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1 **Cabled ocean observatory data reveal food supply mechanisms to a cold-water coral reef**

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19 observatory / Norway

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24 **Abstract**

25 We investigated food supply mechanisms to a cold-water coral (CWC) reef at 260 m depth on the
26 Norwegian continental shelf using data from a cabled ocean observatory equipped with Acoustic
27 Doppler Current Profilers (ADCPs), an echosounder, and sensors for chlorophyll, turbidity and
28 hydrography in the benthic boundary layer (BBL). Tidal currents of up to tens of cm s^{-1} dominated
29 BBL hydrodynamics while residual currents were weak ($\sim 10 \text{ cm s}^{-1}$), emphasizing a supply and high
30 retention of locally produced phytodetritus within the trough. A direct connection between the reefs
31 and surface organic matter (OM) was established by turbulent mixing and passive particle settling, but
32 relative contributions varied seasonally. Fresh OM from a spring-bloom was quickly mixed into the
33 BBL, but temperature stratification in summer reduced the surface-to-bottom connectivity and reduced
34 the phytodetritus supply. A qualitative comparison among acoustic backscatter in the ADCPs (600
35 kHz, 190 kHz) and echosounder (70 kHz) suggests that vertically migrating zooplankton may present
36 an alternative food source in summer. Nocturnal feeding by zooplankton in the upper water column
37 sustains downward OM transport independent from water column mixing and may dominate as food
38 supply pathway over sedimentation of the phytodetritus, especially during stratified conditions. In
39 addition, it could present a concentrating mechanism for nutritional components as compensation for
40 the deteriorating phytodetritus quality. Overall, the observed patterns suggest seasonal changes in the
41 food supply pathways to the reef communities. The moderating role of temperature stratification in
42 phytodetritus transport suggests stronger dependence of the cold-water corals on zooplankton for their
43 dietary requirements with increased stratification under future climate scenarios. This study
44 demonstrates the added value of permanent ocean observatories to research based on dedicated
45 campaigns and regular monitoring.

46 **1. Introduction**

47 Cold-water coral (CWC) reef communities are metabolic hotspots on the seafloor (Van Oevelen et al.
48 2009; White et al. 2012; Cathalot et al. 2015; Rovelli et al. 2015) with organic matter processing rates
49 that are up to 20 times higher than those of the surrounding soft sediments. Such high processing rates
50 require a sufficient supply of organic matter to these reef systems. CWCs and the associated biota may
51 utilise a range of food sources, including dissolved organic matter, phytodetritus, suspended bacteria
52 and zooplankton (Kiriakoulakis et al. 2005; Duineveld et al. 2007; Dodds et al. 2009; Purser et al.
53 2010; Mueller et al. 2014). Opportunistic feeding is a strategy that enables them to meet their energetic
54 and nutritional requirements in a broad range of conditions, including bloom and non-bloom periods
55 (Khripounoff et al. 2014; Mueller et al. 2014), but the mechanisms that transport these potential
56 resources to the reefs are difficult to untangle.

57

58 Various particulate and dissolved organic matter (POM and DOM) sources are produced in the sunlit
59 surface ocean. Whereas DOM needs to be transported to potential consumers (e.g. sponges and cold-
60 water corals; de Goeij et al. 2013, Gori et al. 2014, Mueller et al. 2014) by water movement, which
61 may be advective or turbulent, POM can arrive at the seafloor through gravitational sinking. However,
62 passive organic particle sinking is generally considered insufficient to meet the high metabolic
63 demands of reef communities in the North-Atlantic (Soetaert et al. 2016). An advective environment is
64 therefore essential for the food supply CWC reefs (Thiem et al. 2006; Mienis et al. 2007; Duineveld et
65 al. 2007; Davies et al. 2009; Soetaert et al. 2016). CWCs are found on topographic features that are
66 naturally exposed to enhanced current velocities, including sills (Lavaleye et al. 2009; Wagner et al.
67 2011), canyon walls (Huvenne et al. 2011; Khripounoff et al. 2014) and the continental shelf break
68 (Thiem et al. 2006). Enhanced currents may also resuspend previously settled POM, that is
69 subsequently transported to the reefs (Carlier et al. 2009). CWCs do not only inhabit topographic

70 features on the seafloor, but also modify the seafloor topography through the formation of biogenic
71 reefs and mounds (Roberts 2006) that protrude tens (Correa et al. 2012; Cathalot et al. 2015) to
72 hundreds (De Mol et al. 2002; Van Weering et al. 2003) of meters above the seafloor. These biogenic
73 topographies interact with stratified flows causing internal waves and turbulence with pronounced
74 vertical current components (Mohn et al. 2014; Cyr et al. 2016). Under a tidal regime, this interaction
75 may result in episodic downwelling of organic matter pulses from the surface to the CWC reef
76 communities (Davies et al. 2009; Findlay et al. 2013; Soetaert et al. 2016).

77

78 Feeding experiments, stable isotopes, fatty acid analysis and video observations suggest that
79 zooplankton can present another important food source to CWC (e.g. Duineveld et al. 2007; Dodds et
80 al. 2010; Purser et al. 2010; Naumann et al. 2011; Gori et al. 2015; Van Oevelen et al. 2018). However,
81 it remains challenging to assess the importance of zooplankton as organic matter source for CWCs.
82 Some zooplankton taxa migrate vertically to feed on surface phytoplankton during the night and find
83 shelter from predators in the deeper water at daytime (Hays 2003). In the Gulf of Mexico diel migration
84 of nekton down to two CWC reef systems has been observed with continuous acoustic doppler current
85 profiler (ADCP) measurements (Mienis et al. 2012), suggesting that part of the migrating community
86 may form an additional food source to the CWC communities (Hebbeln et al. 2014). The vertical
87 migration capacity of zooplankton, such as copepods and euphausiids, implies that their presence at
88 CWC reefs is less dependent on advection than that of other organic matter sources.

89

90 It is evident that CWC reef communities can be supported by a range of potential food sources for
91 which transport mechanisms are controlled by various physical and biological factors on scales of
92 hours to weeks. Seasonal variation in for example phytoplankton concentration (Duineveld et al. 2007),
93 water-column stratification and wind forcing are superimposed on this short-term variability (Thiem et

94 al. 2006). Identifying food supply pathways therefore requires a long-term multi-dimensional
95 observational approach, in addition to dedicated short-term campaigns. Several integrative studies have
96 been conducted, but these usually cover weeks of observation (e.g. Duineveld et al. 2012; Hebbeln et
97 al. 2014) and focus on near-bed processes (Mienis et al. 2007; Khripounoff et al. 2014). Ocean
98 observatories provide a means to combine long-term measurement efforts with the required high
99 temporal resolution (Roberts et al. 2005; Soltwedel et al. 2005) to elucidate oceanic processes and
100 present a valuable addition to routine monitoring for both management and scientific purposes (Godø et
101 al. 2014).

102

103 The Norwegian continental shelf hosts among the highest abundance of CWC reefs in the world
104 (Roberts et al. 2006). To better understand their biological and physical settings, a cabled observatory
105 has been installed in the Hola trough, an area with CWC mounds off the Norwegian coast (Godø et al.
106 2012b, 2014; Fig. 1). We used data from this observatory to resolve the seasonality of the physical and
107 biological settings that govern food supply to a CWC reef. More specifically we used observatory data
108 from the years 2014 and 2015 on current velocities throughout the water column, hydrographic
109 parameters, and several proxies for subclasses of POM to (1) assess food availability throughout a
110 productive season by characterising the variability in different food sources, and (2) identify the most
111 important transport mechanisms that bring these food sources to the CWC reef communities.

112

113 **2. Materials and methods**

114 ***2.1 Location of the LoVe observatory***

115 The LoVe (Lofoten-Vesterålen) ocean observatory is located 20 km from the Lofoten Islands (Norway)
116 in the Hola trough (Fig. 1). This glacially-deepened trough of 180 – 260 m deep incises the continental
117 shelf in a north-west to south-east direction from the continental slope to the coast. The location of the

118 observatory (~260 m deep) is enclosed by the two 100-m deep banks; Vesterålsgrunnen in the northeast
119 and Eggagrunden in the southwest. The trough has a diverse topography with sand wave fields of up to
120 7 m high, 10 to 35 m high ridges and approximately 20 m high CWC mounds (Bøe et al. 2009). The
121 CWC mounds are predominantly found in the south-eastern part of the trough at a depth of ~260 m just
122 south of the Vesterålsgrunnen bank.

123 No detailed analysis has been performed on the community composition or the reef mounds in the Hola
124 trough, but still images show that the dominant reef-building coral species is *Lophelia pertusa*
125 (Osterloff et al. 2016b). This scleractinian coral is the dominant reef builder in European waters
126 (Roberts et al. 2006), although *Madrepora oculata* can also occur as smaller parts of the reefs on the
127 Norwegian shelf (Järnegren and Kutti 2014). Still images also show a high abundance of shrimps,
128 presence of the redbass *Sebastes* sp. and soft-coral specimens including *Paragorgia arborea* (Osterloff
129 et al. 2016b, <http://love.statoil.com>), which are typical members of Norwegian reefs (Fosså et al. 2002)
130 Other filter-feeding community members that are usually associated with the *Lophelia* framework are
131 the soft coral, *Primnoa resedaeformis*, sponges (e.g. *Mycale lingua*) and bivalves (e.g. *Acesta*
132 *excavata*; Järnegren and Kutti 2014, De Clippele et al. 2015).

