Assessment of weekly zooplankton monitoring at coastal station S on the Faroe Shelf

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Abstract

This report is intended to document continuing efforts to optimize the monitoring of zooplankton on the Faroe shelf. The present monitoring system, which enables weekly sampling, is based on sampling using a zooplankton net installation on land coupled to an underwater pumping system. A comparison between samples collected on land and towed samples yielded poor results with the land samples generally showing considerably smaller abundances. However, the zooplankton seasonal succession followed the seasonal succession in chlorophyll *a* and the land samples of the smallest organisms such as copepod nauplii look realistic. Unfortunately, the towed samples were collected with a 200 µm net whereas a 100 µm net was used for the land samples. This prevented a quantitative comparison for the smallest organisms and may also have affected the results more generally. Another possible reason for the poor correspondence between towed and land samples may be heavy predation in the inlet to the land station. With the inlet located on the bottom at 18 m depth, the land samples are drawn from the benthic boundary layer, whereas the towed samples are from a water column extending from 50 m depth to the surface in deeper water close to the inlet. It has generally been assumed that the strong tidal currents mix the zooplankton both vertically and horizontally to such an extent that the land and towed samples are drawn from the same habitat, but the poor results from the comparison cast this in doubt. If the monitoring at the land station is to be continued, we recommend a further set of comparative sampling. This should include sampling at various depths with a towed multi-net to investigate possible vertical gradients in zooplankton abundance. In addition, comparative sampling on land and at sea should be repeated, but with the same mesh size. The towed sampling should be in triplicate, at the least.

1. Introduction

Zooplankton are heterotrophic organisms drifting in the ocean. Generally, the zooplankton abundance on the Faroe shelf is limited during winter, but during the summer season blooms are recurrent. The zooplankton species composition can be divided into three major groups:

- The first group is the neritic holoplankton, of which the copepods *Temora longicornis* and *Acartia* sp. are usually the most abundant. Other commonly found copepods are *Pseudocalanus elongatus* and *Microcalanus* sp. In addition cladocerans, *Sagitta* (chaetognaths), *Oikopleura* (appendicularians) and *Limacina* (molluscs) are more or less commonly found.
- The second group is the meroplankton. A large number of different species are found in highly variable concentrations. During spring, barnacle larvae are usually by far the most abundant. Other commonly found meroplankton are decapod larvae, bivalvia veliger larvae and polychaeta larvae as well as ichthyoplankton.
- The third group contains the zooplankton species that were originally advected from the oceanic environment onto the shelf. There are two main copepod species in this category, *Calanus finmarchicus* and *Oithona* sp. Of these two, *C. finmarchicus* is ecologically the most important species.

Existing monitoring of zooplankton on the Faroe shelf includes two recurrent annual cruises: one placed in late April and one placed in the second half of June. These monitoring programs have revealed substantial variations in zooplankton species abundances (Gaard 1999; Jacobsen et al. 2018) as well as total biomass of zooplankton (Jacobsen et al. 2019). The relative abundance of the copepod *T. longicornis* steadily increased in the period 1990's-2015, while the relative abundance of *Acartia* sp. decreased during the same period (www.hav.fo). Furthermore, phenological changes in the species *C. finmarchicus* have been observed (Jacobsen et al. 2018). Interannual variability in emergence from dormancy, primary production (Jacobsen et al. 2018), advection (Gaard and Hansen 2000) and strong within-year variability of the mortality rate (Jacobsen et al. 2019) affect the abundance and composition of the shelf zooplankton, and thus variability at the zooplankton level is of a complex nature and may be difficult to understand. The variations in zooplankton abundance affect next level trophic species i.e. fish larvae growth and survival (Jacobsen et al. 2019), and subsequently also higher level trophic species such as the commercially important fish stocks of cod and haddock and many seabird species (Gaard et al. 2002). A weekly zooplankton monitoring program is therefore warranted. Studies indicate that zooplankton variability can be adequately indexed by within-year changes in abundance, if the temporal resolution of the time series is two weeks (Ji et al. 2010).

To increase our understanding of the observed interannual variability and trends in zooplankton species composition and abundance on the Faroe shelf weekly monitoring of zooplankton at a fixed land based station (station S) on the central shelf was initiated. Samples for chlorophyll *a*, nutrients (Nitrate, Silicate and Phospate) and salinity have been collected weekly at the station since 1997, and temperature has been monitored continuously since 2002. These environmental data have been widely used in the research of the Faroe shelf ecosystem (Hansen et al. 2005; Larsen et al. 2008; Debes et al. 2008; Rasmussen et al. 2014; Eliasen et al. 2017; Bonitz et al. 2018; Jacobsen et al. 2019). The current work is an effort to expand the Faroe shelf monitoring program at the land based station S and ultimately aims to increase our overall understanding of the Faroe shelf ecosystem functioning. This report assesses the land based zooplankton data collected to date by comparing the data with data collected with the Faroese research vessel and by examining the data in relation to the seasonal development in chlorophyll *a*.

