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Abundance and mortality of Northeast Arctic cod and haddock during their first years of life

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Abstract

For Northeast Arctic cod and haddock in the Barents Sea, long time series of year-class abundance are available at several stages before they recruit to the fishery, i. e. before they reach age 3. Several studies have already been made of the influence of various factors on the abundance and survival of these stocks during the first three years of life, in particular for cod. However, revision of existing data series as well as availability of longer data series makes a new analysis worthwhile. The analysis includes VPA estimates of recruitment, as well as estimates of total egg production and survey estimates from pelagic and bottom trawl surveys.

The mortality between various life stages is found to vary considerably between cohorts for both stocks. Although and the mortality is highest during the first months of life, the year-class strength can also be affected considerably by processes taking place between the 0-group stage (ca. 6 months) and age 3. The mortality in this period of life seems to be strongly density –dependent for both stocks. The estimates of 0- and 1-group abundance of cod and haddock from different sources (0-group pelagic trawl and acoustic, 1-group XSA and trawl) give numbers which are compatible with each other. The ratio between haddock and cod recruitment at age 3 is higher in the period after 1980 than before 1980, this may be due to higher temperature in the latter period. High haddock recruitment never occurs when cod recruitment is low.

Key words: Cod, haddock, Barents Sea, recruitment, mortality

Introduction

Northeast Arctic cod reach maturity at an age of 6-9 years, and mature fish undertake spawning migrations southwards along the Norwegian coast, with the Lofoten area as the main spawning ground (Figure 1a). Northeast Arctic haddock mature at age 5-7 years, and spawn farther off the coast than cod does (Figure 1b). Eggs and larvae of both stocks are transported northwards in the upper water layers during April-August, and in August-September the 0-group is distributed in the upper 100m over large areas in the Barents Sea and off Svalbard (Eriksen et al. 2010). During autumn the 0-group descends towards the deeper layers, and age 1-3 cod and haddock are found both at the bottom and in the midwater layers. Both cod and haddock start recruiting to the fishery at age 3, thus it is natural to let the analysis of abundance and mortality at young stages stop at age 3, so that effects of fishery can be ignored. Estimates of the number of young cod caught as by-catch in the shrimp fishery (ICES 2010, Tab. 3.31), indicate that these numbers generally are small compared to the consumption of young cod by cod (cannibalism), and the same is most likely true for the by-catch of young haddock. Thus such by-catches are ignored in our analysis.

Many studies on the influence of various factors on abundance and survival of Northeast Arctic cod during different life stages of its first three years of life have previously been carried out (e.g. Sundby et al. 1989; Helle et al. 2000; Mukhina et al. 2003; Hjermann et al. 2007; Dingsør et al. 2007). However, revision of some data series as well as availability of longer data series makes it worthwhile to address these issues again. Also, most studies have considered the available data only as relative indices of abundance; we will also consider what kind of information about absolute stock levels and mortalities at different stages can be extracted from these indices. Northeast Arctic haddock is also included in the analysis, as the data sources for this stock are almost as extensive as for Northeast Arctic cod.

Materials and methods

The data sources which have been included in the analysis are given in Table 1. The whole range of cohorts for which data are available is given, although we in our analysis mainly will consider the cohorts 1980-2006. The actual data series for those years are given in Table 2 (cod) and 3 (haddock). A number of data series were not included in this analysis. These were: Bottom trawl index from Joint Ecosystem Survey in August/September (ICES, 2010), Russian autumn bottom trawl survey data (0+, 1+, 2+) (Lepesevich and Shevelev, 1997; ICES, 2010) and larvae/early juvenile surveys (Mukhina et al. 2003; Helle and Pennington 1999). Also, for the winter survey on ages 1-3, we have chosen to use only the trawl estimates in our calculations, although acoustic estimates are also available. Highly variable and at times large proportions of cod and haddock are often situated at – or close to – the bottom and not recorded by the acoustic instruments; a matter that contributes to larger annual negative biases in the acoustic estimates than in the swept area ones (Hjellvik et al. 2003). For the 0-group survey, the indices WITH correction for length-dependent catching efficiency are used.

Egg production

The egg production estimates for cod (TEP) are derived from the stock assessments made by the ICES Arctic Fisheries Working Group (ICES, 2010) and from Marshall et al. (2006), and are based on stock assessment data and data on fecundity and size/age/sex composition of the stock. At a later stage these estimates should be updated with newer data and also adjusted downwards by taking skipped spawning into account (Yaragina 2010).

0-group estimates

The 0-group estimates (TR0, AC0) are taken from the annual 0-group survey in August/September (Hylen 1997; Dingsør 2005; Eriksen et al. 2009). Trawl estimates are made annually, while for some years (1991-1994) also acoustic estimates have been made. The trawl and acoustic estimates should be considered complimentary, as both calculate the abundance in the same water volume (same area, and upper 0-60 m). It should be noted that the species distribution of acoustic abundance of 0-group has been split into cod, haddock and other species based on species distribution in the trawl catches. The 0-group trawl abundance estimates have been made both with and without adjusting for length-dependent catching efficiency (TR0). We use the estimates with correction for length-dependent catching efficiency. The geographical coverage of the 0-group cod and haddock distribution is usually fairly complete, although the western boundary of the distribution area is often not determined. It should also be noted that some of the 0-group may have started settling to the bottom at the time of the survey and thus could be missing both in the acoustic and bottom trawl estimates.

Bottom trawl surveys age 1-3

The bottom trawl (and acoustic) survey abundance estimates at ages 1-3 are made from the annual February survey in the Barents Sea (Jakobsen et al. 1997). The estimates from before and after 1994 are not directly comparable, as an inner net in the trawl was introduced in 1994, increasing the catchability of younger fish, in particular age 1. Also the geographical coverage of the survey was extended in 1993-1994. However, also from 1994 onwards the geographic coverage of the distribution of age 1-3 fish during this survey has sometimes been incomplete, due to ice coverage and lack of access to the Russian EEZ. The indices have to some extent been adjusted for this.

The acoustic and bottom trawl estimates calculate the number of fish in different parts of the water column, and should both be considered as underestimates of the total stock abundance. So far, no reliable methodology for combining acoustic and bottom trawl estimates into a single estimate (Hjellvik et al. 2003).

VPA estimates

The Northeast Arctic cod stock's consumption of various prey species is calculated annually, based on stomach content data and an evacuation rate model (Bogstad and Mehl 1997; ICES 2010). Cannibalism is probably the most important and also the most variable cause of natural mortality for cod from the 0-group stage until age 3-4 (Yaragina et al. 2009; ICES 2010). Incorporation of the data on cod cannibalism in the VPA model as additional 'catches' has been shown to improve the overall quality of the assessment and the accuracy of recruitment estimation. Thus, since 1995 the ICES Arctic Fisheries WG (AFWG) has used annual stomach content data to estimate cannibalism in the cod assessment (ICES 2010). Similarly, cod predation on haddock has been included in the haddock assessment. In both cases, it is assumed that the natural mortality M= 0.2 + cannibalism/predation mortality. Also, only predation on age 1 and older cod and haddock has been included in the assessment, although 0-group cod and haddock are also eaten by cod.

