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CRUISE REPORT

North Sea Ecosystem Cruise

RV Johan Hjort 14 April – 13 May 2020

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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. In 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 2020 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 2020 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 zooplankton samples for the analysis of lipid content and contaminants (pilot project), c) collection of fish larvae for the KINO_2 project (IMR 15314), d) sampling at two coastal stations for the coastal monitoring project (IMR 15593) which suffered from cancelled cruises this spring (Covid-19 restrictions).

Due to the Corona situation in spring 2020, extra precautions were taken in order to prevent the spread of coronavirus COVID-19 aboard the vessel. This resulted in additional time for steaming and port calls. However, due to exceptionally good weather conditions, all planned activities were carried out according to the cruise plan, including the extra sampling for other projects.

Cruise name:	JH 2020205, North Sea Ecosystem Cruise
Cruise dates:	14.04.2020 – 13.05.2020
Vessel:	RV Johan Hjort
Master:	Rune Kleppe (14.-28.04)/ Hans S. Troland (28.04-13.05)
Area:	North Sea/Skagerrak (57-60.8ºN, 2.2ºW- 8.6ºE)
Ports of Call:	Hanstholm, Denmark 21.04.20 Kristiansand, Norway, 27.04.20 (crew change ¨corona virus¨ measure) Bergen, Norway, 28-29.04.20 (crew change) Kristiansand, Norway, 11.05.20 (drop off personal, corona virus measure) Bergen, Norway, 13. May (end of cruise)

Projects involved in the NSEC 2020:

- 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)
- KINO_2 project (IMR 15314)
- Monitoring of environment and plankton in coastal waters (IMR 15593)

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 2020 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), KINO_2 project (IMR 15314), Monitoring of environment and plankton in coastal waters (IMR 15593).

The objectives of the North Sea Ecosystem Cruise 2020 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 preliminary data on lipids and contaminant substances in zooplankton.
6) To sample two coastal stations for the Coastal monitoring program (IMR15593)
7) To collect samples of fish larvae for the KINO_2 (IMR 15314)

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 Lipids and contaminant substances in zooplankton

The measurement of contaminants and lipids including isotopes was initiated in 2019 as a pilot study with researchers from the Plankton group and Contaminants and Biohazard group at IMR and is connected to an ongoing interdisciplinary NRC application (MARINE ECOSAFE SEAFOOD 2021). One of the aims is to develop and integrate a contaminant module into ecosystem models (NORWECOM and or Atlantis) and for this purpose, data on contaminants such as persistent organic pollutants (POPs) and lipids from the North Sea Ecosystem Cruise is of crucial importance. The content of contaminants, including POPs, in marine ecosystems is affected by a complex set of factors which may be impacted by the ongoing and future changing marine environment (IPCC 2019). Would the ongoing changes in distribution and composition of zooplankton communities affect the composition of contaminants in seafood? Lipids are essential components of all living organisms being the densest form of energy and, among lipids certain essential fatty acids and sterols are considered to be determinants of marine ecosystem health and stability. Temporal and special time series of lipid content and composition at different trophic level will help detect early warning of ecosystem changes, such as immigration of new warm-water species and loss of cold-water species, implementing the IMR climate changes monitoring effort.

2.5 KINO_2 project (IMR 15314)

The kino_2 project initiated in 2017, was developed as an extension of the Kino 1 project (Dynamic Mapping of North Sea Spawning) which collected historic information from various databases about fish species spawning time in the North Sea (Sundby et al., 2017). KINO-2 aims to improve knowledge about spawning areas, timing and behavior for the main fish species reproducing in the North Sea during 2017-2020. This knowledge is crucial for producing robust management advice for timing and location of seismic surveys to minimize potential negative effects on reproduction and development of early life stages of the North Sea fishes.

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	15.04 - 12.05.20202	1,2
Tone Falkenhaug	Plankton	Plankton 434	15.04 - 27.04.2020	1
Hege Lyngvær Mathisen	Plankton	Plankton 434	15.04 - 27.04.2020	1
Jan Henrik Simonsen	Fish larvae	Plankton 434	15.04 - 12.05.2020	1,2
Monica Martinussen	Plankton	Plankton 434	14.04 - 13.05.2020	1,2
Astrid Fuglseth Rasmussen	Fish larvae	Plankton 434	14.04 - 28.04.2020	1
Marita Helgesen	Plankton	Plankton 434	27.04 - 12.05.2020	2
Bahar Mozfar	Fish larvae	Plankton 434	28.04 - 13.05.2020	2
Lage Drivenes	Instrument	Elektr.instrument. 620	14.04 - 13.05.2020	1,2
Jori Neteland-Kyte	Instrument	Elektr.instrument. 620	14.04 - 28.04.2020	1
William Skjold	Instrument	Elektr.instrument. 620	28.04 - 13.05.2020	2
John Nesheim	Instrument	Elektr.instrument. 620	28.04 - 13.05.2020	2

Table 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)
Continuous measurements	
Echosounder	
ADCP	Water current velocities
Termosalinograph	Temp, Salinity, Fluorescence (surface)
Light sensor on deck	PAR (Photosynthetically active radiation)

3.2 Covid-19 infection control measures

The cruise was performed during the corona crisis. The cruise schedule was adapted to ensure proper infection control measures in order to prevent the spread of coronavirus COVID-19 aboard the vessel.

- All cruise participants stayed at home in quarantine for 14 days prior to the cruise.

- Cruise participants delivered a signed a self-assessment prior to the cruise

- Cruise participants were asked not to use public transportation prior to the cruise, including travel to the ship. In order to avoid flights, cruise participants were allowed to enter (and leave) the ship close to their hometown, in both Bergen and Kristiansand. Thus, it was necessary to spend extra cruise time for port calls and transit between Bergen and Kristiansand.

3.3 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 (14th – 29th April)

The vessel left Bergen after bunkering at 15:00 UTC on April 14th 2020 to transit towards Kristiansand to pick up scientific personnel from the Flødevigen Research Station. On April 15th at 14:30 UTC, J. Hjort headed South to sample the first station of the ***Fredrikshavn-Goteborg*** transect which was undertaken on April 16th at 01:30 UTC. The North Sea Ecosystem Cruise continued sampling at pre-defined stations along standard transects in inner Skagerrak. Two extra stations at the Skagerrak coast (Langesund and Oslofjord1) were added to the standard sampling program in order to support the coastal monitoring program, which suffered from cancelled cruises due to the Covid-19 outbreak. We resumed the standard sampling with the ***Torungen-Hirtshals*** transect (station 227, 58.400N;8.767E). In order to capture the dial migration of plankton and its variability, at the ***Deep Skagerrak Process Study Station*** (58.8N, 9.11E) the ship kept position for 48 hours and sampling was performed at sunrise, mid-day, sunset, and mid-night for two consecutive days using both CTD and MultiNet MAMMOTH equipped with two sets of nets (180µm, 405µm). On April 21st a calibration of the GULF VII was performed and at 00.30 UTC sampling of the ***Oksøy-Hanstholm*** transect started. A short port call was made in Hanstholm (Denmark) between 14:00 and 17:30 UTC. After 12 hours transit on April 22nd we started the transects along the Danish west coast from the southernmost transect, ***Knude dyb*** (55.19N, 8.14E) to the northern most ***Harboør***. The survey continued with the ***Hanstholm-Aberdeen*** transect (57.00N, 8.11E-1.00W). After conducting the ***Egerøya mot SW*** and ***Lista mot SW*** transects on April 27th a short port call was performed in Kristiansand to allow crew change of the participant from Flødevigen Research Station. The ship then headed to Bergen for a full crew change on April 28th.

Leg 2 (30th April-13th May)

The second leg started with the ***Feie-Shetland*** transect (60.45N 4.37E). On May 1st the sampling on the ***Shetland Process Study Station*** started and lasted for 48 hours. Sampling followed the same protocol used for the Deep Process Study Station in Skagerrak. The second

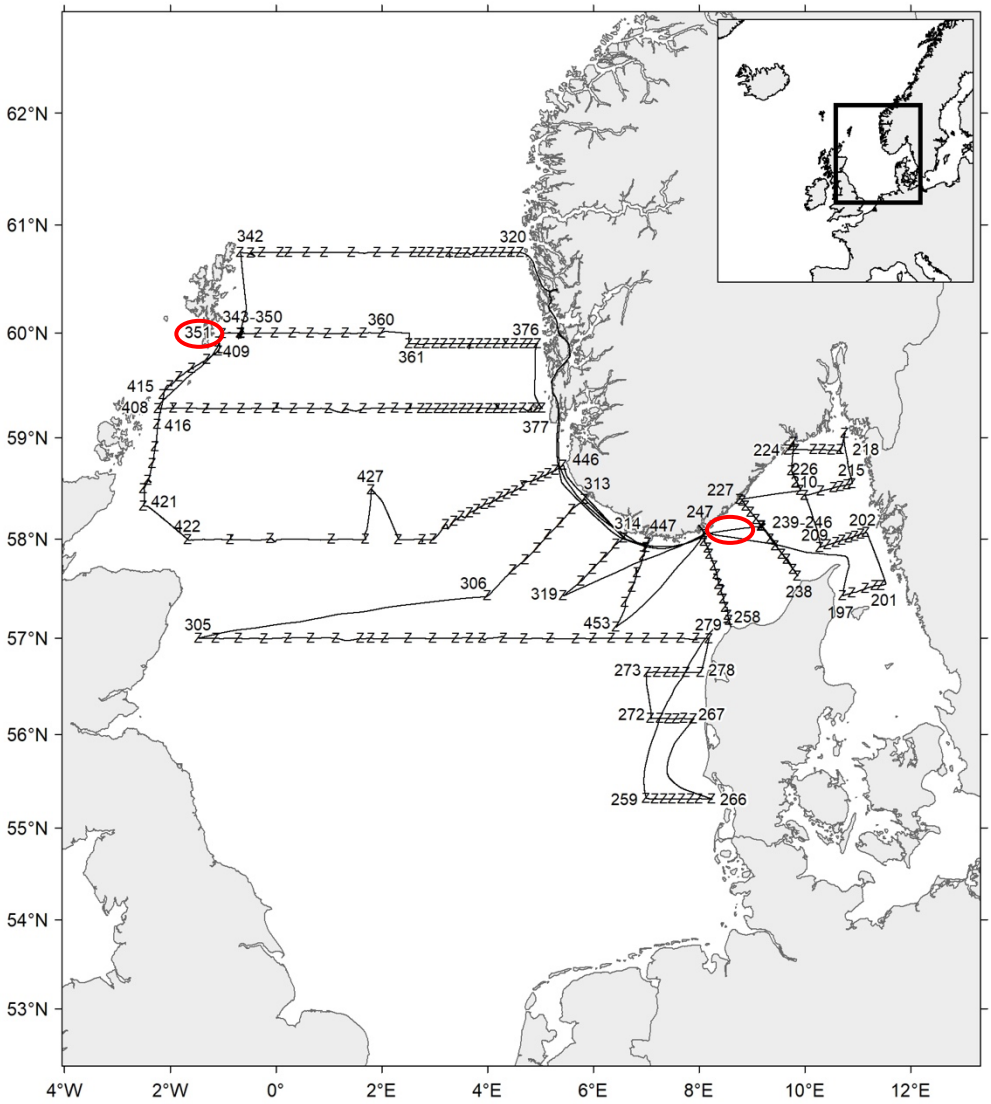
leg continued as planned surveying the Northern part of the North Sea sampling the following transects: ***Slotterøy mot W***, **Utsira**, ***Fair Isle-Pentland*** and ***Jærens Rev mot SSW***. A small detour was undertaken to sample the fixed station ***Sleipne****r* as part of the KINO_2 project. The weather conditions changed during the night between the 9th and the 10th of May. Thus, on the last stations of the ***Jærens Rev mot SW og W*** and ***Lindesnes mot SSW*** transects it was not safe to use neither the MultiNet MAMMOTH nor the Gulf VII. On May 11th at 09.00 UTC the last station of the Lindesnes transect was completed and the ship headed to Kristiansand to allow the participants from Flødevigen Research Station to get off the ship and unload samples. On May 11th 20:00 UTC the ship headed north toward Bergen were the cruise ended on May 13th at 09:30.

The weather conditions that accompanied the North Sea Ecosystem Cruise 2020 were exceptionally good. This allowed us to collect a record number of samples with very few cancellations. All the planned sampling was carried out with success and extra stations were also performed to help other IMR projects that have faced difficulties due to the Covid-19 outbreak.

