperboreus, Paraeuchaeta norvegica)* to amphipods, decapod shrimps, chaetognaths and gelatinous zooplankton. The biomass of the single groups found in the North Sea in April 2021 are shown in Figure 14.



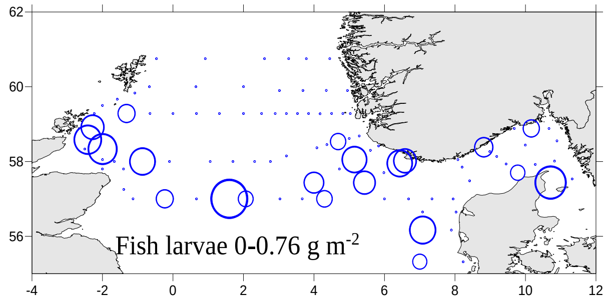


Figure 14. *Biomass of selected groups of zooplankton in the > 2000 µm fraction (in WP2 net tows, 180 µm, bottom-surface). All data square root transformed.*

Overall, the average zooplankton biomass for the whole survey area was 3.0 g m^{-2} which is below the long-term average of 5.6 g m^{-2} (2005-2020; Figure 15). This may be related to the earlier timing of the 2021 North Sea Ecosystem cruise, which was conducted approximately ½ month earlier than in previous years.

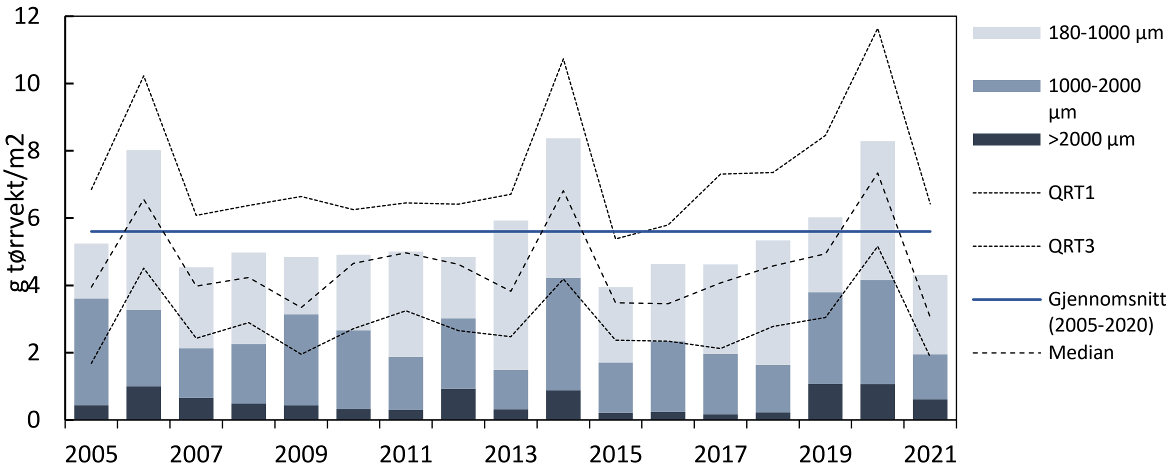


Figure 15. *Annual average zooplankton biomass in April/May 2005-2020. Horizontal line indicates the long-term average 2005-2019. Dashed lines are 25th and 75th percentiles (Q1, Q3).*

Zooplankton taxonomic composition

Copepods was the numerically dominant group of zooplankton across the whole survey area (Figure 16). High densities of copepods were encountered on the western part of the Utsira transect, dominated by small copepods (Oithona and Pseudocalanus). Other important groups were larvaceans (Appendicularia), pteropods (*Limacina retroversa*), euphausiids and meroplanktonic larvae. Crustacean larvae of several benthic decapod species (Brachyura, Anomura) were recorded in the samples but not identified to species level.

