SEASONAL DEVELOPMENT OF MATURITY IN BALTIC COD (*Gadus morhua L.*), WITH SPECIAL EMPHASIS ON THE MOST APPROPRIATE TIMING OF A SPAWNING CLOSURE TO PROTECT THE WESTERN BALTIC COD POPULATION

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This Working Document provides an update of an analysis conducted for the period 1992-2010, presented to STECF in the course of the review of the Baltic cod management plan (STECF 2010).

Abstract

We conducted an update analysis of the spawning activity of female Baltic cod in the western Baltic, separately for the Belt Sea (SD 22) and the Arkona Sea (SD 24), and covering the entire period from 1992-2016 (n = 69,125 fish). The main spawning period of female repeat spawning cod in SD 22, the core spawning area of the western Baltic cod stock, was mid-February to early April. The spawning season in SD 22 apparently started about one month earlier in recent years while the end of the spawning season did not change. The main spawning period of cod in SD24, characterized by a mixture of specimens of the western and eastern Baltic cod stock, was June to early July, with minor spawning activities occurring in March.

Given the present status of the western Baltic cod stock (F >> F_{MSY}, SSB << B_{lim}) a spawning closure is advisable; in SD 22 it should at least cover the period February 15 to March 30. In SD 24, a spawning closure may not be required because there is no directed fishery on summer spawning cod in the Arkona Sea. Alternatively, a spawning closure should cover the period June 1 to July 31 if the aim is to protect the aggregations of cod during peak spawning.

Introduction

A major concern for fisheries management is the ability to recognize the stock structure of the targeted fish species so that each stock can be optimally managed. Populations expressing different life histories are particularly at risk, as less productive populations may be more vulnerable to overexploitation than more productive populations. Information on stock structure is especially important for fish species that are under high exploitation pressure, like cod in the Baltic Sea.

The recruitment success of fish stocks fluctuates, and reproduction periods are among the most sensitive phases in the life-cycle of fish in general and cod in the Baltic Sea in particular. The dynamics of recruitment are influenced by both human use and by the environment. A large number of factors play a role, requiring long-term, continuous and interdisciplinary investigations.

Since 1983, ICES has carried out the assessment of the Baltic cod on the basis of two separate stocks, the western Baltic cod (WBC) stock *Gadus morhua* L., which is assigned to the western Baltic Sea (ICES subdivisions (SD) 22 - 24) and the eastern Baltic cod (EBC) stock *Gadus morhua callarias*, which inhabits the area east of Bornholm up to the Bothnian Sea and the Gulf of Finland (ICES SD 25 - 32) (Aro, 2000; ICES 2009). The border between these two stocks is diffuse and mixing occurs (Aro, 2000; Berner and Müller, 1989; Bagge et al., 1994; Oeberst, 2001, Bleil et al., 2009). The mixing of both Baltic cod stocks in SD 24 has been taken into account in the stock assessment since 2015 (ICES, 2015), after splitting of the catches has been possible.

Annual maturation, spawning period and spawning areas of both Baltic cod stocks differ significantly, with WBC and EBC being considered as spring and summer spawners, respectively (Wieland et al., 2000; Bleil and Oeberst, 2002; Köster et al., 2005; Bleil et al, 2009). Experimental investigations showed that the conditions for successful reproduction of both stocks are different. The lowest salinity limit for the successful fertilization of cod eggs in the central Baltic Sea (EBC) is 11. Fertilization of WBC, in contrast, requires a salinity level of 15 (Westernhagen, 1970; Nissling and Westin, 1997; Vallin et al, 1999). Temperatures between 1.5 °C und 10 °C, as well as an oxygen level of at least 2 ml/l are necessary for the development of eggs of both cod stocks.

Thus, in the Baltic Sea, cod spawning areas are separated spatially, because conditions are sufficient for a successful reproduction only in the deeper areas of the Belt Sea (SD 22), the Arkona Sea (SD 24) and historically in the deep basins of the central Baltic Sea (Fig. 1).

In the last two decades, the salinity, oxygen and temperature have changed significantly to the disadvantage of stable, successful cod stock reproduction, particularly in the deep basins of the eastern Baltic Sea (Karasiova et al., 2008). The inflow of large amounts of salt water (“major inflow“) that could lead to a drastic renewal of the water layers in the deep basins of the central Baltic Sea has occurred more rarely: The last time such an event happened was in January 2003, following a ten year stagnation period. Only recently, a series of major inflow events has been recorded (in December 2014 (Mohrholz et al., 2015), November 2015 and January 2016).

In ICES SD 22 and 24, minor saline water inflows take place more frequently during the course of a year. These inflows kept the environmental conditions for reproduction of cod stable over time, especially in ICES SD 22, but were not sufficient to supply the large central Baltic Sea basins with saline and oxygen-rich water.

Adult cod migrate into the spawning areas from their entire distribution area to form pre-spawning and spawning concentrations. With the end of the spawning activities these concentrations dissolve. Spawning and pre-spawning concentrations traditionally represent an ideal possibility for the fishery to attain the highest catches at the lowest cost.