2. Materials and Methods

2.1 Sampling at station S

The main data set is from samples obtained from 18 m depth off the village Skopun, station S (61°54'N, 6°53'W) (Fig. 1), in 2018-2019. The station pumps large amounts of seawater (about 15 tons per minute) at a location where the water column is well mixed from surface to bottom, and provides good representation of the central water mass on the Faroe Shelf (Eliasen et al. 2017).

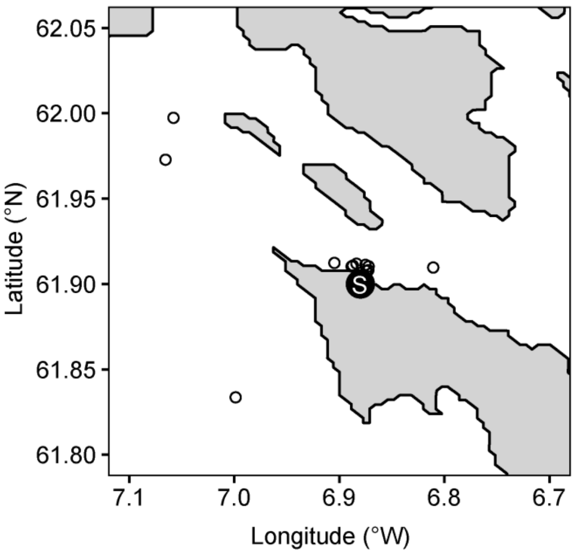

Fig 1 Location of the land based station S. Open circles (o) show towed zooplankton sampling stations used for comparison of samples collected at station S.

Zooplankton samples were collected weekly at the same time as samples for chlorophyll *a* were collected. The samples were collected during the day between 8:00 and 16:00 during the growing season March-September. Zooplankton samples were collected using a net with 100 µm meshes. The net is fixated on land and coupled to an underwater pump, which pumps approximately 195 L min^{-1}. A timer stops the pump after 60 minutes giving a total of 11.7 m^3 of filtered water. The zooplankton sampling setup is shown in Fig. 2.

Fig 2 The zooplankton sampling setup at station S.

After collection the samples were immediately transported to the Faroe Marine Research Institute's laboratory where one half was preserved in 4% formaldehyd (for microscopic analysis) and the other half was preserved in 70% ethanol (for DNA analysis). Before processing, zooplankton samples were purged of formaldehyd and sub sampled with a Motoda cylinder splitter. Classification of the aliquots was done manually by traditional taxonomic procedure using a microscope. Chlorophyll *a* samples were measured spectrophotometrically according to Parsons et al. (1984).

2.2 Sampling with R/V "Magnus Heinason"

To assess the validity of the zooplankton collected at station S, zooplankton samples were collected by tow with R/V "Magnus Heinason" 12 times in close proximity to station S during the 2018-2019 growing season (Fig. 1, Table 1). Zooplankton was collected at station S simultaneously and the two were then compared.

Table 1 Metadata summary of towed zooplankton samples collected with R/V Magnus Heinason.

Station	Date	Time	Bottom depth (m)	Latitude	Longitude	Net type	Mesh size (µm)
18180087	01-05-2018	07:03	62	61.91	-6.88	WP2	200
18220001	17-05-2018	15:20	60	61.91	-6.9	WP2	200
18220060	22-05-2018	02:54	80	61.83	-6.0	WP2	200
18260001	07-06-2018	17:54	61	61.91	-6.87	WP2	200
18280028	19-06-2018	14:27	59	61.91	-6.81	WP2	200
18300188	03-07-2018	22:04	75	62.0	-7.06	WP2	200
19140001	10-04-2019	22:37	66	61.91	-6.86	WP2	200
19160001	24-04-2019	20:12	67	61.91	-6.87	Bongo	100
19200001	14-05-2019	20:58	61	61.91	-6.87	WP2	200
19220068	04-06-2019	05:04	62	61.91	-6.89	WP2	200
19240037	11-06-2019	07:25	59	61.91	-6.89	WP2	200
19280063	25-06-2019	14:55	85	61.97	-7.07	WP2	200

3. Results

After the initial classification zooplankton taxa were merged into species groups (Table 2) based on ecological knowledge of the taxa (Gaard 1999). Copepods and other zooplankton species with low abundances were grouped as “Other copepods” and “Other zooplankton”, respectively.

Overall, cirripedia nauplii constituted ~ 50% of the total abundance and thus were by far the most abundant group in the assemblage followed by copepod nauplii, *T. longicornis*, *Acartia* sp. and unidentified harpacticoids (Table 2). *Pseudocalanus* sp. and *Oithona* sp. constituted ~ 2% of the assemblage, respectively and as a group *C. finmarchicus* constituted 1-2% of the assemblage.

Table 2 Grouping of zooplankton taxa found at costal station S together with class and order based on species traits along with their relative (%) contribution to the group in numbers and their overall (%) contribution in the total abundance.