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

Start		Stop		
Date	**Time (UTC)**	**Date**	**Time (UTC)**	**Activity**
Leg 1				
14.04.	15:00			**Departure Bergen**
14.04	17:00	15.04	12:00	Transfer to K.sand/ pick up participants (Covid19)
16.04.	01:30	16.04.	8:00	Transect Fredrikshavn-Gøteborg
16.04.	11:30	16.04.	18:30	Transect Måseskjær
17.04.	10:06	17.04.	05:38	Transect Väderö
17.04.	9:40	17.04.	11:00	Extra Station Oslofjord (OF1)
17.04.	11:18	18.04.	18:40	Transect Koster-Jomfruland
17.04.	19:10	17.04.	21:30	Extra Station Langesundsbukta (Brevik)
18.04.	03:00	18.04.	19:10	Transect Torungen-Hirtshals
19.04	00:00	20.04	20:39	Skagerrak Deep Process Study_P4
21.04	00:00	21.04	13:53	Transect Oksøy-Hanstholm
21.04	07:20	21.04	07:42	Calibration of Gulf flow meters
21.04	14:00	21.04	17:22	**Port call Hanstholm**
22.04	06:00	22.04	11:12	Transects Knude Dyb
22.04	20:00	23.04	24:24	Transect Huseby Klit
23.04	04:12	23:04	9:34	Transect Harboør
23.04	12:11	25.04	07:15	Transect Hanstholm-Aberdeen
26.04	00.40	26.04	15:00	Transect Egerøya mot SW
26.04	19:00	26.04	04:00	Transect Lista mot SW
27.04	05:00	27.04	12:00	Transfer to K.sand/ drop off participants (Covid19)
27.04	12:00	28.04	10:00	Transfer to Bergen Crew Change
28.04				**Arrival Bergen**
Leg 2				
29.04.	18:10			**Departure Bergen**
30.04	00:04	01.05	10:00	Transect Feie-Shetland
01.05	15:04	03.05	07:27	Shetland Process Study
03.05	12:21	04.05	21:32	Transect Slotterøy mot W
05.05	03:30	07.05	06:13	Transect Utsira-StartPoint
07.05	11:14	08.05	08:38	Transect Fair Isle-Pentland
08.05	11:32	10.05	13:24	Transect Jærens Rev mot SW og W
09.05	06:01	09.05	11:39	Kino_2 Sleipner station
10.05	20:21	11.05	10:41	Transect Lindesnes mot SSW
11.05	11:11	11.05	18:36	Transfer to K.sand/ drop off participants (Covid19)
11.05	20:00	13.05	09:27	**Arrival Bergen**

Figure 1a. *RV Johan Hjort 14.04-15.05.2020. Cruise track with stations for CTD casts and plankton sampling. Process stations are indicated with red circles.*

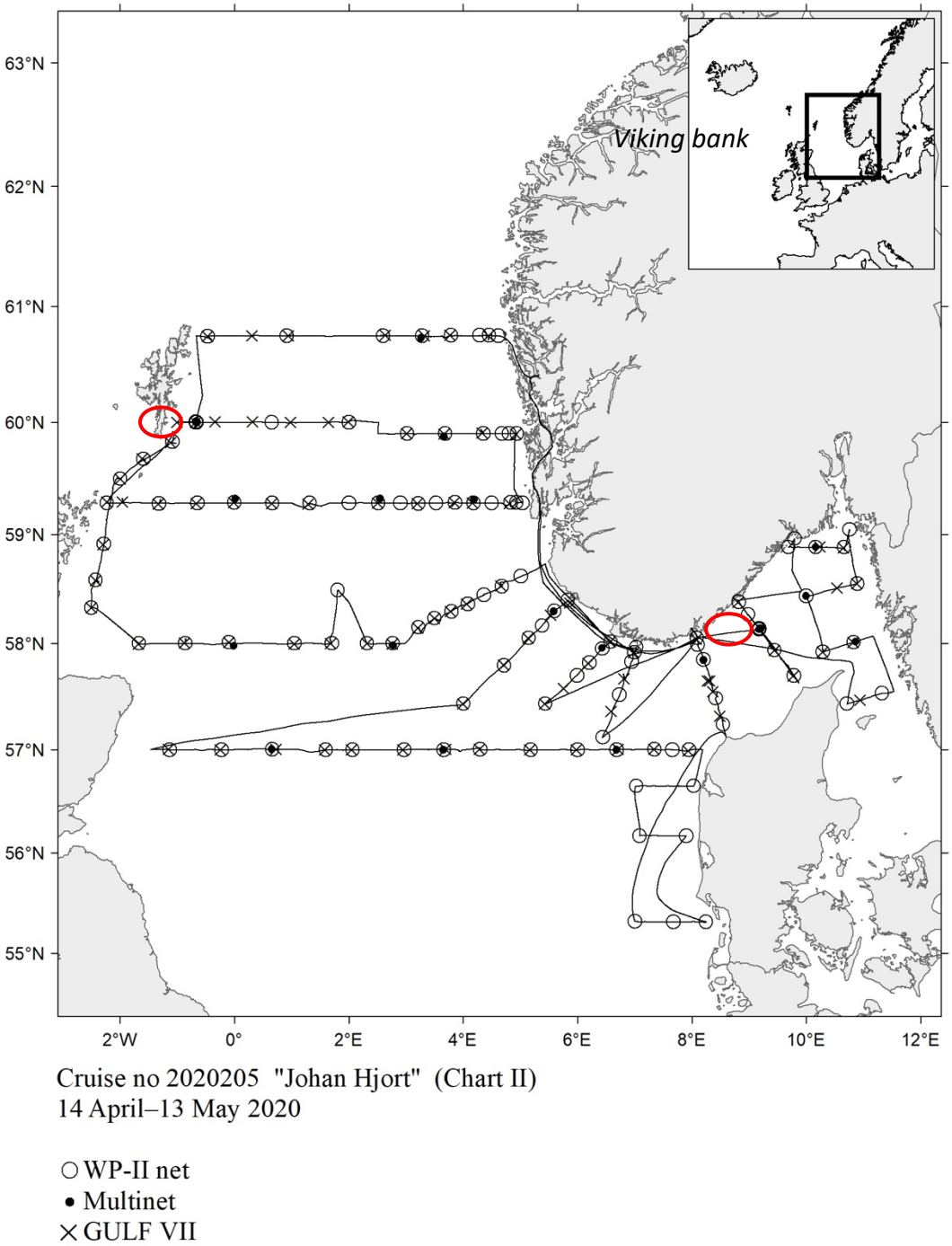


Cruise no 2020205 "Johan Hjort" (Chart I)
14 April–13 May 2020

z CTD st.no 197-453

Standard sections:
Gøteborg-Fr.h: st.no 197-201
Måseskjær: st.no 202-209
Vaderø: st.no 210-215
Jomfruland–Koster: st.no 218-224
Torungen-Hirtshals: st.no 227-238
Oksø–Hanstholm: st.no 247-258
Knude dyb: st.no 259-266
Huseby klit: st.no 267-272
Harboør: st.no 273-278
Hanstholm–Aberdeen: st.no 279-305
Egerøy: st.no 306-313
Lista: st.no 314-319
Fedje-Shetland: st.no 320-342
Utsira W: st.no 351-376
Slotterøy W: st.no 377-408
Lindesnes: st.no 447-453

Figure 1b. *RV Johan Hjort 14.04-15.05.2020. Cruise track with stations for WP2, Multinet and Gulf VII. Process stations are indicated with red circles.*



3.4 Hydrography

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

3.5 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 glassfiber 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 and number of stations where samples for Chemistry analysis were taken*

Transect	**Stations**	**Nuts** **Chla**	**NH_4**	**Total NP**	**Oxygen**
Fredrikshavn-Gøteborg	197-201	**5**	0	5	0
Måseskjär	202-209	**7**	0	7	0
Väderö	210-215	**6**	0	6	0
OF1 (Torbjørnskjær)	216-217	**1**	**1**	**1**	0
Koster-Jomfruland-	218-223	**6**	0	6	0
Langesund	224	**1**	**1**	**1**	0
Hirtshals-Torungen	227-238	**12**	0	**12**	**6**
Oksøy-Hanstholm	247-258	**12**	0	**12**	0
Knude Dyb	259-266	**8**	0	**8**	0
Huseby Klit	267-272	**6**	0	**6**	0
Harborø	273-278	**6**	0	**6**	0
Aberdeen-Hanstholm	279-305	**27**	0	**5**	0

3.6 Phytoplankton

Samples for phytoplankton species composition and abundance were obtained from predefined 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*.

3.7 Microzooplankton

Microzooplankton were collected at 92 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 highly temporal and spatial coverage samples were collected 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 will be analyzed using a Flowcam VS-1 quipped with a 2x magnification and 800 µm flowcell.

3.8 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).

3.9 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 (5cm diameter nosecone with a General Oceanics flow meter for 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.

3.10 Fish larvae sampled for the KINO_2 project

Fish larvae samples within the KINO_2 project were collected at the Sleipner station off the Jærens Rev mot SW og W transect. Samples were collected using a double WP2 net with a mesh size of 180 µm. The double WP2's was hauled two times to increase the number of samples and were performed by a vertical net-haul from 10 m above bottom at a wire speed of

0.5 m sec^{-1} to surface. Before the hauls a CTD profile was performed to characterize the water column. One samples from each haul was preserved in 96% ethanol for the molecular taxonomic analyses, whereas the other was preserved in seawater borax buffered 4% formalin concentration for on shore visual taxonomic identification. Once in the laboratory, the fish eggs and larvae preserved in formalin were separated by visual inspections using a Leica M80 stereomicroscope with focusing arm (Leica Microsystems, Germany) and identified to the lowest taxonomic level possible. The samples preserved in ethanol were used for DNA isolation.

3.11 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). Stations were sampled over a 48 hour period following a schedule of 4 sampling a day: sunrise, mid-day, sunset and mid-night. 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 5 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. *Timeline and parameters collected at the two process study stations.*

		Time	Depth	Continous recording			Nuts	Chl-a	Algae Net 0-30m	Microzoo/ Phytoplankton	Multinet-Mammuth 180µm	Multinet-Mammuth 405 µm
				Acustic	Oxigen	PAR						
Shetland Process Station (60°0'N 0°40'E)	Day	17:30	10	x	x	x	x	x	x	x	0-20	0-20
			20				x	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
	Sunset	22:00	10	x	x	x		x	x	x	0-20	0-20
			20					x		x		
			30					x		x	20-40	20-40
			50					x		x	40-75	40-75
			100					x		x	75-bottom	75-bottom
	Night	01:30	10	x	x	x		x	x	x	0-20	0-20
			20					x		x		
			30					x		x	20-40	20-40
			50					x		x	40-75	40-75
			100					x		x	75-bottom	75-bottom
	Sunrise	06:00	10	x	x	x		x	x	x	0-20	0-20
			20					x		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 (58°8'N 9°11'E)	Night	01:30	10	x	x	x	x	x	x	x	0-50	0-50
			30				x	x		x		
			50				x	x		x	50-100	50-100
			100				x	x		x		
			200				x	x		x	100-250	100-250
			400				x	x		x	250-400	
			600				x	x		x	400-bottom	250-bottom
	Sunrise	04:40	10	x	x	x		x	x	x	0-50	0-50
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x		x	100-250	100-250
			400					x		x	250-400	
			600					x		x	400-bottom	250-bottom
	Day	12:30	10	x	x	x		x	x	x	0-50	0-50
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x		x	100-250	100-250
			400					x		x	250-400	
			600					x		x	400-bottom	250-bottom
	Sunset	19:45	10	x	x	x		x	x	x	0-50	0-50
			30					x		x		
			50					x		x	50-100	50-100
			100					x		x		
			200					x		x	100-250	100-250
			400					x		x	250-400	
			600					x		x	400-bottom	250-bottom

3.12 Radioactivity

Water samples for analyzes of radioactive contamination (project number 15595) are normally collected from 10 preselected stations in the Skagerrak (Figure 2, Table 7). In 2020, samples were collected from 8 of these stations (Table 7). At each station, 50 liters of seawater from the seawater inlet (surface) were filled into 2 x 25 L plastic cans for later analyses for Cs-137 at the Laboratory for inorganic chemistry at IMR, Bergen.