Over the spawning periods, a number of parameters related to spawning and important for recruitment success were observed, such as the duration of the spawning activities, time of peak spawning, the volumes of eggs spawned as well as the quality of these eggs (egg diameter, dry weight and fertilisation rate) in relation to the parameters of the female cod (length, weight and age) and fluctuating hydrographical conditions (temperature and salinity). The analyses demonstrated that larger and thus older cod release a larger quantity of higher quality eggs over a longer period of time. Maturation and spawning behaviour of male and female Baltic cod are different. Male cod start earlier with maturation and spawning and spawn over longer periods than female Baltic cod (Bleil and Oeberst, 1997, Bleil et al., 2009). The release of fertile/developable eggs over the spawning period is asymmetrical with a peak shortly after the onset of spawning and a long decline of egg numbers. The quality (weight, size, fertility) of the released eggs reduces continuously from the commencement of spawning through its conclusion (Bleil and Oeberst, 1998). Similar results were described by Solemdal et al, 1993, Kjesbu et al. 1996, Trippel, 1998, Marteinsdottir and Begg, 2002, Scott et al., 2006 for Atlantic cod. It can be concluded that not only the larger portion of eggs capable of development but also the eggs with the best qualitative perspectives for development are released in the first half of the spawning season. Conservation and protection measures should thus concentrate on this time period. An appropriate timing of measures to protect spawner aggregation is therefore essential to have a maximum positive effect on recruitment while at the same time constraining fishing activities as little as possible.

In the Western Baltic (SD 22-24), the targeted cod fishery has been traditionally prohibited from April 1st – April 30th until 2015. In 2016, the spawning closure was shifted and extended to Feb 15th–March 31st (EU regulation 2015/2072), and in 2017 to Feb 1st–March 31st (EU regulation 2016/1903). Hence, it was deemed necessary to extend the spawning closure from 4 to 6 and finally to 8 weeks. In the Eastern Baltic Sea, cod fisheries are regulated by a seasonal closure from 1 July to 31 August to protect spawning fish. A closure of a central part of the main spawning area in the Bornholm Basin has been implemented and enforced during the main spawning season since the mid- 1990s for all fisheries. A year-round area closure for all fisheries in specific areas of the Bornholm Basin, the Gotland Basin and the Gdansk Deep was introduced in 2005, aiming at reducing fishing mortality. In the years 2006–2016, Eastern Baltic area closures have been enforced from 1 May to 31 October (ICES 2009, EU regulation 2015/2072).

The temporal closures were related to the areas and periods of spawning of both cod stocks. The temporal development of the proportion of spawning cod in SD 22 and SD 24 was analysed in 2010 (STECF, 2010). The comparison of time periods 1992 to 1999 and 2000 to 2010 indicated no significant changes in the seasonal development of spawning activities in SD 22, although spawning might have started slightly earlier in the last two years of the analysed period. Peak spawning of repeat spawning females in the Belt Sea (SD 22) was identified to be in February and March.

In SD 24, the timing of spawning appeared to be even more stable, but the spawning in 2009 was clearly delayed. June was identified as the month with most spawning activity, however the distinctive spawning activities in May in the 1990s were not observed from 2000 onwards anymore. The lower proportion of spawning cod in SD 24 compared to the proportions in SD 22 is likely determined by the mixing of both Baltic cod stocks in this area (ICES, 2015). Eastern Baltic cod spawns later than western Baltic cod (Bleil et al., 2009).

This document describes the seasonal development of maturation of female cod in SD 22 and SD 24 from January to July between 1992 and 2016. We compiled data from recent years and provide an update of an analysis conducted earlier for the period 1992-2010 (STECF, 2010).

Material and Methods

The Thünen Institute and its predecessors collected data on cod maturity and spawning timing since 1992, either from commercial catches or from surveys. Cod samples used for this analysis were obtained from the Belt Sea (ICES SD 22) and the Arkona Sea (ICES SD 24). Data on cod spawning in the Sound (ICES SD 23) were not available.

Samples: A total of 117,460 individuals (females and males) were sampled between January and July (ICES SD 22: n = 55,177; ICES SD 24: n = 62,283). Only female cod were used for analysing the temporal development in spawning activity (Table 1, 2). This avoids a bias because spawning of male cod starts earlier and lasts longer than in females (Bleil and Oeberst, 1997, Bleil et al., 2009).

The potential spawning stock is defined as the total population of fish with a total length greater than or equal to the minimum length at sexual maturity (Berner, 1985; Bleil and Oeberst, 2002). We have used the minimum length at sexual maturity criteria following the method described in Bleil and Oeberst (2002).

The samples were obtained during international research cruises "BITS" and German national surveys related to the reproduction of cod, which were carried out annually in the Belt Sea (SD 22) and in the Arkona Sea (SD 24) in February, March, May/ June and November from 1992 to 2010. In addition, cod were sampled on research cruises in the southern Mecklenburg Bight (SD 22) during January and December from 1993 to 2007 and in the Arkona Sea (SD 24) during July from 2009 to 2010. Also, samples from the German commercial catch sampling programme were utilized.

