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New data and information on the northern shrimp (*Pandalus borealis*) stock in Division 4.a West (Northern North Sea, Fladen Ground)

by

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Abstract

Several new sources of information as well as new analyses of existing historical data have improved the basis for assessing the stock status of the Fladen Ground northern shrimp (*Pandalus borealis*):

- A Norwegian fishery-independent survey of the stock in January 2021 demonstrated high shrimp densities on Fladen Ground, comparable with densities on the ground in the 1980s and 1990s.
- A newly developed stock index based on historical LPUE values from the targeted Danish shrimp fishery showed that in the only three years with a significant targeted fishery since the stop of the fishery (and the minimum index value of the time series) in 2004, the LPUE values have been increasing and in 2021, approaches the overall mean of the time series.
- A newly developed stock index based on harbour samples of shrimp bycatch in the Danish small-meshed trawl fishery for Norway pout back to 1990 demonstrated a high correlation between the proportion of by-caught shrimps in the Norway pout fishery and LPUE in the targeted fishery for shrimp. The by-catch percentage showed a substantial increase in 2020 and 2021, approaching the highest levels of the time series (values from the mid-1990s).
- The total 2020 landings of shrimp from Fladen Ground by the Norwegian fleet were the highest in the commercial landings time series dating back to 1977.

All these different sources of new information point in the same direction: that the shrimp stock on Fladen Ground has increased in recent years.

A Danish observer and self-sampling program for the targeted shrimp fishery was initiated in 2021, which provided biological data from the stock (weight, length and sex). If a commercial shrimp fishery is continued on Fladen Ground, this 2021 data can form the start of a commercially-based time series that together with biological data from the Norwegian survey can enable a full analytical assessment of the stock.

Introduction

From the 1960s up to around 2000, a significant fishery exploited the northern shrimp (*Pandalus borealis*) (hereafter shrimp) stock on the Fladen Ground in the northern North Sea (ICES Division 4.a West). Landings from the Fladen Ground have been recorded since 1970 and have fluctuated between zero and 9000 tons (NAFO/ICES, 2020) (Figure 1, Table 1). The Danish fleet has accounted for the greatest share of these landings, while the Scottish fleet has landed a smaller proportion. The fishery took place mainly during the first half of

the year, with the highest activity in the second quarter. Since 1998, landings decreased steadily and since 2004, the Fladen Ground shrimp fishery has been virtually non-existent. Interview information from the fishing industry obtained in 2004 gave the explanation that this decline was caused by high fuel prices, low shrimp abundance, and low prices on the small shrimp, which are characteristic of the Fladen Ground.

The Fladen Ground shrimp stock was surveyed as part of the annual Norwegian shrimp survey in the Skagerrak and Norwegian Deep in the late 1980s and early 1990s. The stock was surveyed again in January 2021. For many years, due to lack of both fishery and survey data, it was not known if the decline in the fishery reflected a decline in the stock. The last ICES advice was given in 2019, for 2020 and 2021, and due to lack of data, advised that there should be no targeted fishery on the Fladen Ground shrimp stock. EU has still set a shrimp quota for the ICES Division 2.a and Area 4, which mainly comprise the Fladen Ground stock, of between 1500 and 5000 tons (ICES, 2019). In 2021, there is an agreed quota between the EU and the UK which applies to the United Kingdom and European Union waters of Area 4, and the United Kingdom waters of Division 2.a. The 2021 total quota for these areas is 660 tons.

Since 2011, there have been minor Danish and Norwegian landings of shrimp from Fladen Ground, mainly taken as bycatch (landed for industrial purposes) in the Norway pout fishery. Denmark landed 13 and 24 tons from shrimp trawls in a targeted fishery in respectively 2015 and 2021.

Danish commercial catches and fishery data

Targeted shrimp fishery

A commercial Danish shrimp fishery on Fladen Ground took place mainly from 1987 to 2003 and daily catch rates (LPUE) were substantially higher in this area compared with Skagerrak, the Norwegian Deep and Farn Deeps, suggesting higher densities of shrimp on the Fladen Ground (Knutsen et al., 2015). Since 2004, only sporadic targeted fishery (codend mesh sizes of 32-69 mm) has taken place, 1 ton in 2014, 13 tons in 2015 and 24 tons in 2021, and in recent years the largest volumes of shrimp are by-caught in other small-meshed trawl fisheries such as the fishery for Norway pout (Table 2). Especially in 2020 and 2021, total Danish shrimp bycatches were substantial, resembling the values experienced during the primary period of the targeted shrimp fishery on Fladen Ground in the 1990s, indicating that stock biomass has increased.