Group	Class	Order	Taxa	Group contrib. (%)	Overall contrib. (%)
Acartia sp.	Copepoda	Calanoida	*Acartia* sp.		5
Copepod eggs[1]	Copepoda	-	Copepoda		2
Copepod nauplii	Copepoda	-	Copepoda	97	19
		Calanoida	*C. finmarchicus*	3	< 1
C. finmarchicus CI-CII	Copepoda	Calanoida	*C. finm.* CI	52	< 1
			C. finm. CII	48	< 1
C. finmarchicus CIII-CIV	Copepoda	Calanoida	*C. finm.* CIII	49	< 1
			C. finm. CIV	51	< 1
C. finmarchicus CV-CVI	Copepoda	Calanoida	*C. finm.* CV	82	< 1
			C. finm. CVI f	16	< 1
			C. finm. CVI m	2	< 1
Meroplankton	Cirripedia		Cirripedia cyprids	2	1
			Cirripedia nauplii	91	50
	Malacostraca	Decapoda	Decapod larvae	< 1	< 1
	Bivalvia		Bivalvia larvae	6	3
	Polychaeta		*Pectinaria* sp.	< 1	< 1
			Uid. polychaete larvae	1	< 1
	Teleostei		Fish eggs	< 1	< 1
			Fish larvae	< 1	< 1
Oithona sp.	Copepoda	Cyclopoida	*Oithona* sp.		2
Other copepods	Copepoda	Calanoida	*Centropages* sp.	< 1	< 1
			Metridia lucens	< 1	< 1
			Metridia sp.	< 1	< 1
			Microcalanus sp.	5	< 1
	Copepoda	Harpacticoida	*Clytemnestra* sp.	6	< 1
			Laophontidae sp.	2	< 1
			Microsetella sp.	10	1
			Miracia efferata	1	< 1
			Tigriopus sp.	7	< 1
			Tisbe furcata	< 1	< 1
			Harpacticoida	58	3
	Copepoda	Monstrilloida	*Monstrilla* sp.	4	< 1
	Copepoda	Cyclopoida	*Oncaea* sp.	5	< 1
	Copepoda	Poecilostomatoida	*Saphirrina* sp.	1	< 1
	Copepoda	-	Copepoda	< 1	< 1
Other zooplankton	Amphipoda		Amphipoda	57	< 1
	Appendicularia		*Oikopleura* sp.	2	< 1
	Branchiopoda		*Evadne* sp.	16	< 1
	Chaetognatha		Chaetognaths	2	< 1
	Gastropoda		*Limacina* sp.	9	< 1
	Hydrozoa		Hydrozoa	< 1	< 1
	Malacostraca	Isopoda	Cryptoniscidae	9	< 1
			Eurydice pulchra	1	< 1
		Euphausiacea	Euphausiacea nauplii	3	< 1
	Nematoda		Uid. nematodes	1	< 1
Pseudocalanus sp.	Copepoda	Calanoida	*Pseudocalanus* sp.		2
T. longicornis	Copepoda	Calanoida	*T. longicornis*		8

[1] Copepod eggs were not enumerated on a regular basis in 2018, and thus copepod eggs are left out of further data analysis in this report.

The abundance trend of copepod nauplii generally followed the phytoplankton biomass (chlorophyll *a*) with a ~ 2 week delay (Fig. 3).