During the research cruises, different bottom trawl nets were used (in early times: "HG 20/25" and "Warnemünder Dorschzeese"; since 2002: "TV3", following the standard gear specification of the Baltic International Bottom Trawl Survey (BITS) (ICES, 2002)). Total length, wet weight, age, sex and maturity stage were determined for all individuals.

Maturity: Sexual maturation was determined by visual inspection of the gonads using a 10 stage scale (Tomkiewicz et al., 2003). For the analysis the proportion of individuals in these maturity stages were summarized into four groups:

MG1: preparation (immature and resting)
MG2: pre-spawning (ripening and preparing)
MG3: spawning (in the 10 stage scale involving maturity stage
5 = spawning I/initiation of spawning,
6 = spawning II/main spawning period, and
7 = spawning III/Cessation of spawning).
MG4: spent

Data: Data were also split in "recruit spawners" (or "first spawners", total length < 35 cm) and "repeat spawners" (total length ≥ 35 cm) because studies of the general annual succession of the spawning processes indicated that the spawning activity in a spawning period always begun with the spawning of oldest/largest cod "repeat spawners". Smaller individuals follow successively, so that at the end of the spawning period the youngest and smallest fish spawn, also known as "recruit spawners" (Bleil and Oeberst, 1997, 1998).

Research surveys usually cover the whole distribution area, while commercial fisheries target aggregations of fish at specific times and in specific areas. Commercial fishing activity is further influenced by quality and price of the landings. In addition, trawl surveys and commercial fishery used gears with different cod-end mesh sizes. Surveys used a cod-end mesh size of i = 20 mm to capture the total length spectrum. In contrast, commercial operations, either passive or active, target cod larger or equal to the minimum landing size to avoid discards. Therefore, commercial fishery yielded only a limited number of recruit spawners as most of the fish caught was above minimum landing size (38 cm until 2014, 35 cm thereafter) and thus belonged already to the group of repeat spawners.

As a compromise between maximum temporal resolution and sufficient number of samples per time unit, the analysis used thirds of months (roughly 10 day periods), called "decades" (for instance decade 4 denominates the period Feb 1st through Feb 10th).
The area SD 22 is assumed to be dominated by true WBC with little mixing with EBC. In contrast, SD 24 is considered a major mixing area of both stocks (Hüssy et al., 2016). The relatively large number and homogenous distribution of samples in SD 22 (Table 2) and SD 24 (Table 3) provides a

reasonable basis for a thorough analysis of temporal patterns in spawning activity in both areas (fewer samples in April were due to the traditional spawning closure). However, while the proportions of female spawners in SD 22 will reflect the spawning activity of the true WBC stock, the proportions of female spawners in SD 24 will be influenced by both stocks. Consequently, active spawning of WBC in SD 24 will be attenuated by non-spawning EBC in the catch samples while active spawning of EBC in SD 24 will be diluted by non-spawning WBC (that may occur in greater proportions in SD 24 after spawning in SD 22). This results in unknown bias and overall lower proportions of spawning females in SD 24 and exacerbates the identification of the spawning season in this area.

The mean proportions of defined maturity groups by decade were combined as the arithmetic mean to estimate the mean proportion of maturity group of a given period for all years.

Results

Timing of spawning

The main spawning period of female repeat spawning cod in SD 22 was February to early April (Fig. 2). The main spawning period of female repeat spawning cod in SD 24 was June to early July (Fig. 3).

In SD 22 the spawning period of female repeat spawning cod started gradually earlier from about 2008 onwards. Noticeable spawning started in the second decade of February at the beginning of the time series, while it now starts already in the second decade of January (Fig. 4). A similar shift can be identified in female recruit spawners in SD 22. In the 1990s and 2000s, female recruit spawners started spawning in the second decade of February and now may already spawn in the third decade of January (Fig. 5). The relatively large number and homogenous distribution of available samples (Table 1) suggests that the earlier start of the spawning period in SD 22 is real and not an artefact. The end of the spawning activities of repeat and recruit spawning female cod seems to occur in the first or second decade of April, lacking any evidence of temporal shift over the last 24 years (Figs. 4, 5).

In SD 24 female repeat spawning cod were observed in spring (beginning of March) in most years, suggesting that these individuals were mainly WBC spawners in SD 24 (Fig. 6). However, the proportion of spawning females was low compared to estimates of SD 22. Highest proportions of female repeat spawning cod in SD 24 were observed between middle of June and end of July. Similarly, female recruit spawning cod were usually only observed as of June (Fig. 7). The estimates of the latest years suggest an earlier start of spawning also in SD 24, but the signal is much less pronounced than in SD 22. The end of the spawning season in SD 24 may partly extend beyond the end of July but data for this period were not available.

Discussion

The comparison of the updated data (2011-2016) with the results estimated from 1992 to 2010 supports the earlier findings that the main spawning season in western Baltic female repeat spawning cod is the period from February to April (Bleil et al. 2009). A shift of the start of spawning towards the second decade of January was not accompanied by an earlier end of spawning activities in April. Hence, the 8-week spawning closure (February 1 to March 31) imposed for 2017 for the area SD 22, SD 23 and SD 24 fully matches with the spawning season of the western Baltic cod population in SD 22, which is the core spawning area of this stock, and ensures effective protection of the repeat spawning females most valuable for the rebuilding of the stock. There is evidence that the spawning activities of cod in SD 23 (which is not analysed here due to a lack of data) seem to be largely similar to the temporal patterns of cod in SD 22 (Vitale et al., 2005). The protective effect of the present spawning closure for WBC in SD 24 is probably minor given the low level of spawning of the western stock in the Arkona basin (see below).