For the targeted Danish shrimp fishery on Fladen Ground (codend mesh size 32-69 mm informed in logbooks) a landings-per-unit-effort (LPUE) time series was calculated by dividing the total yearly landings with the total yearly kilowatt days in the fishery (Figure 2). This index of stock size shows that in the three most recent years with a significant targeted fishery since the minimum of the time series (and the stop of the fishery) in 2004, the LPUE values have been increasing, and in 2021, it approaches the overall mean of the time series.

For two of the targeted shrimp trips in 2021, catches were sampled at sea (one by an on-board observer and one by self-sampling from the fishermen). The samples were subsequently analysed by DTU Aqua to provide shrimp weights and lengths, which can form the start of a commercially-based time series that with time – if a commercial fishery is continued - can enable a full analytical assessment of the stock (Figure 3).

Bycatch in the small meshed Norway pout trawl fishery (16-31 mm)

The commercial Danish Norway pout landings from Fladen Ground have been sampled in harbour by the Danish Control Agency since 1989. Each catch sample consists of approx. 5 kg of unsorted landings, taken with a bucket from the storage rooms of the trawlers. The data cover the period from 1989 to April 2020, except for 2005 and 2007 when there was no quota and therefore no fishery. The main purpose of the harbour sampling has been to estimate total species composition in weight. In April 2020, a change in the bycatch monitoring of the Danish Norway pout fishery was implemented, increasing the sampling coverage (mainly more samples taken from each vessel, increasing in numbers with increasing landing size), thus for the two most recent years the data and estimates are considered to be more precise.

Based on the two harbour sampling schemes for the Norway pout fishery, two shrimp bycatch indices were defined. The first index (index #1) covers the period from 1989 to 30th of April 2020, and the second index (index #2) covers the later period until October 2021. Index #1 is based on all industrial samples from the Norway pout fishery from the approximately 20 ICES squares which make up the distributional area of the

Fladen Ground shrimp stock, whereas index #2 is based on data from the same fishery, but for the full (slightly larger) area of the Fladen Ground Norway pout fishing grounds. The index #1 time series of shrimp bycatch percentages may potentially be biased by the introduction of a mandatory sorting grid in the Norway pout fishery in 2012, but given the small size of shrimp compared to Norway pout it is very unlikely that the grid has sorted out a significant amount of shrimp.

The by-catch percentage of both indices was calculated as an average over all samples from a given year and plotted together (Figure 4), demonstrating that the two 2020 values were almost identical (adding confidence to the comparability of the two time series/indices) and that the bycatch percentage increased substantially in 2020 and 2021, approaching the highest levels of the time series (values from the mid-1990s). This pattern aligns with the pattern observed for the total yearly bycatches (Table 2) as well as the trend in the LPUE index from the directed shrimp fishery (Figure 2) and supports the perception of the shrimp stock biomass having increased in recent years.

Norwegian fishery data

In the 1970s, 1980s and 1990s there were small Norwegian shrimp landings from the Fladen Ground, between 4 and 32 tons (Table 3). From 2003 to 2015, no Norwegian landings were reported from the area, with the exception of 460 kg in 2012. However, from 2016, Norwegian landings of shrimp have been reported from the area, mainly as bycatch from the Norway pout fishery.

Since 2013, catches of shrimp on the Fladen Ground have been recorded in Norwegian logbooks, primarily from the Norway pout fishery (Table 4), but shrimp trawlers have been out in the area on two occasions, in 2013 and in 2019. Catch rates (CPUE) of shrimp in the Norwegian Norway pout fishery has varied between 4.7 and 55.9 kg/h in the period 2013-2020, where the CPUE index was calculated by dividing the total yearly logbook recorded shrimp bycatches by the yearly effort (hours) of the fishery (all hauls containing shrimp). So far (by October 2021), no shrimp catches have been recorded in the logbooks from Fladen Ground in 2021.

Norwegian survey data

A trawl survey for shrimp in Skagerrak and the Norwegian Deep (ICES Divisions 3.a and 4.a East, and the northeast corner of Division 4.b) has since 1984 been conducted annually by the Norwegian Institute of Marine Research (IMR) with the objective of assessing the distribution, biomass, abundance, recruitment and length distribution of the shrimp stock (Søvik and Thangstad, 2021). In the late 1980s and early 1990s, IMR surveyed also the shrimp stock on the Fladen Ground. A total of seven cruises were conducted in this area in 1986, 1987, 1988, 1989, 1991, 1993 and 1994, all in October/November, as part of the first time series from 1984-2002 using R/V Michael Sars and the Campelen-trawl (Søvik and Thangstad, 2021).