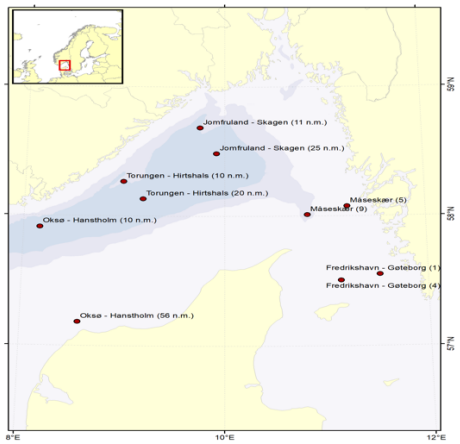


Figure 2. *Stations where seawater has been collected yearly since 2008 for analyses of Cs-137*

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 7. *Station list where samples for monitoring of cesium-137 were collected in April 2020.*

St.	Transect	Lat Degres	Lat Min	Lat Dec East	Long Degres	Long Min	Long Dec North	Collected 2020
1	Fredrikshavn - Gøteborg (1)	57	33	57.55	11	32	11.53	-
4	Fredrikshavn - Gøteborg (4)	57	30	57.51	11	9	11.14	x (CTD 199)
5	Måseskær (5)	58	2	58.03	10	57	10.94	x (CTD 204)
9	Måseskær (9)	57	57	57.95	10	26	10.43	x (CTD 208)
3	Jomfruland - Skagen (11 n.m.)	58	41	58.68	9	45	9.75	x (CTD 225)
5	Jomfruland - Skagen (25 n.m.)	58	29	58.48	9	55	9.92	x (CTD 226)
4	Torungen - Hirtshals (10 n.m.)	58	16	58.27	8	59	8.98	x (CTD 230)
6	Torungen - Hirtshals (20 n.m.)	58	8	58.13	9	11	9.18	-
3	Oksø - Hanstholm (10 n.m.)	57	55	57.92	8	10	8.17	x (CTD 249)
12	Oksø - Hanstholm (56 n.m.)	57	11	57.18	8	34	8.57	x (CTD 258)

3.13 Lipids, stable isotopes and contaminants in zooplankton

Zooplankton samples were collected at preselected stations with either a Multinet MAMMOTH (0-50m) or GULF VII (100-0m). Bulk subsamples of zooplankton were collected from the >1000µm biomass fraction, stored in plastic bags and frozen for subsequent analysis of contaminant concentration and composition. Samples will be analysed using IMR chemical method 292 (dioxins, furans, PCBs, PBDE) and 197 (metals including heavy metals) after being identified taxonomically from the formaldehyde samples. From taxonomic analysis, subsamples of zooplankton biomass >1000µm containing approximately 200 individuals were stored in 20ml test tubes and fixed with 4% formaldehyde. Additionally, 10 individuals belonging to the most dominant species present in the samples were identified, stored in 2ml tubes and frozen as quickly as possible (in -80°C if possible) for lipid and stable isotopes analysis.

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

Transect	Station	CTD	Nuts-Chla	NH_4	Tot NP	Phyto Abun	Phyto net 10µm	Micro zoopl.	O_2	Gulstoff CDOM	Radio activity (water)	Lipid/ contamin	WP2 180µm	WP3 1000µm	MultiNet MAMMOTH 180 µm	MultiNet MAMMOTH 405 µm	Gulf VII +PUP
Fredrikshavn-Gøteborg	197-201	5	5		5	2	1	2			1		2				1
Måseskjär	202-209	7	7		7	3	1	3			2	1	2		1		2
Väderö	210-215	6	6		6	6	1	6				1	2		1		2
OF1 (Torbjørnskjær)	216-217	2	1	1	1	1	1	1	2	1							
Koster-Jomfruland-	218-223	6	6		6	3	2	3					3		1		2
Langesund	224	1	1	1	1	1	1			1			1				
Jomfruland-Skagen	225-226	2	0	0	0	0	0	0	0	0	2						
Hirtshals-Torungen	227-238	12	12		12	12	3	5	0	0	3	1	5	0	1		3
Process Station: Skagerrak Deep	239-246	8	8	0	0	0	8	8	0	0	0	2	0	0	8	8	0
Oksøy-Hanstholm	247-258	12	12	0	12	5	2	2	0	0	2	0	3	0	1	0	3
Knude Dyb	259-266	8	8	0	8	3	3	2	0	0	0	0	2	0	0	0	0
Huseby Klit	267-272	6	6	0	6	3	2	2	0	0	0	0	2	0	0	0	0
Harborø	273-278	6	6	0	6	3	2	2	0	0	0	0	2	0	0	0	0
Aberdeen-Hanstholm	279-305	27	27	0	5	10	8	8	0	0	0	0	13	4	3	0	13
Egerøya mot SW	306-313	8	8	0	8	1	1	1	0	0	0	1	5	3	1	0	5
Lista mot SW	314-319	6	6	0	0	3	1	3	0	0	0	0	4	3	1	0	4
Fedje-Shetland	320-342	23	23	0	0	6	6	6	0	0	0	1	6	3	1	0	7
Process Station: Shetland	343-350	8	8	0	0	0	8	8	0	0	0	0	0	0	8	8	0
Slotterøy	351-376	26	26	0	0	7	7	7	0	0	0	1	7	3	1	0	11
Utsira-W	377-408	32	32	0	0	8	8	8	0	0	0	1	18	3	3	0	12
Fair Isle-Pentland	409-421	13	13	0	0	6	6	5	0	0	0	0	6	0	0	0	6
Jærens rev mot SW- W	422-426 428-446	24	24	0	0	8	7	8	0	0	0	0	14	1	2	0	12
KINO2	427	1											1				
Lindesnes SSW	447-453	7	7	0	0	2	1	2	0	0	0	0	4	3	0	0	3
SUM		**256**	**252**	**2**	**83**	**93**	**80**	**92**	**2**	**2**	**10**	**9**	**102**	**23**	**33**	**16**	**86**

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).

Based on the hydrographic measurements from the Ecosystem Cruise from April 14 to May 13, the NCC can easily be identified in the resulting surface salinity map in the areas with the minimum values (Figure 3a, left panel, blue and yellow colours). The NCC is normally located closer to the Norwegian south coast, but during April/May 2020 the main core of low-saline water extended further southward towards Hanstholm in Denmark, due to local winds from the north/northwest.

The surface temperatures varied from about 6-6.5ºC along the Norwegian southwest coast to 9-9.5ºC in the northwestern North Sea. We can clearly see relatively warm water flowing eastward between Shetland and the Orkneys with North Atlantic origin (the Fair Isle Current). These are typical spring conditions were the local waters resulting in the NCC are slightly colder than the Atlantic waters dominating the northern North Sea (Figure 3b). In relation to the long-term average, both the surface temperatures and the deep-water temperatures were slightly warmer than normal.

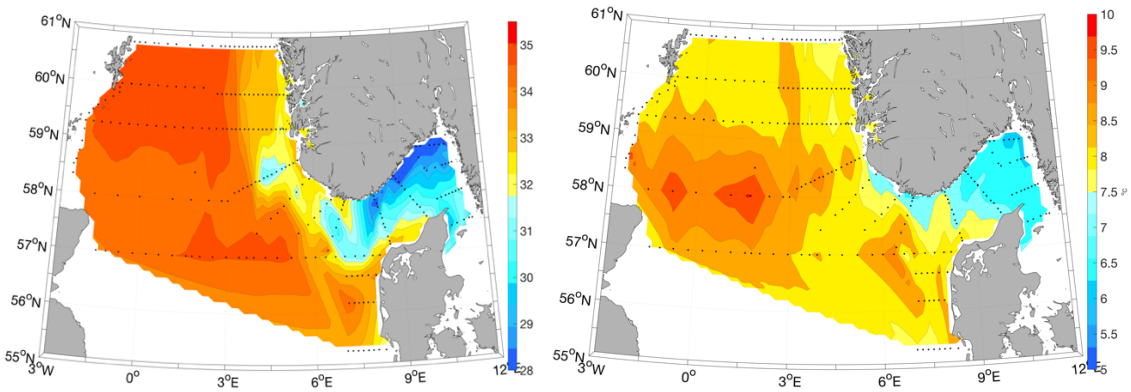


Figure 3. *Salinity (left panel) and temperature (right panel, in ºC) at 5m depth based on the hydrographic stations (marked with black dots) taken between 14/4 and 13/5 2020.*

4.2 Satellite image

Figure 4 shows the evolution of chlorophyll a concentration in the studied area during the period April 15 to May 14. The images are mean values over 8 day period.

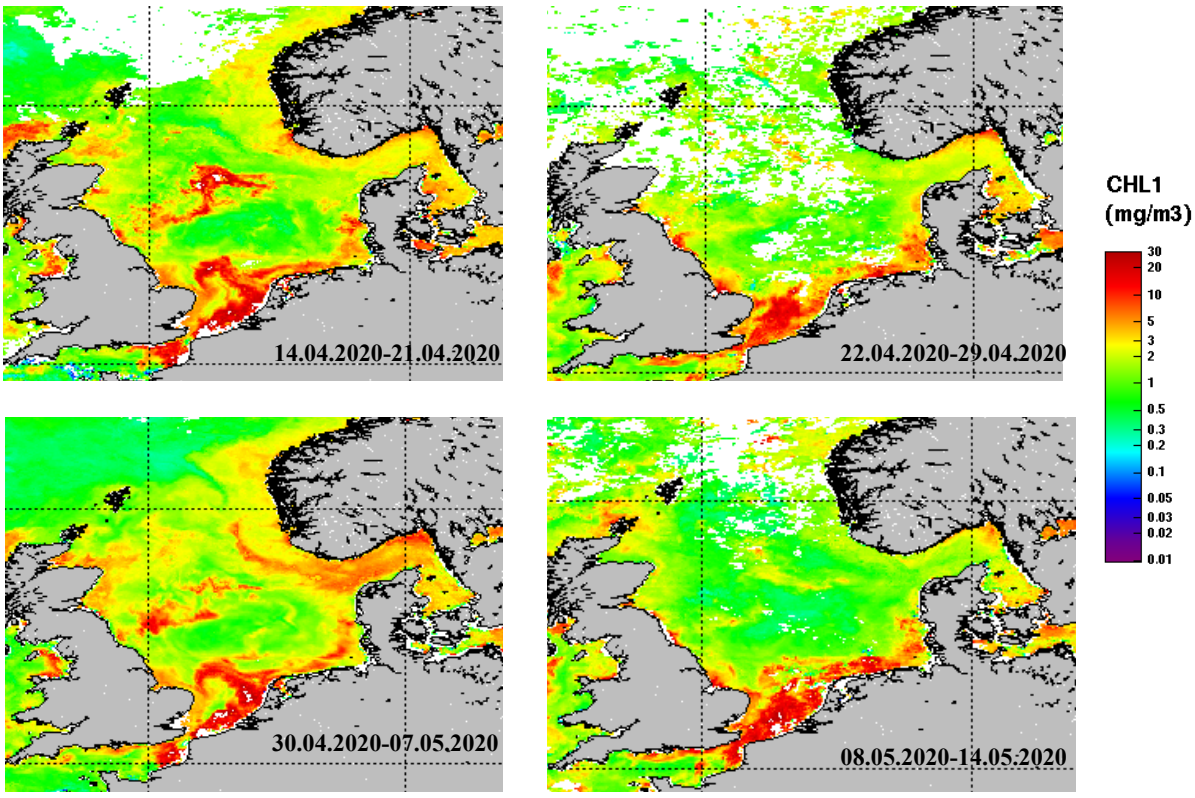


Figure 4. *Evolution of the 8 days mean surface chlorophyll-a concentrations from MODIS satellite imagery over the period 15.04.2020 to 14.05.2020.*

4.3 Biogeochemistry

Two phytoplankton biomass maxima (measured as Chl-*a*) were found in surface waters in this survey (Figure 5). One Chl-maximum was found in the north-western part of the North Sea, immediately south of major dissolved nutrient concentrations (DIN, SiO4) and due east of the Orkneys. The other Chl-maximum was detected off the west coast of Denmark, immediately north of a major plume of DIN that showed low concentrations of PO4 and SiO4. Surface concentrations of SiO4 were extremely high in the Norwegian Trench and northwards in the Norwegian Coastal Current (Figure 5) but remained low relative to DIN and PO4 in the entire region investigated (Figure 5). Elevated nutrient concentrations (most notably DIN conc.) extended from North-Atlantic water entering the North Sea from the north. Overall,

surface PO4 concentrations remained higher than DIN (Figure 6). In fact, the N:P-ratio remained higher than the Redfield relationship of 16 in the entire region investigated only with one exception, the surface nutrient plume off the west coast of Denmark contained unusually low concentrations PO4 and SiO4 levels relative to DIN (Figure 5).

