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Assessment of the International Fishery for Shrimp (*Pandalus borealis*) in Division 3M (Flemish Cap), 1993-2018

by

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Abstract

The development of the international shrimp (*Pandalus borealis*) fishery in NAFO Division 3M is described. Various indices show that even though the stock was in high levels in 2006 and 2007 the lack of good recruitments in the last ten years and the progressive disappearance of the strong year classes 2001 and 2002 have caused a drastic decline of the stock. Although the fishing effort in recent years was low and from 2011 a moratorium over shrimp fishery was established, predation by redfish and cod contributed to the decline of shrimp especially after 2007-2008. The increment of large specimens in the cod stock, especially since 2010, increased the predation mortality on redfish, inducing the decrease of the redfish stock and as consequence the decline of the predation mortality on shrimp favouring the increase of shrimp stock in the last years.

No catches have been recorded since 2011 due to the moratorium. The female biomass from EU survey was variable though without trends at a relative high level from 1998 to 2007 but since then the estimated biomass initiated a drastic decline to lowest levels in the EU survey series from 2011 to 2014. Although in recent years 2015, 2016, 2017 and 2018 the total biomass indexes increased significantly compared to previous year (around 72%, 62%, 14% and 52% respectively) it remains at low level. Also after the strong 2002 year-class (i.e. age 2 in 2004), all the subsequent year classes have been weak and the recruitment prospects remain uncertain.

Considering the 15% of the maximum survey female biomass index as a limit reference point for biomass (B_{lim}), the stock have been from 2011 to 2017 in the collapse zone defined by the NAFO PA framework. Although the new information in 2018 indicates a slight improvement and the stock is now outside the collapse zone, it remains in a state of impaired recruitment that confirms the recommendation carried out within Scientific Council during autumn 2017 and therefore the fishing mortality would be set as close to zero as possible in 2019-2020.

1. INTRODUCTION

The fishery for northern shrimp at Flemish Cap began in the spring of 1993 and has since continued with estimated annual catches (as estimated by STACFIS, Table 1) of approximately 26 000 t to 48 000 t in the years 1993 through 1996. After 1996 the catches were lower and rising slowly from 26 000 t in 1997 to 53 000 t in 2000 and 2001. There was 50 000 t taken in 2002. The catch increased in 2003, reaching the highest value in the catches series (64 000 t). After 2003 the catches decreased all years until 1 988 t in 2010. Due to the

moratorium initiated in 2011, no catches have been recorded since then, and by 2018 only very low catches of discards from other fisheries are expected.

Since 1993 the number of vessels ranged from 40-110, and in 2006 there were approximately 20 vessels fishing shrimp in Div. 3M compared to 50 in 2004. There is not a lot of information on the number of vessels taking part in the shrimp fishery since 2007 but probably they do not exceeded 13 units in 2010. Since 2011 due to the moratorium there is no vessels directed to shrimp fishery in Div. 3M.

With the closure of the international shrimp (*Pandalus borealis*) fishery in NAFO Division 3M, various indices from the EU surveys are listed to assess the status of the Flemish Cap shrimp stock. Among these the indices of female stock from the EU surveys is used. The results from the ageing are presented and some recruitment indices from the EU survey are provided.

2. MATERIAL AND METHODS

Samples

From 2011 due to the moratorium shrimp samples were only taken from EU-Flemish Cap research summer surveys. They were separated into 3 categories namely, males, primiparous females (including transitional) and multiparous females according to the sternal spine criterion (McCrary. 1971), oblique carapace lengths were measured using sliding callipers and grouped into 0.5 mm length-classes.

Modal analysis (MacDonald and Pitcher, 1979) was conducted each year on length frequency distribution by sex group resulting from the survey. This analysis provided the proportion; mean lengths and standard deviations of the mean length (sigma) for each age component and sex group. The total number of individuals in every age/sex group according to the estimated biomass was calculated transforming the mean length to weight using the weight length relationship. So, the mean lengths were converted to mean weights to estimate the annual abundance and biomass indices by year and sex group (Skúladóttir and Diaz, 2001).