Belt Sea (SD 22)**:** The spawning activities of repeat spawning females in SD 22 currently begins in the second decade of January, peaks from the middle of February to end of March and ends in the middle of April. These individuals were defined as “spring spawners” (Bleil and Oeberst, 2002). The spawning activity in 1992 – 2008 differed only slightly from that determined in the previous century (Poulsen, 1930, 1931; Apstein, 1911; Berner, 1960, 1985 and Thurow, 1970). The earlier start of spawning in January is a new development which might be influenced by the warmer water temperature in the deeper parts of the Mecklenburg Bight in winter (Cruise reports of Leibniz Institute of Baltic Sea Research (IOW), Warnemünde, Germany). It could be speculated that changes in the proportion of pre-spawning and spawning first spawners in January in the latest years were linked to a shift of the maturity ogive in direction of cod smaller 35 cm (decreasing length where 50 % of individuals spawn) but no such change has been observed in SD 22 (M. Bleil, unpublished data).
It is noteworthy that low WBC recruitment in the last years was correlated with high fishing pressure and a “spawning” closure in April, i.e. a period largely outside the main spawning season of both the WBC and EBC. The 2015-WBC year class was extraordinary low, similar to the cod recruitment in the Kattegat and North Sea stocks (ICES 2016). There are now indications that the 2016–WBC year class could be above average or even strong (unpublished data Thünen Institute, 2016 Baltic International Trawl Survey in quarter 4; evidence from German and Danish pound net fishers), coinciding with the first year that the spawning closure matches the peak spawning period of the WBC stock (i.e. Feb 15 to March 31). This suggests that the spawning closure in SD 22 may be effective to improve spawning conditions for the WBC stock – although it has to be acknowledged that there is presently just one data point in time. Given the present status of the WBC (F >> F_{MSY}, SSB << B_{lim} (ICES 2016), 2017 commercial TAC is -56% of 2016 TAC), a spawning closure in SD 22 is recommended to support a rapid stock recovery.
The peak spawning period in SD 22 coincides with peak catchability of WBC due to spawning concentrations in the deeper areas of the Belt Sea. The spawning closure, thus, effectively reduces fishing pressure. This is also the period when largest specimens (cod with individual weights of 4-20 kg) are landed (ICES 2015), involving also the profitable sale of cod roe.

Arkona Basin (SD 24)**:** The Arkona basin is a transitional area with intermediate water depths between the Belt Sea (SD 22) and the Bornholm Sea (SD 25), which have been described as typical spawning areas for the western and the eastern Baltic cod stock, respectively. The knowledge about spawning activities in Arkona Sea was inconsistent. Some studies concluded that the Arkona Sea had a minor importance for overall spawning activity, as spawning was sporadic and took place only during spring (Kändler, 1944; Berner, 1960; Berner and Borrmann, 1977; Berner and Vaske, 1981; Bagge et al., 1994). Bleil et al., 2009 demonstrated on the other hand that spawning of cod has occurred in Arkona Sea regularly every year, with a peak during summer in the period 1992–2005. Our update analysis confirmed that the Arkona basin is an important spawning ground for cod in June-July (probably of EBC origin) while minor spawning had been occurring in March (probably WBC). Since spawning activities of spring spawning WBC in SD 24 seem to be minor and there is no directed fishery on summer spawning aggregations of cod in the Arkona basin, a spawning closure may not be required here. However, if a closure is considered aiming at protecting spawners during the peak spawning season, it should cover the period of June 1 to July 31.

Finally, it can be concluded that the overall spawning season did not significantly change over time. The main spawning period of female cod in SD 22 was February to early April. The main spawning period of female cod in SD 24 was June to early July. Further investigations should assess the reasons for the earlier start of spawning in SD 22 in recent years.
The main spawning periods depend on spawning stock structure and hydrographical conditions which can change over time. Therefore, regulations on closed spawning seasons should be reconsidered in regular intervals and be adjusted if necessary.

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Tables

Table 1: SD 22: Number of sampled female cod between January and July by year, month (1-7) and decade (1-3) within month. The sum of fish per decade is given below. Red bars indicate relative contribution to total sample size of 31,858 female cod.