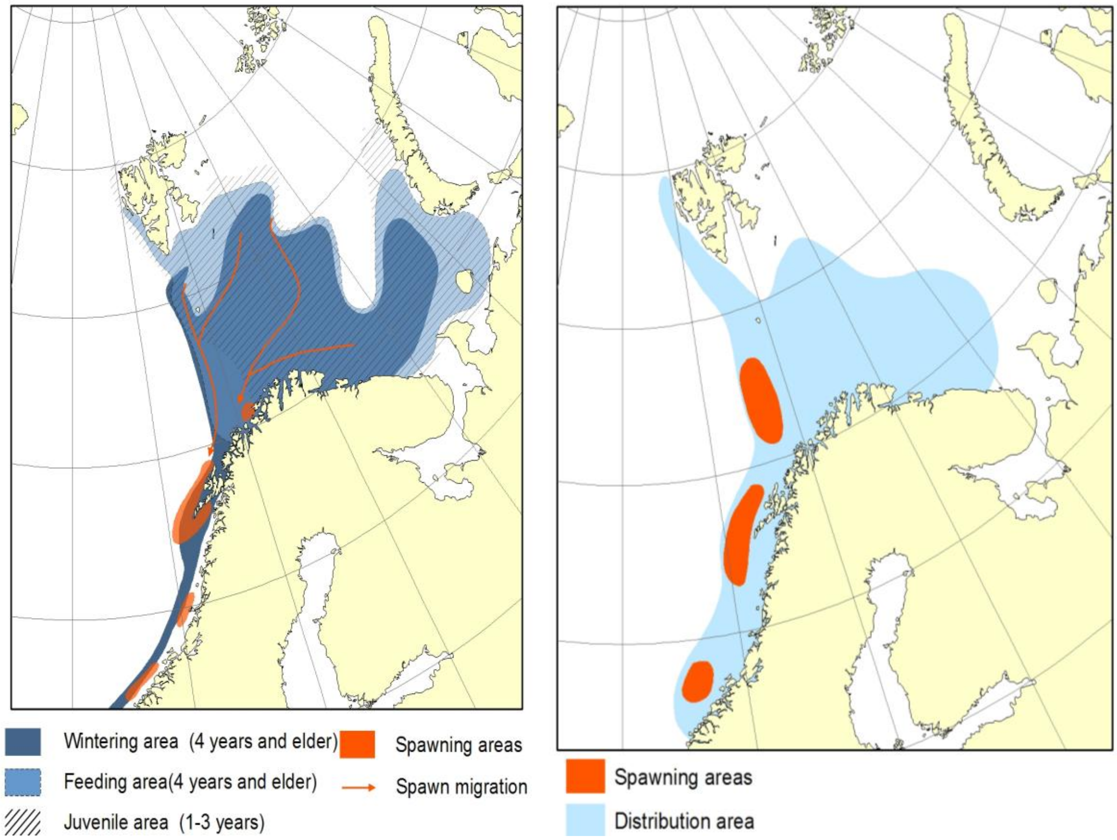


Fig. 1a-b. Distribution area for Northeast arctic cod (left) and haddock (right).

Results and Discussion

The following quantities and correlations were calculated:

- Mortality between different stages
- Correlation between abundance at age 0 and 1
- Correlation between abundance at age 1 and 3
- Correlation between different estimates at the same stage
- Cod-haddock correlations
- Biomass at the different stages

Mortality between different stages

Fig. 2 shows that the mortality from spawning to 0-group fluctuates considerably. There is no particular time trend except for very high values in the first years. This is caused by very low 0-group indices in 1980-1981. The reason why these indices were extremely low is not known.

The estimates of 0-group abundance made by Sundby et al. (1989) are considerably lower than those calculated by Eriksen et al. (2010) and used in our study. As Nakken et al. (1995) pointed out, the estimates by Sundby et al. (1989) are underestimates, due to incorrect handling of towing time and of logarithmic indices, and these facts may explain a lot of the difference. However, the egg abundances calculated by Sundby et al. (1989) ($3\text{-}5 \times 10^{13}$ for the years 1983-1985) generally are similar to those found by Marshall et al. (2006). Thus, the mortality from eggs to the 0-group stage is somewhat lower than that calculated by Sundby et al. (1989).

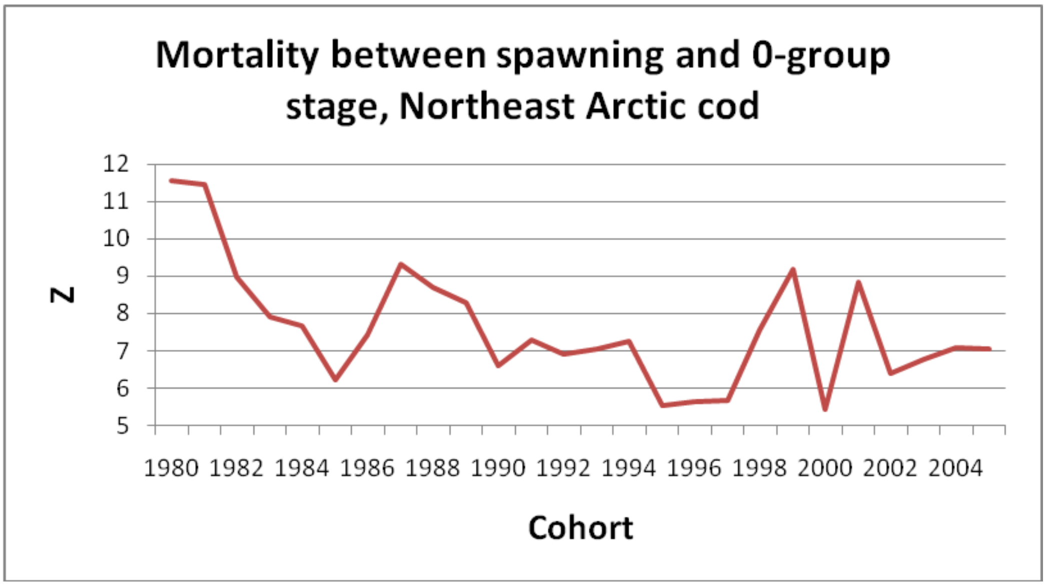


Fig. 2. Mortality between egg and 0-group stage for cod.