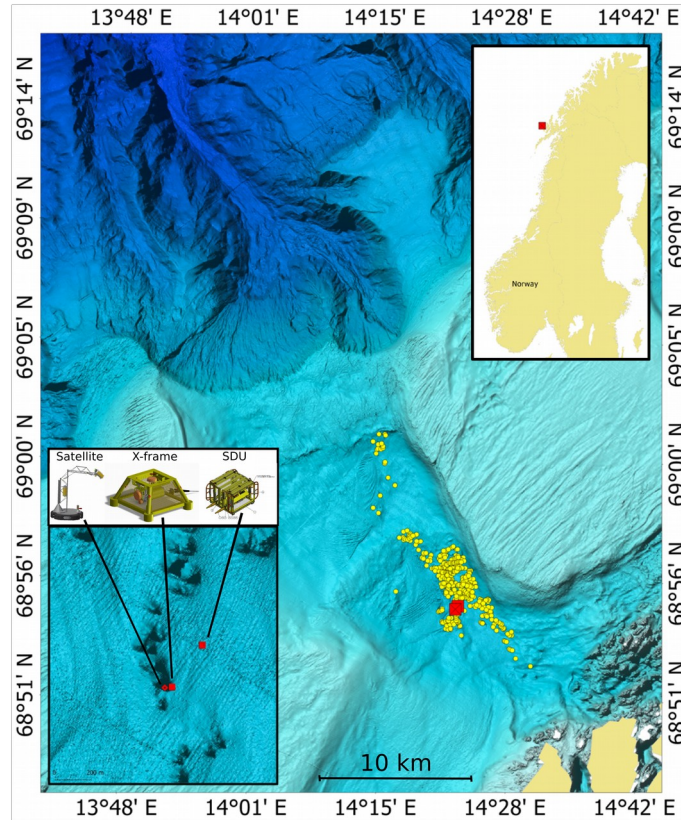
133 The coral mounds are associated with trailing erosional scour marks that hint at a local predominant
134 northward or north-westward current direction. These scour mark patterns are consistent with an anti-
135 clockwise circulation, which is characteristic for these northern troughs (Buhl-Mortensen et al. 2012).
136 However, local lithology also suggests a high spatial variability in current direction and strength,
137 ranging from several cm s⁻¹ to 1 m s⁻¹ (Bøe et al. 2009). The seafloor in the coral-dominated part of the
138 trough slopes at an angle of approximately 4° in a north-east direction towards the Vesterålsgrunnen
139 bank (Godø et al. 2012b).

140 The spatial-temporal variability in current structures and water transport is further influenced by two
141 major current systems. Firstly, the North Atlantic Current (NAC) transports comparatively warm saline

142 North Atlantic Water (NAW) northward along the continental shelf edge. This water mass is usually
143 identified by salinities in excess of 35 (Pedersen et al. 2005, Zhu et al. 2009, Skagseth et al. 2011).
144 Secondly, the Norwegian Coastal Current (NCC) transports cold, less saline, Norwegian Coastal Water
145 (NCW) northward along the coast, with current velocities in excess of 1 m s^{-1} (Ersdal 2001). This water
146 mass is characterised by salinities below ~ 34.5 (Pedersen et al. 2005, Zhu et al. 2009, Skagseth et al.
147 2011) In general, NCW has a stronger influence on the shallower banks, while the NAW is more
148 restricted to the deeper troughs such as the Hola trough. However, this pattern varies seasonally.
149 During winter the NCW forms a deeper wedge close to the coast, while in summer it exists as wider
150 thinner layer that covers the larger part of the continental shelf (Skagseth et al. 2011, and references
151 therein). The inflow of NAW in the northern glacial troughs varies over time and depends on, among
152 others, the interplay between the strength of the NAC and trough morphology (Sundby 1984). Because
153 of gradual mixing of NAW and NCW in northward direction, salinity signatures show less contrast in
154 the northern troughs (Pedersen et al. 2005). Mixing of both water masses is facilitated in winter and
155 spring by mesoscale eddies that find their origin in the topographic steering of the NCC, that takes the
156 form of a coastal jet at this time (Buhl-Mortensen et al. 2012) .

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178 Fig. 1: Overview of the observatory's location (red squares) in the Hola trough. The relevant region is
179 scattered with coral mounds (yellow dots). The sensor platforms (satellite and X-frame) are located
180 near a cold-water coral mound (lower left).
181

182 **2.2 Infrastructure of the LoVe observatory**

183 The LoVe observatory was launched in September 2013 and has a modular configuration consisting of
184 three connected subunits (Fig. 1): (1) the Subsea Distribution Unit (SDU), (2) the X-frame and (3) the
185 satellite unit. The SDU is connected with a cable to the main land for power supply and data transfer.
186 The X-frame is connected to the SDU and contains, amongst others, an upward-looking 3-beam 600
187 kHz Nortek Aquadopp Acoustic Doppler Current Profiler (ADCP, henceforth called short-range or SR-
188 ADCP), an upward-looking 3-beam 190 kHz Nortek Continental ADCP (henceforth called long-range
189 or LR-ADCP) and an upward-looking 70 kHz Simrad EK60 echosounder. The satellite unit is placed
190 within meters of the CWC reef framework and has a still camera, hydrophone and sensors for salinity,

191 temperature, chlorophyll *a*, turbidity, and pressure (depth). Technical details of the three subunits and
192 sensors are available on the website dedicated to the observatory (<http://love.statoil.com>). This website
193 is also a portal to all data and still images, which are publicly available. The data used in this
194 manuscript were downloaded from the website on December 9, 2015.

195

196 **2.3 Data selection**

197 2.3.1 LoVe observatory data

198 This study focused on variables that were measured in 2015 relating to water movement, particle
199 concentration, and hydrography, because this is the most complete data set of the two years (2014-
200 2015) ensuring the best overlap between the ADCPs and other sensors. The SR-ADCP measured from
201 0.5 to 40.5 mab (meters above bottom) with a bin size of 2 m. The LR-ADCP measured from 2 mab to
202 the surface (262 mab) with a bin size of 5 m. Both systems measured current velocities in a geographic
203 reference system (East–North–Up) in 10-minute intervals. Hourly sampled data on chlorophyll *a*
204 fluorescence (Seapoint), turbidity (Seapoint), salinity, pressure (used as proxy for tides), and
205 temperature were available from multi-sensor probes on the satellite unit. But part of these time series
206 was not available due to sensor malfunction (see below and appendix).

207 Echosounder data were compared with the ADCP backscatter intensities. Whereas ADCPs are
208 developed to measure velocities and produce acoustic backscatter information as by-product,
209 echosounders are designed to monitor acoustic backscatter, mainly from fish and zooplankton. The
210 echosounder operates at 70 kHz with a ping rate of 2 s⁻¹. The system was calibrated using the standard
211 sphere method (Foote et al. 1987) before launch, but no calibration at depth was available to
212 compensate for potential changes of instrument performance with time and/or depth. Acoustic data
213 were processed and visualized using the LSSS software package (Korneliussen et al. 2016). One
214 echosounder time series from before and one from after the spring bloom were included in this study to

215 contrast against the uncalibrated ADCP backscatter intensities.

216

217 2.3.1 Complementary and climate data

218 Chlorophyll a concentration and sea surface temperature (SST) data from the MODIS-Aqua satellite
219 platform were downloaded for the year 2015 as additional external data (OBPG, 2017) in order to (1)
220 check for data consistency, and (2) place the local observations at LoVe observatory in a larger spatial
221 context. The 8-day standard mapped image composites with a spatial resolution of 4 km were used to
222 obtain a consistent coverage for a maximal time span (no winter values due to solar zenith-related
223 limitation of the atmospheric correction algorithms) and to reduce the impact of local cloud cover. In
224 these level-3 products, chlorophyll a is estimated with the OCx algorithm merged with a colour index
225 (https://oceancolor.gsfc.nasa.gov/atbd/chlor_a/, and references therein), and SST is derived from the
226 11-12 μm long-wave radiation in the underlying satellite data
227 (<https://oceancolor.gsfc.nasa.gov/atbd/sst/>, and references therein).

228 Wind speed and direction data for the period 2014 – 2015 from the weather station at Bø, Vesterålen,
229 were downloaded from the “eKlima” data portal (eklima.met.no) from the Norwegian meteorological
230 institute.

231

232 **2.4 Data download and processing**

233 2.4.1 ADCP

234 ADCP data were downloaded from the data portal of the observatory as raw binary output files from
235 the respective devices. Conversions from binary to ASCII were performed with the Continental and
236 Aquapro software packages from Nortek AS. Individual ASCII files, containing data for a few days at
237 10-minute intervals, were imported into R Statistical Software (R Core Team 2016). Velocity data were
238 taken at 10-minute sampling intervals and consecutive data files usually had temporal gaps of not more

239 than 30 minutes between them. To obtain regular samples, time series data were binned per hour by
240 taking median values. Remaining gaps were filled in by linear interpolation if longer regularly sampled
241 time series were needed for particular analyses. Care was taken not to interpret potential artefacts that
242 might arise from this interpolation (see for instance section 3.1).

243 Velocity readings from the ADCPs that were associated with raw backscatter data below the theoretical
244 thresholds (45 and 33 counts for the Continental and Aquadopp respectively; Nortek forum) were
245 replaced by linearly interpolated values (along the time dimension). The velocity readings above 120
246 mab from the LR-ADCP had to be discarded because of a systematic bias, most likely due to low
247 backscatter intensities or high noise levels in one of the beams (Appendix). The SR-ADCP velocity
248 data above 20 mab were also associated with large uncertainty (Appendix). Because of the larger range
249 of the LR-ADCP, the limited added value of the higher resolution in the SR-ADCP, and its velocity
250 discrepancies with the LR-ADCP between 20 and 40 mab (see section 3. and Appendix), only the
251 current velocities from the LR-ADCP are reported here. The acoustic backscatter intensity was
252 investigated over the entire profiles (20 and 46 cells in the SR-ADCP and LR-ADCP respectively).
253 Backscatter intensities were corrected for beam spreading, including non-spherical spreading in the
254 near field (Downing 1995), and sound attenuation along the beams due to the water.

255

256 2.4.2 Echosounder

257 The echosounder data were downloaded and examined with LSSS software package. Thresholding of
258 s_v (acoustic volume backscattering coefficient) was used to study vertical distribution patterns and
259 dynamics of organisms of various sizes. This approach facilitated an appropriate comparison of the
260 echosounder and ADCP backscattering data.