	Month	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7
Year	Decade	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1992		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993		0	0	0	0	0	75	114	0	0	0	8	0	0	0	0	0	156	0	0	0	0
1994		0	65	77	46	88	8	297	0	38	0	0	0	0	0	0	0	0	118	0	0	0
1995		0	0	140	0	0	0	430	0	92	41	0	0	0	111	0	0	0	47	0	0	0
1996		0	100	0	0	0	127	49	163	21	18	104	62	0	65	0	50	218	0	0	0	0
1997		0	88	359	75	0	0	34	179	117	38	0	87	0	0	336	0	0	0	0	0	0
1998		0	190	192	89	0	0	137	198	0	121	0	0	0	395	70	0	0	0	0	0	0
1999		104	171	207	206	122	26	0	297	124	0	61	66	181	126	32	384	0	104	0	0	0
2000		93	0	259	127	122	0	31	655	0	132	105	0	0	0	134	105	198	0	0	0	0
2001		165	74	0	109	120	91	156	474	65	298	0	0	0	166	86	79	138	0	0	0	0
2002		0	280	137	139	279	0	120	577	0	81	0	0	0	166	33	135	0	0	0	0	0
2003		0	186	101	93	188	15	104	333	0	147	0	0	0	0	0	0	0	0	0	0	0
2004		0	186	194	128	85	213	0	423	125	0	104	0	0	0	0	74	0	0	0	0	0
2005		0	114	69	0	241	141	665	0	0	0	0	0	0	0	289	0	118	59	0	110	127
2006		124	269	177	0	321	0	185	449	0	0	0	0	0	0	298	15	0	0	0	0	0
2007		0	102	258	163	333	95	118	349	0	0	0	0	0	0	98	0	267	0	0	132	0
2008		0	136	84	61	117	247	198	0	0	0	0	0	0	0	51	0	0	0	136	85	0
2009		0	74	123	66	149	60	51	79	1	0	0	0	0	0	38	0	0	0	0	0	1
2010		0	97	96	95	268	21	123	53	0	0	0	0	0	0	50	0	0	0	0	0	0
2011		0	0	0	105	146	29	303	0	121	0	0	0	0	0	20	0	0	43	0	0	158
2012		267	203	340	140	0	41	97	0	0	0	90	0	0	0	43	0	99	0	0	0	0
2013		72	72	83	85	230	64	177	129	113	148	0	0	0	0	143	0	0	0	0	0	0
2014		0	51	37	219	0	102	0	137	73	0	0	0	0	54	47	80	0	0	0	131	0
2015		1	42	87	96	100	166	0	253	0	0	73	0	0	0	0	0	0	57	0	0	113
2016		0	65	14	118	37	40	548	123	0	64	34	0	0	46	0	0	0	82	0	216	0
	sum	826	2565	3034	2160	2946	1561	3937	4871	890	1088	579	215	181	1129	1768	922	1194	510	136	674	399

Table 2: SD 24: Number of sampled female cod between January and July by year, month (1-7) and decade (1-3) within month. The sum of fish per decade is given below. Green bars indicate relative contribution to total sample size of 37,540 female cod.

	Month	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7
Year	Decade	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1992		0	0	0	0	0	57	0	22	0	0	0	0	0	60	0	0	0	0	0	0	0
1993		0	0	0	398	12	27	128	0	0	0	0	40	47	0	0	390	0	0	0	0	0
1994		0	0	0	0	0	0	327	108	0	0	0	0	0	0	0	0	490	45	482	0	0
1995		0	0	0	267	32	0	506	0	0	43	0	122	0	0	126	0	0	0	0	0	0
1996		0	0	0	0	0	1	497	0	0	0	0	62	0	0	115	445	90	0	0	0	0
1997		0	53	0	0	171	0	0	194	0	0	0	0	0	0	56	327	0	0	0	0	0
1998		0	119	148	155	94	15	148	0	317	0	0	136	0	0	538	0	0	0	0	0	0
1999		153	0	148	166	82	199	0	0	436	0	0	105	0	0	0	39	436	0	0	0	0
2000		122	0	166	134	66	99	0	190	3	0	86	0	0	149	0	655	112	0	0	0	0
2001		144	0	147	0	305	58	6	173	0	0	0	0	0	0	0	571	112	0	0	0	0
2002		133	0	0	0	3	156	142	128	257	0	0	0	0	82	0	621	0	0	0	0	0
2003		131	64	128	228	0	301	189	307	298	0	127	0	0	0	0	40	0	0	0	0	0
2004		0	0	13	0	126	435	18	96	465	0	88	66	132	0	0	500	0	0	0	0	0
2005		0	74	297	160	262	214	232	309	0	0	0	0	150	100	605	280	0	0	0	0	193
2006		0	109	139	205	0	310	44	222	126	0	0	0	0	115	347	82	120	0	0	91	0
2007		0	0	147	0	136	162	161	213	90	0	0	0	0	0	14	498	58	0	0	0	139
2008		0	0	0	0	0	222	133	103	0	0	0	0	0	125	162	237	0	183	18	0	142
2009		0	14	0	0	136	299	221	191	1	0	0	0	0	131	102	178	0	0	211	53	174
2010		0	0	0	0	133	48	156	103	0	0	0	0	126	165	127	188	275	0	65	62	0
2011		0	0	0	0	220	59	148	39	0	0	0	153	249	0	0	253	0	0	68	0	0
2012		0	74	190	273	328	145	235	29	528	267	151	198	0	0	0	213	0	0	146	86	0
2013		0	0	0	104	4	204	58	134	0	0	0	0	0	0	120	0	0	0	145	0	0
2014		113	0	140	98	109	0	113	1	223	0	0	0	118	91	0	0	0	0	0	0	0
2015		0	75	0	0	94	105	416	180	275	121	46	144	0	0	201	85	0	0	0	0	0
2016		0	53	0	4	304	554	14	0	19	8	0	104	94	0	122	14	0	0	0	47	0
	sum	796	635	1663	2192	2617	3670	3892	2742	3038	439	498	1130	916	1018	2635	5616	1693	228	1135	339	648