Fig. 3a-b shows the mortality from 0-group pelagic trawl estimates (0GR) to age 3 (VPA3) for the year classes 1983-2006 for cod and haddock. In both cases we see strong fluctuations over time, from 1.0 to 6.0 (cod) and from 1.0 to 5.0 (haddock), with the lowest values found in the late 1980s for both species. Fig. 3c-d shows the same mortality plotted vs. 0-group abundance. The mortality seems to be density-dependent, with cod showing a clearer pattern than haddock.

Variations in survival can of course also be explained by other factors than density-dependence (variable predation by cod, capelin abundance, temperature, geographical distribution, ‘leakage’ from stronger to weaker year classes due to uncertainty in age readings, etc.) and such analyses should be performed.

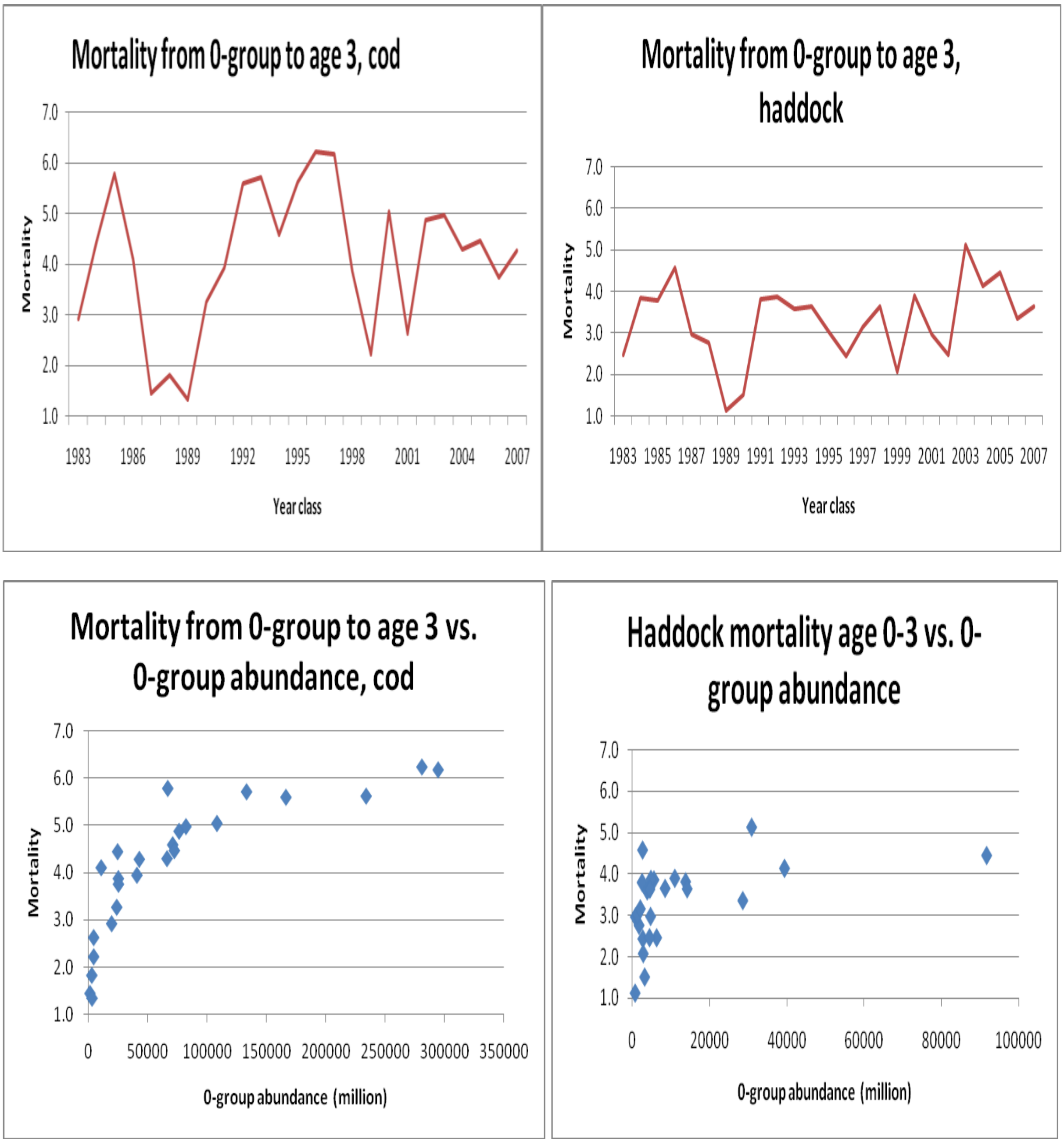


Fig 3a-d. Mortality from age 0 to 3 of cod and haddock, vs. time (a,b) and vs. 0-group abundance (c,d)

Correlation between TEP and 0-group abundance (cod only)

Fig. 4 shows that there is a significant correlation (R^2=0.33, p<0.01, N=26) between TEP and 0-group abundance for cod. It is noteworthy that the three ‘outlying’ plots at the top are three consecutive year classes (1995-1997)