3. CATCH and CPUE

The total catch per year is listed by nations in Table 1. The annual catches come mostly from Statlant 21A reports and in some cases from the shrimp specialists of individual countries. Because the moratorium no catches have been recorded from 2011 and to 10 September in 2018 the table was only revised and updated (Fig. 1).

The closure of shrimp fishery from 2011 and therefore the lack of commercial catches of shrimp do not permit to follow the evolution of the stock using the standardized CPUE series estimated from the international fleet directed to the fishing shrimp in Div. 3M.

4. EXPLOITATION RATE

Considering the Exploitation rate estimated as nominal catches divided by the EU survey biomass index of the same year (Figure 2 and Table 2), this was high in the years 1994-1997 when biomass was generally lower. In the years 1998-2004 the catch rate has been rather stable at a lower level. From 2005 to 2008 despite the exploitation rate remained stable at relative low values (between 1.9-1.5), the UE survey indexes estimated decreased year after year. This trend continued in the recent years despite the moratorium established on 3M shrimp stock since 2011. In October 2011 Scientific Council noted that there are indications of factors other than fishery that may be involved in the current decline of the stock.

5. FEMALE INDICES

The biomass indices from EU surveys have been corrected in the years 1988 to 2002 for adjusting for the more efficient research vessel taken into use in 2003 (Casas *et al*. 2004). The spawning stock (female biomass) as determined from the EU survey biomass index (Figure 3 and Table 3) increased rapidly during the years

prior to the fishery, from 1989 and 1990 to 1992. This may have been due to a gradual increase in stock size after the cod biomass declined in the area. But this was also a reflection of the very strong 1986 year class, most of which were female during 1992. With the beginning of the shrimp fishery in 1993 the biomass declined up to 1997. After that the stock recovered reasonably well although with high annual variability (historical maximums in 2002 and 2005 were followed by years with lower biomass but at a relative high level). In 2009 the female biomass decreased to values close to the historical minimums in the survey series. In 2010 despite of the biomass increase about 77% compared to 2009 this was still among the lowest in the historical series. The female biomass estimated from the moratorium (2011-2014) were the lowest values in the EU survey series, well below B_{lim} proxy and shows the depletion state of the shrimp stock. Although in recent years 2015, 2016, 2017 and 2018 the female biomass indexes increased significantly compared to previous year (around 51%, 84%, 16% and 76% respectively), it remains at low level.

6. SHRIMP PREDATION BY COD AND REDFISH

Studies based in multispecies model developed in Gadget which covers the main commercial stocks in Flemish Cap over the period 1988-2012. (Pérez-Rodríguez et al. 2016) and 1988-2016 (Pérez-Rodriguez and D. González-Troncoso 2018), suggest that, predation by redfish, together with fishing have been the main factors driving the shrimp stock to the collapse (Table 3 and Figure 4). Predation by cod contributed to the decline of shrimp especially after 2007-2008. Also, the increment of large cod in the stock, especially since 2010, has raised the predation mortality on redfish, inducing the decline of redfish stock in the last years, the decreasing of the predation mortality on shrimp and as consequence favouring its recovery.

7. AGE ASSESSMENTS

Age analysis and sex composition was carried out on biological samples obtained from commercial fishery of a few nations in the past years (1993-2005). Since 2006 the samples obtained from the fishery were insufficient to assess the age of the catches and from 2011 due to the moratorium no sampling is available. So, the perception of the age composition and evolution of different year class along the years in the shrimp stock come from the age composition estimated in EU surveys (tables 4 and 5).

From those tables, some strong year-classes may be followed according the abundance by age groups from EU surveys (1988-2006). If the assignation of the age is right, the 1986 year-class stand out in the beginning of historical series with 4, 5 and 6 years olds in the years 1990, 1991 and 1992. The individuals with 4 year olds were also especially abundant in the years 1999-2002 indicating the strong of year-classes 1995, 1996, 1997 and 1998. The 1999 year-class stand out especially judging by the high number of 3 and 6 year olds in 2002 and 2005 years respectively. In these two years both the biomass and the abundance reached out the highest values in the series, especially in 2005 where the strong 2002 year class with 3 years old was also present. From 2004 to present the virtual absence of age group 1 in the catches and very low values for the ages 2 and 3 show the weakness of the 2003 -2017 year classes.