No scientific survey has covered the shrimp stock on Fladen Ground since the mid-1990s. However, as recent bycatches of shrimp in the Danish and Norwegian Norway pout fisheries in the area have indicated increasing densities of shrimp on the Fladen Ground, a cruise was again conducted by IMR, in January 2021. The timing of the annual IMR shrimp survey shifted to the 1st quarter in 2006 (Søvik and Thangstad, 2021). There have also been changes in the vessel used, but the gear is still the standard Campelen-trawl.

The high abundance of shrimp on the Fladen Ground perceived from the fisheries data was confirmed by the 2021-cruise. In fact, the two highest trawl catches of shrimp (157 and 342 kg, in 30 minutes tows) in the whole 2021 survey were taken on Fladen Ground (Figure 5). Mean abundance was considerably higher in 2021 compared with the time series 1986-1994, mainly due to the two high trawl catches, while the median in 2021 was on the same level as the earlier years (Figure 6). The same pattern is seen for the density of shrimp (kg per trawled nautical mile) (Figure 6).

The Fladen stock in the first quarter consists mainly of three year-classes (Figure 7), similar to the shrimp stock in Skagerrak and the Norwegian Deep (Søvik and Thangstad, 2021). The stage structure is also similar, with males, intersex shrimp and berried females in the first quarter. The size- and stage structure from the survey in January 2021 are similar to the Danish commercial samples (above). The length distribution confirms that the Fladen Ground shrimp are smaller compared with the Skagerrak shrimp, but corresponding age groups on Fladen and in the Norwegian Deep have similar mean sizes (Søvik and Thangstad, 2021).

Length frequency distributions from the 1980s and 1990s indicate that the Fladen Ground shrimp stock in the fourth quarter consists mainly of two age groups, the 1- and 2-year old shrimp (Figure 8). The 0-group is visible in the plots in some years. The length frequency distribution from 1986, however, show four, maybe five age groups on Fladen Ground, with shrimp up to 30 mm carapace length. As large shrimp are absent in the size distributions the following years, it seems likely that the large fishery in 1997 (9306 tons) fished out this portion of the stock.

The abundance of the 1-year old shrimp in 2021 was relatively large. In comparison, the size of the 1-group in the neighbouring area the Norwegian Deep is more or less always small, and Skagerrak seems to be the nursery area for the Skagerrak/Norwegian Deep stock. The different stock dynamics on the Fladen Ground compared with in the Norwegian Deep suggests a self-recruiting population on Fladen Ground, which is supported by results from genetic investigations which suggested a separate population (Knutsen et al., 2015).

Cold and calm weather made possible the scientific cruise on Fladen Ground in January 2021. Visiting this area has been on the agenda for the IMR cruise for many years, but stormy weather in the North Sea has not allowed it. It is therefore unlikely that the area will be surveyed on an annual basis in the years to come.

Conclusions

Several new sources of information as well as new analyses of historical data have substantially improved the knowledge basis for assessing the stock status of the Fladen Ground shrimp stock.

Overall, these different sources of new information, i) a Norwegian fishery-independent survey, ii) a new LPUE-based stock index, iii) a new bycatch-based stock index, and iv) historically high shrimp landings by the Norwegian fleet in 2020, all point in the same direction: that the shrimp stock on Fladen Ground has increased in recent years and likely is at a relatively high level.

A Danish observer and self-sampling program for the targeted shrimp fishery was initiated in 2021, which provided biological data of the stock (weight, length and sex). If a commercial shrimp fishery is continued on Fladen Ground, these 2021 data can form the start of a commercially-based new time series that together with biological data from the Norwegian survey may enable a full analytical assessment of the stock. Due to likely irregular visits to Fladen Ground by the annual IMR shrimp survey an analytical assessment will have to be based primarily on fishery data.

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Table 1. Official landings of shrimp from the Fladen Ground, by country and total, 1970-2021. The 2021 data are until October.

Year	Denmark	Norway	Sweden	UK-Scotland	Total
1970	3115			104	3219
1971	3216			436	3652
1972	2204			187	2391
1973	157			163	320
1974	282			434	716
1975	1308			525	1833
1976	1552			1937	3489
1977	425			1692	2117
1978	890	9		2027	2926
1979	565	10		268	843
1980	1122	4		377	1503
1981	685			347	1032
1982	283			352	635
1983	5492	8		1827	7327
1984	4553	13		25	4591
1985	4188	7		1341	5536
1986	3416			301	3717
1987	8620			686	9306
1988	1662			84	1746
1989	2495			547	3042
1990	1616		4	365	1985
1991	421	25		53	499
1992	1212			116	1328
1993	1516			509	2025
1994	1202			35	1237
1995	4552	30		1298	5880
1996	3689	32		1893	5614
1997	2886			365	3251
1998	2801			1365	4166
1999	934	9		456	1399
2000	1358			378	1736
2001	1117	18		397	1532
2002	1061	9		70	1140
2003	935		1		936
2004	21				21
2005					
2006					
2007					
2008					
2009					
2010					
2011					
2012					
2013					
2014	1				1
2015	19				19
2016		10			10