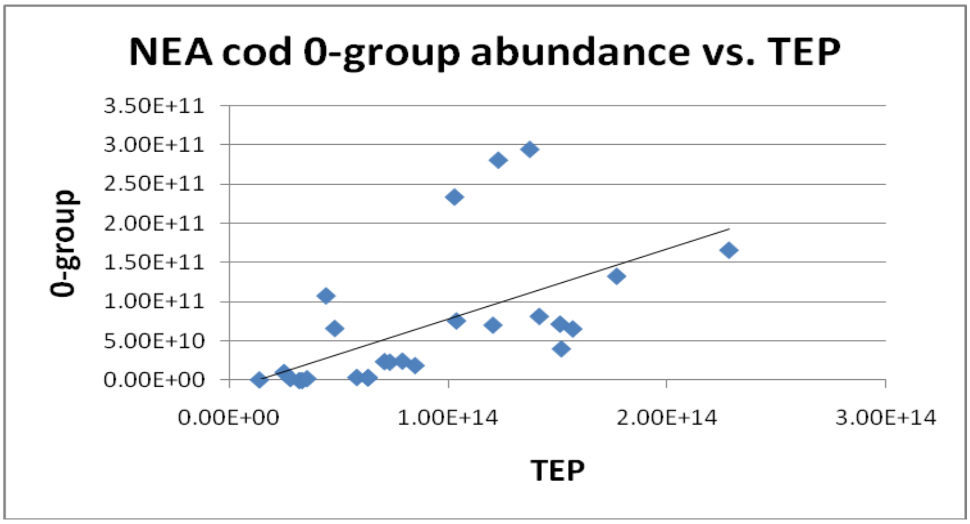


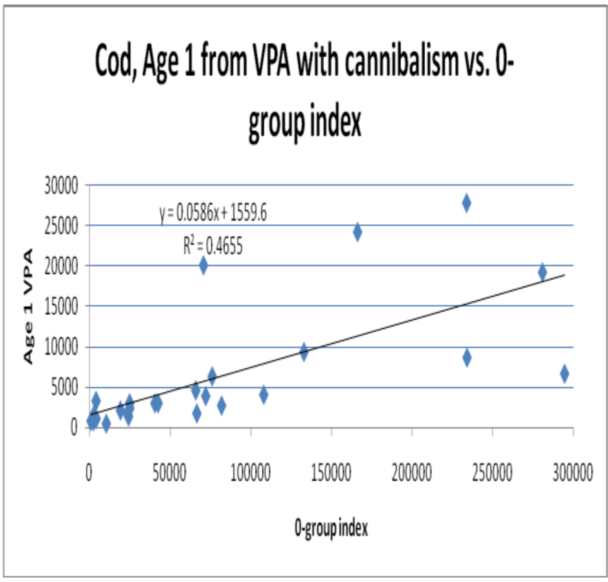
Fig 4. Correlation between Total Egg Production (TEP) and 0-group abundance for cod.

Correlation between abundance at age 0 and age 1

We also tried to correlate the abundance from the 0-group survey without adjustment for catching efficiency (TR0), with estimates of abundance at age 1 (VPA1 and BT1). For BT1, we tried correlating both for the entire period (1980-2009 cohorts) as well as only for the period after the inner net was introduced (1993-2009 cohorts). For VPA1, we used the 1983-2008 cohorts. We found a significant correlation between the abundance estimates from the 0-group survey and the VPA estimate for age 1 with predation from cod included, both for cod (R^2=0.47, N=26, p<0.001) and for haddock (R^2=0.61, N=26, p<0.001) (Fig. 5a-b). For the bottom trawl vs. 0-group estimates (Fig. 6a-d), we found a significant positive relationship both for cod and haddock for both periods:

(cod: 1980-2009: R^2=0.32, p<0.01, N=30; 1993-2009: R^2=0.27, p<0.05, N=17)

(haddock:1980-2009: R^2=0.43, p<0.001, N=30; 1993-2009: R^2=0.54; p<0.001, N=17).



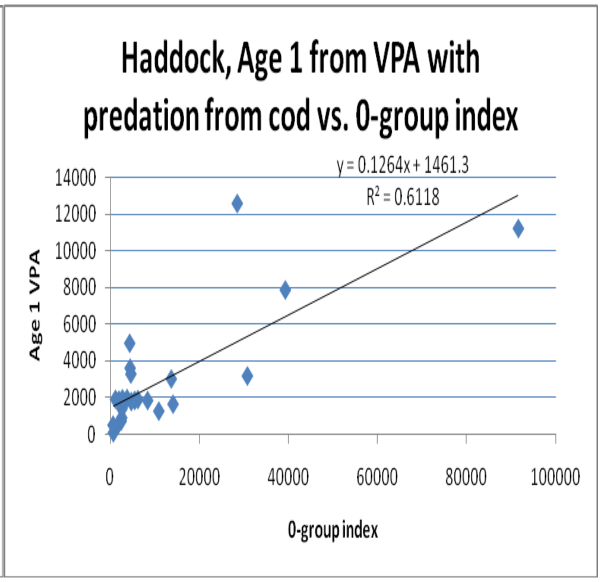


Fig 5a-b. Cod and haddock VPA age 1 vs. 0-group index.

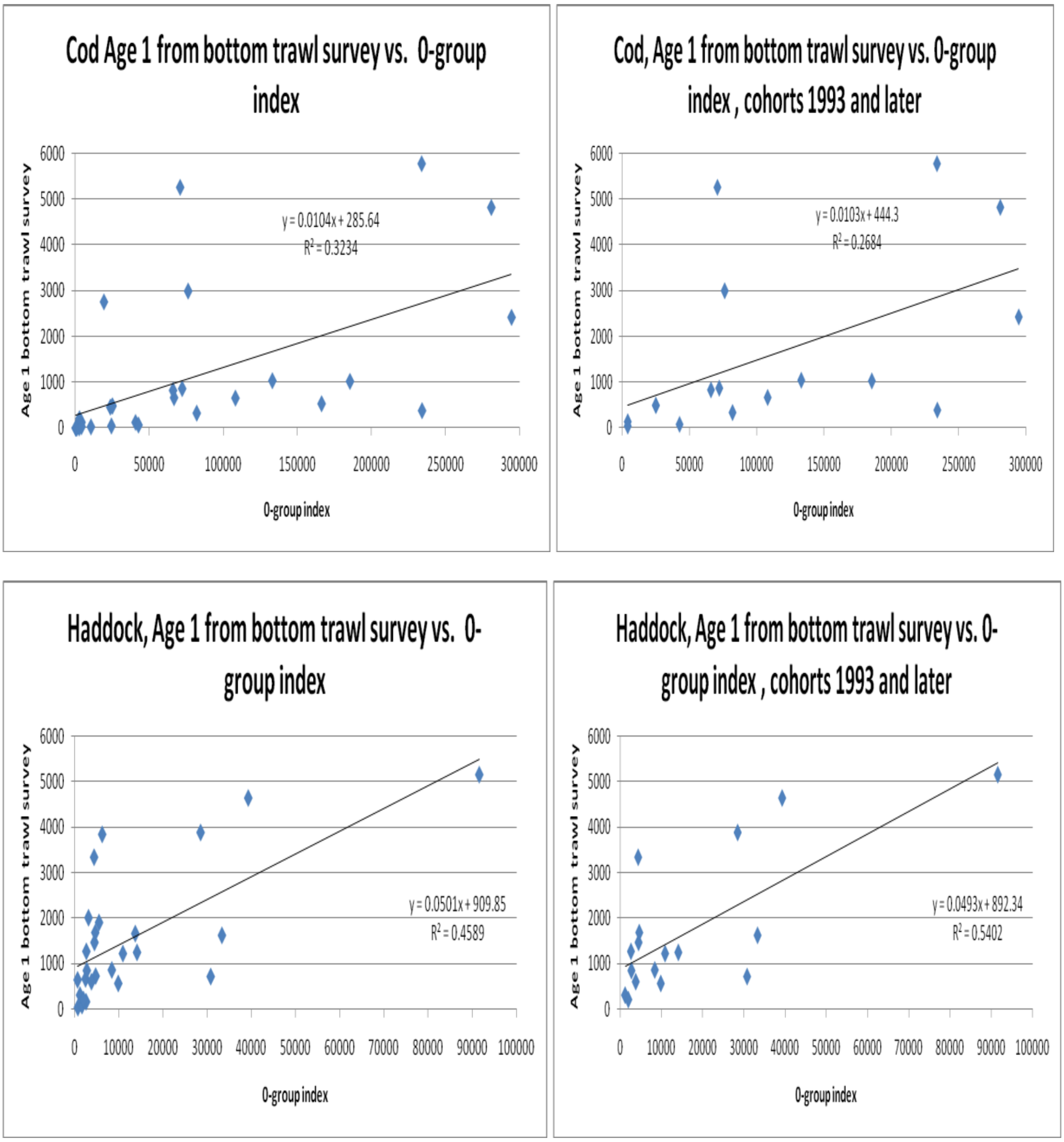


Fig 6a-d. Cod and haddock bottom trawl survey at age 1 vs. 0-group index, for cohorts 1980-2009 (a,c) and 1993-2009 (b,d)