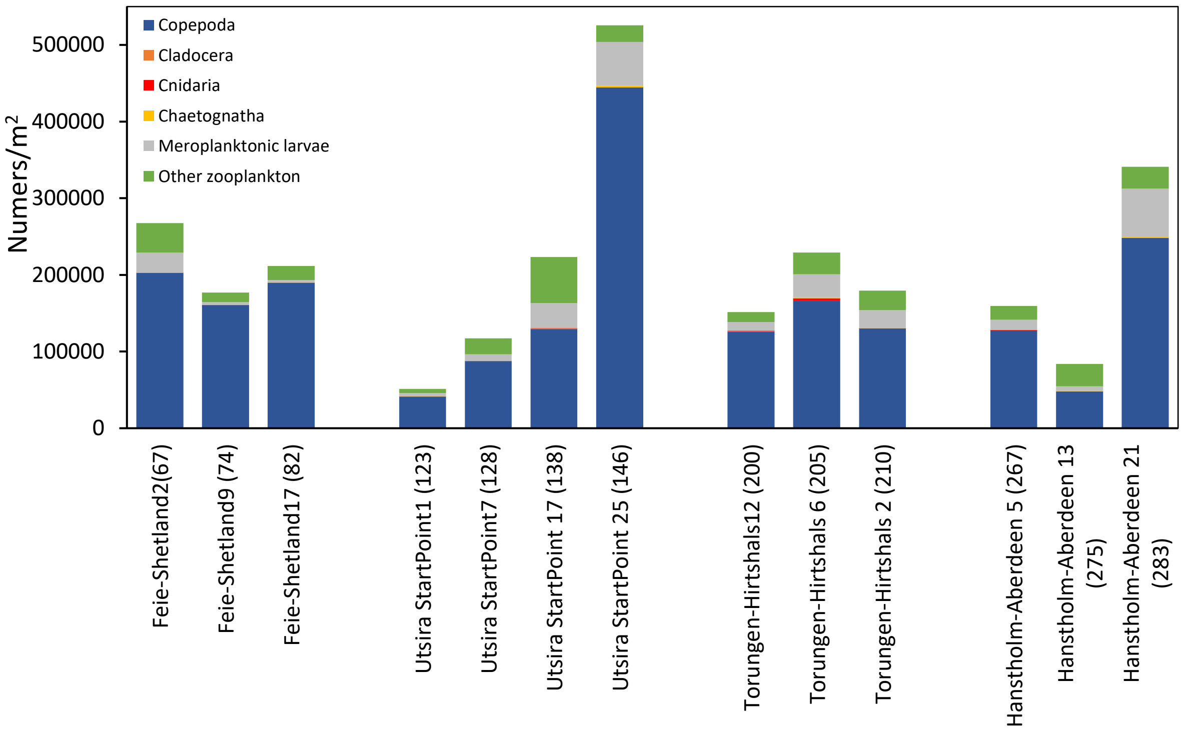


Figure 16. *Zooplankton taxonomic composition (numbers/m^2) on selected stations (positions shown in map, Figure 1a).*

The contribution of different taxa to the copepod community in the North Sea is presented in figure 17. More in detail, *Pseudocalanus* was the numerically dominating taxa in the Skagerrak and in the northeastern part of the survey area. *Temora longicornis* and *Metridia* were typically abundant in the near-shore stations on Torungen-Hirtshals and Hanstholm-Aberdeen), while *Microcalanus spp* were most abundant in northern North Sea (Feie transect).