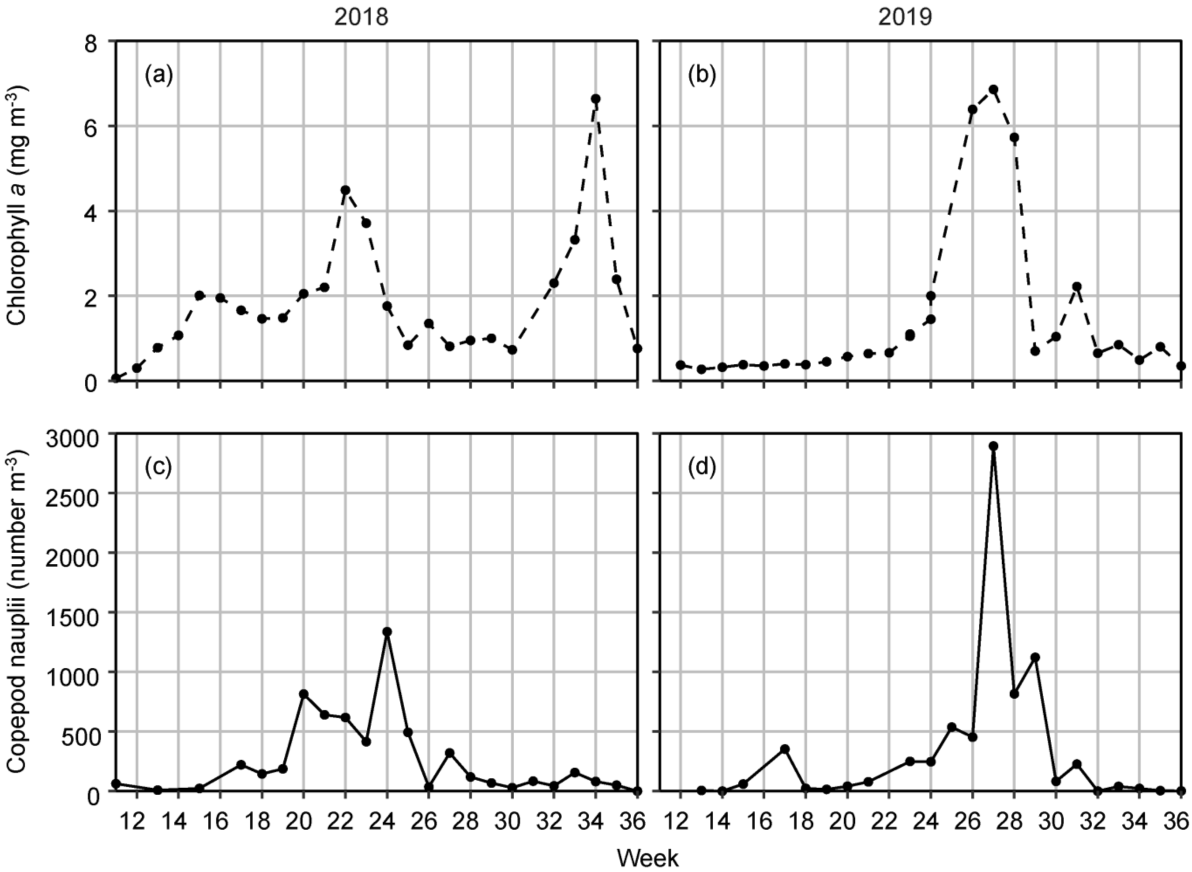

Fig 3 Chlorophyll *a* (a-b) and copepod nauplii abundance (c-d) at station S 2018-2019.

The abundance of the main copepod groups was also highest during the growing season (Fig. 4). *Acartia* sp. and *Pseudocalanus* sp. generally dominated the community during spring, while *T. longicornis* dominated the community during summer and autumn.