Comparison between trawl and acoustic estimates of 0-group

Fig. 7 shows the ratio between acoustic and pelagic trawl estimates for cod and haddock for the years where both estimates are available (1991-1994). We see that these estimates are of the same order of magnitude, and that the acoustic/trawl ratio is considerably larger for haddock than for cod. The few years of data make it difficult to draw more conclusions, but it is encouraging that these estimates are of the same order of magnitude. It should be noted that the trawl catches are used for splitting the acoustic estimates of 0-group by species.

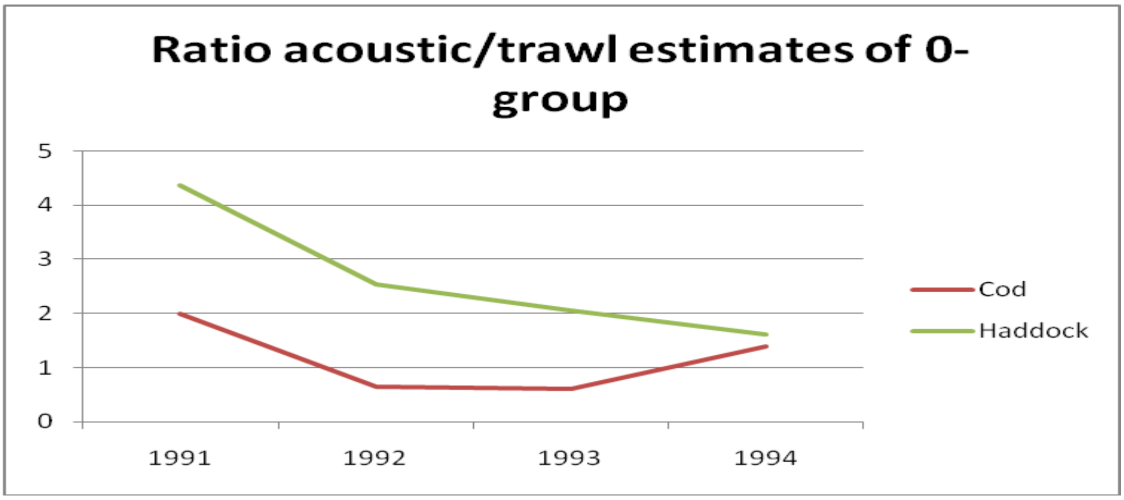


Fig. 7. Ratio between acoustic and pelagic trawl estimates of 0-group cod and haddock.

Correlation between abundance estimates at ages 1-3

Yaragina et al. (2009) showed that for cod age 1-3, there is good correlation between bottom trawl survey estimates from VPA (with cannibalism) estimates of abundance. The relationship was found to be linear for age 1 and 2, while a curvilinear relationship was found for age 3. Corresponding plots for haddock, using VPA estimates where predation by cod on haddock is included, are shown in Fig 8a-c. A strong linear relationship is found in all cases.

These strong correlations between survey estimates and VPA estimates with predation from cod included are encouraging. The uncertainty in the estimates of consumption comes not only from the stomach sampling itself, but also from the uncertainty in determining the stomach content (some prey are not determined to species and/or not length measured), as well as the age-length keys and weight-length used to convert from consumption in biomass by prey species and length group to predation in numbers by prey age group.