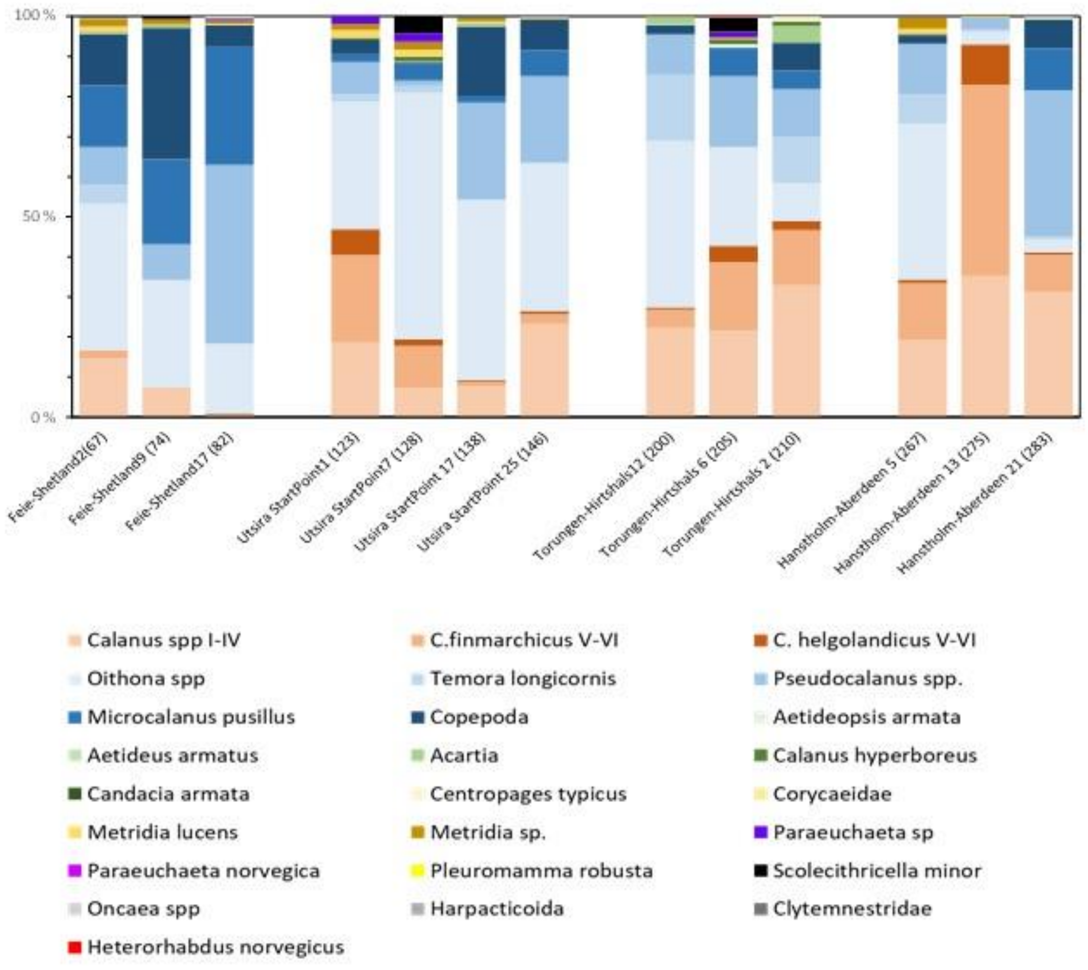


Figure 17. *Taxonomic composition (%) of copepods on selected stations (positions shown in map, Figure 1a*

High abundances of *Calanus spp* were recorded on the westernmost station on the Utsira-transect, dominated by small copepodite stages (CI-CIII). Although both species of *Calanus* co-occurred all across the survey area, *C. finmarchicus* was the numerically dominating species on all stations (*C.finm/C.helg* index >0 in Figure 18a). The highest proportion of *C. helgolandicus* were found in the westernmost station on the Feie-Shetland transect.

To explore the stage composition of *Calanus*, the mean copepodite stage index (CSI) is presented in Figure 18b as an abundance-weighted mean stage (CSI=1 when all CI, and 6 when all adults). The CSI ratio varied between stations (2.3 – 4.4) which can be interpreted as variations in phenology in different parts of the surveyed area. CSI values less than 3 on the westernmost stations of Feie-Shetland and Utsira transects, suggests that *Calanus* was in an earlier phase of the seasonal reproduction in this area compared to stations further east. There was a tendency towards higher CSI on the coastal stations of the Utsira and Torungen-Hirtshals transect, indicating an earlier onset of the spring reproduction in coastal waters.