8. RECRUITMENT

Considering the abundance at age 2 as indicator of recruitment, the EU survey provided two recruitment indices. The abundance of two years olds obtained in the main trawl since 1996 and the abundance for this age group in the juvenile shrimp bag attached to the main gear since 2001. Both are presented together in table 6 and Figure 5.

Since 2005, the survey indices from Lofoten gear showed high variability in the estimated values but lower than in previous years, and confirming the absence of strong year classes. A similar trend can be observed from juvenile bag's indexes. In 2018 these indexes increased but remain low and confirm the weakness of the last recruitments.

9. PRECAUTIONARY APPROACH

In the absence of other suitable methods to indicate a limit reference point for biomass, the EU survey biomass female index was used (SCS Doc. 04/12). Scientific Council considers that a female survey biomass index of 15% of its maximum observed level provides a proxy for Blim. This corresponds to an index value of 2 564 t (Figure 6).

A limit reference point for fishing mortality has not been defined.

10. SUMMARY

Catches of shrimp on the Flemish Cap have been maintained at a high level averaging 43 000 t. between 1995 and 2005. However since 2006 they decreased gradually being in 2010 around 1990 t. No catches have been reported since 2011 as consequence of the moratorium of this fishery.

After some years with exploitation rates stables at relative low values (1.9-1.5 from 2005 to 2008) the UE survey indexes estimated decreased year after year up to 2013. Although in 2015-2018 the EU survey indexes increased compared to previous years, they remain at low level despite the moratorium established on 3M shrimp stock from 2011.

The female biomass index from the EU survey decreased between 1993 and 1994, increased since 1997 to 1998 and stayed stable to 2007. In 2008 and 2009 declined abruptly and from 2011 to 2014 decreased successively recording the lowest values in the historical series and falling below B_{lim}. Since 2015 the biomass index showed an upward trend and considering the 15% of the maximum survey female biomass index as a limit reference point for biomass (B_{lim}), the stock is now above B_{lim} and outside the collapse zone defined by the NAFO PA framework.

The successive weak recruitments in the last fourteen years and the still relative good condition of cod stock (one of the most important predators) make the recovery of the stock difficult.

Although the new information in 2018 indicates a slight improvement and the stock is now outside the collapse zone, it remains in a state of impaired recruitment that confirms the recommendation carried out within Scientific Council during autumn 2017 and therefore the fishing mortality would be set as close to zero as possible in 2019-2020.

11. ACKNOWLEDGEMENT

Appreciation is expressed to those who provided data for inclusion in this paper. Most of data used in this paper have been funded by the EU through the European Maritime and Fisheries Fund (EMFF) within the National Program of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy.

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Table 1. Annual nominal catches (t) by country of northern shrimp (*Pandalus borealis*) caught in NAFO Div. 3M.