261

262 2.4.3 Other LoVe variables

263 Turbidity, salinity, temperature, depth, and chlorophyll a and coloured DOM data were downloaded as
264 single ASCII text files per variable with hourly values. Environmental variables were checked for
265 sensor saturation and noise levels. Based on these checks, we decided to use only the chlorophyll a
266 fluorescence data (raw values) and the hydrographic parameters and discard the turbidity and coloured
267 DOM data (Appendix).

268

269 2.4.4 Satellite and climate/weather data

270 From the chlorophyll a imagery that was downloaded from the NASA Ocean Color website (
271 <https://oceancolor.gsfc.nasa.gov>; cf. section 2.3.1) on in February 2017, two subsets were selected: (1)
272 a local subset covering a square of 10 by 10 nautical miles centred around the X-frame location
273 (henceforth referred to as local chlorophyll signal), and (2) a regional subset covering the larger part of
274 the Hola trough (bounding box: 67° 36' N, 8° E – 69° 24'N, 16° 54' E; henceforth referred to as
275 regional chlorophyll signal). From the SST imagery that was downloaded together with the chlorophyll
276 imagery, only the local subset was selected and used to estimate a seasonal trend by spline smoothing.
277 95% estimation bands were constructed from jackknife residuals of this smooth spline estimation.

278

279 **2.5 Data analysis**

280 2.5.1 Time series analysis techniques

281 Spectral analyses were used to identify the scales that contributed significantly to the overall variance
282 in the various time series, and coherence analysis was used to study the co-variation between different
283 time series (e.g. Shumway and Stoffer 2006).

284 Coherence and spectral analyses are based on either a Fourier transformation (standard frequency
285 domain analysis; e.g. Bloomfield 2000) or a wavelet transformation (e.g. Percival and Walden 2000).

286 Here we used both transformations to analyse the same process or relationship. If the wavelet-based

287 analysis gave the same result as Fourier-based analysis, the Fourier-based method was reported because
288 of the higher frequency resolution. If results of both approaches differed because of a limited temporal
289 extent of the investigated process/relationship, only the results from the wavelet-based method were
290 reported. As a result, variance contributions from tidal drivers are here reported with Fourier-based
291 methods (see section 3.2), while wavelet-based results are reported the mixing regimes. Wavelet-based
292 coherence was calculated using a continuous wavelet transform with a complex Morlet wavelet
293 (Torrence and Compo 1998).

294 Smoothing and frequency band selection from time series were accomplished, where applicable, by
295 multi-resolution decompositions, based on the Maximal Overlap Discrete Wavelet Transform
296 (MODWT with symlet s8 as filter; Daubechies 1992, Mallat 1999). In contrast to the observatory data,
297 the Modis-Aqua SST data were smoothed with smooth spline estimation, because the occurrence of
298 multiple values per time point (due to spatial extent of the selected region) excluded wavelet-based
299 smoothing.

300

301 2.5.2 Acoustic backscatter (ADCP)

302 Linear relationships between acoustic backscatter and suspended matter proxies (chlorophyll a, bottom
303 current speed as proxy for resuspended material) were investigated by means of linear regression
304 analysis (Gostiaux and Van Haren 2010). Logarithmic transformations were applied whenever needed
305 to obtain symmetric residual distributions.

306

307 All data manipulation and analyses were performed in R Statistical Software (R Core Team 2016).

308 Wavelet analyses were performed with the R-packages 'waveslim' (Whitcher 2015) and 'wmtsa'

309 (Constantine and Percival 2013) for the discrete methods, and 'biwavelet' for the continuous wavelet

310 methods (Gouhier et al. 2016).

311

312 **3. Results**

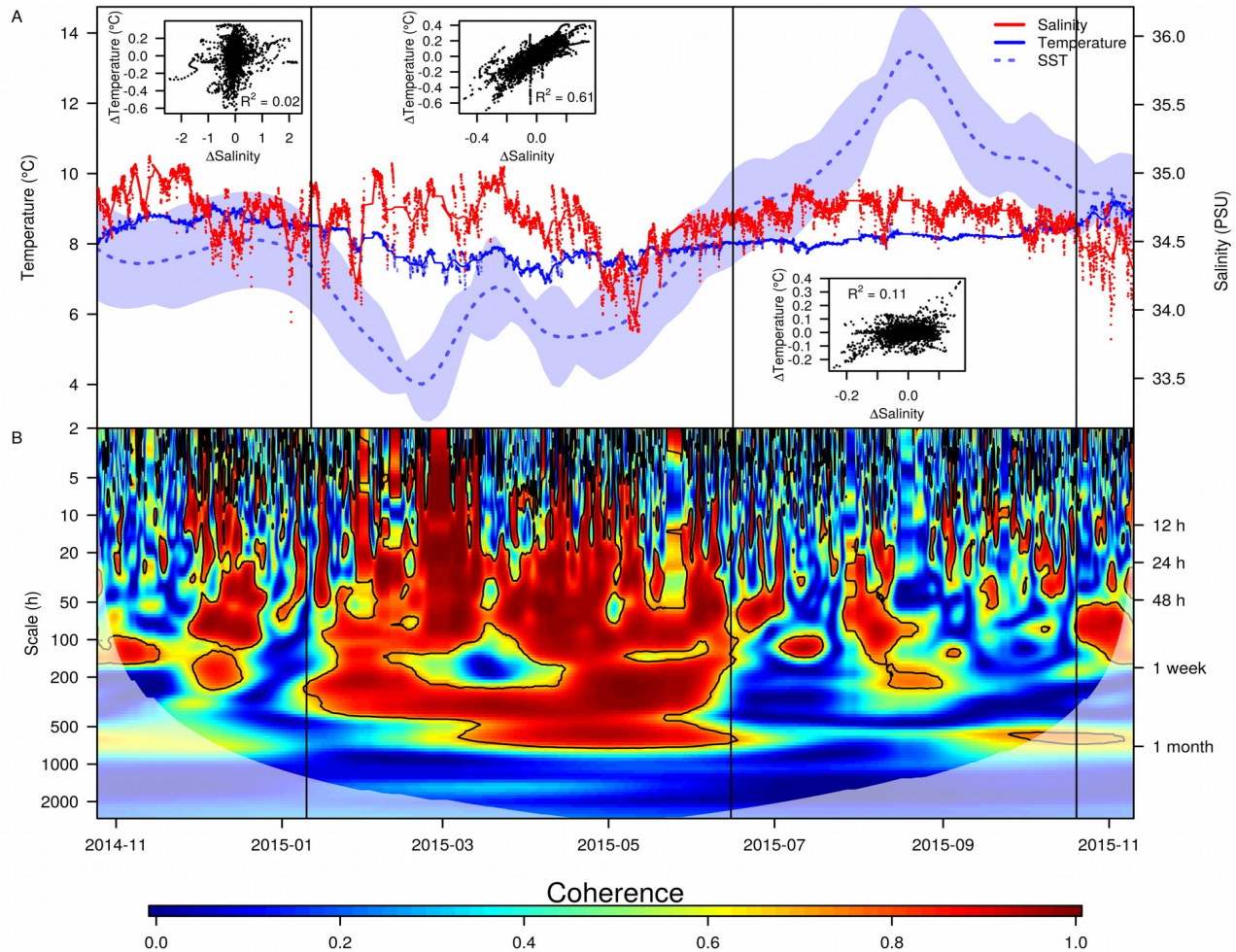
313 **3.1 Hydrography**

314 Bottom water temperature (BWT) varied between 8 and 9 °C in the period November 2014 to February
315 2015, after which it decreased to values between 6.5 and 8 °C (Fig. 2A). From the second half of May
316 onwards BWT values gradually increased again to winter values above 8 °C. Bottom water salinity
317 (BWS) exhibited a fairly weak seasonal signal with values ranging between 34.3 and 35.0 in the period
318 November 2014 - April 2015, followed by a sudden decrease at the end of April to 33.8 and a gradual
319 increase to > 34.5 throughout the remainder of 2015. Whether this is a yearly recurring pattern is not
320 clear from the observatory data (Appendix).

321

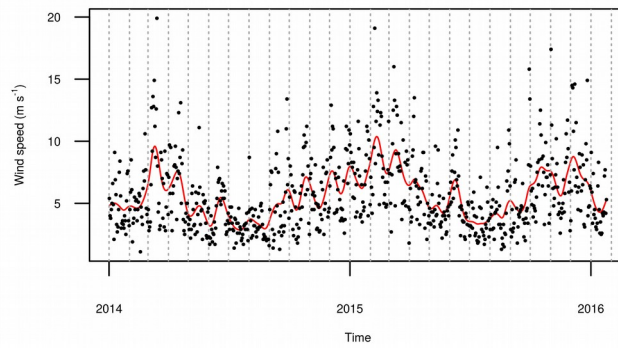
322 A comparison of the 2015 BWT signal with an average sea surface temperature (SST) signal from the
323 MODIS-Aqua satellite revealed three distinct hydrographic periods (Fig. 2A): (1) during early winter
324 (November to January) SST was similar to BWT, (2) from January to May, the SST fell below the
325 BWT, and (3) from June until the end of October, the SST was higher than the BWT.

326 Wavelet coherence analysis of the BWT and BWS revealed strong coherence in spring (Fig. 2B),
327 indicating strong covariation between these signals. This was also reflected in a positive correlation
328 between BWT and BWS changes (Fig. 2A; middle inset). The period of high coherence between BWT
329 and BWS coincided with high wind speeds (Fig. 3A). When SST increased above the bottom water
330 temperature, coherence weakened (Fig. 2A; right inset). CTD data from a maintenance cruise from
331 June 2015 indicated that during this period of low coherence between BWT and BWS, temperature
332 stratification had developed (Fig. 3B). Note that figure 2B shows two artefacts from linear interpolation
333 at the beginning of March and at the end of May, respectively. Since these reside mainly in the lower
334 scales and are localized in time, they do not affect the overall outcome of this analysis.