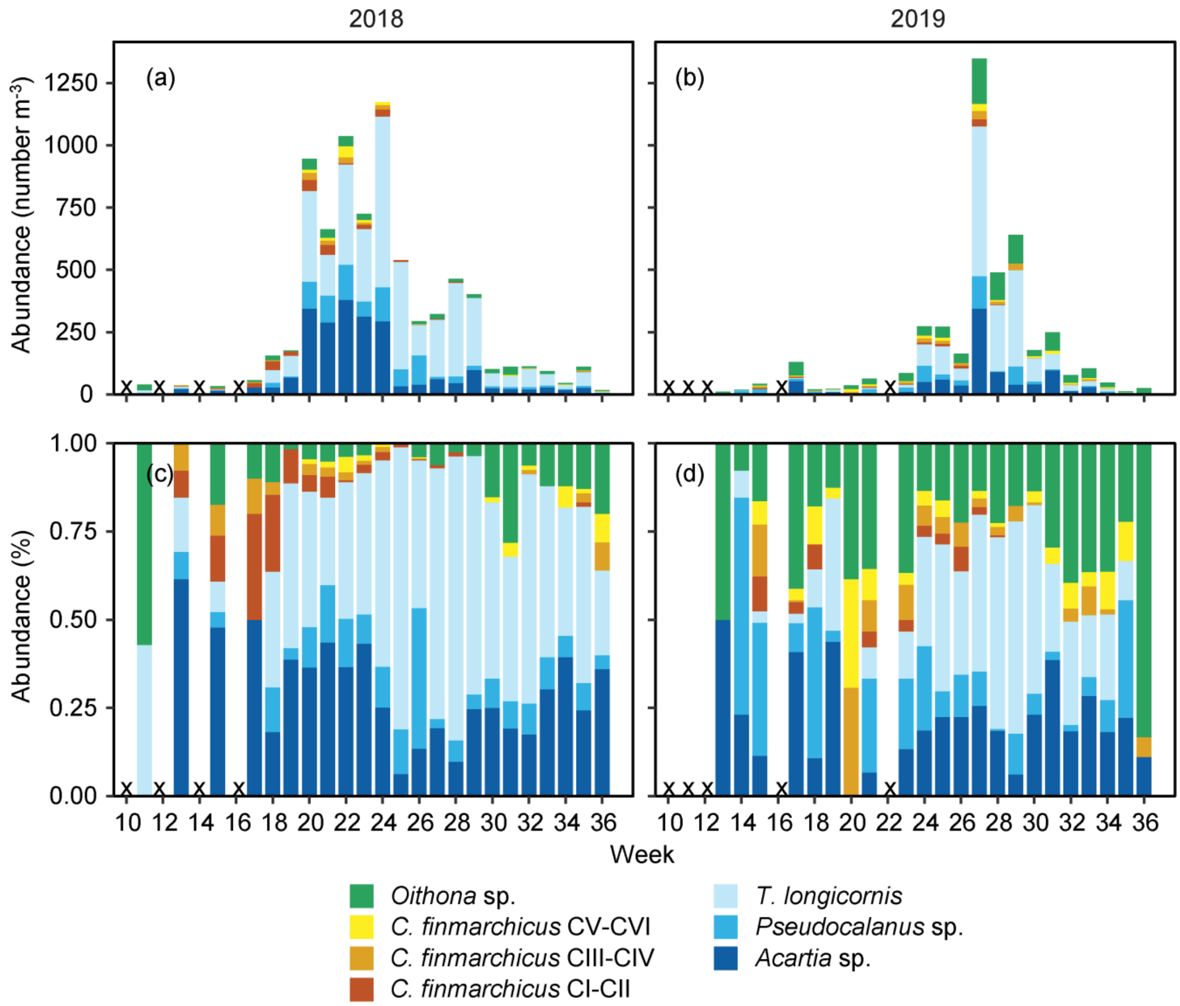

Fig 4 Copepod absolute abundance (a-b) and relative abundance (c-d) at station S 2018-2019. The crosses signify weeks with no data.

The abundance of *C. finmarchicus* was highest during spring and early summer and very low during autumn. The *C. finmarchicus* stage composition indicates that there were 2 generations of *C. finmarchicus* in both 2018 and 2019 (Fig. 5).

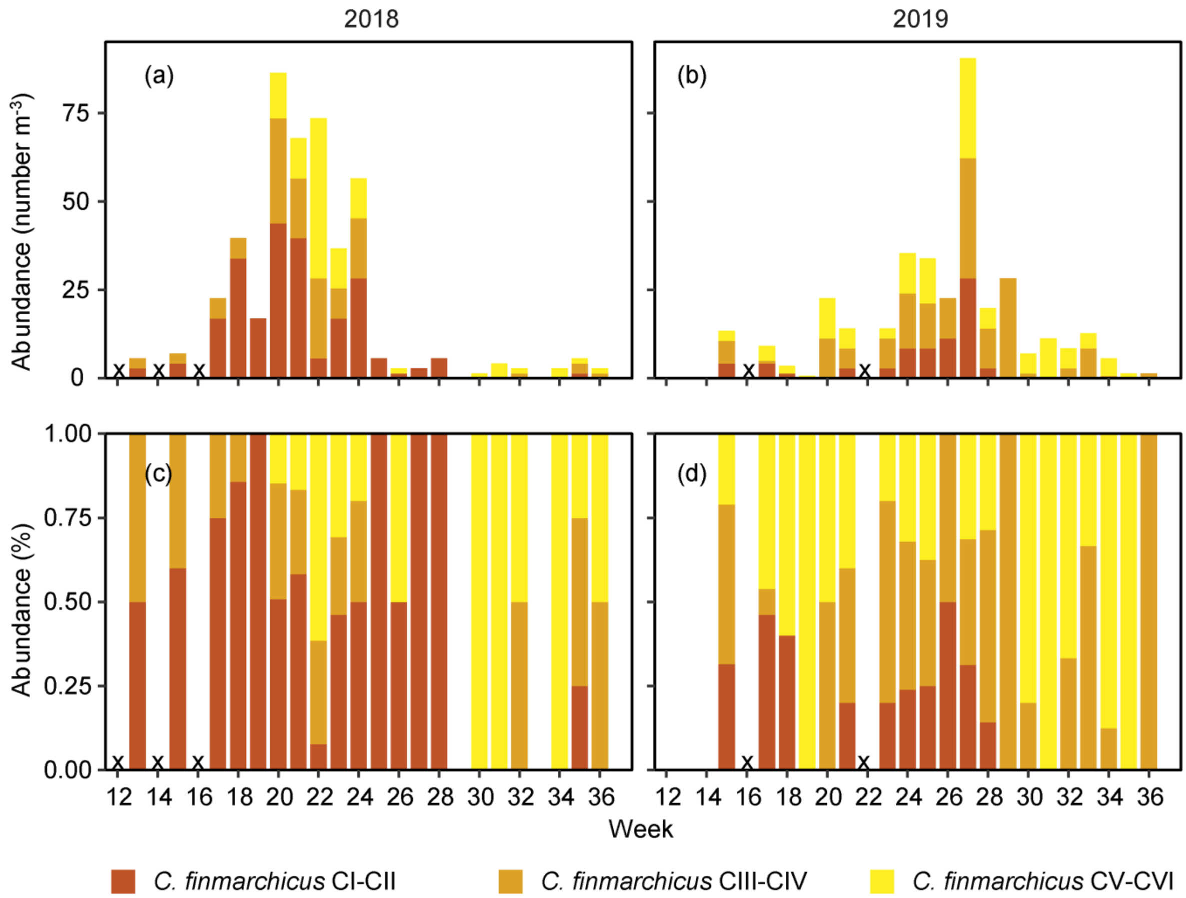

Fig 5 *C. finmarchicus* absolute abundance (a-b) and relative abundance (c-d) at station S 2018-2019. The crosses signify weeks with no data.