Nation	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011*	2012*	2013*	2014*	2015*	2016*	2017*	2018*
Canada	3724	1041	970	906	807	484	490 [2]	618 [2]	295 [1]	16				10 [1]												
Cuba							119	46 [1]	1037 [1]	1537 [1]	1462 [1]	969 [1]	964 [1]	1126 [1]	446 [1]	11										
EU/Estonia		1081	2092	1900	3240	5694	10835 [1]	13256 [2]	9851 [1]	14215 [2]	12851 [1]	13444 [1]	12009 [1]	8466 [2]	10607 [2]	10255 [2]	2152 [2]	266 [2]								
EU/Denmark	800	400	200			437	235		93 [1]	359 [1]																
EU/Latvia		300	350	1940	997 [1]	1191 [1]	3080 [1]	3105 [1]	2961 [1]	1892 [1]	3533 [1]	3059 [1]	2212 [1]	1330 [1]	1939 [1]	1285 [1]	1194 [1]	611 [1]								
EU/Lithuania		1225	675	2900	1785 [1]	3107 [1]	3370 [1]	3529 [1]	2701 [1]	3321 [1]	3744 [1]	4802 [1]	3652 [1]	1245 [1]	1992 [1]	485 [1]		102 [1]								
EU/Poland					824	148 [1]	894 [1]	1692 [1]	209 [1]			1158 [1]	458 [1]	224 [1]												
EU/Portugal	300		150		170 [1]	203 [1]	227 [1]	289 [1]	420 [1]	16 [1]		50 [1]					3									
EU/Spain	240	300	158	50	423 [1]	912 [1]	1020 [1]	1347 [1]	855 [1]	674 [1]	857 [1]	1049 [2]	725 [2]	997 [2]	768 [1]	406 [2]	537 [1]	507 [2]								
EU/United Kingdom											547 [1]															
Faroe Is.	7333	6791	5993	8688	7410	9368	9199	7719 [2]	10228 [2]	8516 [2]	12676 [2]	4952 [1]	2457 [1]	1102 [1]	2303 [1]	1201	1349 [1]	495 [1]								
France (SPM)					150			138 [1]	337 [1]	161 [1]			487		741 [1]		193 [1]									
Greenland	3788 [1]	2275 [1]	2400 [1]	1107 [1]	104 [1]	866 [1]	576 [1]	1734 [1]		644 [1]	1990 [2]		12 [1]	778 [2]												
Iceland	2243	2355 [1]	7623	20680 [1]	7197 [1]	6572 [1]	9277 [2]	8912 [2]	5265 [2]	5754 [1]	4715 [1]	3567 [1]	4014 [1]	2099 [1]												
Japan								114 [1]	130	100 [1]	117 [1]															
Norway	7183	8461	9533	5683	1831 [1]	1339 [1]	2975 [1]	2669 [2]	12972 [1]	11833 [1]	21238 [1]	11738 [1]	223 [1]	890 [2]	1914 [1]	321 [2]										
Russia		350	3327	4445	1090		1142	7070 [1]	5687 [1]	1176 [1]	3 [1]	654 [1]	266 [1]	46 [1]	73 [1]	21 [1]	20 [1]	7 [1]								
Ukraine									348 [1]		237 [1]	315 [1]		282 [1]												
USA								629 [1]																		
Total	25611	24579	33471	48299	26028	30321	43439	52867	53389	50214	63970	45757	27479	18595	20741	13985	5448	1988	0	0	0	0	0	0	0	0 [3]

[1] NAFO Statlant 21 A
[2] From the fisheries biologist of respective countries
[3] Reported to NAFO provisionally
* Moratorium

Table 2. Exploitation Rate of Shrimp (Div. 3M) as Nominal Catches (t) divided by UE Survey Female Index (t).

	Nominal Catches	UE Survey Female Index	Exploitation Rate
1993	25611	6923	3.7
1994	24579	2945	8.3
1995	33471	4857	6.9
1996	48299	5132	9.4
1997	26028	4885	5.3
1998	30321	11444	2.6
1999	43439	13669	3.2
2000	52867	10172	5.2
2001	53389	13336	4.0
2002	50214	17091	2.9
2003	63970	11589	5.5
2004	45757	12081	3.8
2005	27479	14381	1.9
2006	18595	11359	1.6
2007	20741	12843	1.6
2008	13985	8630	1.6
2009	5448	1764	3.1
2010	1988	3819	0.5
2011	0	1132	0.0
2012	0	791	0.0
2013	0	691	0.0
2014	0	717	0.0
2015	0	1079	0.0
2016	0	1982	0.0
2017	0	2304	0.0
2018[1]	0	4051	0.0

[1]Provisional to 10 September

Table 3. Shrimp female, cod and redfish biomass indices from the EU survey series.

Year	Northern shrimp		Cod	Redfish
	Female Biomass ('000t)	St error	Biomass ('000t)	Biomass ('0000 t)
1988	4525	842	40839	18833
1989	1359	256	114050	16254
1990	1363	172	59362	12676
1991	6365	750	40248	7696
1992	15472	2623	26719	13021
1993	6923	995	60963	7261
1994	2945	445	26463	16253
1995	4857	521	9695	8764
1996	5132	383	9013	11966
1997	4885	345	9966	16582
1998	11444	816	4986	7083
1999	13669	1038	2854	9865
2000	10172	775	3062	17799
2001	13336	909	2695	7735
2002	17091	1493	2496	12131
2003	11589	921	1593	9382
2004	12081	761	4071	25061
2005	14381	933	5242	45122
2006	11359	1238	12505	76692
2007	12843	1564	23886	46463
2008	8630	1399	42195	56613
2009	1764	238	75228	35848
2010	3819	381	69295	21221
2011	1132	133	106314	19703
2012	791	166	113218	30595
2013	691	58	72289	21974
2014	717	90	163420	17993
2015	1079	198	114807	15800
2016	1982	264	80583	17100
2017	2304	291	89367	16209
2018	4051	433	75621	10048