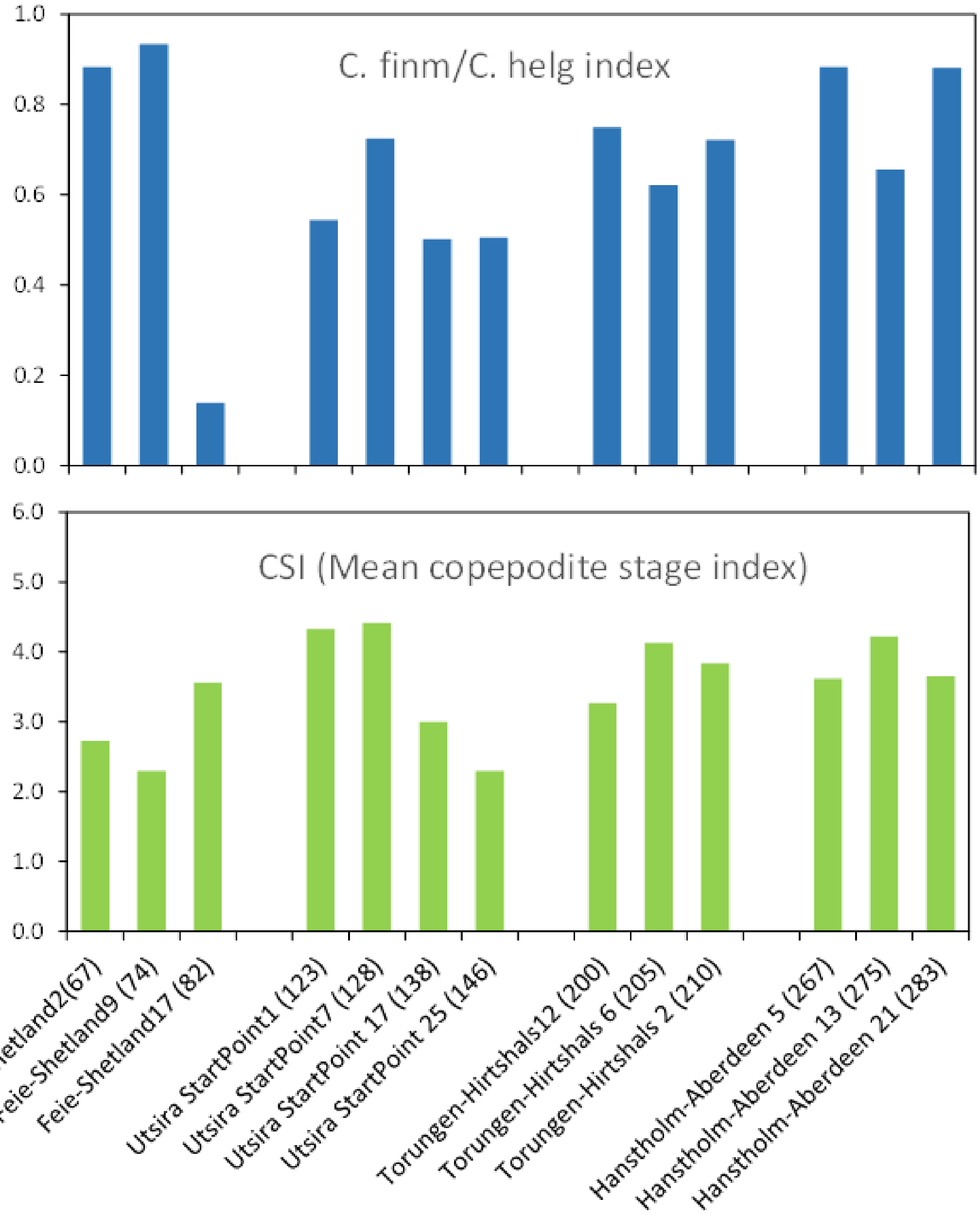


Figure 18. *Stage composition and species composition of Calanus spp on selected stations along four transects (positions shown in map, Figure 1a. a Mean copepodite stage index (CSI) of Calanus spp (C. finmarchicus and C. helgolandicus) CSI is calculated as abundance-weighted average stage number, and the ratio between 1 (all CI) and 6 (all adults). B C. finmarchicus/C. helgolandicus index. Ratio varies between -1 (all C. helgolandicus) and 1 (all C. finmarchicus) and is 0 when there are equal proportions.*

4.7 Radioactivity

The Baltic Sea is the largest source of radioactive contamination to Norwegian waters today. The reason for this is that land areas around the Baltic Sea received significant amounts of fallout from the Chernobyl accident in 1986. Run-off from these contaminated land areas is transported with ocean currents from the Baltic Sea through the Kattegat to Norwegian waters. To monitor the supply of cesium-137 (Cs-137) to Norwegian waters, samples of seawater have been collected yearly since 2008 from the 10 stations shown in Figure 2. The coordinates for each station are listed in Table 8.