2017	1	6	7
2018			
2019	2	6	8
2020	153	66	219
2021	277		277

Table 2. Catches of shrimp in the Danish targeted fishery, bycatches in other small-meshed trawl fisheries and total Danish landings from 1990 to 2021. Data are provided by the national Danish Fisheries Agency based on information from EU logbooks, landings data, sales slips and harbour sampling of the industrial fishery.

	Targeted shrimp fishery with mesh sizes of 32-69 mm (tons)	Bycatch in other small-meshed trawl fisheries (tons)	Total landings (tons)
1990	1358	257	1616
1991	393	28	421
1992	976	237	1212
1993	799	717	1516
1994	1155	47	1202
1995	4452	100	4552
1996	3514	175	3689
1997	2798	88	2886
1998	2689	113	2801
1999	900	34	934
2000	1295	64	1358
2001	1116	1	1117
2002	1043	18	1061
2003	903	33	935
2004	18	3	21
2005	0	0	0
2006	0		
2007	0		
2008	0		
2009	0		
2010	0		
2011	0	0	0
2012	0		
2013	0	0	0
2014	1	0	1
2015	13	5	19
2016	0	0	0
2017	0	1	1
2018	0	0	0
2019	0	2	2
2020	0	153	153
2021*	24	252	277

*until October 25th 2021

Table 3. Norwegian landings of shrimp from Fladen Ground, 1977-2021. The 2021-landings are until October 2021. Landings numbers were checked and updated in October 2021 and vary somewhat from numbers presented in earlier NIPAG reports. Data from the Norwegian Directorate of Fisheries.

Year	Landings (tons)	Year	Landings (tons)
1977		2000	
1978	9	2001	18
1979	10	2002	9
1980	4	2003	
1981		2004	
1982		2005	
1983	8	2006	
1984	13	2007	
1985	7	2008	
1986		2009	
1987		2010	
1988		2011	
1989		2012	0.5
1990		2013	
1991	25	2014	
1992		2015	
1993		2016	10
1994		2017	6
1995	30	2018	0.5
1996	32	2019	6
1997		2020	66
1998		2021	
1999	9		

Table 4. Bycatches of shrimp in the Norwegian Norway pout fishery on Fladen Ground, 2013-2020: number of hauls containing shrimp, mesh size in bottom trawls, CPUE in the Norway pout fishery (kg shrimp/hour trawled over all hauls containing shrimp), and total registered shrimp catches in the logbooks (tons). Norwegian official shrimp landings (tons) from the Fladen Ground are included for comparison. By October 2021, there were no data yet from 2021 in the logbooks or in the official landings.

Year	# Hauls	# Hauls (N. pout fishery)	Mesh size (N. pout fishery)	CPUE (N. pout fishery)	Log book catches	Commercial landings
2013	50	47	16-32	40.0	25.0	
2014	28	28	19-35	4.7	1.3	
2015	30	30	16-24	12.6	2.9	
2016	46	46	16-30	22.7	10.1	9.6
2017	42	42	16-22	16.4	7.0	5.7
2018	12	12	16-24	7.3	0.9	0.5
2019	61	60	16-40*	9.9	6.3	6.2
2020	76	76	16-40	55.9	38.4	66.5
2021						

2013: 2 hauls targeting herring, 1 haul targeting shrimp
2019: 1 haul targeting shrimp