Table 4. Abundance (10^6) at age by years in EU Flemish Cap surveys.

Year Age-class	1988	1989	1990	1991	1992	1993	1994[1]	1995	1996	1997	1998[2]	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1											94	1	9	3	181	14							8			1			0		
2									342	63	5497	474	107	332	1100	1257	2742	179	58	30	22	118	110	60	23	6		111	23	69	91
3	13	1		47	159	788	43	243	857	289	4235	2392	1704	1877	4787	1774	960	6903	301	387	646	161	387	90	89	18	35	41	109	128	163
4	123	82	404	260	146	376	88	276	153	241	707	1496	1074	2015	1128	548	643	524	1949	1221	857	169	236	109	56	60	43	93	214	245	191
5	233	81	92	465	440	205	73	120	273	322	789	601	572	1184	1047	907	783	1050	1205	1276	575	91	80	31	12	40	42	17	49	11	132
6	163	83	33	389	1129	446	181	215	65	115	414	204	349	323	311	243	133	758	522	588	40	25	15	0	1	3	6	9	6		29
7	15	11	2	103	398	49	8	122	44	16	15	8	61	16	55	9	21	141	65	129		7									5
8				33																											
total ('000000)	548	258	530	1296	2271	1864	391	976	1734	1046	11751	5177	3876	5750	8608	4753	5281	9554	4098	3631	2141	570	836	290	179	128	126	271	401	452	612

[1]Codend mesh-size 40 mm.
[2]Codend mesh-size 25 mm.

Table 5. Biomass estimated (tons) at age by years in EU Flemish Cap surveys.

Year Age-class	1988	1989	1990	1991	1992	1993	1994[1]	1995	1996	1997	1998[2]	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1											60	0.5	6	2	114	6							9			1			0.3		
2									609	139	9039	832	183	572	2178	2541	4660	187	57	38	33	303	372	177	63	21		359	65	190	267
3	44	2		166	610	2144	145	685	4552	1270	16203	7811	5924	5018	16710	7134	3730	15782	586	837	2094	600	2029	461	450	85	141	228	535	651	903
4	575	387	2053	1214	705	2083	554	1658	1071	1705	4099	9016	5233	9992	6436	2762	3969	2109	5882	4764	4491	892	1690	726	431	379	316	687	1395	1920	1460
5	2377	626	888	3843	3683	1823	681	892	2703	2853	5719	4784	3838	8321	7758	6197	6206	5702	5547	6330	4084	635	644	250	104	323	379	179	450	124	1353
6	2334	1053	436	4094	13637	4948	2374	2313	827	1249	4038	2138	3112	3087	2696	2339	1430	5531	3606	3971	390	224	149	5	7	35	64	98	75		333
7	285	183	28	1478	5801	675	124	1728	700	234	207	112	706	215	616	108	254	1365	621	1105		81									79
8				557																											
total (ton.)	5615	2252	3405	11352	24436	11673	3879	7276	10461	7449	39365	24695	19002	27206	36508	21087	20248	30675	16299	17045	11092	2735	4893	1619	1055	844	900	1551	2521	2885	4394

[1]Codend mesh-size 40 mm.
[2]Codend mesh-size 25 mm.