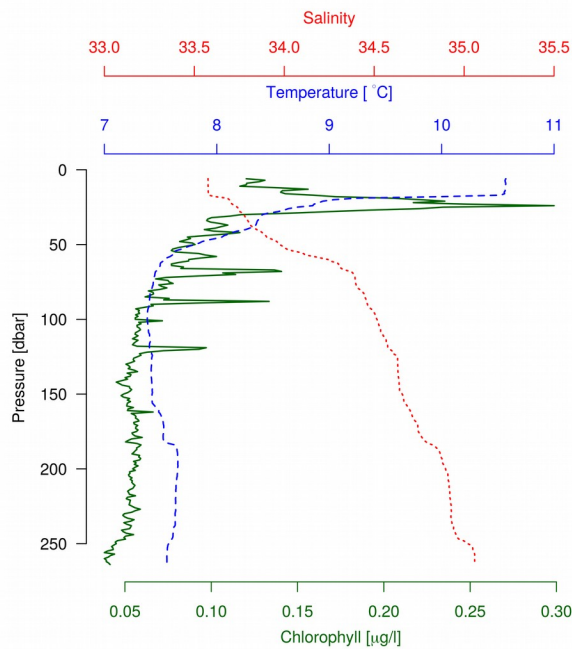


336 Fig. 2: Time series plots (A) of sea surface temperature (SST; blue dashed), bottom water temperature
 337 (BWT; blue solid), and bottom water salinity (BWS; solid red), and wavelet coherence analysis of the
 338 BWT and BWS series (B). The blue envelope around the SST signal (spline) is the approximate 95%
 339 estimation interval based on jackknife residuals. Raw BWT and BWS values are given as points; the
 340 corresponding lines are the smooth signals of a Maximal Overlap Discrete Wavelet Transform
 341 (MODWT)-based multiresolution decomposition, that exclude tidal variability. The small scatterplots
 342 in panel A depict the linear relationships between the first differences (Δ) of BWS and BWT for the
 343 regimes indicated by the vertical lines.

A



B.



345 Fig. 3: Panel A: Wind speed data near Bø from eKlima (black dots) with a smoothed trend line (red).
 346 Winter and spring are characterised by high wind speeds. Panel B: Vertical profile of salinity (red
 347 dotted line), temperature (blue dashed line) and chlorophyll a concentration (green solid line) near the
 348 observatory during a maintenance cruise from June 2015. The summer chlorophyll maximum resides in
 349 the upper mixed layer of the water column.

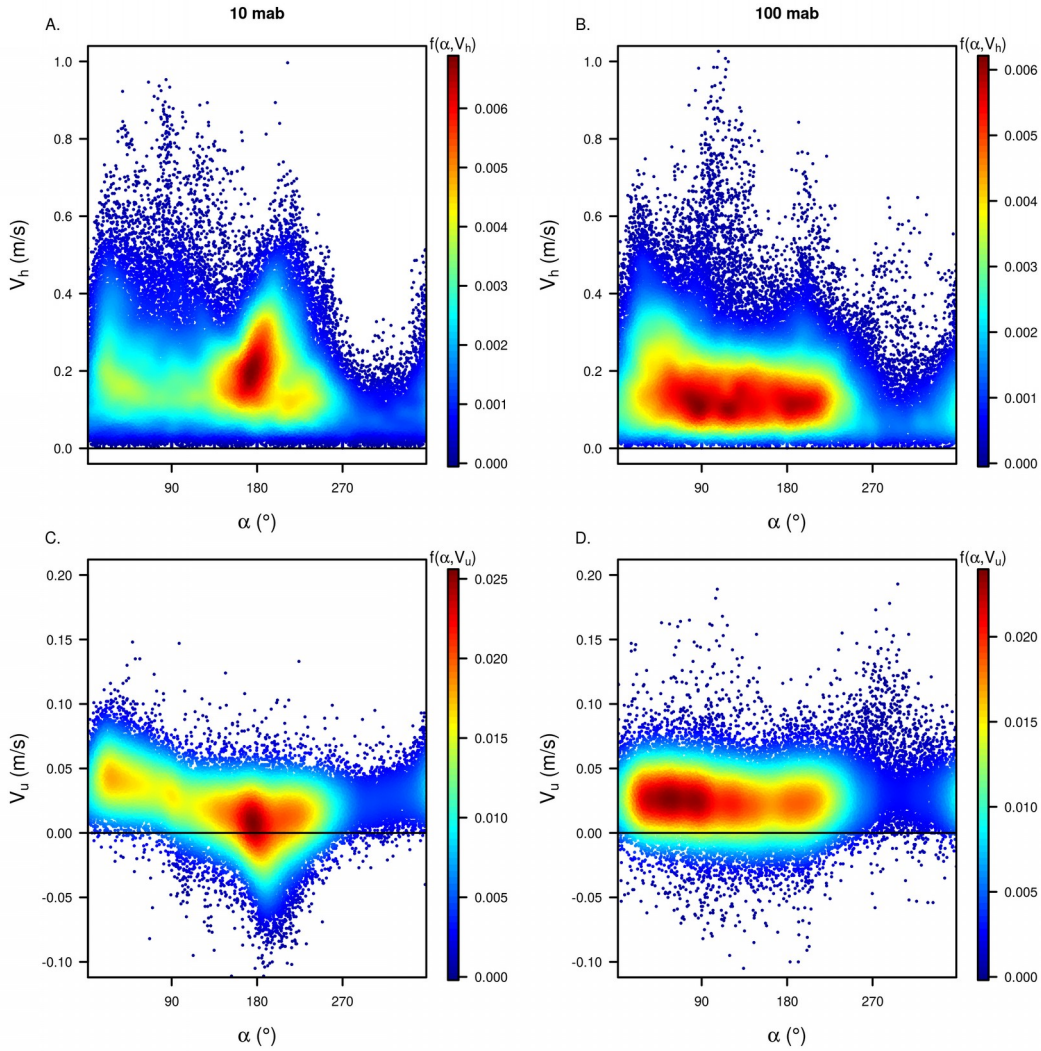
350

351 **3.2 Hydrodynamics**

352 The highest current speeds in the lower 120 m of the water column were 1 m s^{-1} (99.9-percentile of the
353 hourly median values), but 90% of the values were below 0.34 m s^{-1} . In the lower 20 meters the
354 velocity distribution was very similar, with 0.89 m s^{-1} and 0.34 as 99.9- and 90-percentile, respectively.
355 In general, current velocities exhibited similar variation at different depths throughout the water
356 measured column (data not shown). From January to May and in November, events with strong V_{east}
357 and (to a lesser extent) V_{north} components were observed (data not shown), which covered the water
358 column from 0 to 120 mab and often coincided with increased wind stress. But a clear 1:1 relationship
359 with wind speeds was not found (data not shown).

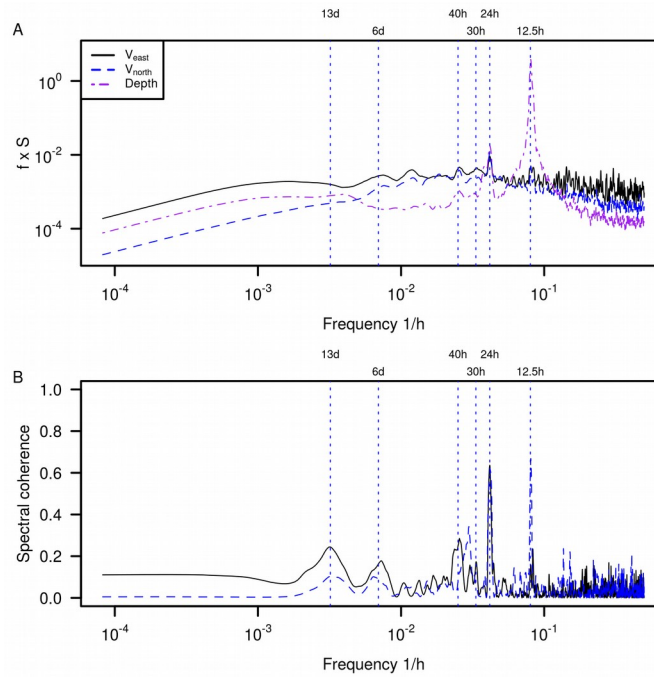
360 Two dominant current directions were observed at 10 mab (Fig. 4A). The vertical velocity component
361 of the LR-ADCP exhibited an upward bias of approximately 2.5 cm s^{-1} , relative to the SR-ADCP
362 measurements (i.e. the distribution of the SR-ADCP vertical velocities at 10 mab was similar to that of
363 the LR-ADCP (Fig. 4C), except that the point cloud was centered on the horizontal axis rather than
364 above it; Appendix). The origin of this bias is currently unknown. Taking this bias into account, south-
365 to south-westward currents were directed downward, whereas north-eastward currents had a positive
366 vertical velocity component due to topographic steering (Fig. 4C; remember the overall upward bias).
367 Higher current velocities in excess of 0.5 m s^{-1} were fairly specific south-to-south-westward, or varied
368 from north to southeast (Fig. 4C). In contrast, at 100 mab low and moderate current velocities ($< 0.4 \text{ m}$
369 s^{-1}) were less specific in direction, but higher velocities tended to cluster along a north-east and east
370 direction (Fig. 4B). No clear relationship between the vertical and horizontal components existed at 100
371 mab (Fig. 4D). Westward currents were rare at both 10 and 100 mab.