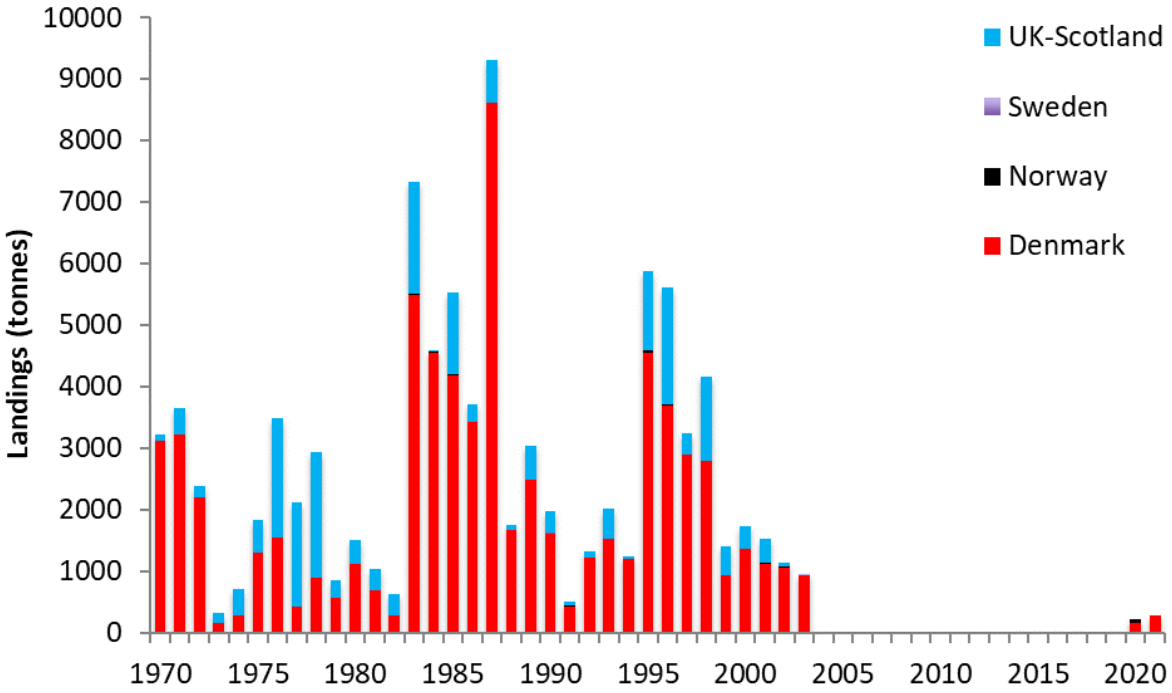

Figure 1. Official landings by country from Fladen Ground, 1970-2021. 2021-numbers are until October.

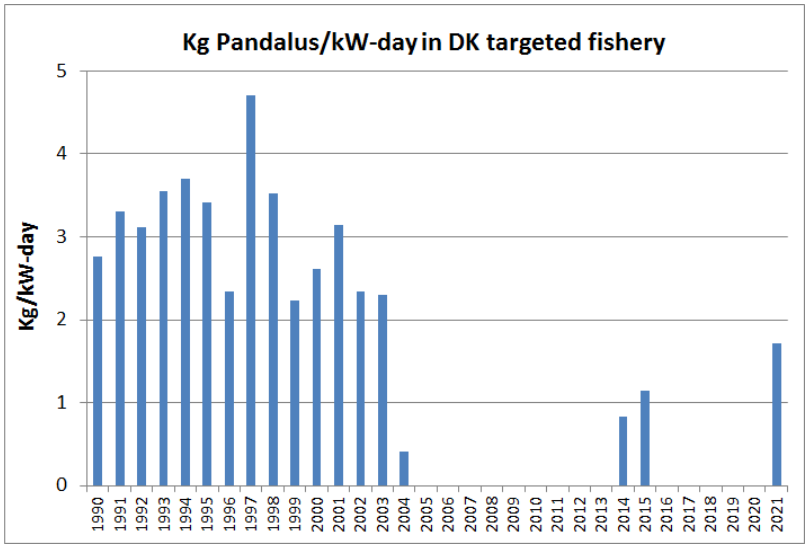

Figure 2. Landings-per-unit-effort (LPUE) time series (kg/kW-days) for the targeted Danish shrimp fishery on Fladen Ground (codend mesh size 32-69 mm informed in logbooks), 1990-2021.