Table 6. Abundance at age 2 and average-weighted as indicator of recruitment (R) in the survey (lofoten gear) and from juvenile bag.

year	R (age 2) juvbag ('000)	R (age 2) Lofoten ('00000)	R(2)juvbag Av_weighed	R(2)lofoten Av_weighed
1996		3424		0.97
1997		629		0.18
1998				0.00
1999	4735	4735		1.35
2000	1069	1069		0.30
2001	1361	3321	0.33	0.94
2002	2125	11004	0.51	3.13
2003	0	12572	0.00	3.57
2004	41818	27415	10.06	7.79
2005	3741	1792	0.90	0.51
2006	7498	582	1.80	0.17
2007	3824	301	0.92	0.09
2008	4969	221	1.20	0.06
2009	3011	1177	0.72	0.33
2010	954	1106	0.23	0.31
2011	2440	601	0.59	0.17
2012	160	229	0.04	0.07
2013	102	63	0.02	0.02
2014	56	0	0.01	0.00
2015	427	1111	0.10	0.32
2016	390	230	0.09	0.07
2017	1411	695	0.34	0.20
2018	552	912	0.13	0.26

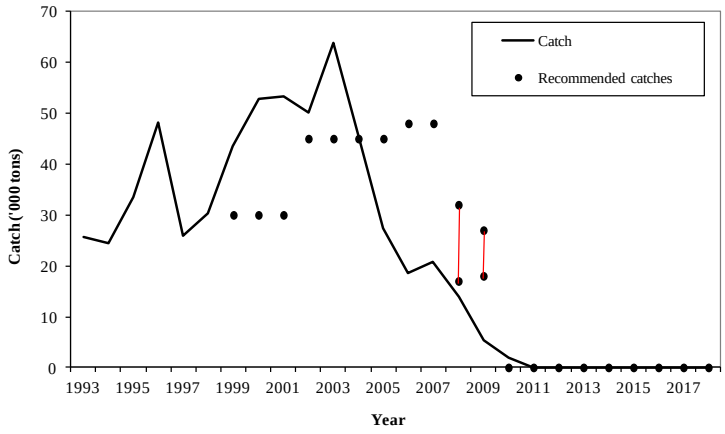

Fig.1. Catches (t) of shrimp on Flemish Cap and catches recommended in the period 1993-2018. Due to a moratorium, the shrimp catch is expected to be zero in 2018.

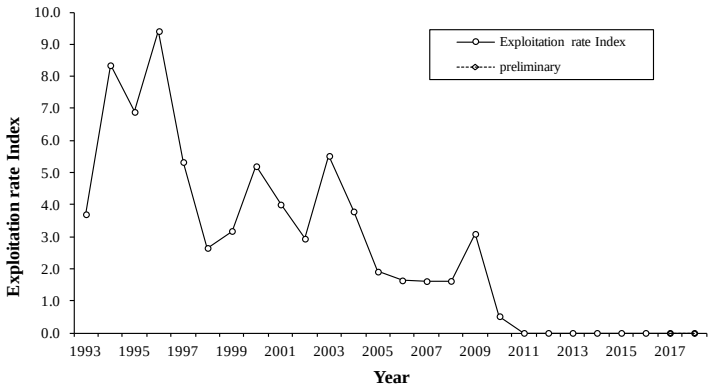

Fig. 2. Exploitation rates as nominal catch divided by the EU survey biomass index of the same year.

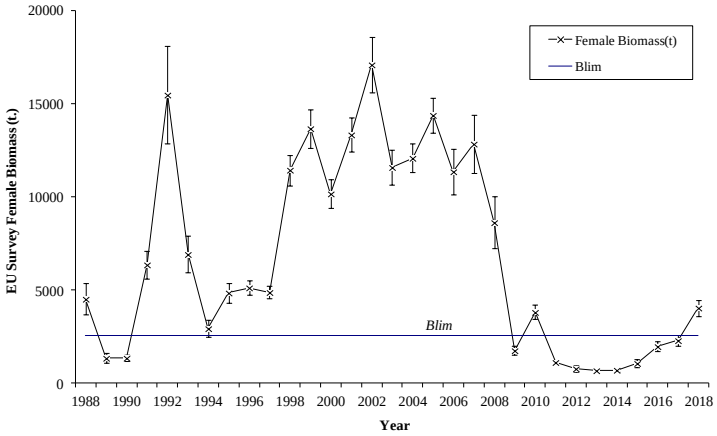

Fig. 3. Female biomass index from EU surveys, 1988-2018.