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401 The variance-preserving spectrum of water height (i.e. pressure) showed a high contribution of a semi-
402 diurnal and a lower contribution of a diurnal tidal periodicity, indicating that the tidal height is
403 dominated by a semi-diurnal periodicity (Fig. 5A). In contrast, the horizontal velocity components from
404 100 mab showed a predominant diurnal contribution in their overall variance spectrum. This resulted in
405 a clear coherence between the tidal signal (water depth) and V_{north} at both frequencies (the semi-diurnal
406 and diurnal frequency), while coherence of V_{east} at the semidiurnal scale was low. Elevated coherence

407 values were also found at frequencies related to the spring-neap tidal cycle (i.e. 6 and 13 days), but
408 their contribution in the respective spectra (i.e. overall variance) was low. No dominant frequencies
409 were identified in the vertical velocity component at 100 mab. At 10 mab, horizontal velocity
410 components showed similar variability and coherence to tides as at 100 mab (data not shown). The
411 vertical current velocity component at 10 mab exhibited significant diurnal variation, similar to the
412 horizontal components. This variability is visible as the upward and downward tails in figure 4C.



414 Fig. 5: Variance preserving spectrum ($f \times S =$ frequency \times spectrum; panel A) of the horizontal current
 415 velocity components (V_{east} = black solid line, and V_{north} = blue dashed line) and their spectral coherence
 416 (panel B) with the tidal signal (water depth = purple line in spectral plot). Periodicities that are
 417 associated with tides or relevant in this analysis are indicated at the top of the graphs.
 418

419 The residual east and north velocity components at 10 mab averaged $3 \pm 7 \text{ cm s}^{-1}$ and $-5 \pm 5 \text{ cm s}^{-1}$,
 420 respectively and the residual east and north components at 100 mab averaged at $4 \pm 11 \text{ cm s}^{-1}$ and -0.6
 421 $\pm 5 \text{ cm s}^{-1}$, respectively. In the benthic boundary layer (10 mab), the residual current had a predominant
 422 eastward orientation, which changed to south-southwest from May to October in 2015.

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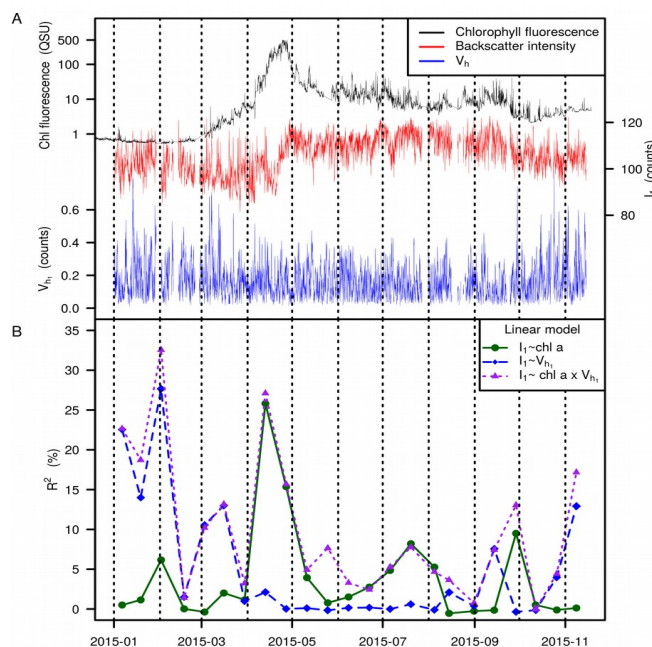
424 **3.3 Acoustic backscatter**

425 Acoustic backscatter in the lowest bin (2 -7 mab) of the LR-ADCP exhibited strong variation at short
 426 time scales (on the order of hours to weeks; Fig. 6A). The overall seasonal trend showed slightly lower
 427 values in February-March, that increased in April, parallel to the increase in chlorophyll a fluorescence
 428 (Fig. 6A). Hereafter, backscatter intensity remained high throughout summer, until a decrease occurred
 429 at the end of September. The latter was mirrored in the chlorophyll a fluorescence. Despite this

430 mirroring of the seasonal pattern in backscatter intensity and chlorophyll a fluorescence in the BBL, no
431 covariance seemed to exist at shorter time scales of a few months (Fig. 7B). To assess the stability or
432 temporary nature of a potential relationship of acoustic backscatter with chlorophyll fluorescence, local
433 (in time) linear regressions were investigated on successive subsets of 2 weeks of data. The predictive
434 power (R^2) of chlorophyll a fluorescence on variability in LR-ADCP backscatter intensity in the lowest
435 bin peaked to 25% during the spring bloom, but varied between 0 and 7% for the rest of the year (Fig.
436 6B).

437

438 Similar analyses showed that bottom current speeds (here used as proxy for sediment resuspension)
439 explained up to 27% of the variability in this backscatter intensity, but only in winter (Fig. 6B). Just as
440 for the relationship with chlorophyll fluorescence, a global relationship over the entire season of
441 backscatter intensity with current speed was not found.



443 Fig. 6: Panel A: Time series of chlorophyll a fluorescence (log-scale), and acoustic backscatter (I_1) and
 444 current speed (V_{h1}) in the bottom bin (2 – 7 mab) of the LR-ADCP. Panel B: R^2 (goodness-of-fit; %)
 445 values from linear regression analyses performed on consecutive subsets of 2 weeks of LR-ADCP data
 446 from the series in panel A. Linear regressions were performed with backscatter intensities (I) and
 447 horizontal current speed (V_h ; used as surrogate for turbidity) from the lowest bin (index 1 in legend)
 448 and chlorophyll fluorescence (chl a) in the benthic boundary layer (log-transformed).
 449

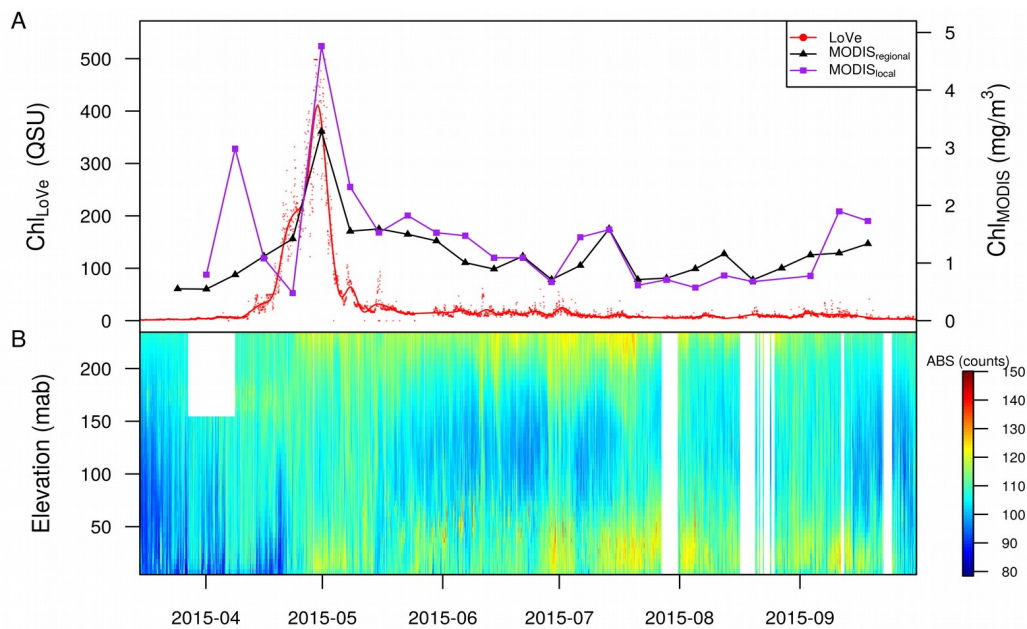
450 **3.4 Phytoplankton bloom conditions at LoVe observatory**

451 The bottom chlorophyll increased from negligible fluorescence in winter to a peak in early May (Fig.
 452 7A). The first visible fluorescence increases in figure 7A followed a peak in chlorophyll concentration
 453 at the surface approximately one week earlier. However, a first very modest increase, which was only
 454 visible in log-transformed fluorescence values, was already found early March (Fig. 6A).

455 After the spring bloom surface chlorophyll values and fluorescence in the benthic boundary layer were
 456 more decoupled. Surface concentrations were still ~25% of those during the spring peak, while bottom
 457 fluorescence was only ~5% of its peak value.

458 During the spring bloom (end of April – beginning of May), when the predictive power of chlorophyll
 459 a fluorescence on variation in backscatter intensity was highest (Fig. 6B), increased backscatter

460 intensities extended from the surface down to the bottom (Fig. 7B). Similar backscatter features,
461 extending over the entire water column are discernible in mid-June, beginning of July, and mid-July in
462 figure 7B. Nevertheless, surface and bottom chlorophyll a signals seemed largely uncoupled
463 throughout summer in comparison to the spring peak.