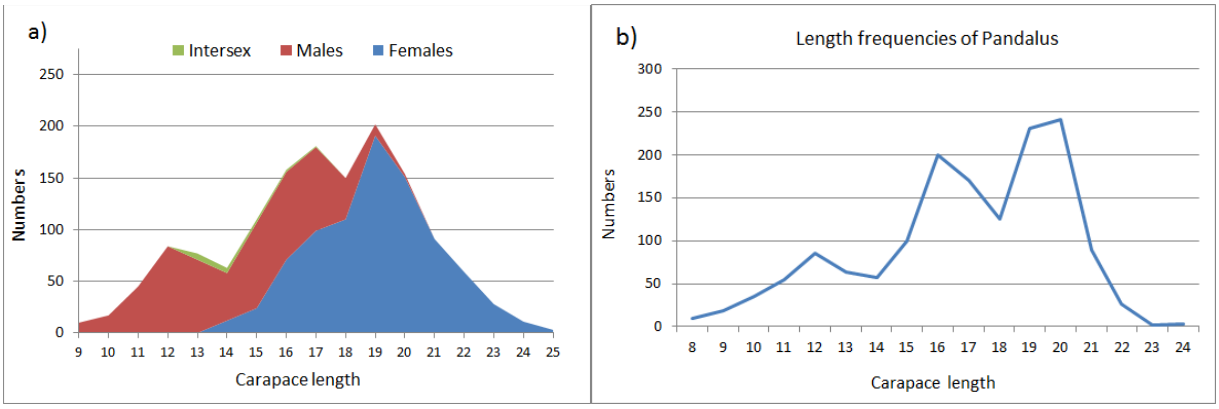

Figure 3. Length frequency distributions of on-board samples from two targeted Danish shrimp fishing trips (codend mesh size 32-69 mm) to Fladen Ground in quarter 1 of 2021. Panel a) is based on samples taken by an on-board observer and panel b) is based on data from self-sampling of the fishermen. For both sample types laboratory analyses (weight, length and sex) were conducted by DTU Aqua.

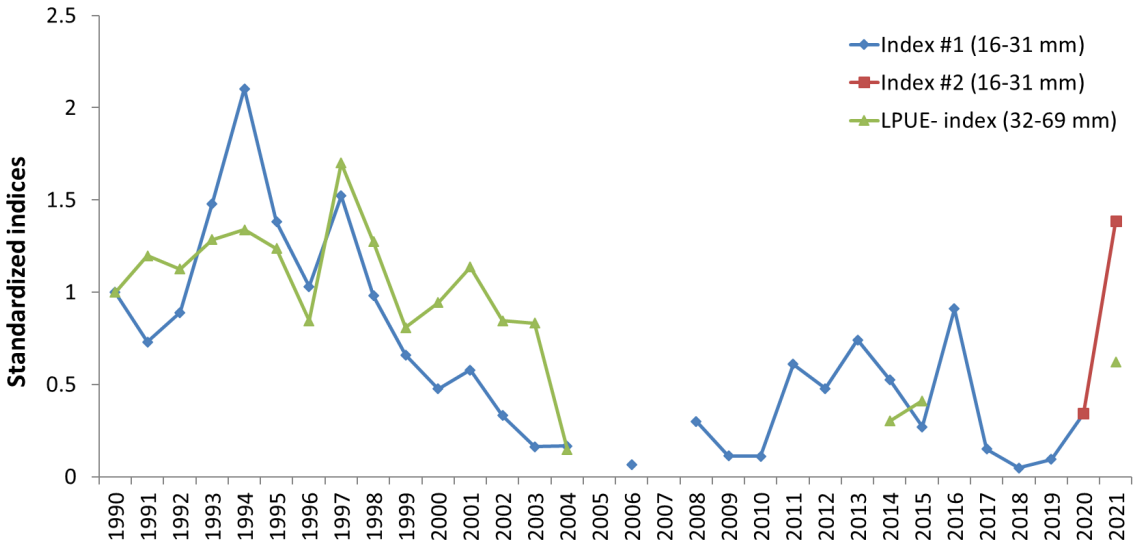

Figure 4. Time series of two shrimp stock size indices based on harbour sampling of shrimp bycatch in the Danish small meshed trawl fishery (codend mesh size 16-31 mm) for Norway pout (1989-2020 and 2020-2021), plotted together with the LPUE from the directed Danish shrimp fishery, 1990-2021. Index #1 and the LPUE-index are standardised to the first year of the time series (1990) while Index #2 is standardised to the 1990 estimate of Index #1.