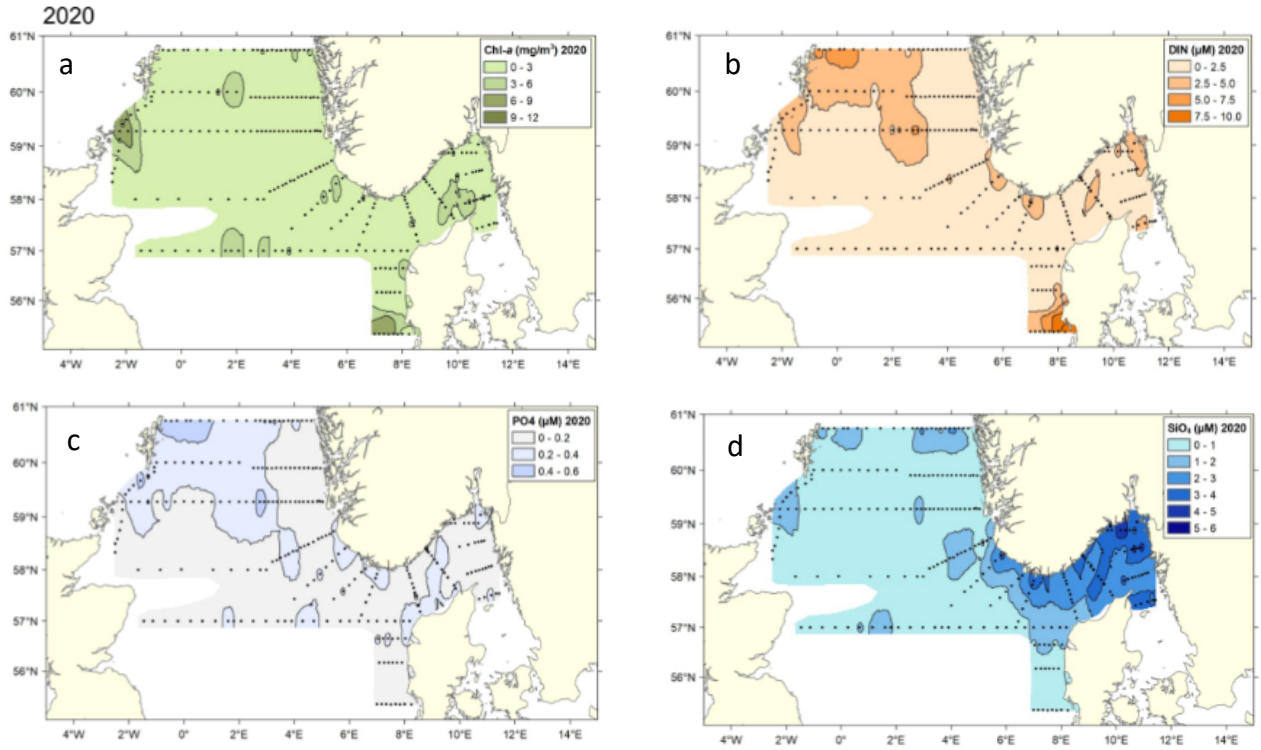


Figure 5. *(a) Surface concentrations of Chlorophyll-a (Chl-a), (b) combined nitrate + nitrite (Dissolved Inorganic Nitrogen (DIN), (c) Phosphate (PO4) and (d) Silicate (SiO4) from samples collected at 0-10 m depth during the Ecosystem cruise in the North Sea and Skagerrak region, April 14 – May 11, 2020.*

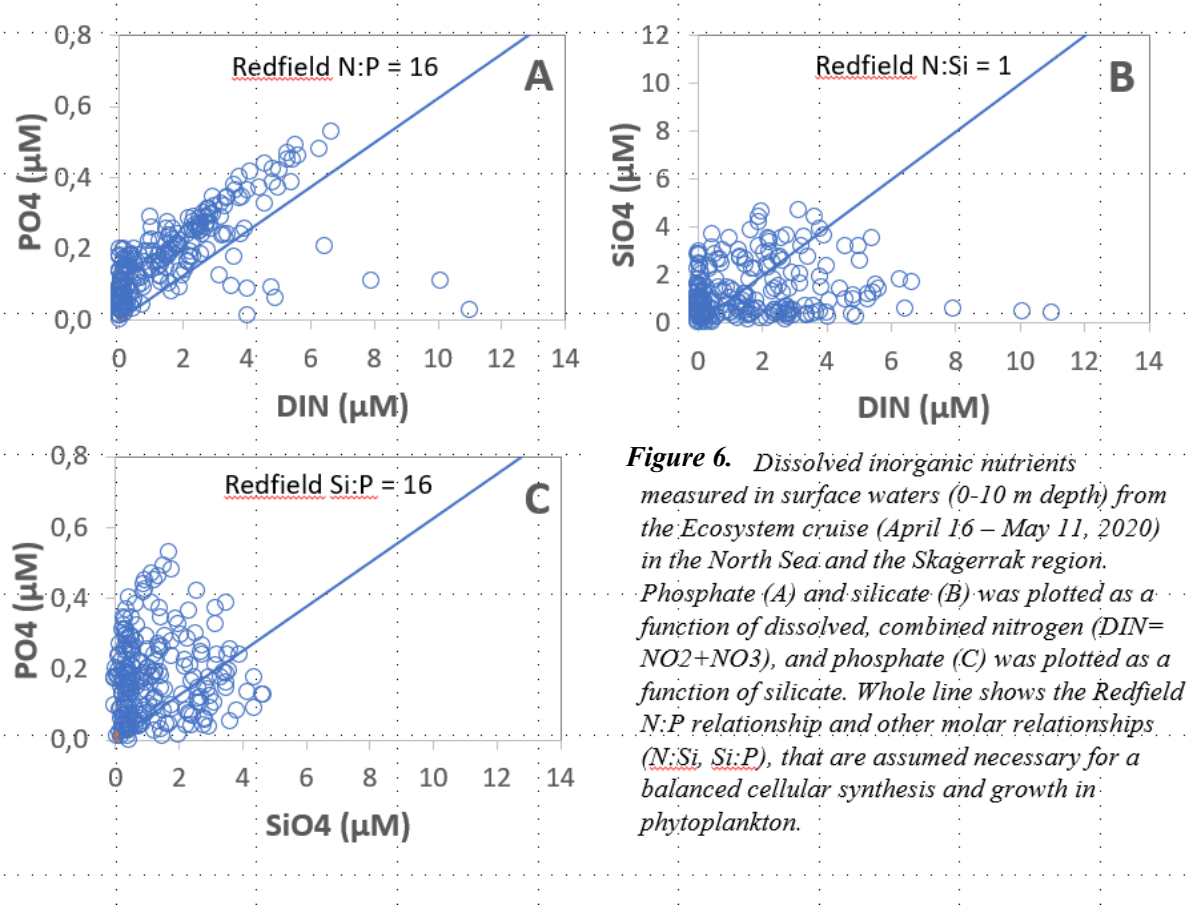


Figure 6. *Dissolved inorganic nutrients measured in surface waters (0-10 m depth) from the Ecosystem cruise (April 16 – May 11, 2020) in the North Sea and the Skagerrak region. Phosphate (A) and silicate (B) was plotted as a function of dissolved, combined nitrogen (DIN= NO2+NO3), and phosphate (C) 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.*

4.4 Phytoplankton taxa

Phytoplankton was identified through microscopic analysis following the Utermöhl method that enables better resolution of individual species abundance.

Preliminary results show that the highest abundance measured in the North Sea, in spring 2020, was recorded along the Danish coast within the Kunde Dyp transect. At station 263 phytoplankton abundance reached 8 million cells per ml, while most of the other stations registered numbers below the 1 million cells per ml (Figure 7a). As for phytoplankton composition, the North Sea was largely dominated by cell smaller than 10µm. The most abundant phytoplankton were small unidentified flagellates which represented usually between 46 and 93% of total population. At station 263, where the highest phytoplankton abundance was recorded, small flagellates accounted for 85% of the total abundance and, microscopy analysis revealed a high concentration of *Phaeocystis* colonies. Cryptophyceae in the size class <10µm were also important contributors at many stations throughout the region. Despite a widespread dominance of small phytoplankton, the coastal areas of the North Sea

were often characterized by a large contribution of diatoms. In particular, at this stage of the analysis, all the stations within the Norwegian trench (St. 312, 321, 377, 384) presented diatoms contribution higher than 50%. These stations were dominated by large chain forming diatoms belonging to the *Skeletonema* spp. and *Guinardia flaccida* species (Figure 7b).

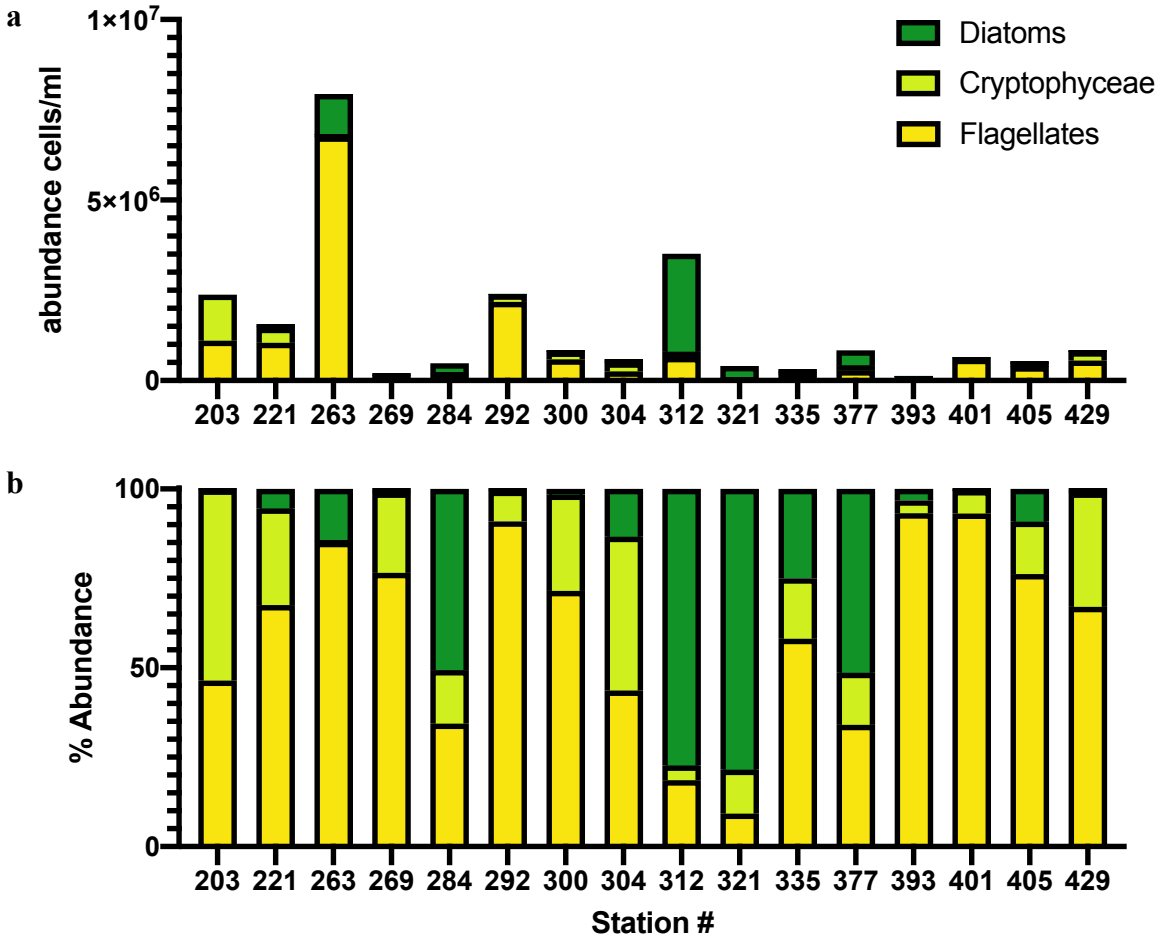


Figure 7. *Phytoplankton concentration (a) and (b) percentage contributions at few selected stations part of the standard NSEC transects.*

4.5 Microzooplankton

Microzooplankton samples from selected stations of fix transects have been analyzed though a flow imaging system (FlowCam). To assign taxonomic and functional determination a machine learning approach will be used. Due to the novelty of the method, we are working on the training set to utilize. We expect to have complete result by the end of summer 2021.

4.6 Mesozooplankton

Horizontal distribution

Depth integrated zooplankton biomass (g dry weight/m^2) in April-May 2020 is presented as total biomass (>180µm, Figure 8 and 9) and as three different size fractions (Figure 10a-c). The highest biomass values were registered east of Scotland, and above the Norwegian Trench (23 g/m^2, Figure 8). The average zooplankton biomass for the whole survey area was 8.3 g m^{-2} which is above the long term (2005-2019) average of 5.4 g m^{-2} (Figure 9).