A comparison between the zooplankton abundance in towed samples and samples collected at station S showed that there is a fair to excellent correlation between the two sampling methods for the groups *Acartia* sp., *C. finmarchicus* CI-CII, *C. finmarchicus* CIII-CIV and *T. longicornis* (p < 0.1) (Table 3, Fig. 6). For the remaining groups, i.e. *C. finmarchicus* CV-CVI, Meroplankton, *Oithona* sp., Other copepods and *Pseudocalanus* sp., the agreement was poor (p > 0.1). In addition, for most groups, the samples collected at station S showed lower abundances compared with the towed samples.

Table 3 Results from linear regression analyses between abundance estimates ($\log_{10}$ individuals m^{-3}) on towed samples and samples collected at station S. The regression slope (a) and intercept (*b*), sample size (*n*), F-value (*F*) and proportion of variance explained (R^2) are given together with their respective significance levels (*p*).

Group	a	*b*	*n*	*F*	R^2	*p-value*
Acartia sp.	0.92	-0.93	12	3.45	0.26	0.09
C. finmarchicus CI-CII	0.35	0.38	12	4.35	0.30	0.06
C. finmarchicus CIII-CIV	0.45	-0.04	12	3.93	0.28	0.08
C. finmarchicus CV-CVI	-0.32	1.14	12	0.50	0.08	0.36
Meroplankton	0.45	0.86	12	1.24	0.11	0.29
Oithona sp.	-0.02	1.30	12	0.49	0.00	0.93
Other copepods	-0.08	2.19	12	1.14	0.10	0.31
Pseudocalanus sp.	0.57	0.10	12	2.46	0.20	0.15
T. longicornis	1.01	-0.90	12	27.2	0.73	<0.001