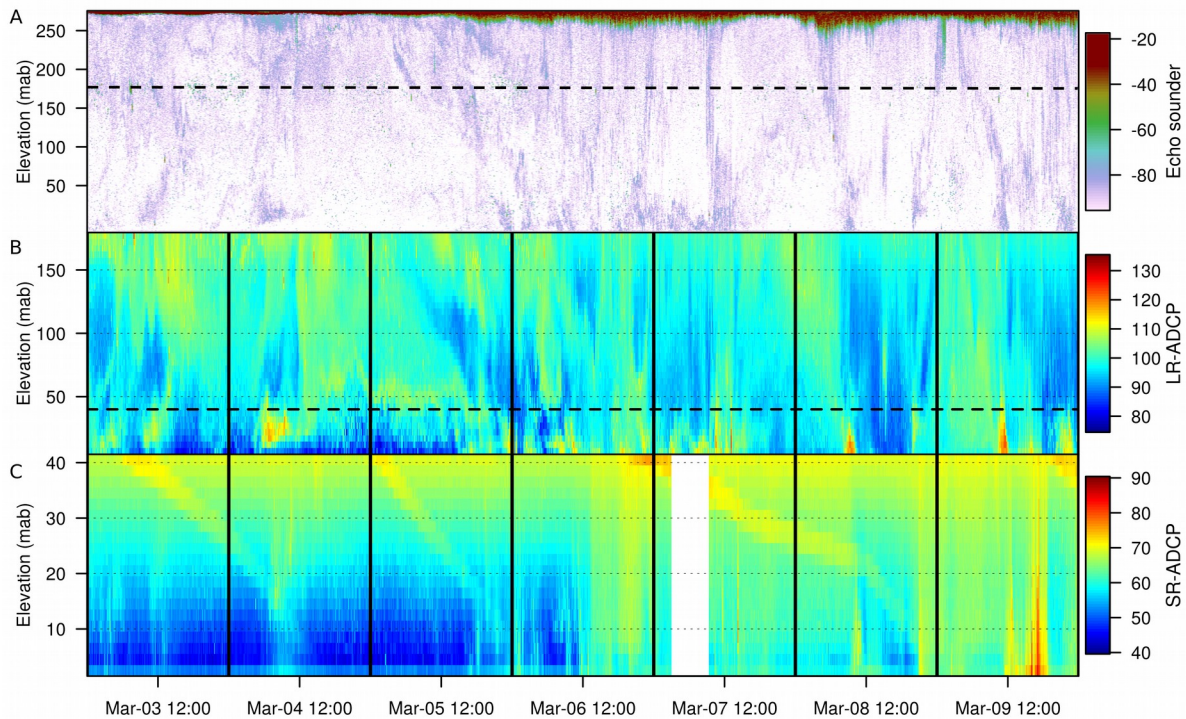
465 Fig. 7: Phytoplankton bloom conditions (A) and acoustic backscatter from the LR-ADCP (B) at LoVe
 466 observatory. Raw chlorophyll fluorescence (left axis in “Quantitative Scientific Units”; red line =
 467 smooth spline; dots = raw data) and surface chlorophyll concentrations from MODIS-Aqua (right axis;
 468 black triangles = regional; purple squares = local) show a consistent pattern throughout 2015.
 469

470 **3.5 Pre-bloom backscatter variability**

471 No SR-ADCP data was available for spring 2015, so the backscatter intensity of both ADCPs and
 472 SIMRAD echosounder was compared for pre-bloom conditions during March 2014 (Fig. 8). The SR-
 473 ADCP (600 kHz) backscatter exhibited a few “descending” backscatter signals on March 3, 5 and 7
 474 (Fig. 8C, lower) for which no corresponding backscatter patterns existed in the LR-ADCP (190 kHz;
 475 Fig. 8B) or echosounder data (70 kHz; Fig. 8A). Similar line patterns were also found in other parts of
 476 the time series, which at present we cannot explain.

477 From March 5 onwards, noise in the echosounder backscatter intensified at the surface (Fig. 8A), which
 478 can be attributed to bubble formation in stormy weather as indicated by the high wind speeds around
 479 that time (Fig. 3A). During this stormy period, patterns of increased echosounder backscatter emerged,
 480 that in some cases reached the bottom. The steepness of these backscatter features suggests strong

481 mixing during this time of the year (section 3.1). Similar backscatter excursions were found in the LR-
482 ADCP, but these were generally less pronounced (Fig. 8B). The SR-ADCP backscatter (Fig. 8C)
483 showed a sudden increase on March 5 and 6 that roughly corresponds to backscatter increases in the
484 LR-ADCP. During this stormy period both ADCPs showed increased backscatter at the bottom.



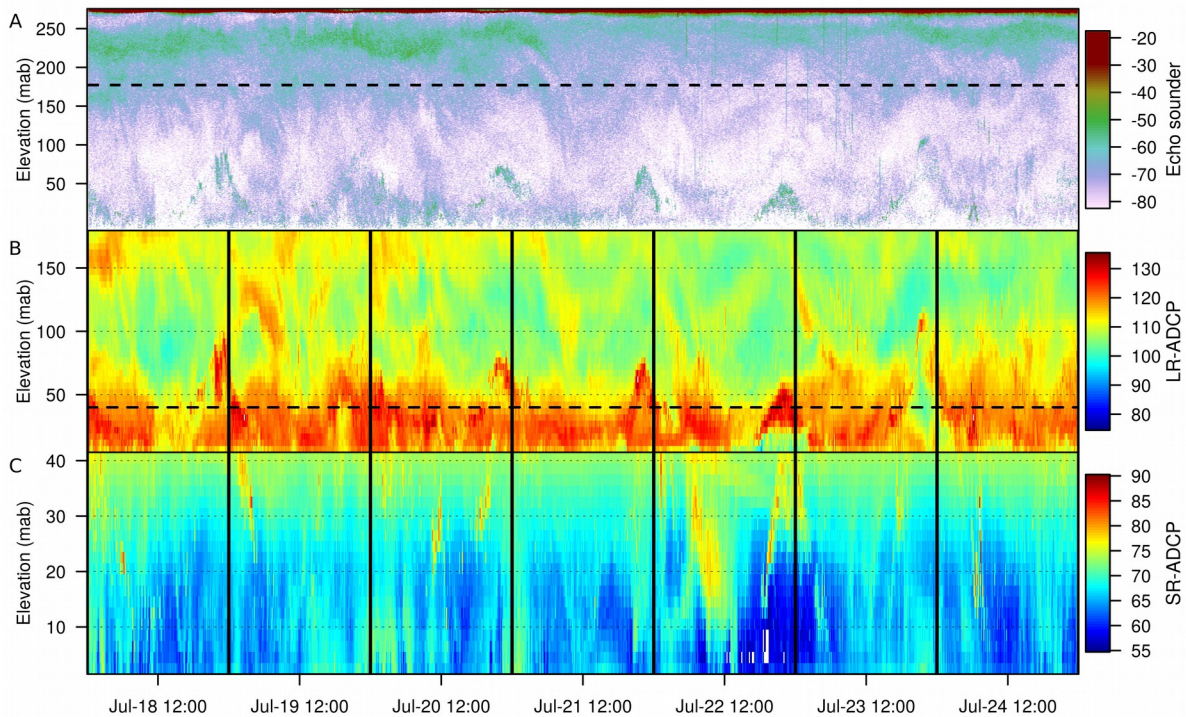
485 Fig. 8: Acoustic backscatter intensity from the echo sounder (A), the LR-ADCP (B), and the SR-ADCP
 486 (C) throughout the water column over time for the March 2014 (pre-bloom conditions). Intensities are
 487 in dB for the echo sounder, and in corrected counts for the ADCPs (Materials and methods). Horizontal
 488 dashed lines in the upper and middle graphs indicate the range of the instruments in the middle and
 489 lower graphs.

490

491 **3.6 Post-bloom backscatter variability**

492 A qualitative comparison of backscatter intensities among the ADCPs and echosounder during post-
 493 bloom conditions was made with data from July 2015 (Fig. 9). Above 150 mab, increased backscatter
 494 in the echosounder data reflected the presence of fish (blue-green colour; roughly -60 – -50 dB) and
 495 smaller material (roughly < -65 dB, purple; Fig. 9A). Below 100 mab, a clear up- and downward
 496 backscatter pattern with intensities between -60 and -50 dB was visible in the echosounder data, with a
 497 daily periodicity (Fig. 9A). The backscatter intensity ascended at the end of the day, and reached a
 498 maximal height above the bottom just before midnight. This backscatter signal descended towards the

499 seafloor during the late night and remained there during daytime. In the LR-ADCP data the migrating
500 patterns of increased backscatter (roughly > 120 counts, red) were wider, and the echosounder patterns
501 corresponded to the upper edges with highest intensities (> 130 counts, deep red; Fig. 9B). The SR-
502 ADCP data again showed the migrating edges (> 75 , yellow-red, Fig. 9C) from the LR-ADCP patterns,
503 but the contrast with the background was weaker than in the echosounder profiles.



504 Fig. 9: Acoustic backscatter intensity from the echo sounder (upper), the LR-ADCP (middle), and the
 505 SR-ADCP throughout the water column over time for July 2015 (post-bloom conditions). Intensities
 506 are in dB for the echo sounder, and in corrected counts for the ADCPs (Materials and methods).
 507 Horizontal dashed lines in the upper and middle graphs indicate the range of the instruments in the
 508 middle and lower graphs.
 509

510 4. Discussion

511 4.1 Residual water movement and organic matter origin

512 Available data suggest that the particulate organic matter (POM) arriving at the CWC of the LoVe
 513 observatory is likely of local origin. The horizontal residual transport at 10 and 100 mab is in the order
 514 of $5 - 10 \text{ cm s}^{-1}$. As surface currents could not be reliably estimated from the LR-ADCP readings, we
 515 assume a similar residual current for the upper part of the water column. This implies that POM is
 516 transported over distances of 4 – 10 km per day. Assuming further a passive settling velocity of 50 -
 517 100 m d^{-1} for phytoplankton (Iversen and Ploug 2010) at the LoVe observatory (depth: $\sim 260 \text{ m}$), the
 518 settling POM is likely produced within $\sim 20 \text{ km}$ from the station, i.e. within the Hola trough area and
 519 neighbouring coast. This is in line with the increased fluorescence over a trough relative to the

520 neighbouring banks reported for a region further North (Nordby et al. 1999). Nevertheless, the
521 neighbouring bank, Vesterålsgrunnen, may also be a potentially important source of organic material
522 via southward down-slope bottom currents (Fig. 4). The suggested local origin of the POM in the
523 trough is further supported by particle tracking simulations that revealed a residence time of ~1 week
524 for particles released in the surface layer (Silberberger et al. 2016). Based on primary production
525 estimates of $130 \text{ g C m}^{-2} \text{ y}^{-1}$ from Skogen et al. (2007) and taking a surface area of 350 km^2 for the Hola
526 trough (based on bathymetric data from the Mareano website: <http://www.mareano.no>), the total
527 organic matter production is estimated at $45 \cdot 10^3 \text{ tons C y}^{-1}$. Oxygen consumption rates measured at
528 the Traena reef (Norway) using the aquatic eddy covariance method indicate an organic matter demand
529 of CWC communities of $409 \text{ g C m}^{-2} \text{ y}^{-1}$ (Cathalot et al. 2015). With a surface area of 3.32 km^2 of
530 CWCs in the Hola trough (based on visual classification of the bathymetric data from the Mareano
531 website), the total CWC-reef organic matter demand in the Hola trough amounts to $1.4 \cdot 10^3 \text{ tons C y}^{-1}$,
532 which is equivalent to ~3 % of the total primary production above the trough. The export production
533 for the northern troughs is estimated at $57 \text{ g C m}^{-2} \text{ y}^{-1}$ (Slagstad et al. 1999) or 43% of the total primary
534 production. These rough estimates indicate that the local primary production and export into the Hola
535 trough is sufficient to sustain the reef communities.