Figures

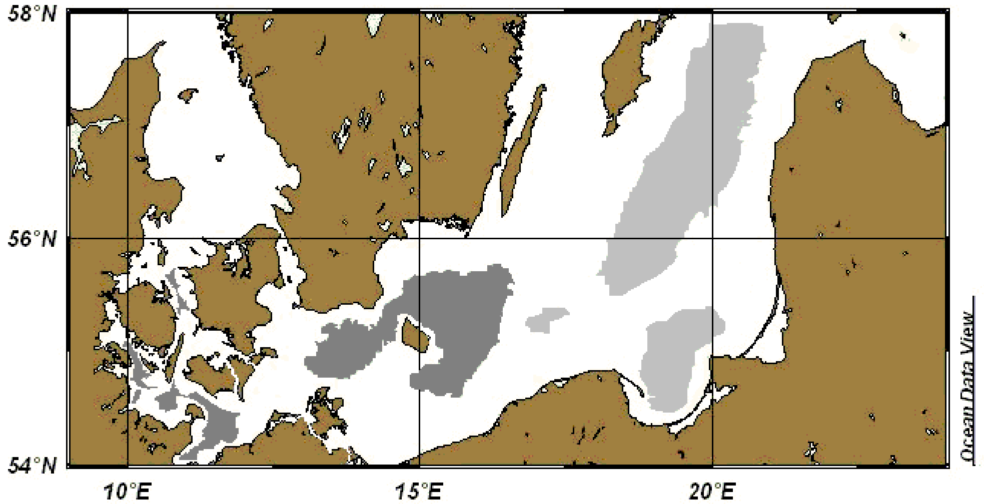

Figure 1: Spawning areas of cod in the Baltic Sea (dark grey: active spawning areas; grey: historical spawning areas, without regular, annual spawning success in the recent years)

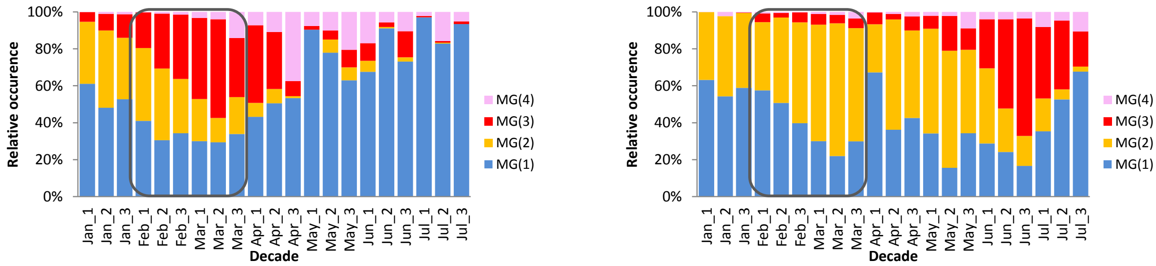

Figure 2: Female **repeat spawning** cod (defined as total length ≥ 35 cm). Mean temporal development of the proportion of maturity groups (MG 1: preparation, MG 2: pre-spawning, MG 3: spawning, MG 4: spent) in SD 22 (left) and SD 24 (right) by 10-day periods (decades) between January and July for 1992 to 2016. The 2017 spawning closure from February 1 to March 31 is indicated.

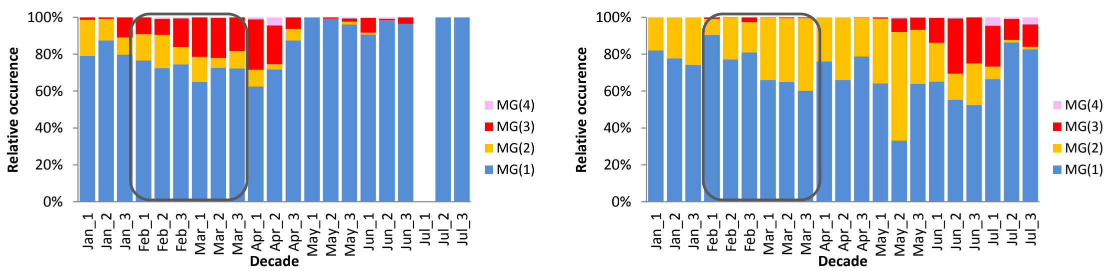

Figure 3: Female **recruit spawning** cod (defined as total length < 35 cm). Mean temporal development of the proportion of maturity groups (MG 1: preparation, MG 2: pre-spawning, MG 3: spawning, MG 4: spent) in SD 22 (left) and SD 24 (right) by 10-day periods (decades) between January and July for 1992 to 2016. The 2017 spawning closure from February 1 to March 31 is indicated.