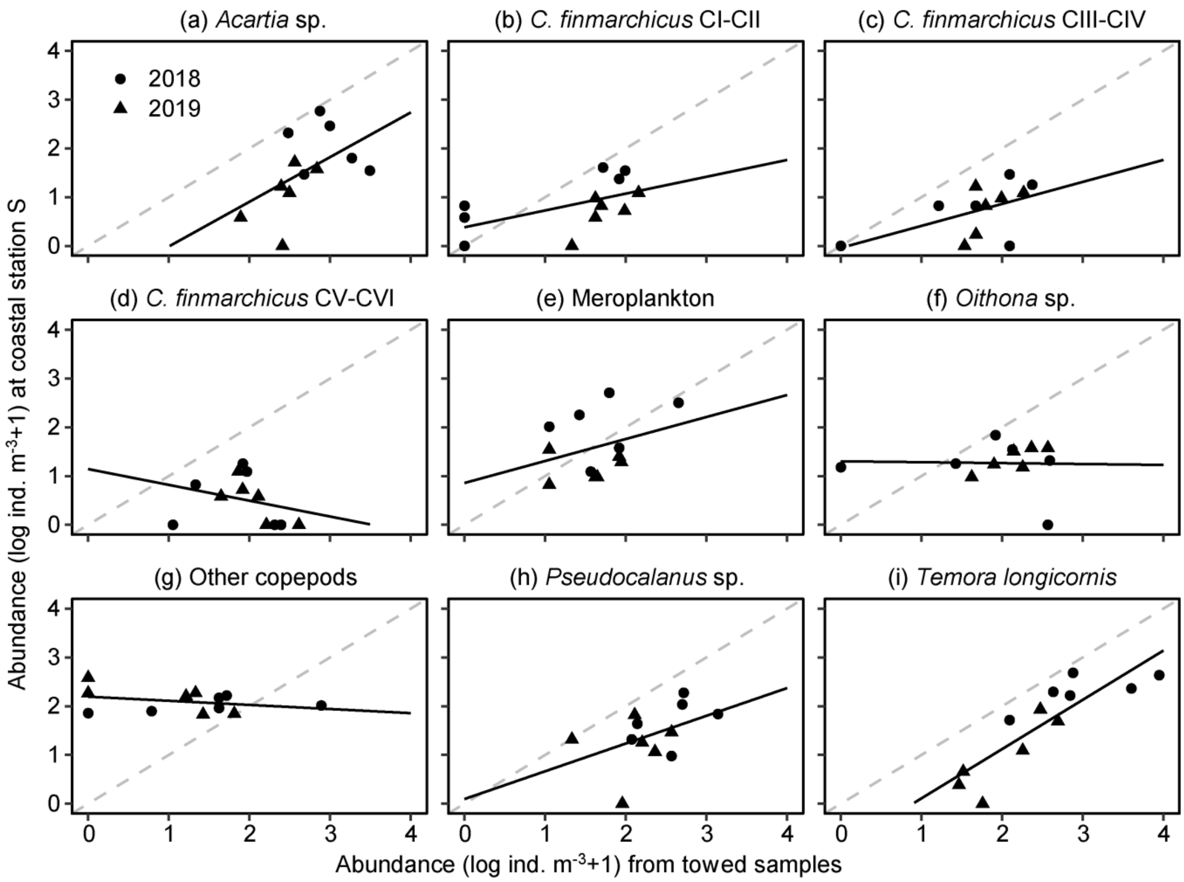

Fig 6 Scatterplots of $\log_{10}$-transformed abundance estimates on towed samples and samples collected at station S for 9 groups of meso-zooplankton. The continuous line represents best fits of linear regressions, while the dashed line is the 1:1 line. *n* =12.

Overall, the comparison of variations between the two methods is reasonable with some exceptions (e.g. 14-05-2019) (Fig. 7). Note, that the towed zooplankton samples were mainly collected with a WP2 net with 200 µm meshes, while the zooplankton at station S was collected with a net with 100 µm meshes. Thus, no comparison was done in the case of the smallest zooplankton i.e. copepod eggs and copepod nauplii.

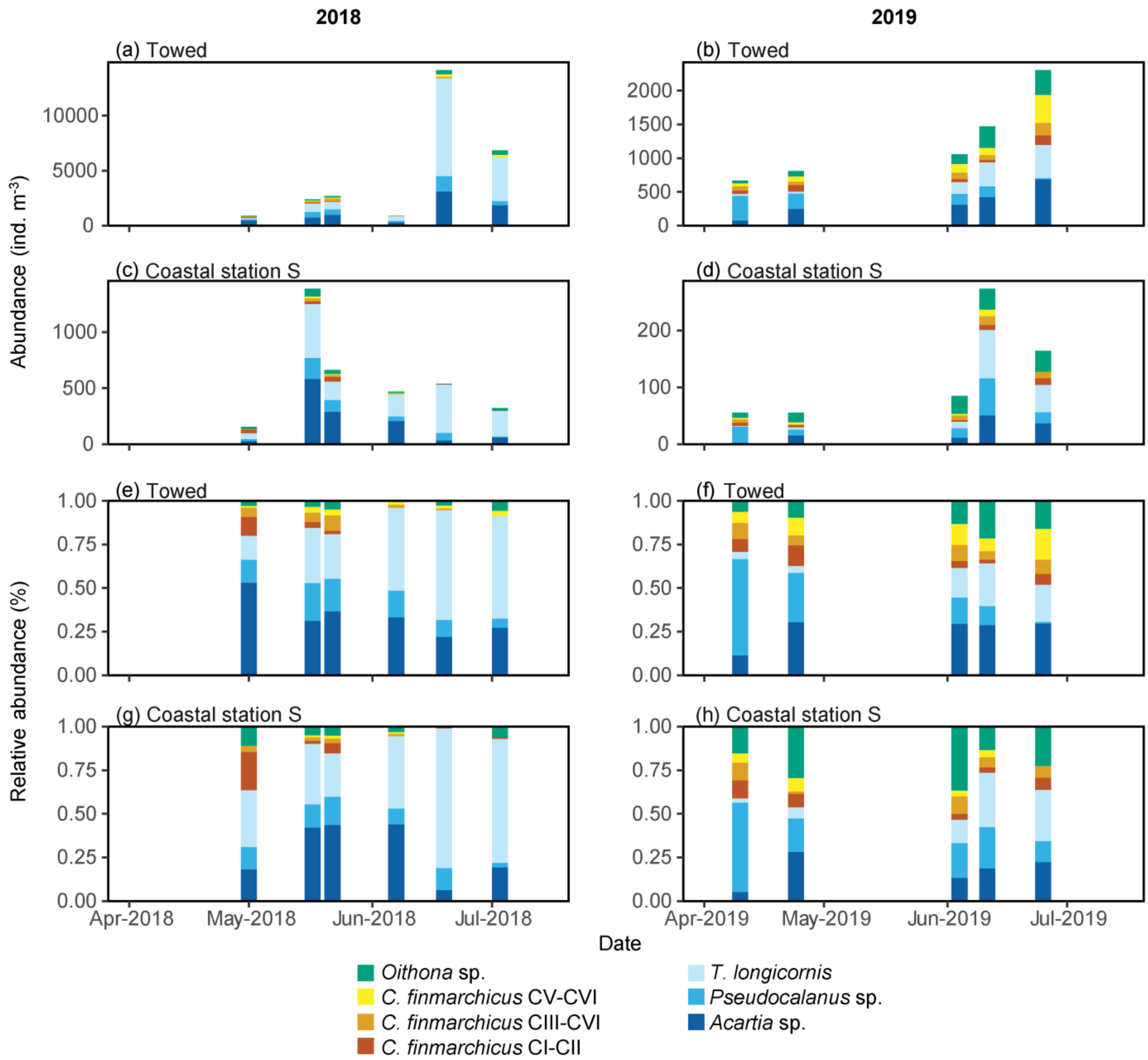

Fig 7 Comparison of trends between copepod abundance estimates on towed samples and samples collected at station S. a-d) absolute abundances, e-h) relative abundances.