536

537 ***4.2 Hydrography and vertical transport***

538 CWC communities depend on vertical transport of organic matter from surface primary production for
539 their food supply (Thiem et al. 2006; Davies et al. 2009). Turbulent mixing is considered a key factor
540 in this vertical transport on continental shelves and slopes (White et al. 2005; Wagner et al. 2011), but
541 its strength depends on the governing hydrography. The hydrographic conditions at LoVe observatory

542 show considerable seasonal variation, consistent with earlier reported vertical profiles of salinity and
543 temperature (Sundby 1984, Zhu et al. 2009). The water column is completely mixed in winter – spring.
544 This was in our analysis reflected in the similarity between the temperature at the surface (derived from
545 MODIS data) and the bottom (LoVe data). Bottom water salinity was during winter typical of a
546 mixture of NAW (salinity typically ≥ 35) and NCW (salinity typically ≤ 34.5) water masses. The
547 reason for this mixed signature is the progressive mixing of these water masses as they move northward
548 towards the Barents Sea (Helland-Hansen and Nansen 1909, Pedersen et al. 2005). This is consistent
549 with vertically homogeneous water column in terms of density as reported by Sundby (1984) for
550 nearby troughs in spring, and the notion of a deep wedge-shaped NCC that take the form of a coastal jet
551 in winter (Ikeda et al. 1988, Nordby et al. 1999, Sætre 2007, Skagseth et al. 2011). The lack of a
552 density stratification, implies that there is little resistance against turbulent downwelling induced by the
553 increased wind shear at this time of year. In addition, this coastal jet is known to produce mesoscale
554 eddies in an interaction with bottom topography (Ikeda et al. 1988, Pedersen et al. 2005). Such eddies
555 transport isolated packages of water with distinct temperature and/or salinity signatures, which
556 (together with smaller scale turbulence) could explain our observed coherence between temperature
557 and salinity signals at the LoVe observatory at scales up to a few weeks. It is understood that mesoscale
558 eddies concentrate organic matter, harbour increased levels of biomass such as zooplankton and fish
559 larvae, and transport it to deeper layers (Zhu et al. 2009, Godø et al. 2012a, Waite et al. 2016). Beside
560 turbulent mixing and eddy-mediated downwelling, cooling-induced cascading (e.g. Ulses et al. 2008)
561 of water masses from over the nearby bank could also explain the high coherence between bottom
562 water salinity (BWS) and temperature (BWT). This is supported by the sudden decrease in sea surface
563 temperature (SST) in February–March, at the beginning of the period of high coherence. Such cold-
564 water cascading has been observed in canyons along the continental margin (Canals et al. 2006), and
565 could provide an additional means of transport of organic matter produced above the nearby bank

566 towards the reef communities. Unfortunately, due to several periods of ADCP malfunctioning in early
567 spring, current velocity data are inconclusive to support this type of transport.

568

569 Towards summer, SST values increase substantially above the bottom water temperature as part of a
570 development of temperature stratification. This was verified by CTD casts during a maintenance cruise
571 in summer 2015, and corresponds with patterns reported by Zhu et al. (2009). Such a seasonal
572 stratification is common for the region and lasts until autumn. Stratification reduces turbulent
573 diffusivity and counteracts the vertical turbulent transport induced by wind shear. In addition, wind
574 stress decreases to a seasonal minimum in summer at the LoVe observatory. In the northern part of the
575 Norwegian continental shelf the summer minimum in wind stress seems to coincide with a minimum in
576 eddy kinetic energy (Andersson et al. 2011), and seasonality in wind forcing is considered a driver of
577 seasonality in the NCC (Skagseth et al. 2011). Although the distinction in water masses is less clear in
578 the northern part of the Norwegian continental shelf, the observed summer stratification fits within the
579 commonly accepted picture of a deep narrow coastal jet (NCC) in winter, that flattens to a layer of
580 NCW that covers the larger part of the continental shelf in summer, with somewhat denser NAW in the
581 trenches underneath (Nordby et al. 1999, Skagseth et al. 2011). The weakening of this coastal jet and
582 reduced turbulence can explain the absence of coherence between the bottom water temperature and
583 salinity in our analyses, and implies a reduced transport of surface organic matter to the reefs
584 throughout summer. This reduced vertical transport, together with lower primary production in the
585 surface layer, results in lower chlorophyll a fluorescence at the reefs, reflecting low phytodetritus
586 quantity and quality on the reefs. Note that the moderating role of hydrography for vertical transport
587 enhancement has important implication in a climate change context, since earlier and stronger water-
588 column stratification on the continental shelf (Holt et al. 2010) may shorten the period of intense
589 mixing, thus reducing the duration and intensity of phytodetritus supply to the benthic environment

590 (Järnegren and Kutti 2014).

591

592 **4.3 Role of local hydrodynamics**

593 At LoVe observatory, tides are the dominant driver of water movement, with instantaneous current
594 speeds being roughly 3 - 5 times stronger than residual currents. The resulting shear stress may bring
595 and keep POM in suspension in the benthic boundary layer and make it more available to filter feeders
596 (Jones et al. 1998; Guihen et al. 2013; Davies et al. 2009). In addition, tidal currents enlarge the surface
597 area of the local primary production that can be filtered by the reef communities. Considering the
598 general counter-clockwise circulation in the Hola trough (Bøe et al. 2009) and the position of the
599 observatory relative to this circulation, the accessibility mainly extends towards the shelf break, where
600 primary production tends to be higher (Slagstad et al. 1999). Furthermore, tidal currents with diel
601 periodicity repeatedly ‘pump’ phytodetritus through the trough and hereby over the CWC reefs, which
602 increases the trapping efficiency of particulate material by the filter-feeding community. Hence, tidal
603 current dynamics not only act as an important transport component, but also as a catalyst for enhanced
604 trapping of the locally produced organic matter by the reef communities. This may partially
605 compensate for the lower supply from the surface and the lower nutritional quality of the phytodetritus
606 under stratified conditions.

607

608 **4.4 A seasonal menu**

609 In winter, suspended matter concentrations are generally low, except during isolated storm events when
610 increased backscatter can be observed. The higher particle concentrations can be caused by sediment
611 resuspension, as indicated by the concurrent increases in bottom currents and relatively high
612 explanatory value of the local linear regression with horizontal current speed. However, initial

613 increases in fluorescence also coincided with this period of stormy weather. Indeed, phytoplankton
614 production in winter and early spring (prior to the bloom) can also represent a substantial carbon export
615 flux from the surface to the benthos during stormy weather (Thomsen et al. 2014), and appears to be
616 more common than expected (e.g. Bishop and coworkers 2016). Particularly, the picoplankton grows
617 all year long and may contribute to these early aggregates (Behrenfeld and Boss 2014). Nevertheless,
618 the initial increase in fluorescence in March was not translated to substantial R^2 values for the
619 regression of acoustic backscatter intensity with chlorophyll a fluorescence, suggesting that the
620 acoustic backscatter in our data was mainly due to resuspended material. Increased turbidity during a
621 resuspension event on March 9 and March 14 of 2014 were also observed in the still camera images
622 from the observatory (Fig. 10). In summary, at the LoVe observatory stormy conditions in early spring
623 can cause increased concentrations of suspended matter in the water column that mainly seems to
624 consist of older resuspended material. However, small quantities of fresh phytoplankton/detritus from
625 early production are present in the benthic boundary layer and may represent an important higher
626 quality component of the available food to the reef communities, that is otherwise low in nutritional
627 value this early in the season. *Lophelia pertusa* can tolerate extended periods of food deprivation by,
628 albeit modest, reductions in its respiration rate (Larsson et al. 2013). However, the modest food supply
629 may be of particular importance for the reproductive season, considering that Norwegian *L. pertusa*
630 spawns in late winter (Waller 2005; Brooke and Järnegren 2013).

631

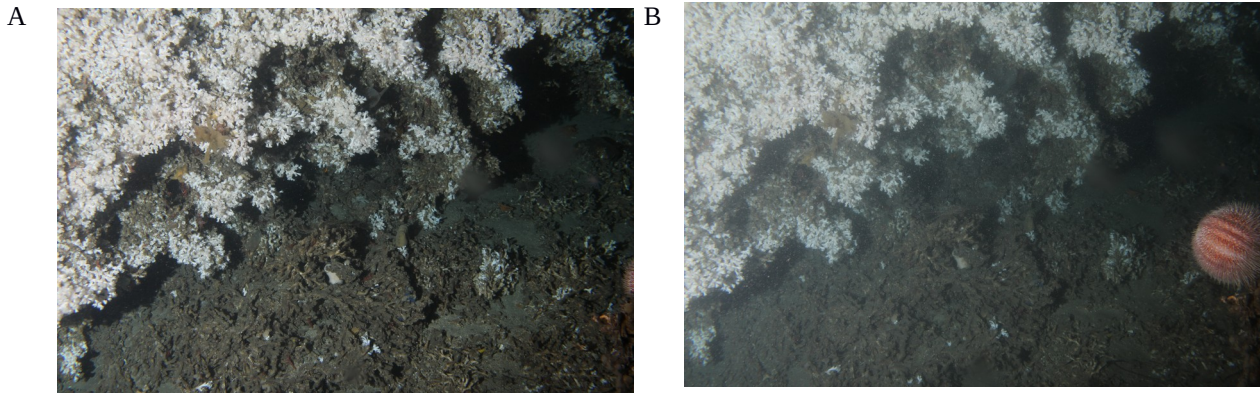


Fig. 10: Still camera images of the cold-water coral reef, dominated by *Lophelia pertusa*, near the satellite unit. The images were taken 3:31 UTC (A) and 17:19 UTC (B) on March 14, 2014. A resuspension event occurred in the afternoon, resulting in increased turbidity (B).