Results from 2008 to 2020 are shown in Figure 19. The samples collected in 2021 are not yet analysed. The highest activity concentrations of Cs-137 are, as expected, found at the Fredrikshavn–Gøteborg section, which best represents the outflow from the Baltic Sea. All stations along the Måseskær and the Jomfuland–Skagen transects have slightly lower levels of Cs-137 as North Sea and Atlantic waters enters the Skagerrak from the west and mixes with the Baltic water. The three stations in the Skagerrak above the Norwegian Trench (Torungen-Hirtshals 10 and 20 n.m. and Oksø–Hanstholm 10 n.m. are influenced by water masses from all surrounding sea areas and indicate lower values than Kattegat waters. The lowest activity concentrations of Cs-137 are found at the station Oksø–Hanstholm 56 n.m., close to Hanstholm/Denmark, where the concentration has been more or less constant throughout the sampling period. This is as expected as this station is dominated by water masses from the southern and central North Sea.
Although there is a constant supply of Cs-137-contamination from land to the Baltic Sea, the data indicate a general decreasing time trend (Figure 19). This is mainly due to radioactive decay of Cs-137, which has a physical half-life of 30 years.

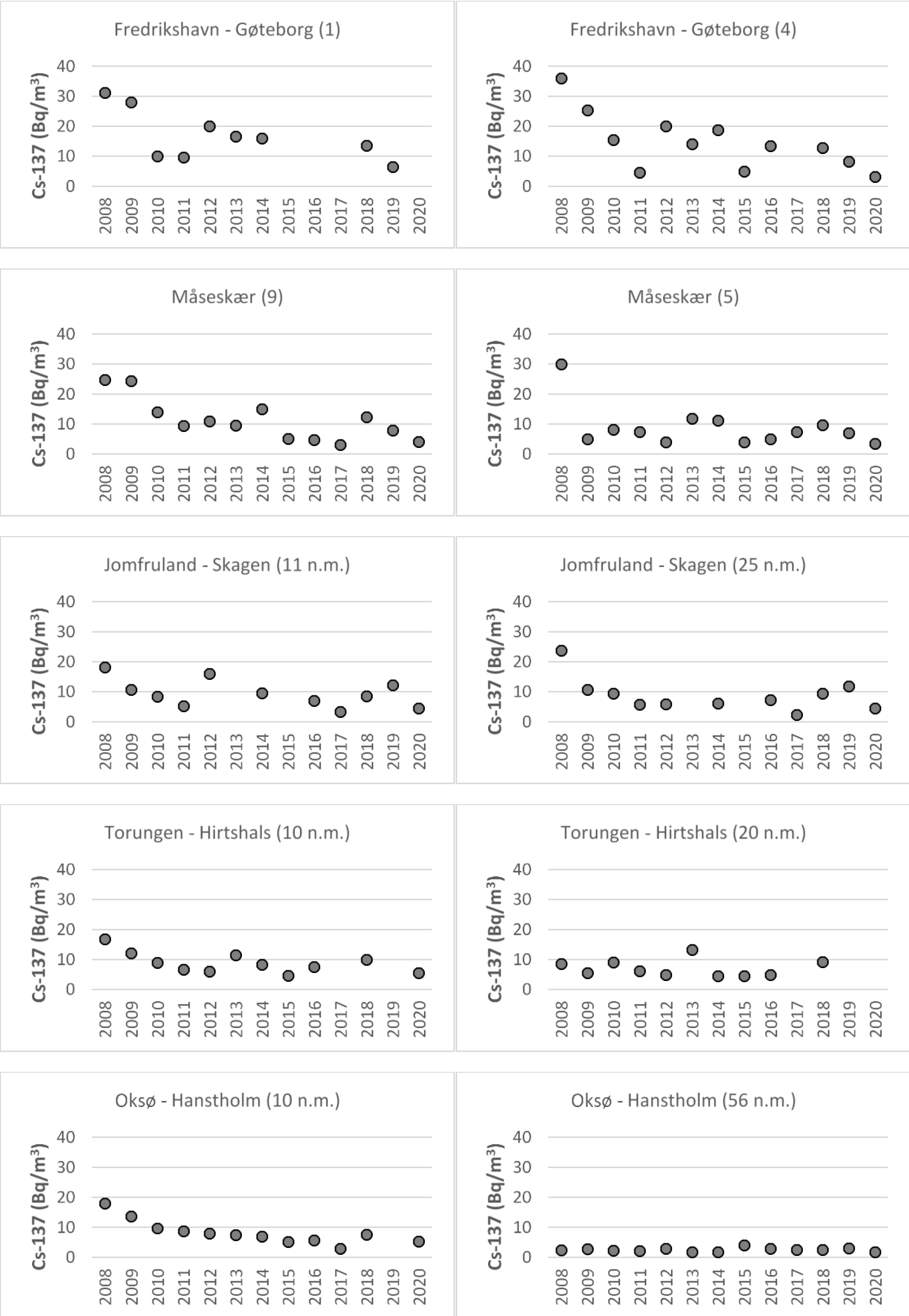


***Figure 19**. Activity concentrations of cesium-137 (Cs-137) (Bq/m^3) in samples of seawater collected yearly in the period 2008 – 2020 at the stations shown in Figure A.*

Yearly variations in Cs-137 levels are due to variations in precipitation and run-off from land and oceanographic processes (e.g. variable, long-periodic inflow of North Sea and Atlantic waters), among other things. Figure 20 shows activity concentrations of Cs-137 (Bq/m^3) at each station plotted against salinity. The Baltic Sea has brackish water, and the salinity