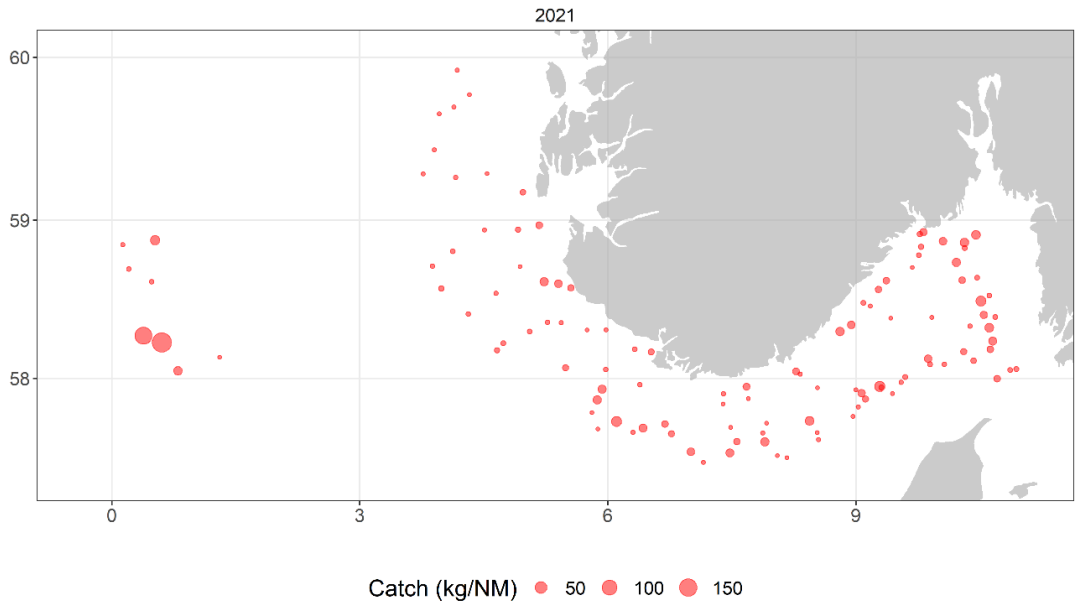

Figure 5. Shrimp catches per trawl station (kg/nm) from the Norwegian shrimp survey in ICES Divisions 3.a and 4.a (Skagerrak, the Norwegian Deep and Fladen Ground) in January 2021. Figure by Fabian Zimmermann.

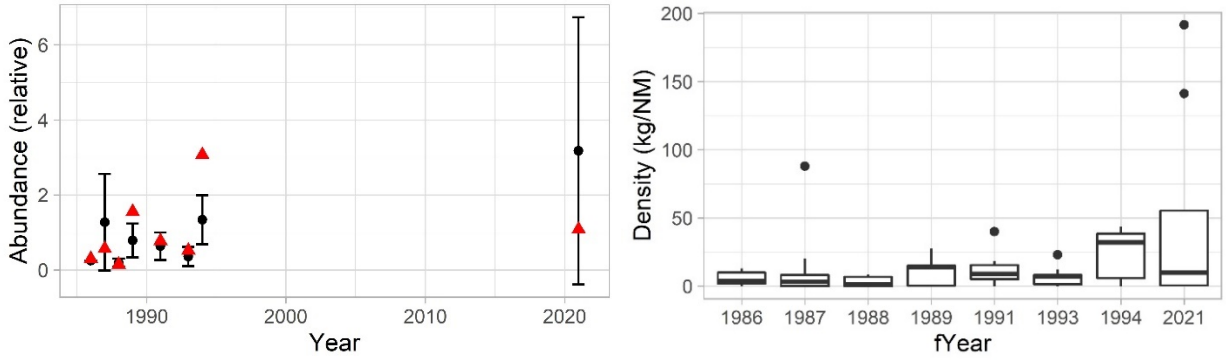

Figure 6. Time series of shrimp on Fladen Ground, 1986-1994 and 2021, abundance (relative index), mean ± 95 % confidence interval (black dots) and median (red triangles) (left), and density (kg/nm) (right), boxplot showing median (bold line), first and third quartiles (hinges, the 25th and 75th percentiles), and whiskers spanning 1.5 times the inter-quantile range above and below the hinges. Dots indicate outliers outside of the inter-quantile range. Figures by Fabian Zimmermann.