4. Discussion

In this report we have investigated the validity of zooplankton data sampled at a fixed land based station on the Faroe shelf, station S, as representative for the zooplankton in the central shelf ecosystem. In the following we will summarize and discuss the main results.

4.1 Overall seasonal trend

The seasonal variation in abundance of copepod nauplii followed the variation in phytoplankton biomass (chlorophyll *a*) (Fig. 3). These observations thus comply with the general assumption that reproduction of copepods is dependent on the primary production (Gaard 1999; Debes and Eliasen 2006; Jacobsen et al. 2018).

The overall seasonal variation regarding the main copepod species was as expected with the copepod succession following the succession in phytoplankton (Fig. 4-5), although the land based abundance estimates were ~10 times lower than estimates made from towed samples (Fig. 7). The neritic copepod *Acartia* sp. and the cosmopolitan copepod *Pseudocalanus* sp. dominated during spring, while *T. longicornis* dominated during summer and autumn (Fig. 4). *C. finmarchicus* abundance was highest during spring and until mid-summer (Fig. 5). This is in agreement with other studies on the seasonal succession of copepods on the Faroe shelf (Gaard 1999; Debes and Eliasen 2006).

4.2 Disparity between species groups at station S and in towed samples

The comparison between abundances of species groups in samples collected at station S and in towed samples was generally poor. One species had a high correlation coefficient (*R*) (*T. longicornis*: R^2 = 0.73, p < 0.001) but even in this case, the values at station S were typically an order of magnitude smaller than the towed ones. The samples are not collected at the exact same location and not in the exactly same manner, thus some differences are expected and should be accepted. Several studies have pointed out that even when sampling back to back in exactly the same place using the same equipment the total catches may be several orders of magnitude different. However, to improve the comparability between the different sampling methods we strongly suggest that future sampling should be done with the same net mesh sizes (preferably 100 µm) and that the towed samples are done in triplicate. Overall, the results shown in Table 3 and Fig. 6 raise some concerns that need to be addressed.

4.2.1 The inlet to station S

The under estimation of abundances of many species groups at station S may be related to the position of the main inlet in to the station, which is near the bottom of the sea floor. In comparison, the towed samples are towed from ~ 50 m depth to the surface. Although the Faroe shelf water is generally well mixed (Larsen et al. 2008), the zooplankton abundances may be higher in the upper layers of the water. We recommend testing this hypothesis by sampling at fixed depths using a multi-net.

The position of the main inlet probably also explains the high number of benthic (i.e. harpacticoid) copepod species in the land based samples (Table 2) that were rarely observed in the towed samples.

Finally, the relatively high number of Meroplankton at station S is most likely mainly a result of over-representation of cirripedia nauplii (Table 2) due to a high number of sessile cirripedia inside the main inlet (Edmund Nielsen, pers. comment). Thus, in future work, we recommend that cirripedia larvae are disregarded.

4.2.2 Zooplankton swimming behavior and selective predation

The correlation between the two sampling methods in case of the group *C. finmarchicus* CV-CVI was negative. Even though the number of *C. finmarchicus* CV-CVI may be rather low on the Faroe shelf, their large size makes them dominant when it comes to biomass. Therefore, it is very important to know whether the problem with *C. finmarchicus* CV-CVI can be dealt with or not. Two main reasons for the discrepancy are suggested: 1) Being one of the largest organism represented in the zooplankton community, *C. finmarchicus* CV-CVI may have behavioral mechanisms leading them to avoid getting caught in the water flow in to the station. For instance, *C. finmarcicus* CV-CVI may have better capabilities than the smaller zooplankton to stay in the upper layers of the water column. This hypothesis can be tested by sampling at fixed depths using a multi-net. 2) There may be selective predation on *C. finmarcicus* CV-CVI in the main inlet as both macro-zooplankton and small fish have been observed in the inlet.

5. Conclusions

In this report we have assessed weekly monitoring of zooplankton at a land based station on the Faroe shelf. The zooplankton seasonal trend generally followed the seasonal succession in chlorophyll *a*. However, in most cases the abundance of species groups was an order of magnitude lower at the land based station than in towed samples. Furthermore, comparisons between samples collected on land and towed samples yielded poor results. Possible reasons for the poor correspondence between land based and towed samples include vertical gradients in zooplankton abundance, selective predation on the zooplankton in the inlet to the land based station and different net mesh sizes used. Continued monitoring requires a further set of comparative sampling. This should include sampling at various depths with a towed multi-net and sampling with the same mesh sizes. The towed sampling should be in triplicate, at the least.

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