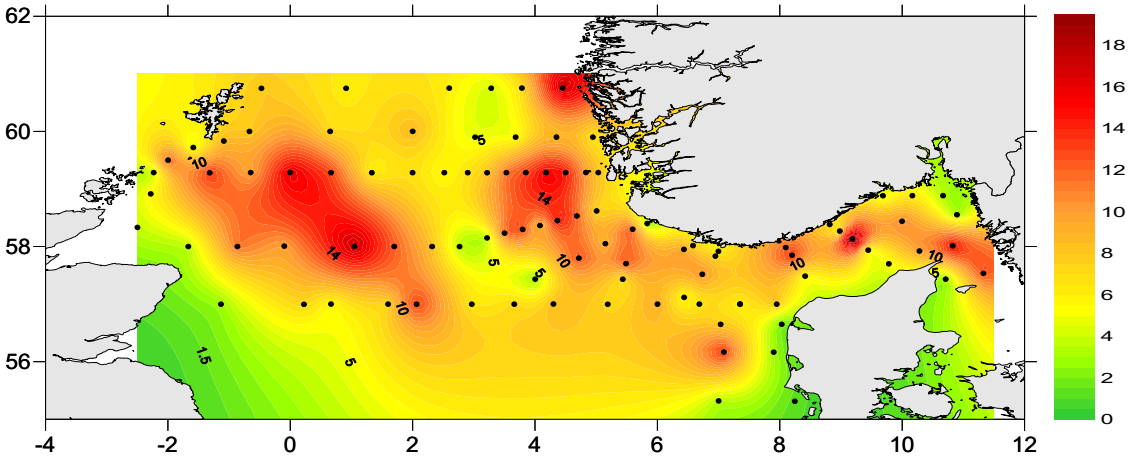


Figure 8. *Zooplankton biomass (g dry weight m^{-2}) in depth integrated net tows (bottom surface, WP2, 180 µm).*

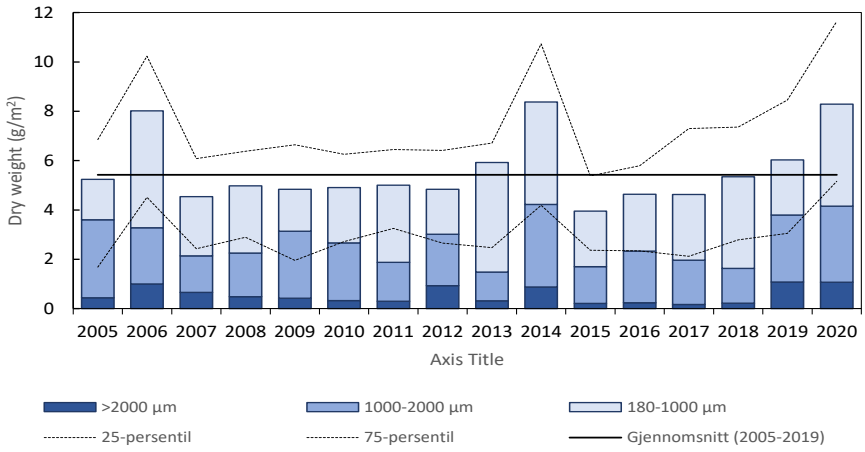


Figure 9. *Annual average zooplankton biomass in April/May 2005-2020. Horizontal line indicates the long-term average 2005-2019. Dashed lines are 25th and 75th percentiles (Q1, Q3).*

The 180-1000 µm size fraction (Figure 10a) contains small sized copepods (*Oithona* sp, *Pseudocalanus* spp), juvenile stages of large copepods (*Calanus*) and benthic larvae. However, this fraction may also contain phytoplankton. This year, the samples contained a large amount of radiolarians/acantharians which contributed to the <1000µm size fraction. The highest biomass values of this smallest fraction were observed in the northwest (Shetland) and in the inner Skagerrak. The 1000-2000 µm size fraction, which is dominated by *Calanus* spp, showed similar distributions, with highest values in the shallow areas east of Scotland (Figure 10b). The size fraction >2000 µm was found in the deeper areas over the Norwegian trench (Figure 10c). This fraction contains large sized copepods (*Calanus hyperboreus, Paraeuchaeta norvegica)*, amphipods, decapod shrimps, chaetognaths and gelatinous zooplankton whose biomass is shown in Figure 11.

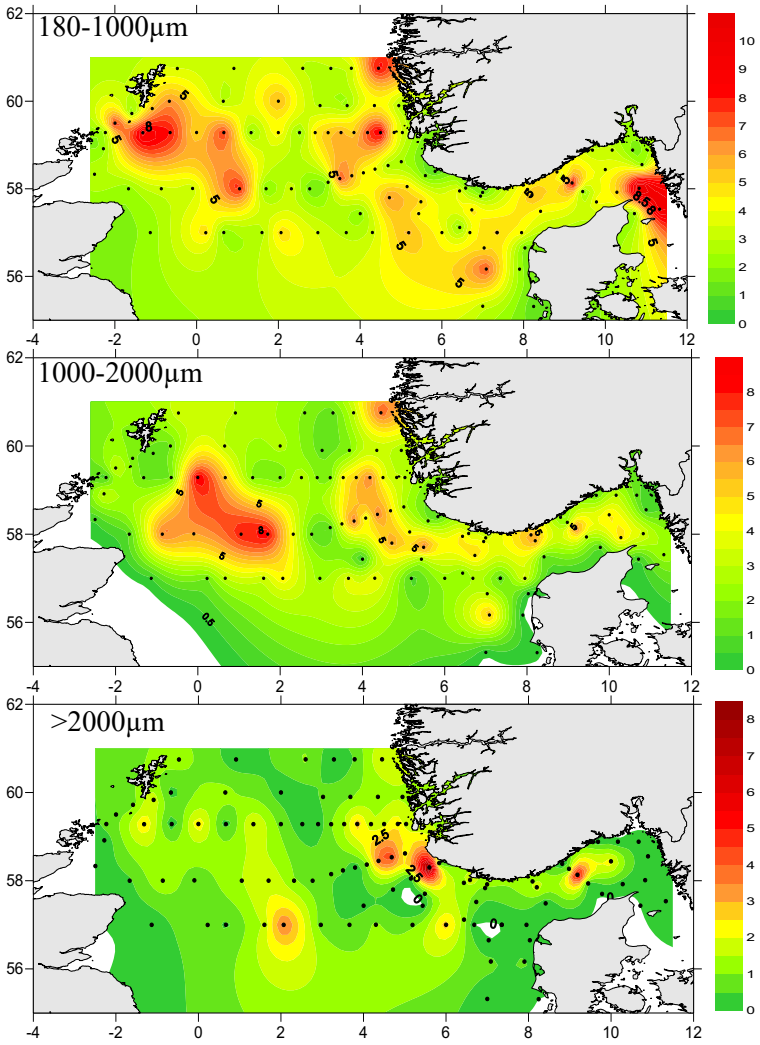


Figure 10. *Zooplankton biomass (g dry weight m-2) in depth integrated net tows (bottom – surface, WP2, 180 µm). Biomass in a) Size fraction 180-1000 µm, b) Size fraction 1000-2000 µm, c) Size fraction >2000 µm.*

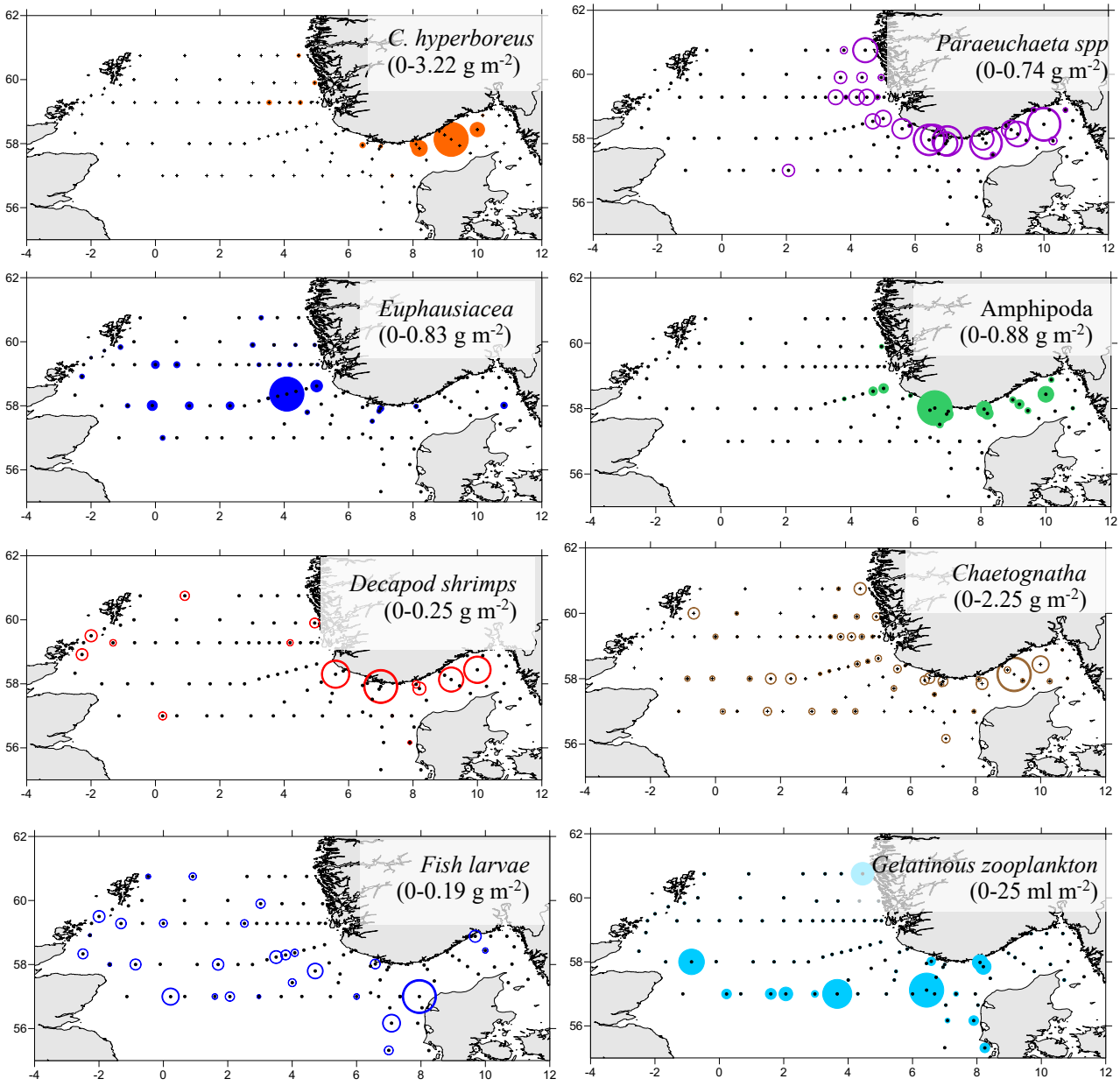


Figure 11. *Biomass of selected groups of zooplankton in the > 2000 µm fraction (in WP2 net tows, 180 µm, bottom-surface). All data square root transformed.*

Vertical distributions of zooplankton biomass

The zooplankton biomass was mainly distributed in the upper 0-100 m layer on most stations, irrespectively time of day (Figure 12). However, indications of diurnal variations were observed on the deeper stations in the Norwegian Trench, especially for the size fraction >1000 µm. This includes the easternmost stations on Feie-Shetland, Slotterøy and Utsira W, which were sampled during daytime and where the >1000 µm biomass was mainly distributed below 100m.

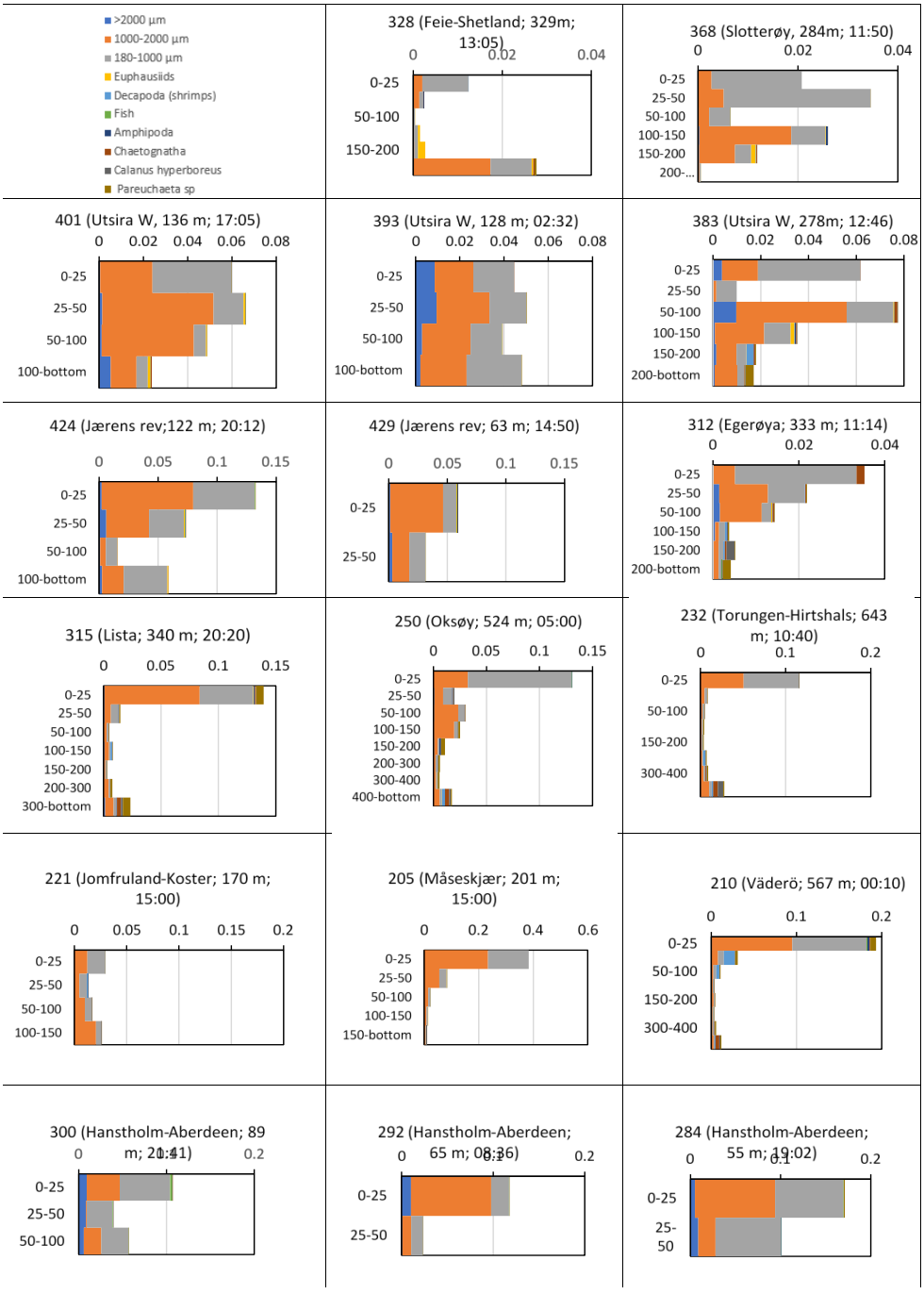


Figure 12. *Vertical distributions of zooplankton biomass (g dry weight m^{-3}). Depth stratified sampling by Multinet, oblique tows, 180 µm, bottom-surface.*

Zooplankton taxonomic composition

Copepods was the numerically dominant group of zooplankton across the whole survey area (Figure 13). High densities of copepods were encountered in the inner Skagerrak (Måsekjær), where *Calanus* was the most numerous copepod taxa. High copepod abundances were also registered along the Utsira transect, while the southern transect, Hanstholm-Aberdeen, generally had low densities. Other important groups were larvaceans (Appendicularia) and meroplanktonic larvae, especially in the shallow areas on Utisra and Hanstholm-Aberdeen transects. Gelatinous plankton (Chaetognaths, Cnidarians and Ctenophores) were most abundant in the Skagerrak.