632

633

634 Phytoplankton biomass in surface waters near the observatory peaks in April – May ($3 - 4.5 \text{ mg Chl m}^{-3}$) and during a secondary bloom in July ($1.5 - 2 \text{ mg m}^{-3}$). Strong mixing rapidly transports the fresh
 635 3) and during a secondary bloom in July ($1.5 - 2 \text{ mg m}^{-3}$). Strong mixing rapidly transports the fresh
 636 material to the BBL. The observed chlorophyll a fluorescence explained respectively up to 25% and
 637 7% of the variability in backscatter intensity in the LR-ADCP bottom bin during these two periods,
 638 indicating that phytodetritus contributed substantially to the suspended material in the BBL. The LR-
 639 ADCP picked up pulses of vertical organic matter transport as repeated increases of backscatter
 640 intensity throughout the entire water column during this bloom period, reflecting a strong surface-to-
 641 bottom connectivity of high quality phytodetritus to the CWC reef communities.

642

643 Senescence of the spring bloom in the second half of May coincides with an increase of the SST above
 644 the BWT and the development of water-column stratification, which impairs the downward transport of
 645 surface-derived particulate material. This was supported by the low acoustic backscatter intensities at
 646 mid-depth relative to the surface in summer and the entire water column during the periods of full
 647 water-column mixing. In addition, the reduced connectivity between surface and bottom in summer

648 was manifested in the decoupling of two phytoplankton signals at the surface and near the bottom. The
649 observed comparatively low chlorophyll fluorescence near the bottom in summer indicates that
650 phytodetritus concentration and/or quality must have been substantially reduced near the CWC reefs
651 relative to the spring mixing condition (Beaulieu 2002). Note, however, that chlorophyll sensors that
652 measure at the 685nm wavelength can also respond to other optically active substances within the
653 DOM pool. Fluorescence variability as measured by the fluorescence sensor may therefore not have a
654 linear response to chlorophyll a dynamics. Still, several deep mixing events occurred during the
655 stratification regime, when backscatter intensities temporarily increased again throughout the water
656 column, hinting at a temporary coupling between surface and bottom. These are probably isolated
657 eddies that still may originate from dynamic shelf waters. They have been previously identified from
658 echosounder data as specific patterns of increased backscatter (Godø et al. 2012a), and may present
659 important concentration and vertical transport mechanisms during a period of reduced vertical
660 exchange (Waite et al. 2016).

661

662 In summer, when fresh phytodetritus at the seafloor was scarce, we observed a pronounced diurnal
663 pattern of elevated acoustic backscatter intensity in the lower 100 meters of the water column, which
664 suggests that migrating organisms were a dominant source of backscatter. Migration patterns above
665 CWC reefs were also reported for the Gulf of Mexico (Davies et al. 2010; Mienis et al. 2012).
666 The migration patterns in backscatter intensity between -60 and -50 dB in the calibrated echosounder
667 were also pickup by the SR-ADCP and can be attributed to fish. However, the broader patterns in the
668 LR-ADCP, of which the upper edge corresponds to the migration patterns in the echosounder and SR-
669 ADCP, suggest that an additional source of backscatter must have been present. The scattering model
670 of Lavery et al. (2007) suggests that this scattering source, with a high sensitivity at 190 kHz (LR-
671 ADCP), but low sensitivity at 70 kHz (echosounder) and 600 kHz (SR-ADCP), may well correspond to

672 euphausiids. Several studies have indicated that zooplankton can be an important food source for cold-
673 water corals at least for a part of the year (Kiriakoulakis et al. 2005; Naumann et al. 2011; Orejas et al.
674 2016) and feed on whatever zooplankton is available, which can vary spatially and temporally (Dodds
675 et al. 2009). Zooplankton is hypothesized to present an important food source in permanently stratified
676 tropical (Hebbeln et al. 2014) and oligotrophic waters (Carlier et al. 2009). Lipid analyses have pointed
677 out that particularly copepods are readily taken up by cold-water corals and can at times be their
678 primary food source at the North-East Atlantic margin (Kiriakoulakis et al. 2005). Both copepods and
679 euphausiids have been used in feeding experiments (e.g. Dodds et al. 2007; Orejas et al. 2016), and
680 both can be part of the natural CWC diet (Dodds et al. 2009; Khripounoff et al. 2014). The specific
681 backscatter profiles suggest that the migrating zooplankton were most likely euphausiids, while
682 indications for copepod migration – which should be visible in the SR-ADCP acoustics (600 kHz;
683 Lavery et al. 2007) – were not found.

684 *Meganyctiphanes norvegica*, one of the most abundant euphausiid species on the Norwegian shelf, is
685 an opportunistic omnivorous feeder that, depending on food availability, can shift between benthic
686 feeding on mainly phytodetritus and a more carnivorous lifestyle with diurnal vertical migration
687 (Schmidt 2010). The absence of copepods in the backscatter signal of the SR-ADCP could be caused
688 by avoidance behaviour of the copepods towards their potential predator, *M. norvegica*, which can
689 reside close to the bottom during daytime (Falk-Petersen et al. 2000; Dalpadado 2006; Schmidt 2010).
690 The copepods may therefore have been out of range of the SR-ADCP. Although we lack zooplankton
691 surveys for backscatter calibration and ground-truthing, our observations are inline with a vertical
692 migration after the spring bloom by zooplankton. This zooplankton migration is not a direct evidence
693 of zooplankton feeding by CWC or associated fauna, but polyp feeding activity of *L. pertusa* increased
694 from the beginning of May (Osterloff et al. 2016a).

695

696 Zooplankton has been shown to comprise a substantial part of the cold-water coral diet in oligotrophic
697 regions (Carlier et al. 2009). CWC feeding on zooplankton at the LoVe observatory throughout
698 summer would compensate for the scarcity of fresh phytodetritus in the lower part of the Hola trough
699 during summer in two ways, and explain the comparatively high zooplankton diet contribution for the
700 nearby Traena communities (Van Oevelen et al. 2018). Firstly, diurnally migrating zooplankton grazes
701 in the upper water column at night and bridges the distance that passively sinking organic matter has to
702 travel to reach the BBL. In addition, fecal pellets tend to sink fast and may provide another form of flux
703 enhancement (Youngbluth et al. 1989). This zooplankton-mediated transport of organic matter is also
704 less dependent on water column mixing, since diurnal vertical migration behaviour does not depend on
705 stratification conditions (Baumgartner et al. 2011). Secondly, zooplankton grazing may act as an
706 intermediate step that upgrades the nutritional value of the CWC diet by concentrating particular
707 elements or nutritional components. For example, the similarity in C/N ratio between CWCs and
708 zooplankton (e.g. Mueller et al. 2014) may increase the efficiency of N acquisition by the CWCs and
709 compensate for the higher C/N ratio that is generally observed for aged phytodetritus (e.g. Beaulieu
710 2002). Zooplankton is also richer in poly-unsaturated fatty acids (PUFAs) than sinking detritus and
711 may present an essential PUFA source to benthic communities (e.g. Tiselius et al. 2012). Such an
712 upgrade in food quality would compensate for the deteriorating quality of the algal material throughout
713 summer, particularly in the case of *M. norvegica* which is known to be predominantly phytophagous in
714 spring and summer (Schmidt 2010). A similar seasonal succession in coral diet was also suggested for
715 corals living in a canyon in the Bay of Biscay (Khrpounoff et al. 2014).

716

717 **5. Conclusions**

718 Ocean observatories are a means to elucidate oceanic processes over extended spatial scales. In this
719 study, data from a new observatory on the Norwegian continental shelf were used to shed light on the

720 seasonal importance of physical and biological drivers of a nearby cold-water coral reef.

721

722 CWC reefs in the Hola trough receive organic matter from local primary production that is mixed down
723 to the bottom by strong turbulence. However, water-column mixing is reduced in summer due to
724 stratification, resulting in an impaired supply of phytodetritus to the reef communities.

725

726 Horizontal currents are predominantly tidally driven in the trough and enhance the accessibility of
727 organic matter to the reef communities by extending the horizontal range of organic matter transport to
728 the larger part of the trough. The consistency in current direction and repetitive character of the
729 currents probably enhances the capturing efficiency of the filter feeders by repeatedly flushing
730 phytodetritus past the reef communities.

731

732 Our results suggest that the reduced supply of fresh phytodetritus in summer at the Lofoten-Vesterålen
733 observatory is compensated by a seasonal succession in food type. Vertically migrating zooplankton
734 may counterbalance the observed lower phytodetritus availability in summer by shunting passive
735 vertical transport of fresh organic material and upgrading the nutritional value of the food for the filter
736 feeders. Food deprivation seemed to be limited to the non-productive winter season, when only storm-
737 induced resuspension of (low quality) particles into the bottom water.

738

739 Although many of the investigated signals did not provide direct quantitative evidence, for instance due
740 to absence of calibrations and ground-truth data, a consistent picture emerged by combining different
741 sources of information. Studies like the one presented can provide a valuable basis to give direction to
742 more dedicated in-depth campaigns. Our study contributes to a growing body of literature that
743 illustrates the vast potential of large permanent research infrastructure like the LoVe observatory.

744

745 **Appendix: Data quality of the Lofoten-Vesterålen ocean observatory (Statoil)**

746

747 **References**

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