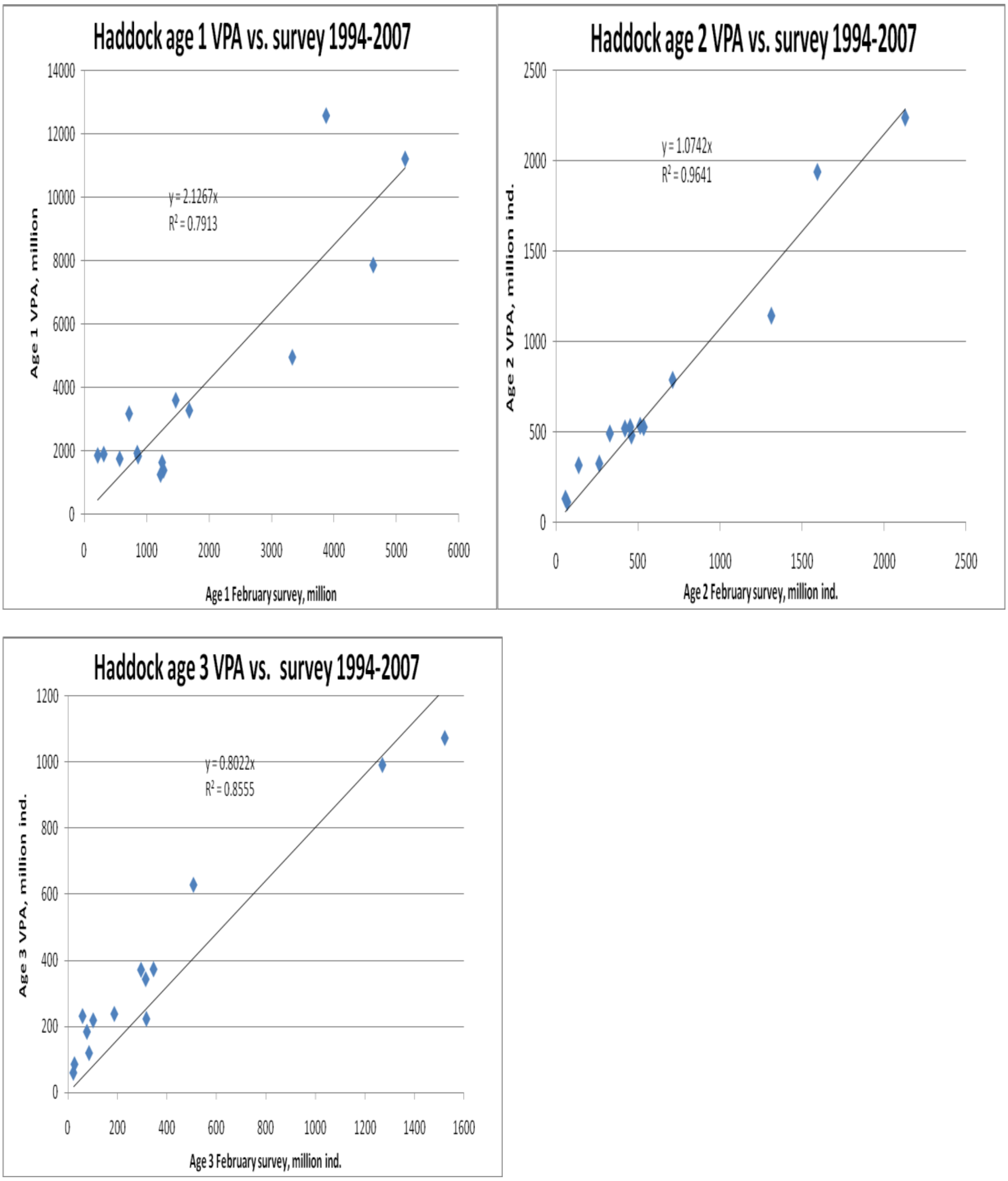


Fig 8a-c. VPA estimates with predation from cod included (1 January) vs. bottom trawl survey estimates of age 1-3 haddock (in February) of the corresponding age group. Data for cohorts 1994-2007, million individuals. (a) Age 1, (b) Age 2, (c) Age 3

Correlation between cod and haddock

There is no significant correlation between the abundance of 0-group cod and haddock in the same year for the cohorts 1980-2009 (and the same is true for 1980-2006), as shown in Fig. 9a. However, there is a significant ($p<0.05$) correlation for the 3-group (VPA3) abundance of the two stocks both for the period 1947-1979 and 1980-2006 (Fig. 9b). The haddock/cod ratio at age 3, indicated by the slope of the regression lines, is higher in the latter period (0.51 vs. 0.35). The reason for this may be that the temperature was higher during the latter period, which could affect haddock more than cod as cod can handle lower temperatures than haddock (generally few cod are found in waters colder than 0 °C while few haddock are found in waters colder than 2 °C). The data for the two time periods are not quite comparable, as by-catch of young fish probably was higher during the first period, and predation by cod on cod and haddock are only included in (most of) the second period. However, it is not obvious whether and in which direction these differences would affect the haddock/cod ratio.

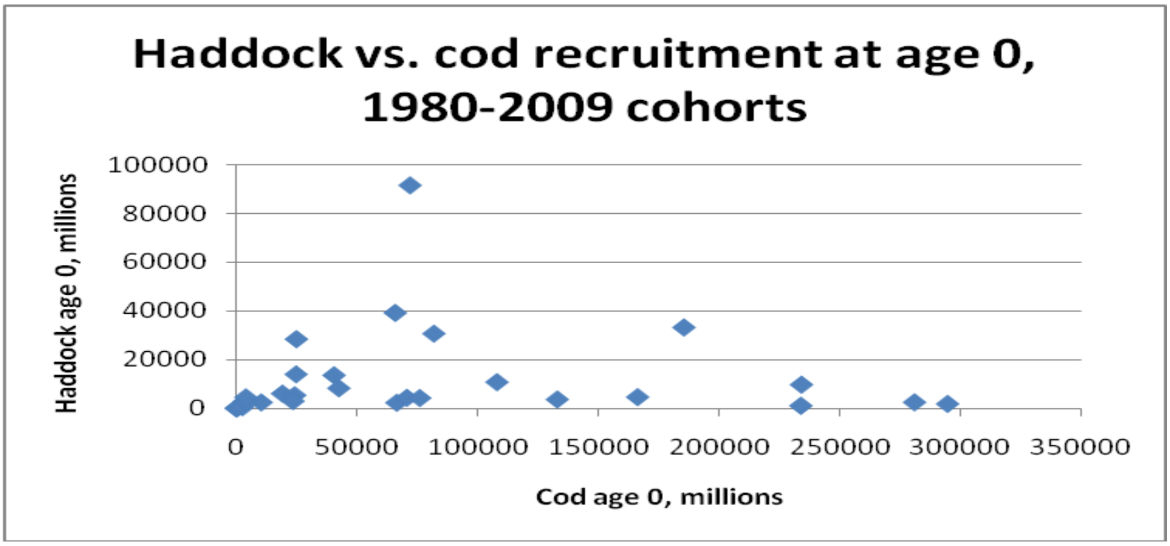


Fig. 9a. Haddock vs. cod 0-group abundance, cohorts 1980-2009.