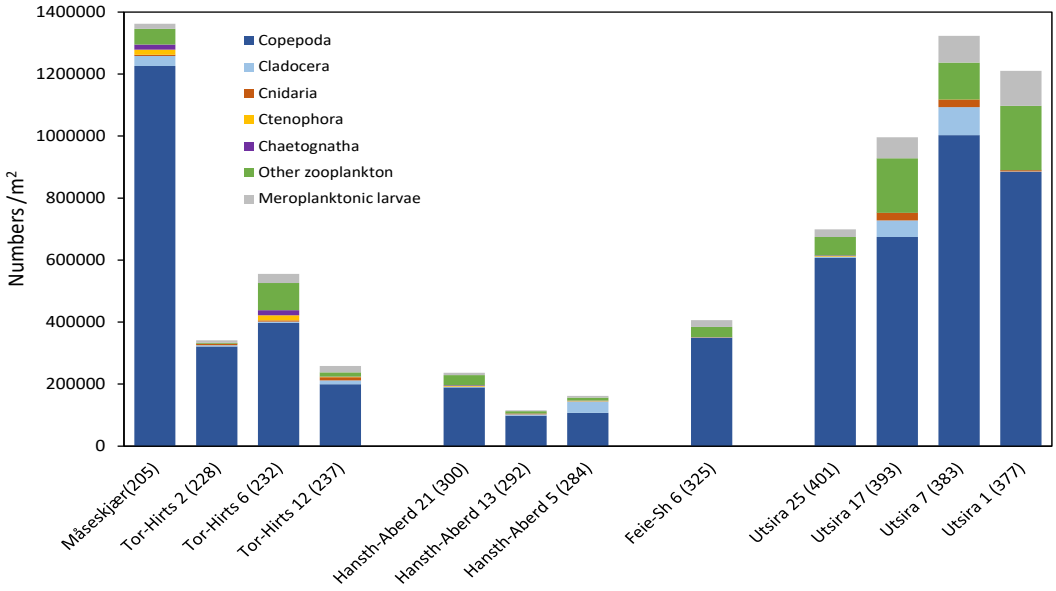


Figure 13. *Zooplankton taxonomic composition (numbers /m²) on selected stations (positions shown in map, Figure 1a).*

The contribution of different taxa to copepod community in the North Sea is presented in figure 14. More in detail, *Pseudocalanus* was the numerically dominating taxa in the Skagerrak and in the southern area (Hansthom-Aberdeen transect). *Temora longicornis* were typically abundant in the near-shore stations on Måseskjær, Torungen-Hirtshals and Utsira), while *Metridia spp* were most abundant in northern North sea (Utsira transect). Surprisingly high abundances of *Calanus spp* were recorded in inner Skagerrak (Måseskjær) and also in the Norwegian Trench, on the Torungen-Hirtshals transect. Both *Calanus finmarchicus* and *C. helgolandicus* co-occurred all across the survey area. Higher proportion of *C. helgolandicus* were found in the southern Hanstholm-Aberdeen transect, while *C. finmarchicus* dominated in

the northern area, and in the Skagerrak. There was also a tendency for an east-west gradient with increasing proportions of *C. helgolandicus* towards west (Figure 15). Higher proportions of small copepodite stages of *Calanus* (I-III) in the southern area (Hanstholm-Aberdeen) indicates variations in phenology in different parts of the surveyed area.

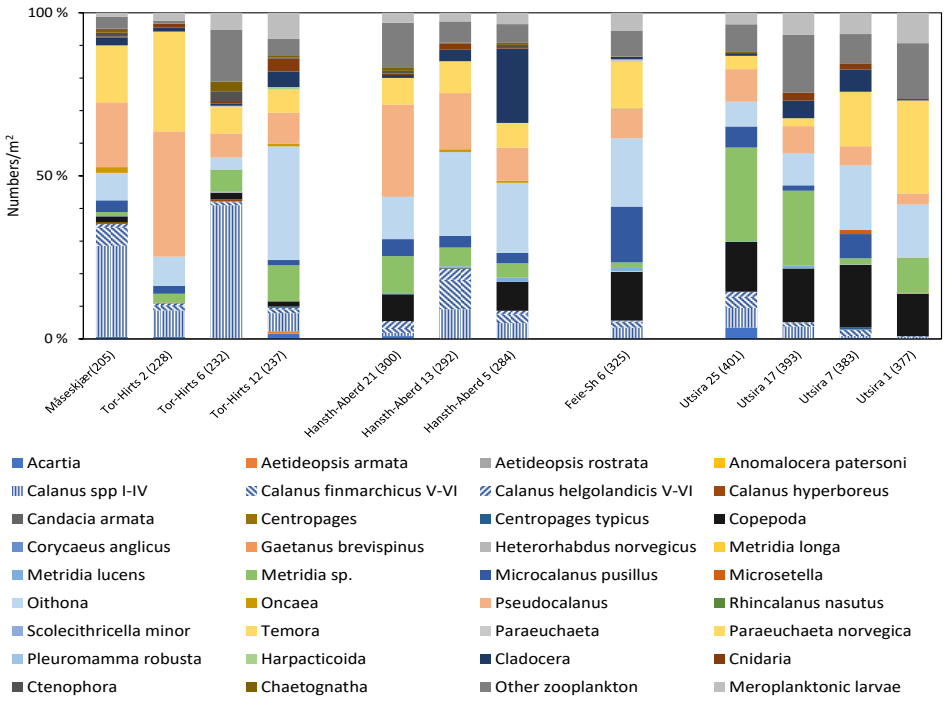


Figure 14. *Taxonomic composition (%) of copepods on selected stations (positions shown in map, Figure 1a).*

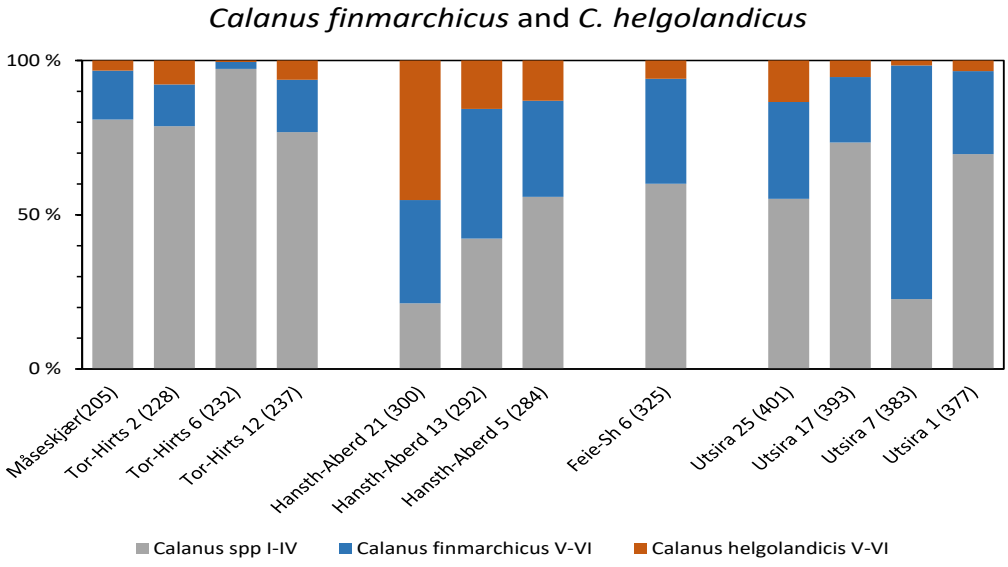


Figure 15. *Proportion of Calanus finmarchicus and C. helgolandicus (%) on selected stations (positions shown in map, Figure 1a).*

4.7 Fish eggs and larvae

A series of 81 Gulf VII high-speed sampler tows were made over standard stations in the norther North Sea in April/May 2020. Eggs and larvae were sorted from the samples 'at sea' and identified to the lowest possible taxon. The results presented here represent preliminary data as final identification and quality assurance still needs to be undertaken.

In general fish eggs occurred almost everywhere across the northern North Sea. Higher abundances were in the north-west to the east of the Shetlands (Figure 16). Low egg abundances generally occurred over the length of the Norwegian Trench. Attempts were made to identify eggs with approximately 20% of the samples not having any identifications undertaken. Of the those identified some mackerel (*Scomber scombrus)* occurred along the Feie-Shetland transect, south of Viking Bank, east of the Orkneys, off Utsira and to the north of Denmark in the Skagerrak. Rockling eggs were quite widespread across the northern North Sea with Callionymid and the lesser argentine (*Argentina sphyraena*) tending to occur in the north west of the survey area.

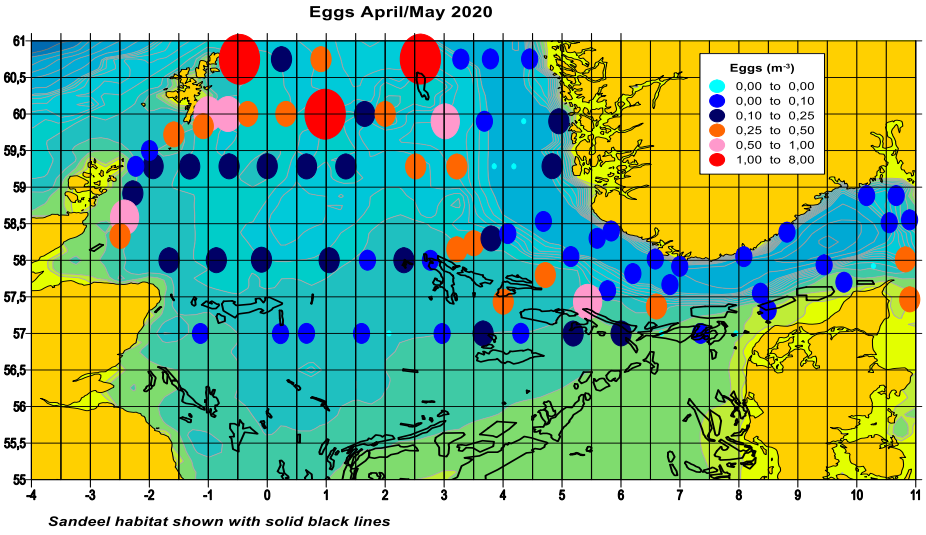


Figure 16. *Distribution of eggs caught with the Gulf VII high speed plankton sampler.*

The higher concentrations of gadoid larvae tended to be in the northwest part of the survey area (in the vicinity of Shetland), which is a typical distribution (Figure 17a). The highest abundances of identified larvae were Norway pout (*Trisopterus esmarkii*) and whiting (*Melangius merlangus*). Ling larvae were generally in the northern part of the survey area generally north of 58º 30'N. Rockling larvae had a slightly wider distribution but the main concentrations generally overlapped with ling.

Flatfish larvae were generally distributed with greater concentrations to the south (Figure 17b). This year the greater abundance was in the central part of the northern North Sea. As in previous years there were very few flatfish larvae over the Norwegian trench. The sand dab (*Limanda limanda*) was the most abundant flatfish larvae over much of the area. There were relatively localized concentrations of lemon sole (*Microstomus kitt*) and witch (*Glyptocephalus cynoglossus*), primarily in the north western North Sea and long rough dab (*Hippoglossoides platessoides*) in the southern part of the surveyed area.