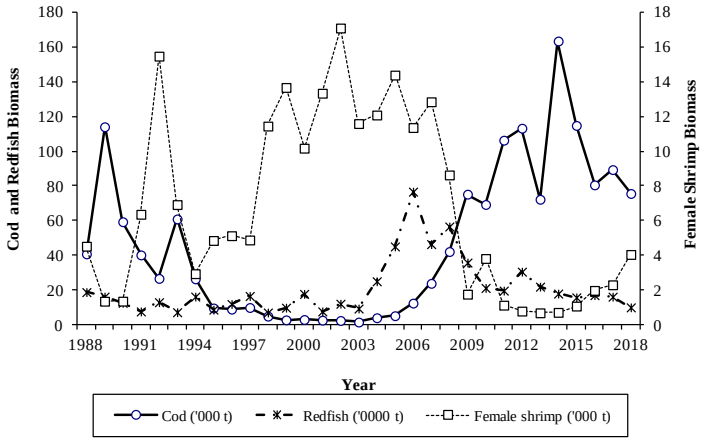

Fig. 4. Cod, Redfish and Female shrimp biomass from EU trawl surveys, 1988-2018.

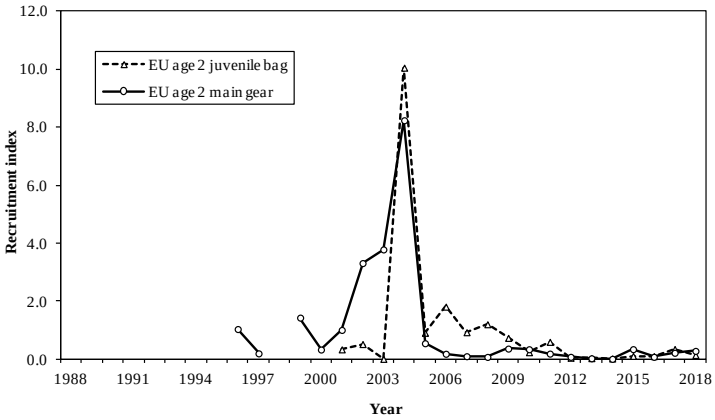

Fig. 5. Recruitment indices, abundances of age 2 in EU Survey from main gear and juvenile bag. Each series was standardized to its mean.

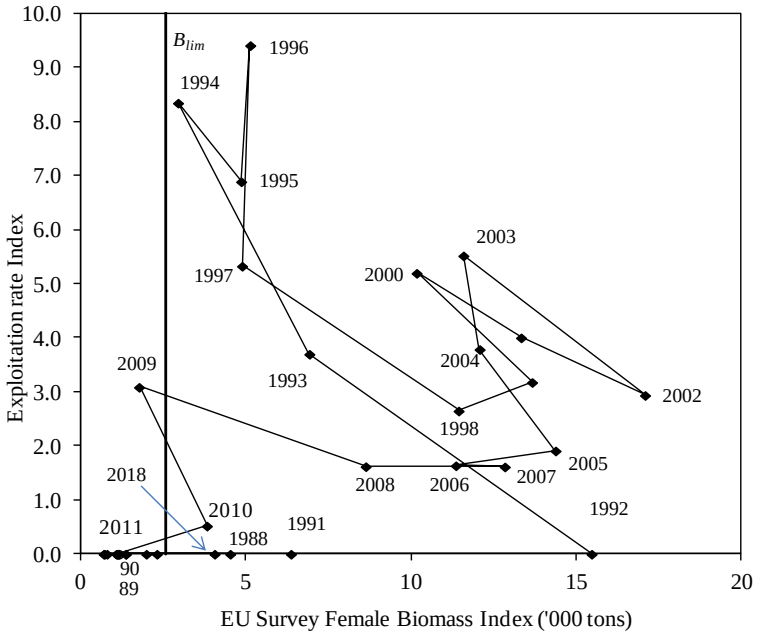

Fig. 6. Exploitation rate index plotted against female biomass index from EU survey. Line denoting B_{lim} is drawn where biomass is 15% of the maximum point in 2002. Due to the moratorium on shrimp fishing the expected catch in 2018 is 0 t.