Decade	Jan_1	Jan_2	Jan_3	Feb_1	Feb_2	Feb_3	Mar_	Mar_	Mar_	Apr_1	Apr_2	Apr_3	May_	May_	May_	Jun_1	Jun_2	Jun_3	Jul_1	Jul_2	Jul_3
1992																					
1993						0	20				63						8				
1994		0	0	2	0	13	51		16									41			
1995			1				22		5	9				1				29			
1996		0				5	21	19	24	14	18	22		5		0	8				
1997		2	1	0			57	76	59	24		2			4						
1998		2	1	0			26	39		33				4	10						
1999	0	1	5	2	23	38		57	58		2	0	2	3	0	10		0			
2000	1		4	31	25		84	67		72	45				1	13	0				
2001	0	8		27	37	56	61	47	20	29				0	15	13	0				
2002		1	2	0	35		63	40		32				1	14	3					
2003		0	0	4	5	38	35	52		31											
2004		2	1	11	42	25		49	44		30					7					
2005		1	5		24	8	23								1		0	0		0	0
2006	0	2	3		22		49	56							6	0					
2007		0	1	13	26	48	21	60							12		1			0	
2008		8	32	26	65	64	75								17				1	0	
2009		15	46	45	44	76	60	96	0						15						0
2010		0	1	15	9	29	21	68							18						
2011				23	17	38	29		44						18			0			1
2012	35	45	30	30		17	55				0				17		0				
2013	0	30	48	51	28	34	49	30	55	87					2						
2014		3	14	12		28		21	28					26	2	30				2	
2015	0	38	58	24	59	41		58			4							30			5
2016		21	43	52	43	65	57	71		89	85			0				0		1	

Figure 4: SD 22 (Belt Sea): Proportion of female **repeat spawning** cod (defined as total length ≥ 35 cm) by year and decade (defined as one third of a month). Numbers in the cells show the proportion of spawners (maturity group 3) with colours indicating ranges of 20 % 0 24 60 80 100; white cells: no data. The 2017 spawning closure from February 1 to March 31 is indicated.