Argentine larvae were generally distributed in the northwestern part of the northern North Sea (Figure 17c). The greater argentine (*Argentina silus*) tends to occur in deeper water and off the shelf whereas the lesser argentine (*A. sphyraena*) occurs in shallower water). This larvae distribution is in general agreement with the distribution of lesser argentine eggs.

There were fewer sandeel larvae than in previous years. The greatest number of sandeel larvae occurred along the east coast of the Shetland, Orkney and north-east Scottish coasts (Figure 17d). In general, the larvae tended to be in the vicinity of the known sandeel habitats (banks). As in previous years there were also sandeel larvae occurring in the deeper water areas over the Norwegian trench and into the Skagerrak and Kattegat.

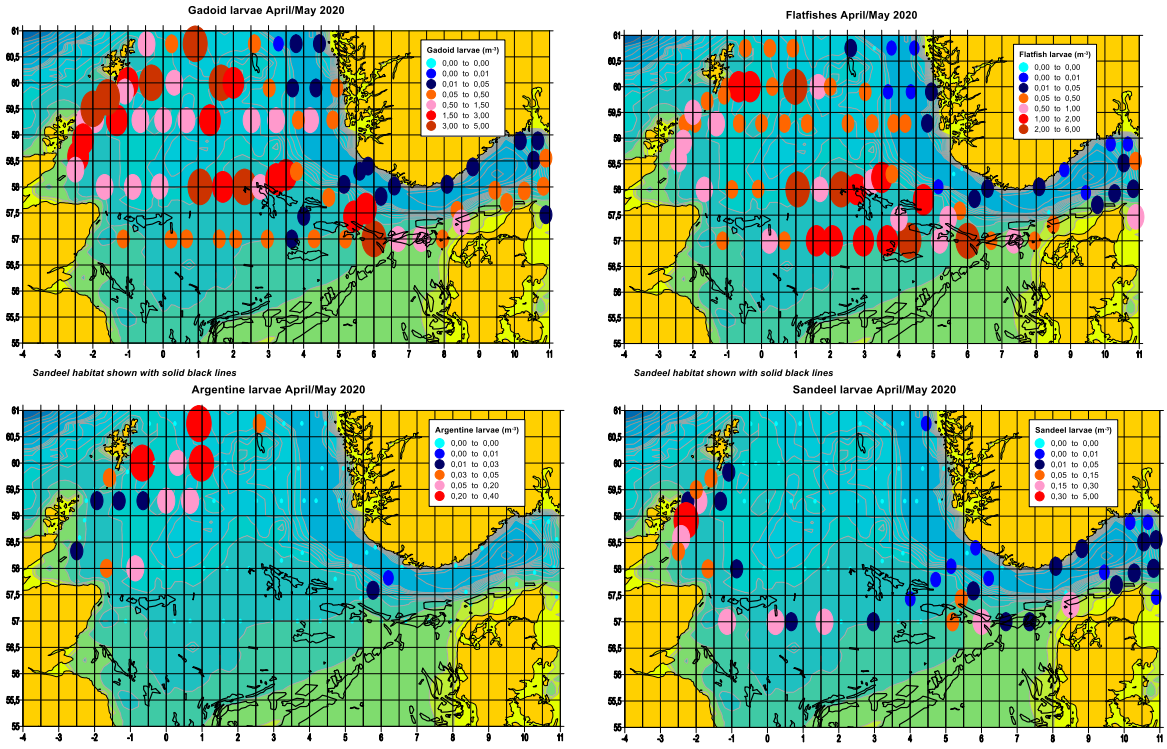


Figure 17. *Distribution of fish larvae caught with the Gulf VII high speed plankton sampler. a) Gadoid larvae, b) Flatfish larvae c) Argentine larvae, and d) Sandeel larvae.*

4.8 Process studies

Shetland Process Station

A series of eight Multinet Mammoth samplings were undertaken over a 48hour period, sampling four depth strata with 405µm mesh nets. The sampling strategy aimed for samples at dawn, day, dusk and at midnight. Additional samples were taken over a similar depth range with 180µm mesh nets for zooplankton which were dried for dry weight estimations of zooplankton abundance.

Physical structure of the water column at the Shetland Process Station

There was a thermocline between approximately 33 and 48m (Figure 18). The multinet sampling strategy used four nets sampling approximately 120-75m,75-40m, 40-20m and 20-0m. With the thermocline between 33 and 48m the 75-40m and 40-20m sampling strata sampled in the thermocline. Only the upper and lower strata had relatively uniform and differing water densities (Figure 18).

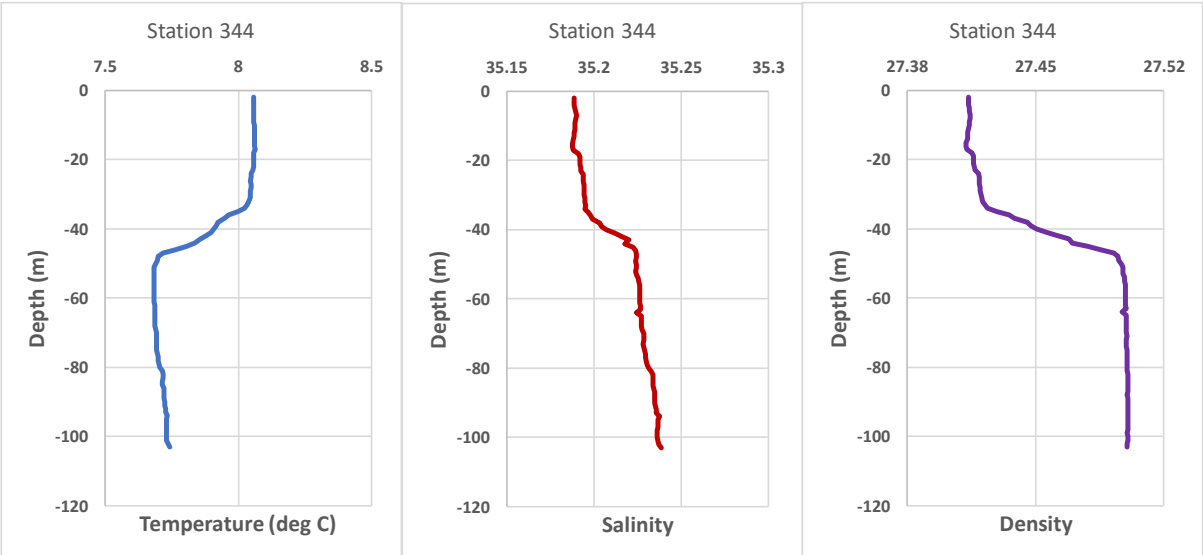


Figure 18. Temperature, salinity and density profiles at one of the sampling times at the Shetland Process Station.

Microzooplankton

Preliminary results from the Deep Skagerrak process station showed reduced vertical migration of the main microzooplankton groups. Both heterotrophic and mixotrophic ciliates and dinoflagellates presented higher abundances in the upper layer (10m) unreceptively of the time of day (Figure 19). One exception was a slighter higher abundance observed for ciliates at 50m depth during the dusk sampling. In the upper layer, ciliates abundance was high at night (7897 cell7L) and reached the highest number at dawn (10145 cell/L). Dinoflagellates, on the other hand, reached their pick in abundance at mid-day (28841 cell/L).

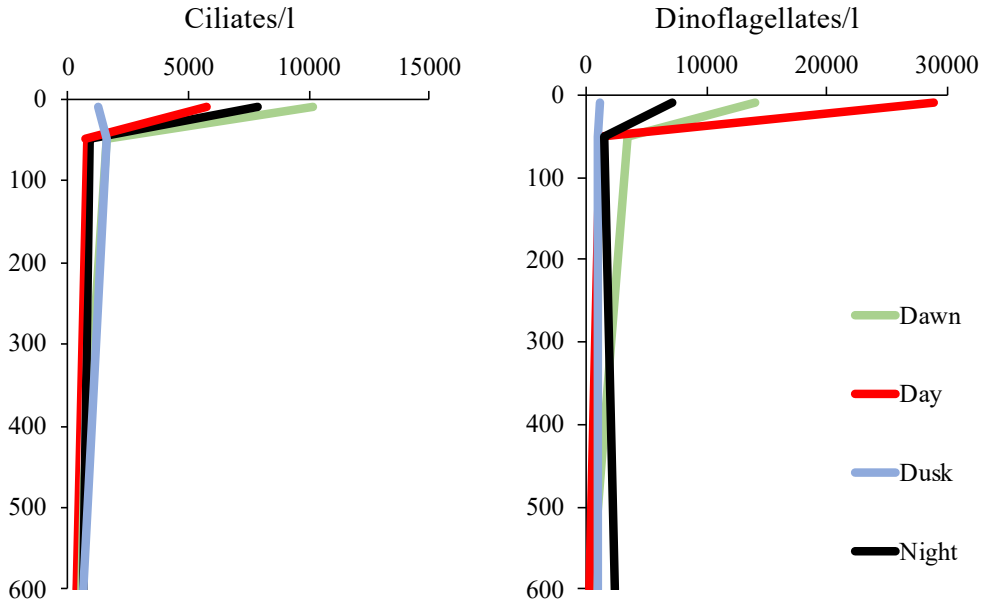


Figure 19. *Vertical distribution of ciliates (left panel) and dinoflagellates >20 µm (right panel) abundance (cell/l) recorded at 4 different time point: Dawn, Day, Dusk and Night.*

These high number, were connected to dinoflagellates smaller than 20µm (Figure 20c). despite the methodology used to preserve our samples (acid Lugol) does not allow us to distinguish the trophic status of cells, based on taxonomic characterization we identified these small dinoflagellates as mostly autotrophic. Thus, is not surprising that they presented their higher abundances in the upper layer during daytime (Figure 20c). Below 10m depth a sharp decrease in numbers was observed. However, it is worth of notice that at 600m depth ciliates and dinoflagellates abundance ranged between 300 and 620 cell/L and 78 and 791 cell/L

respectively. At this depth, the highest abundances were measured at nighttime for all the microzooplankton groups (Figure 20).

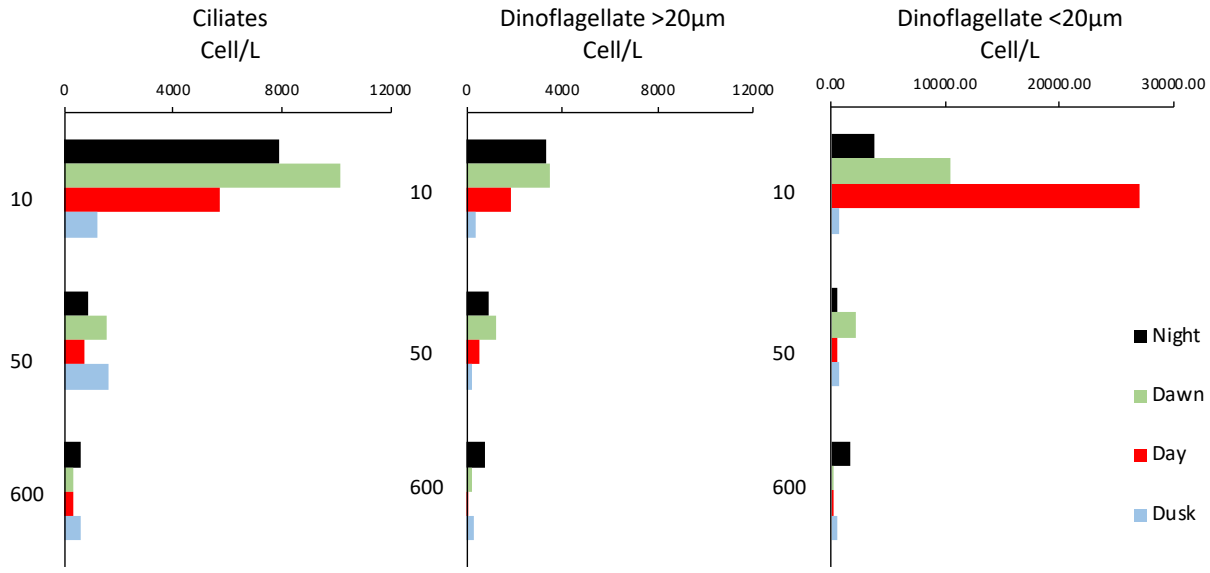


Figure 20. *Distribution of the main microzooplankton groups through the water column and over time.*

Mesozooplankton

In general, the vertical distributions of zooplankton biomass showed small diurnal variation on both process stations (Fugure 21). On the Skagerrak Deep process station, the major part of the zooplankton biomass was distributed in the upper 0-50 m layer both day and night. However, for the >2000 µm fraction, a clear diurnal migration was evident. Euphausiids, decapods and *Paraeuchaeta* were present in upper 0-50 m layer during night but distributed below 50 m during day. The subarctic copepod *Calanus hyperboreus* was found below 400 m both day and night, probably associated with Atlantic water in the Norwegian Trench.