in the surface layer varies from 1–2 in the northernmost Bothnian Bay to around 20 in the Kattegat compared to values up to 35 in the North Sea and above 35 for Atlantic water inflow. Thus, low salinity implies larger degree of "Baltic Sea characteristics" although there is a substantial inflow of fresh water from all rivers along the Skagerrak coast in Sweden and Norway. The low-salinity waters, both due to local rivers and Baltic outflow enters the same area in the Skagerrak and forms the Norwegian Coastal Current which flows northward along the Swedish west coast and continues westward along the Norwegian Skagerrak coast. Higher salinity implies larger degree of "North Sea characteristics". This generally agrees with our Cs-137-results. For example, at the station Fredrikshavn–Gøteborg (1), the lowest activity concentrations of Cs-137 were found in 2010, 2011 and 2019 (Figure 19). All these samples have salinities above 25 (Figure 20). Other years that stand out are labelled in Figure 20.

***Figure 20**. Activity concentrations of cesium-137 (Cs-137) (Bq/m^3) in samples of seawater collected yearly in the period 2008 – 2020 at the stations shown in Figure A plotted against salinity.*

4.8 Dutch Downs Recruitment Survey

On all stations large samples were caught, with high volumes of jellyfish, and high numbers of sandeel and clupeid larvae. On all stations large samples were caught, with high volumes of jellyfish, and high numbers of sandeel and clupeid larvae. Of all stations sampled 11 did not contain herring larvae and 7 of these were station sampled during the North Sea Ecosystem cruise (Figure 21). These stations were on the two most northern transects and in the northwest corner of the sampling area. Highest numbers of herring larvae were found in the southern stations and just above the Wadden Sea isles.