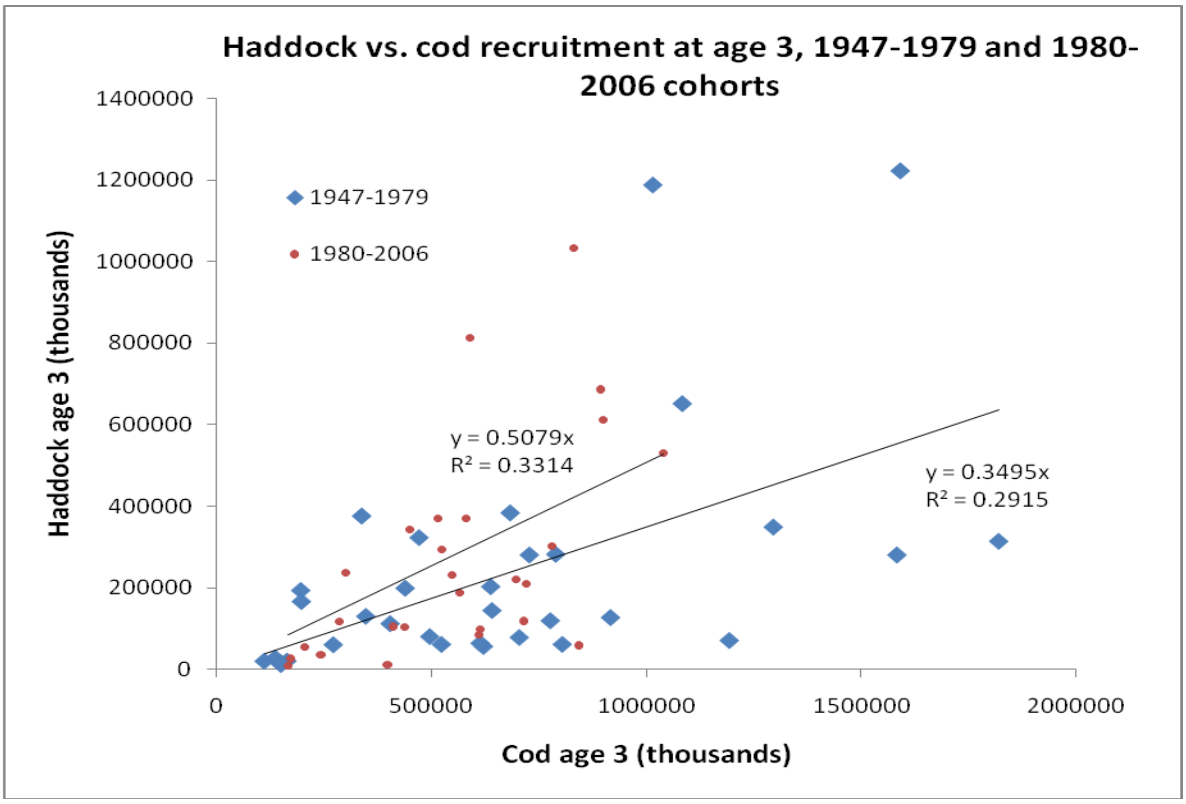
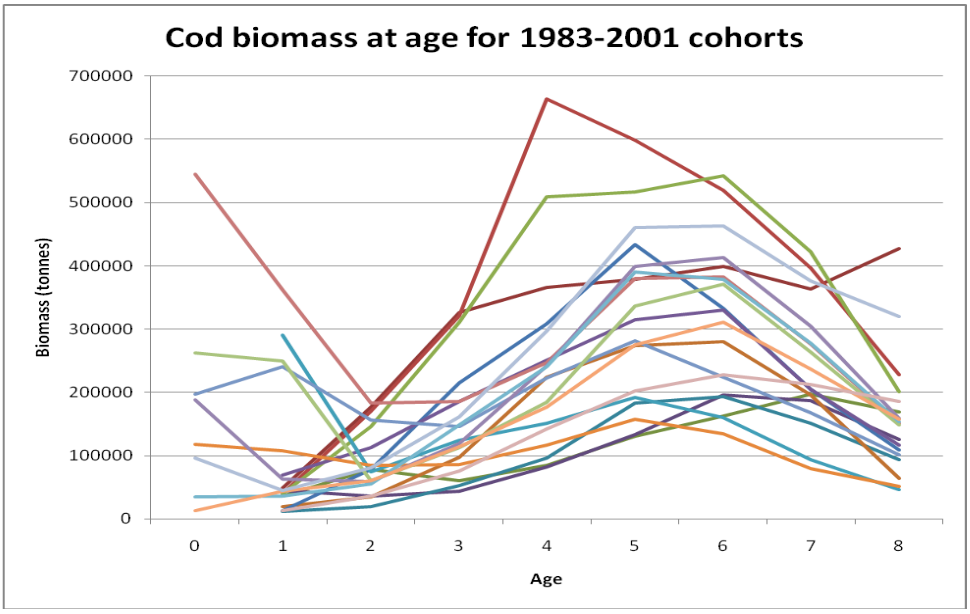


Fig. 9b. Cod vs. haddock recruitment at age 3, cohorts 1947-1979 (diamonds) and 1980-2006 (circles).

Biomass at age by cohort

The development of biomass at age for cohorts was calculated using TR0 and VPA estimates for age 1 and older fish. We calculated the biomass at age up to age 8 (cod) and age 6 (haddock), in order to determine at which age the biomass of a cohort was highest. The results for cod and haddock are shown in Fig. 10a-b.

It is interesting to note that for year classes with high abundance at the 0-group stage, the biomass at this stage may actually be the higher than at any older stage. This violates the 'textbook assumption' of the biomass at age peaking much later in life. We see that due to variation in exploitation pattern and rate as well as growth rate and natural mortality, the age with highest biomass after the 0-group stage has varied from 4 to 8 (the 1983 year class!) for cod and 3 to 5 for haddock.



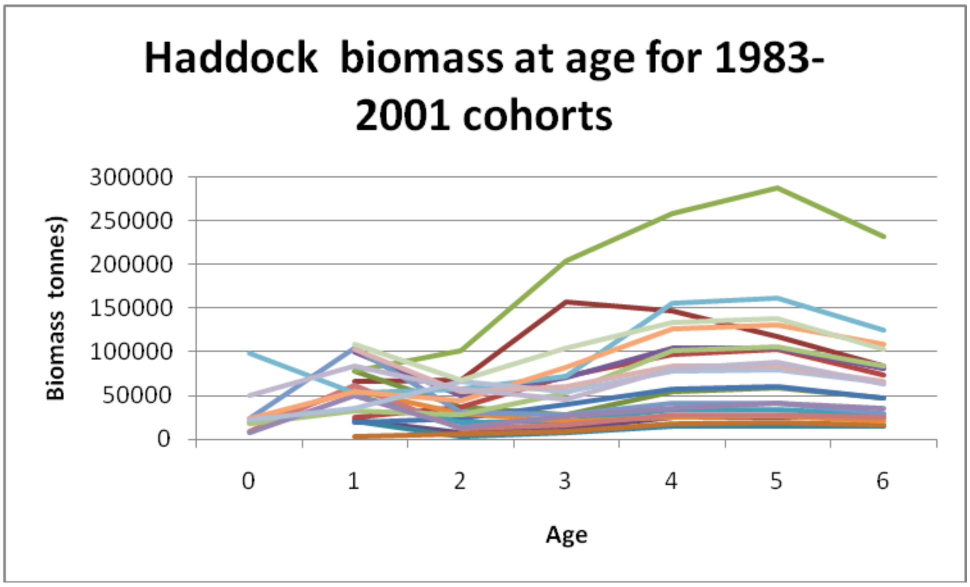


Figure 10a-b. Abundance and biomass at different life stages, for cod and haddock cohorts 1983-2001.

Conclusions and further work

Some main points which emerge from this analysis:

- The estimates of 0- and 1-group abundance of cod and haddock from different sources (0-group pelagic trawl and acoustic, 1-group VPA and trawl) give numbers which are compatible with each other
- In the period from 1980 and onwards, the recruitment of haddock and of cod is correlated at age 3, but not as 0-group. At both stages, high haddock recruitment never occurs when cod recruitment is low. The ratio between haddock and cod recruitment at age 3 is higher in the period after 1980 than before 1980, this may be due to higher temperature in the latter period.
- Some cod year classes which are strong or very strong at the 0-group stage, can be reduced to an average level at age 3. Haddock year class variability is stronger than for cod, and haddock year classes which are strong at the 0-group stage seems to stay strong at later stages although mortality is large.

These analyses can be extended considerably, both by also including spatial variations in the analysis as done e.g. by Cianelli et al. (2007), and also by including temperature, predator and prey abundance and other factors to explain the annual variations in mortality.