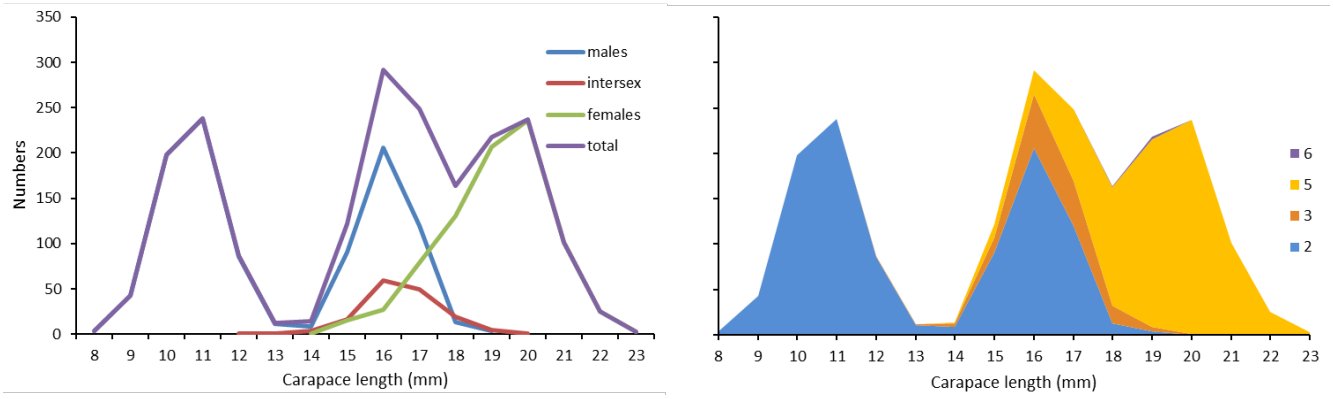

Figure 7. Length frequency distributions of numbers per length (all survey samples pooled) of the shrimp stock on Fladen Ground for males, intersex, females and total (left) and by stage (right), in January 2021. Stages: 2 = males, 3 = intersex, 5 = berried females, 6 = breeding dress.

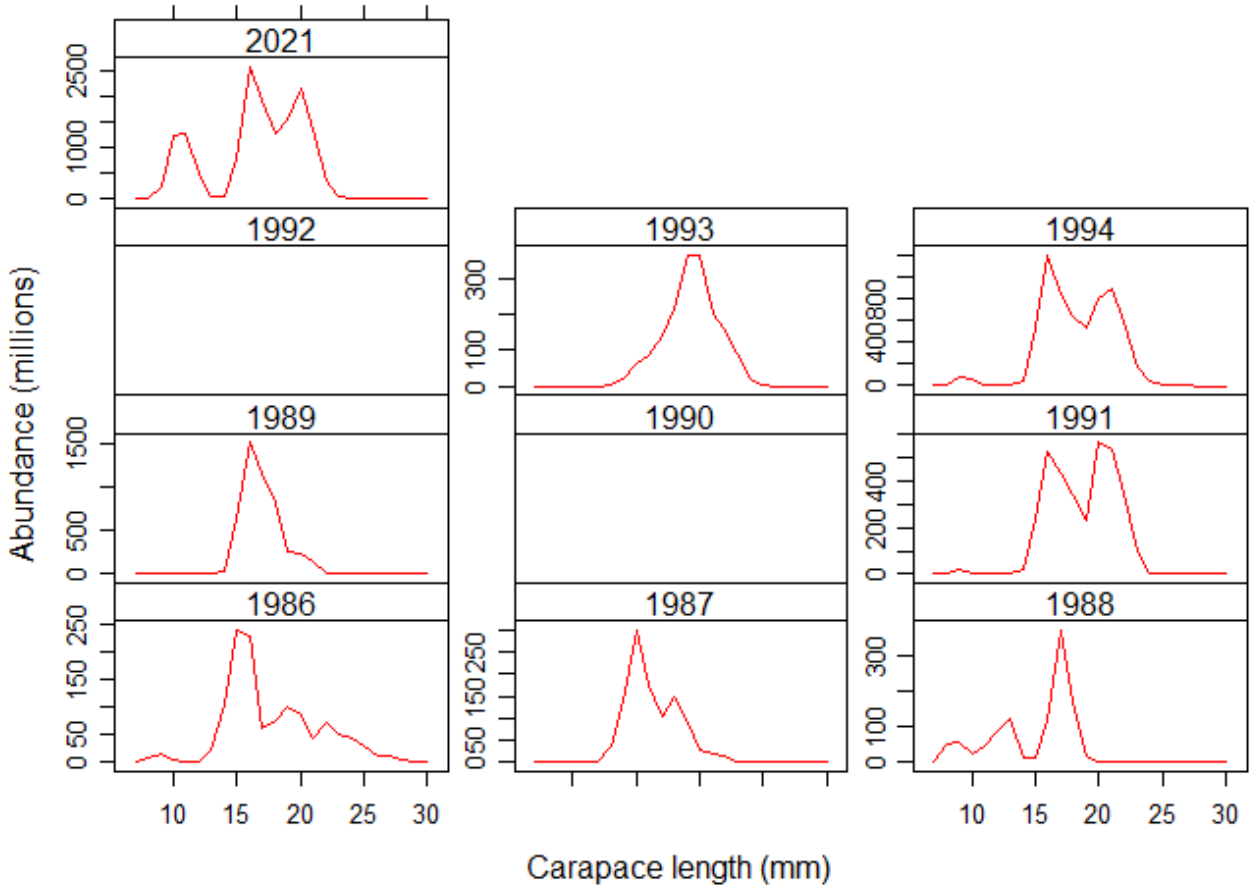

Figure 8. Length frequency distributions from the IMR scientific cruises on Fladen Ground in October/November 1986-1994 (no surveys in 1990 and 1992), and in January 2021. Note different y-axes.