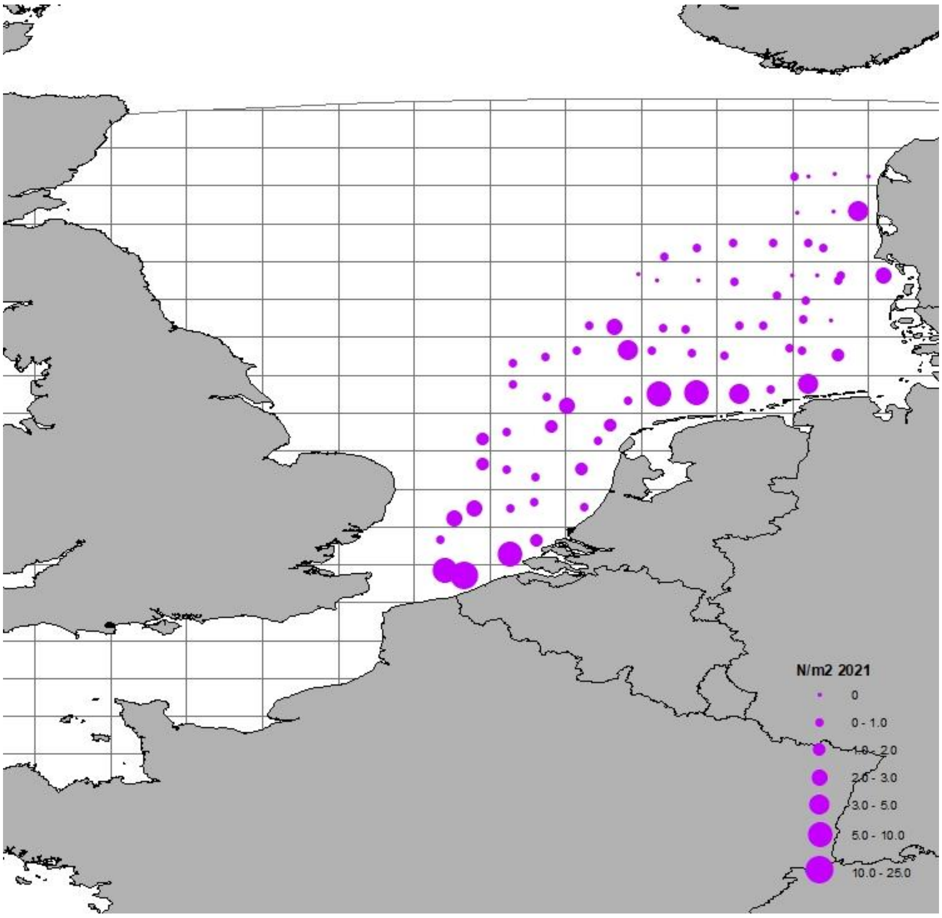


***Figure 21**. Herring larvae distribution by haul from the 2021 DRS.*

5 Conclusions

The sampling of North Sea and Skagerrak during the ecosystem cruise 2021 was quite challenging particularly during the first half of the survey that covered the Northern part of the North Sea. We encountered several storm systems that forced us to cancel some multinet and Gulf sampling. The high winds and heavy waves kept the water column well mixed and phytoplankton accumulation was not observable (Figure 6d). The second half of the survey was characterized by a more favorable weather, phytoplankton accumulated in the upper layer and thus higher chlorophyll a concentration were observed (Figure 6d). ***Overall, the Southern section of the North Sea was characterized by an active food web structure where high phytoplankton and heterotrophic/mixotrophic microzooplankton concentrations supported high zooplankton numbers which in turn might explain the higher numbers of fish eggs and larvae observed in this area (Figure 14).***

The collaboration between the two IMR projects, Monitoring of climate and plankton in the North Sea Skagerrak (IMR 14920) and Early life history dynamics of North Sea Fishes (IMR 14917) provide a comprehensive overview of the distribution of phytoplankton, microzooplankton, zooplankton and fish species in the Northern North Sea and Skagerrak. Combining data on composition, distribution, abundance and carbon budget of phytoplankton, microzooplankton and zooplankton with species composition and distribution of fish eggs and larvae provide essential and unique information on the prey field and the bottom up drivers that affect survival and good development of the early life history stages (eggs and larvae) of a wide range of commercially valuable and non-commercial species. Using these data in a modelling effort will improve our predictive power and management effort.

6 Acknowledgements

We greatly appreciate and thank the masters and crew onboard RV Dr Fridtjof Nansen for outstanding collaboration and practical assistance at the North Sea Ecosystem cruise 2021. We are indebted to all the participants of the North Sea Ecosystem Cruise 2021 for their valuable work during collection and processing of samples and to all the technicians who help with the postprocessing of the samples in the Labs.

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