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Data source	Abbreviation	Fish age (months)	Cohorts (cod)	Cohorts (haddock)	Number (N)/ biomass (B)	Reference
Total egg production	TEP	0-1	1946-2001	N/A	N	Marshall et al. 2006
0-group pelagic trawl survey , with KEFF	TR0	5	1980-2009	1980-2009	N, B	Dingsør 2005, Eriksen et al. 2009; Eriksen et al. 2010.
0-group acoustic	AC0	5	1991-1994	1991-1994	N	Hylen 1997
Age 1 VPA, predation by cod included	VPA1	9	1983-2008	1983-2008	N, B	ICES 2009
Age 1 bottom trawl	BT1	10	1980-2009	1980-2009	N, B	Jakobsen et al. 1997, ICES 2010
Age 2 VPA, predation by cod included	VPA2	21	1982-2007	1982-2007	N, B	ICES 2010
Age 2 bottom trawl	BT2	22	1979-2008	1979-2008	N, B	Jakobsen et al. 1997, ICES 2010
Age 3 VPA, predation by cod included	VPA3	33	1981-2006	1981-2006	N, B	ICES 2010
Age 3 bottom trawl	BT3	34	1978-2007	1978-2007	N, B	Jakobsen et al. 1997, ICES 2010

Table 1. Data sources used in the analysis of Northeast Arctic cod and haddock abundance.

Cohort	*TEP*	*TR0*	*AC0*	*VPA1*	*BT1*	*VPA2*	*BT2*	*VPA3*	*BT3*
1980	31890644	276			4.6		2.9		25.0
1981	33177200	289			0.8		13.4	402.8	97.5
1982	63268658	3480			152.9	670.4	379.1	528.7	166.8
1983	84811956	19299		2116.8	2755.0	1355.5	660.0	1047.5	805.0
1984	70807468	24326		1375.8	49.5	786.2	399.6	287.8	240.4
1985	48086961	66630		1758.1	665.8	563.4	445.0	206.6	148.0
1986	24950792	10509		492.7	30.7	238.2	72.8	174.6	46.4
1987	13648841	1035		821.9	3.2	300.7	15.6	245.9	28.4
1988	35367819	2570		818.7	8.2	540.0	56.7	416.5	45.9
1989	27815582	2775		1519.2	207.2	1129.6	220.1	729.7	158.3
1990	73241353	23593		1728.8	460.5	1278.2	570.9	904.9	273.9
1991	151637073	40631	80996	3009.3	126.6	1532.9	420.4	791.3	296.5
1992	228221335	166276	107000	24215.6	534.5	1474.8	535.8	621.7	274.6
1993	176924200	133046	80693	9362.9	1035.9	1379.8	541.5	443.2	170.0
1994	120384902	70761	99040	20108.9	5253.1	2544.9	707.6	723.0	238.0
1995	102810481	233885		27824.6	5768.5	3097.2	1045.1	853.5	396.0
1996	122847427	280916		19232.1	4815.5	1270.3	643.7	553.5	211.8
1997	137189156	294607		6673.5	2418.5	1075.0	340.1	616.5	235.2
1998	79006573	24951		3010.7	484.6	826.5	248.3	521.8	191.1
1999	58142177	4150		3297.2	128.8	678.5	76.6	453.4	88.3
2000	44096640	108093		4074.9	657.9	1293.2	443.9	702.8	377.0
2001	63331514	4150		1098.9	35.3	486.3	79.1	302.0	76.6
2002	103697123	76146		6350.3	2991.7	1271.3	235.4	584.6	246.9
2003	141535589	81977		2727.9	328.5	867.6	224.6	570.1	118.1
2004	156814849	65969		4602.8	824.3	1241.2	288.4	903.8	367.7
2005	151071486	72137		3902.0	862.7	1250.5	393.9	833.5	190.2
2006		25061		2400.7	485.9	833.8	95.1	589.8	118.3
2007		42628		3011.7	70.4	873.9	39.1	592.2	36.0
2008		234144		8672.4	382.7	1083.2	104.4		
2009		185457			1020.2				

Table 2. Abundance estimates of cod cohorts 1980-2009 at various life stages. Unit: Million

Cohort	*TR0*	*AC0*	*VPA1*	*BT1*	*VPA2*	*BT2*	*VPA3*	*BT3*
1980	265			3.1		1.5		3.1
1981	75			3.9		4.8	12.1	18.9
1982	2927			2919.3	375.1	514.6	293.1	475.9
1983	6217		1884.3	3832.6	655.3	1593.8	529.2	384.6
1984	5512		1838.5	1901.1	413.8	370.3	116.6	154.4
1985	2457		709.2	665.0	67.63	79.9	55.3	25.3
1986	2579		889.7	163.8	33.1	15.3	26.5	14.1
1987	708		73.7	35.4	44.8	9.5	36.5	4.5
1988	1661		464.1	81.2	170.7	54.6	105.0	33.4
1989	650		492.8	644.1	273.1	300.3	210.3	150.5
1990	3122		1737.8	2006.0	1008.5	1375.5	686.4	507.7
1991	13713	59932	3010.3	1659.4	553.3	599.0	302.8	339.5
1992	4739	12000	1778.6	727.9	210.1	228.0	98.9	53.6
1993	3785	7802	1937.7	603.2	308.0	179.3	104.0	52.5
1994	4470	7206	3601.0	1463.6	323.5	263.6	118.4	86.1
1995	1203		1897.4	309.5	111.0	67.9	58.7	22.7
1996	2632		1386.0	1268.0	314.5	137.9	230.6	59.8
1997	1983		1855.1	212.9	129.6	57.6	84.45	27.2
1998	14116		1634.7	1244.9	525.6	452.2	370.8	296.0
1999	2740		1928.7	847.2	478.4	460.0	342.5	314.7
2000	10906		1252.8	1220.5	525.0	534.7	222.0	317.4
2001	4649		3277.8	1680.3	532.7	513.1	237.0	188.1
2002	4381		4957.9	3332.1	787.1	711.2	372.5	346.5
2003	30792		3173.7	715.9	517.6	420.4	182.8	77.4
2004	39303		7866.9	4630.2	1141.4	1313.1	628.4	507.7
2005	91606		11220.7	5141.3	1936.5	1593.8	1073.6	1522.4
2006	28505		12587.4	3874.4	2236.7	2129.4	991.8	1270.4
2007	8401		1834.4	860.2	489.8	328.0	217.8	102.8
2008	9864		1750.4	564.7	260.3	111.2		
2009	33339			1619.5				

Table 3. Abundance estimates of haddock cohorts 1980-2009 at various life stages .Unit: Million