On the Shetland Process station, the vertical distribution was more variable, illustrating the variability in currents and water masses on this station. There was a small indication of diurnal migration, with reduced densities in the surface water during day concurrent with a small increase in the 20-40 m layer. This indicates that zooplankton were migrating down to the thermocline during day.

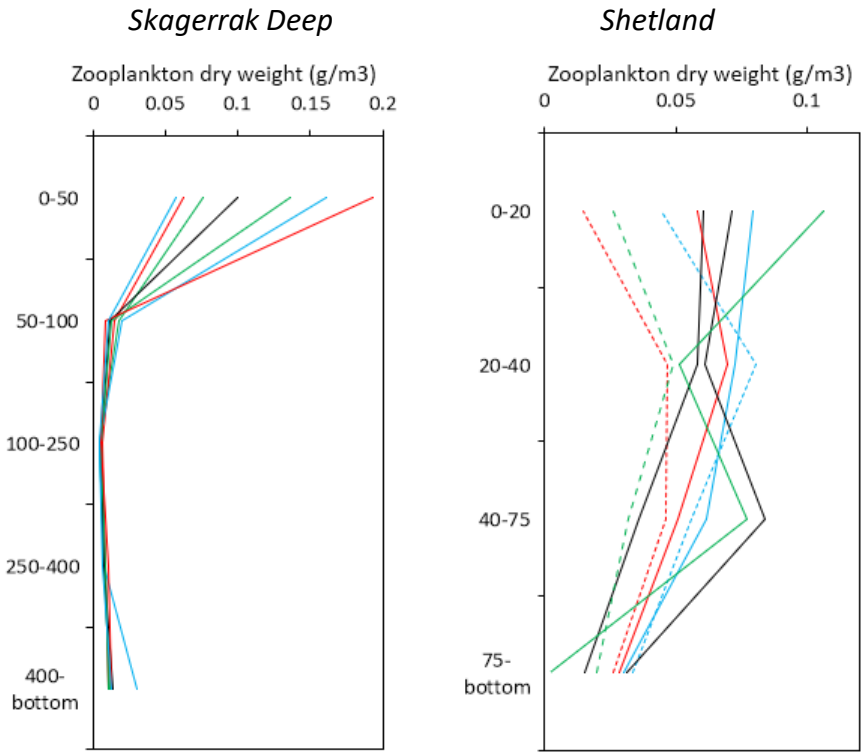


Figure 21. *Vertical distributions of zooplankton biomass (g dry weight m^{-3}) over time (hour of sampling in the legend). Red=day; Blue= dusk; Black= night; Green= dawn.*

Ichthyoplankton

Relatively few of the fish eggs were identified to species, therefore, only the total egg densities are presented here. Eggs are generally not anticipated to undertake any diel vertical migration (DVM) therefore all samples are plotted on the same axes. It is known that eggs of a species will occur at different heights in the water column based on the water column density and will differ during egg development due to temporal changes in egg density.

Figure 22 illustrates the variability in density of eggs over time. The sampling locations did not vary substantially over time therefore this is a consequence of patchy distributions which are moving with the currents. In general, there were lower densities of eggs in the upper water column, above the thermocline than below.

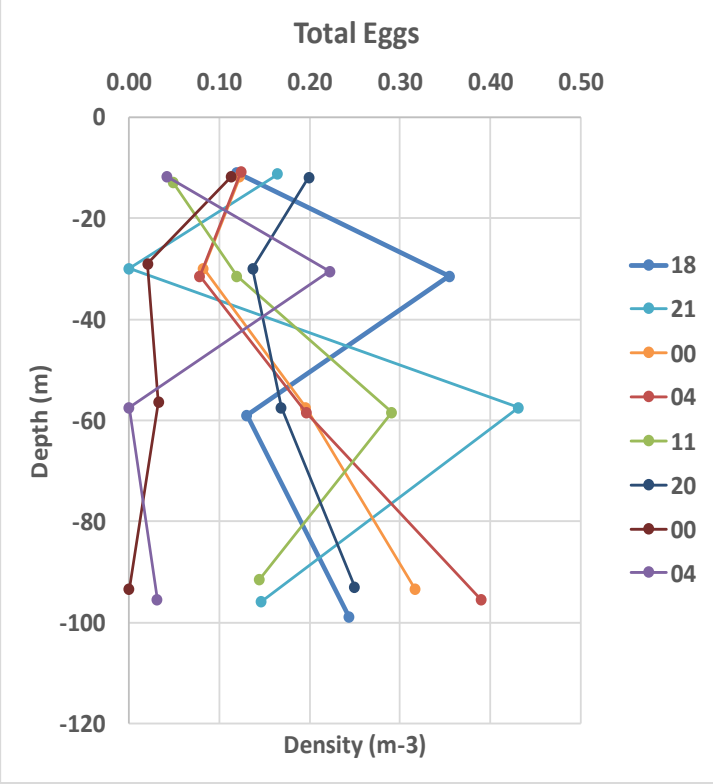


Figure 22. *Distribution of fish eggs through the water column and over time (hour of sampling in the legend to the right of the figure).*

The preliminary fish egg and larvae data presented here reflect identifications undertaken at sea and may not be complete and have not been quality checked.

In general, the highest concentrations of larvae occurred in the central part of the water column (75-20m depth). Elevated densities generally occurred above the thermocline and there was a small indication that densities were elevated in the surface water at night (Figure 23a).

Since the gadoid larvae were a substantial part of the fish larvae assemblage the diel distribution is very similar to that seen for the total fish larval assemblage (Figure 23b).

Rockling larvae are distinct and as such can be easily identified. As such results are available for this group of gadoids. These larvae are generally fond in the upper water column. There is variability in the vertical distribution over the day, however, there is not a clear pattern (Figure 23c). This may compound by having more than one species within this taxonomic group.

Lemon sole is a commercially valuable flatfish which has been the subject of a recent study on the spawning time and distribution of larvae, especially in the winter, in the northern North Sea. The vertical distribution and any DVM is important for input to particle tracking models from which one can discern both potential spawning and nursery grounds. Figure 23d here illustrate the variability in abundance (patchiness) and diel variability in vertical distribution. Generally, the larvae are found lower in the water column by day and in the upper water column and above the thermocline during night.

Dragonets *Callionymus* spp are non-commercial species that are generally very abundant. The larvae are also distinctive and easy to identify. Very little is known about the early life history stages of these species other than their development. In general, they are distributed through the central water column and only appear in the upper water column at night (Figure 23e).

The two Argentine species found in the area are *Argentina sphyraena* and *A. silus*. These larvae are also distinctive and easily identified, at least to genus. The Shetland Process Station occurs in an area where there were relatively high abundances of larvae in the northern North Sea (see above). Here there is a very clear diel variation in vertical distribution with these larvae only occurring in the surface layer during nighttime (Figure 23f).

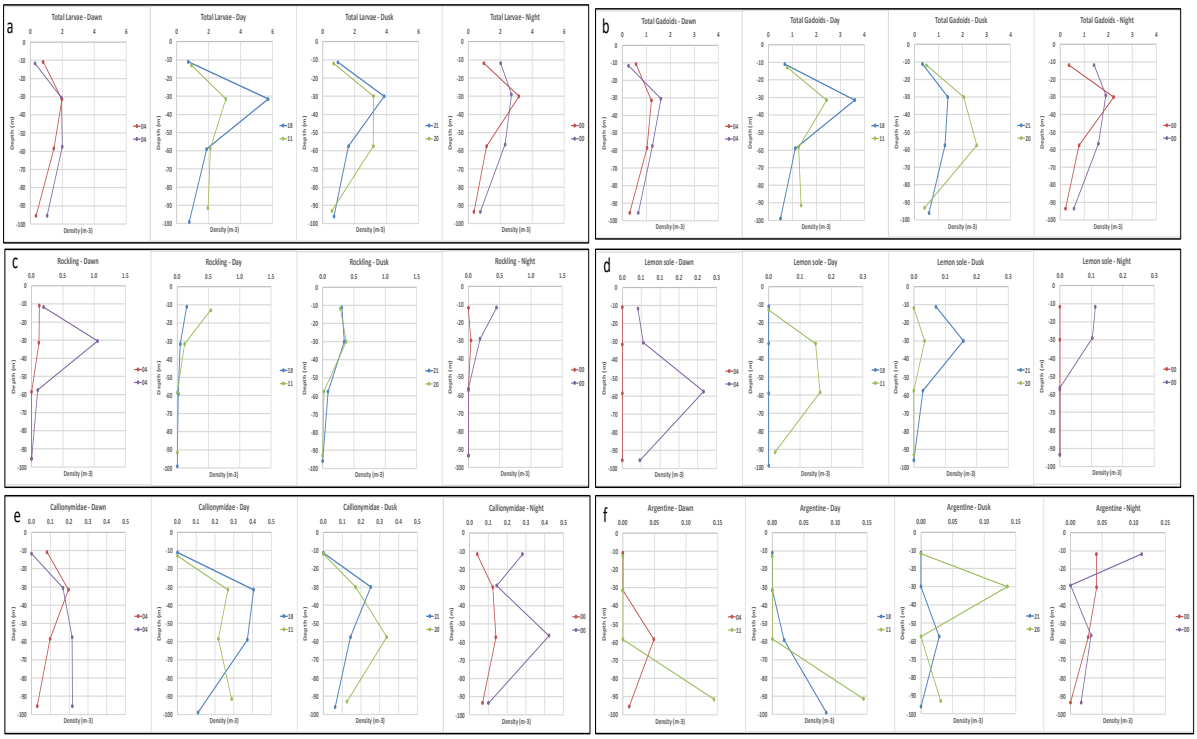


Figure 23. *Diel vertical distribution of larvae at the Shetland Process Station: a) Total larvae, b) Gadoid larvae, c) Rrockling larvae, d) Lemon Sole (Microstromus kitt), e) Callionymid larvae, f) Argentine larvae*

4.9 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. Run-off from these contaminated areas is transported with ocean currents from the Baltic Sea to Norwegian waters. To monitor the supply of cesium-137 (Cs-137) from the Baltic Sea to Norwegian waters, samples of seawater have been collected yearly since 2008 from the 10 stations shown in Figure A. The coordinates for each station are listed in Table 7.

Results from 2008 to 2019 are shown in Figure 24. The highest activity concentrations of Cs-137 are, as expected, found at the stations nearest the outlet of the Baltic Sea. The data indicate a general decreasing time trend, but this is not evident at all stations. Yearly

variations are due to variations in precipitation and run-off from land and oceanographic processes, among other things. The lowest levels are found at the station at the Oksø-Hanstholm section, near Hanstholm. This is as expected as seawater at this station has characteristics more like the North Sea.

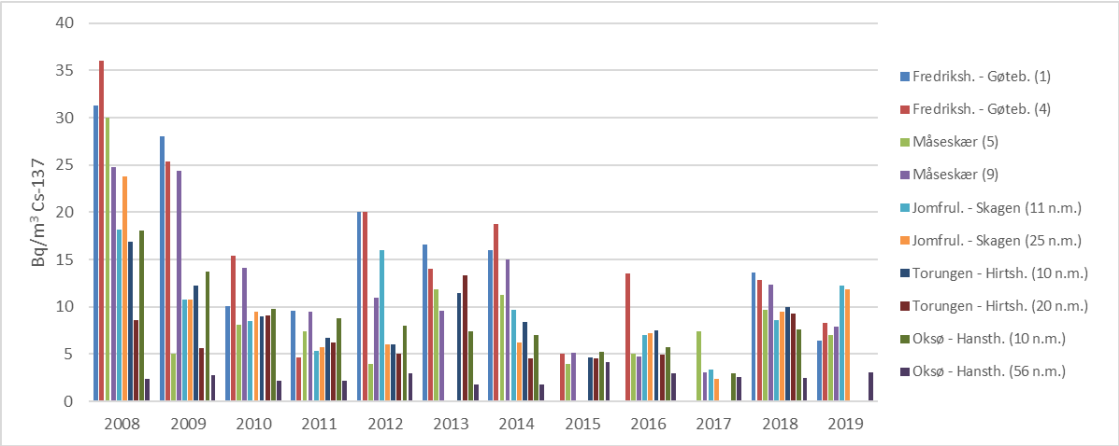


***Figure 24**. Activity concentrations of cesium-137 (Cs-137) (Bq/m³) in samples of seawater collected yearly in the period 2008 – 2019 at the stations shown in Figure 2.*

4.10 Lipids, stable isotopes and contaminants

Results on contaminants are not yet finalized, the samples are being stored and will be analyzed by the end of summer 2021

5 Conclusions

The sampling of North Sea and Skagerrak during the ecosystem cruise 2020 was very successful. The exceptional weather conditions allowed a complete coverage of the area, giving us the opportunity to collect fundamental data to better understand the ecological dynamics of the lower levels of the pelagic food web and the implications for the higher trophic levels.

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 Johan Hjort for outstanding collaboration and practical assistance at the North Sea Ecosystem cruise 14 April – 13 May 2020. We are indebted to all the participants of the North Sea Ecosystem Cruise 2020 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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