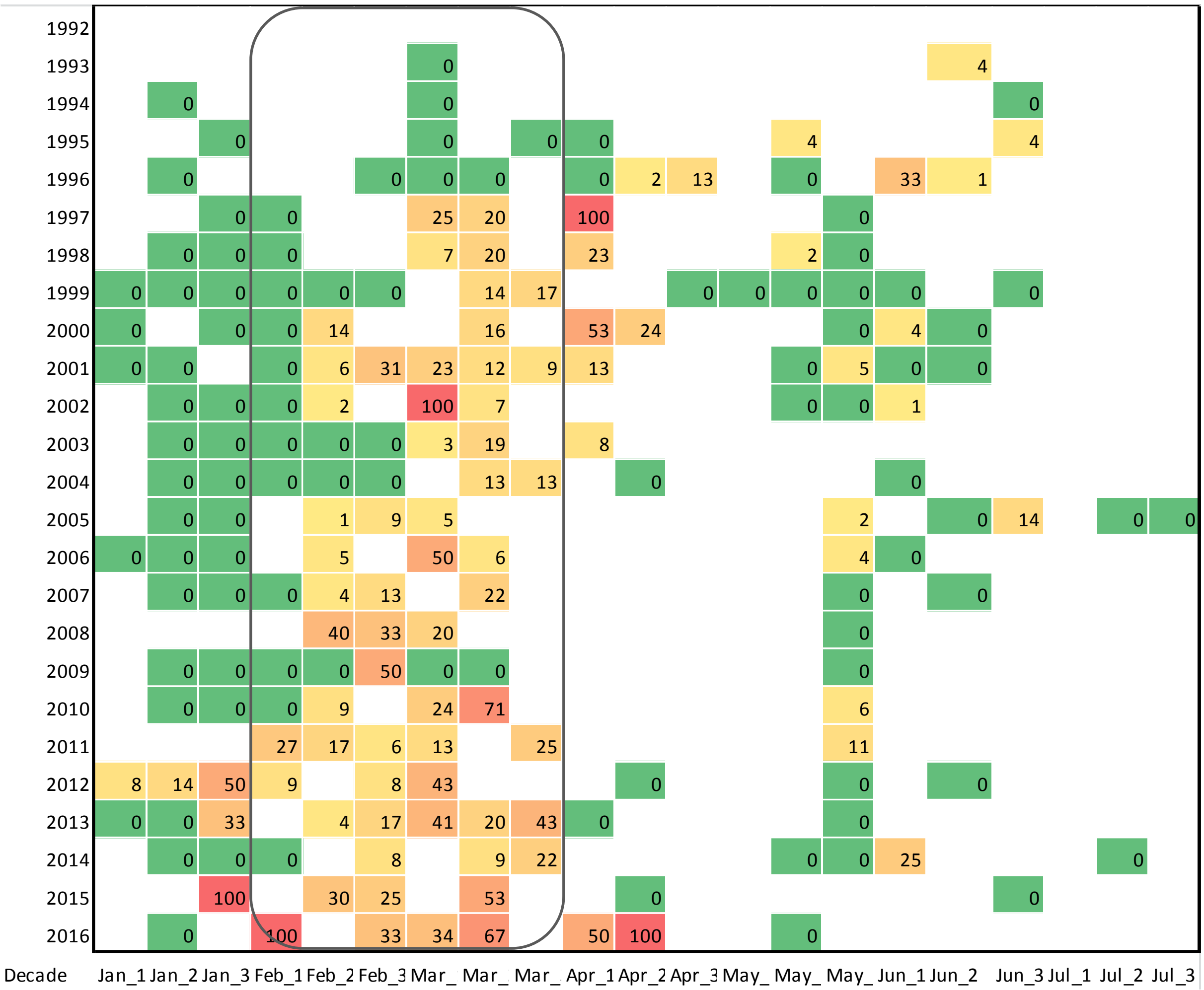

Figure 5: SD 22 (Belt Sea): Proportion of female **recruit spawning** cod (defined as total length <35 cm) by year and decade (defined as one third of a month). Numbers in the cells show the proportion of spawners (maturity group 3), with colours indicating ranges of 20 % 0 24 60 80 100; white cells: no data. The 2017 spawning closure from February 1 to March 31 is indicated.

Decade	Jan_1	Jan_2	Jan_3	Feb_1	Feb_2	Feb_3	Mar_	Mar_	Mar_	Apr_1	Apr_2	Apr_3	May_	May_	May_	Jun_1	Jun_2	Jun_3	Jul_1	Jul_2	Jul_3
1992						3		3						46							
1993				1	0	0	12					55	34			24					
1994							3	2									69	88	33		
1995				0	7		2			0		2			35						
1996						0	4					3			17	21	3				
1997		0			1			17							4	35					
1998		0	0	0	0	13	0		16			5			14						
1999	0		0	0	0	3			8			6				0	26				
2000	0		0	0	0	0		8	0		4			9		27	75				
2001	0		0		2	0	33	8								25	90				
2002	0				0	0	3	8	9					18		20					
2003	0	0	0	0		0	1	1	4		4					67					
2004			0		0	2	11	0	9		0	2	2			47					
2005		0	1	1	4	2	3	7					0	4	10	14					0
2006		0	1	1		2	2	10	14					8	22	26	7			1	
2007			0		1	1	4	4	2						0	38	76				10
2008						1	13	3						2	8	15		39	0		1
2009		0			3	4	7	2	0					2	13	21			28	75	66
2010					1	0	2	4					3	10	1	17	39		30	25	
2011					0	2	1	0				3	3			21			51		
2012		0	0	41	19	68	6	0	0	0	0	0				24			69	84	
2013				8	0	3	11	10							16				60		
2014	0		0	4	3		2	0	6				2	69							
2015		0			0	7	2	0	1	0	7	1			8	55					
2016		0		0	4	3	0		0	25		1	5		3	7				2	

Figure 6: SD 24 (Arkona Sea): Proportion of female **repeat spawning** cod (defined as total length ≥ 35 cm) by year and decade (defined as one third of a month). Numbers in the cells show the proportion of spawners (maturity group 3) with colours indicating ranges of 20 % 0 24 60 80 100; white cells: No data. The 2017 spawning closure from February 1 to March 31 is indicated.

Decade	Jan_1	Jan_2	Jan_3	Feb_1	Feb_2	Feb_3	Mar_	Mar_	Mar_	Apr_1	Apr_2	Apr_3	May_	May_	May_	Jun_1	Jun_2	Jun_3	Jul_1	Jul_2	Jul_3
1992						0		0						0							
1993				0	0	0	0					0	0			16					
1994							0	0									5	50	13		
1995				0	0		0			0		0			6						
1996							0					0			3	0	0				
1997		0			0			0							0	8					
1998		0	0	0	0		0		0			2			0						
1999	0		0	0	0	0			2			0				0	5				
2000	0		0	0	0	0		0			0			5		8	65				
2001	0		0		0	0		2								11	92				
2002	0				0	0	0	0	1					0		8					
2003	0	0				0	0	1	2							53					
2004			0			0			0							6					
2005		0	0	0	0	0	1	1					0	5	23	23					0
2006		0	0	0		0		2	0						10	0	0			0	
2007			0		0	0		0	0						11	8	44				17
2008						0	0	2						0	9	8		0	0		0
2009		0			0	0	3	0						0	0	11			8	10	33
2010					0	0	0	0					0	0	0	14	27		21	15	
2011					0	0	0	0				0	4			14			38		
2012		0	0	9	1	44	0	0	0	0	0	0				4			27	32	
2013				0	0	0	0	0							11				48		
2014	0		0	0	0		0		0				0	50							
2015		0			0	5	1	0	0	0	0	0			7	52					
2016		0		0	0	3	0		0	0		0	0							0	

Figure 7: SD 24 (Arkona Sea): Proportion of female **recruit spawning** cod (defined as total length < 35 cm) by year and decade (defined as one third of a month). Numbers in the cells show the proportion of spawners (maturity group 3), with colours indicating ranges of 20 % 0 24 60 80 100; white cells: no data. The 2017 spawning closure from February 1 to March 31 is indicated.