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An update of maturity estimates for Greenland halibut in NAFO Div. 2J+3K

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Abstract

This paper updates maturity estimates from the Div. 2J+3K area and reexamines the data for trends. It also compares estimates from survey data for Div. 2J+3K with those derived from commercial sampling of the same area. Average A50 over the time period is 10 years for males and 12.7 years for females. For males the average L50 over the time period is 62 cm while for females it is 78 cm. For both males and females there is an indication of maturation at a smaller size and younger age for more recent cohorts. The effect of cohort was significant in all cases. A comparison of A50 for females from survey and commercial data showed that the estimates of A50 were very similar for most of the cohorts that could be compared. There was more difference observed when the entire ogives were compared, although there was no consistency in which source of data indicated earlier maturity. These results indicate that the old age at maturity estimated from the survey data is not an artefact of very few old fish in the sample. Estimates of maturity at length by year were similar to those estimated by cohort for both males and females. This indicates that ageing error is not a factor in estimating that Greenland halibut mature at an old age and a large size in Div. 2J+3K. There may be some retrospective pattern in estimates by cohort and it may be prudent at this time not to use estimates for cohorts that have not reached 13 years of age.

Key Words: Greenland halibut, *Reinhardtius hippoglossoides*, maturity, age, size

Introduction

The proportion of adult fish at size and age in Greenland halibut has been found to be highly variable both geographically and temporally (Junquera, MS 1994; Junquera and Saborido-Rey, MS 1995; Morgan and Bowering, 1997; Morgan and Bowering, MS 1999; Morgan *et al*., 2003). The occurrence of immature fish at large size appears to be common (Fedorov, 1971; Jorgensen, 1997; Morgan and Bowering, 1997). Greenland halibut may have a peak and secondary spawning period with some fish in spawning condition being found in most months (Fedorov, 1971; Junquera, MS 1994; Junquera and Zamarro, 1994). There is some evidence that this species may not spawn every year (Fedorov, 1971; Junquera *et al*., 2003; Simonsen and Gundersen, 2005).

The maturity schedule of Greenland halibut in Div. 2J+3K has not been examined since 2003 (Morgan et al., 2003). They compared maturity at age and size for four populations across the North Atlantic. They found that maturation was similar for the different populations, except for fish from Div 2J3K, which matured at a considerably older age and larger size than in other populations.

Estimates of maturity at age for Greenland halibut from Div. 2J+3K derived from survey data have shown substantial variability, while maturity estimates incorporating data covering the stock distribution (Div.

2GHJ+3KLMNO) tended to be less variable (Morgan and Bowering, MS 2001). This lower variability, coupled with the apparent lack of trend in the Div. 2J+3K time series, led them to recommend the use of a single invariant maturity ogive, derived from data covering the entire stock area.

This paper updates maturity estimates from the Div. 2J+3K area and reexamines the data for trends. It also compares estimates from survey data for Div. 2J+3K with those derived from commercial sampling of the same area.

Materials and Methods

Most data came from autumn surveys conducted by Canada from 1978 to 2006. Data from Div. 2J and Div. 3K were used. Available data from the commercial fishery in the same area were also examined. Fish were assigned to the categories immature (juvenile) or mature (adult) according to the classification of Tempelman et. al. (1978). All data were collected in a length stratified manner, and for the survey data, bias was removed using the method of Morgan and Hoenig (1997).

Maturities were modelled by sex using a generalized linear model with a logit link function and binomial error (McCullagh and Nelder, 1983; SAS Institute Inc., 1993). Length or age was modelled as a continuous variable, with each cohort fitted separately. For the logit link function,

$$g(\mu) = \log\left(\frac{\mu}{1-\mu}\right)$$

and $\mu^{-1} = \left(\dfrac{1}{1+\exp(-\eta)}\right) = proportion\,mature$

where $\eta = \tau + \gamma A$, τ is an intercept, γ age or length effect, A is age or length.

In addition the significance of cohort effects was tested using generalized linear models of the same form. Cohort was assumed to be a class variable and significance was tested after first removing the effect of age or length (Type 1 analysis) using a model of the form: $\eta = \tau + \gamma A + \beta$, τ is an intercept, γ age effect, A is age or length, and β is the cohort effect. This tests to see if there is variation that can be explained by cohort after the variation that can be explained by age or length is removed. This does not test for a significant interaction between cohort and the slope (age or length)

Data from the research vessel surveys does not contain many older fish. This has led to speculation that the old age at maturation is an artefact of having few older ages in the estimation. To shed some light on this issue, estimates of maturity at age were produced from commercial data which should have more observations from older fish and compared to the estimates from the autumn survey.

Ageing error could also introduce a bias in the estimates, not only at age, but also at length since estimation at length is also carried out by cohort. To investigate this, estimates of maturity at length were produced by year, where age does not enter any calculations.

In estimating maturity by cohort, estimates are updated with each additional year until the cohort has finished maturing. Depending on the year to year variability, this can result in a 'retrospective pattern' in the maturities. To examine if this is a problem with Greenland halibut from the RV survey, proportion mature at age was estimated for 3 cohorts (1991, 1992, and 1994), removing one year's data each time. This was done from 2006 to 2003, except for the 1994 cohort which did not have a significant model fit until 2005.

Results and Discussion

Estimates of maturity at age and size for Div. 2J+3K Greenland halibut are consistent with previous estimates for this area (Morgan et al, 2003). Average A50 over the time period is 10 years for males and 12.7 years for females (Fig. 1). The observed and predicted proportions mature at age for females are presented in Figure 2. Only ages that occurred in the data are shown. In most cases the model appears to fit the observed data fairly well.

For males the average L50 over the time period is 62 cm while for females it is 78 cm (Fig. 3). For both males and females there is an indication of maturation at a smaller size and younger age for more recent cohorts. For males A50 in the first half of the time series was 10.5 years, while in the second have it has been 9.8. For females the equivalent values are 13 and 12 years. Length at 50% maturity for females has decreased from 80 to 75 cm from the first to the second half of the time series while for males the decrease has been only 2 cm from 63 to 61 cm. The effect of cohort was significant in all cases:

Males length

Source	Deviance	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Intercept	3692.9381						
length	1066.4771	1	657	2486.07	<.0001	2486.07	<.0001
cohort	694.1001	25	657	14.10	<.0001	352.47	<.0001

Females length

Source	Deviance	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Intercept	7494.5060						
length	802.4385	1	853	7622.42	<.0001	7622.42	<.0001
cohort	748.8872	26	853	2.35	0.0002	61.00	0.0001

Males age

Source	Deviance	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Intercept	1761.7468						
age	513.0657	1	210	716.27	<.0001	716.27	<.0001
cohort	366.0930	22	210	3.83	<.0001	84.31	<.0001

Females age

Source	Deviance	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Intercept	6906.3599						
age	844.7738	1	296	2532.10	<.0001	2532.10	<.0001
cohort	708.5948	25	296	2.28	0.0007	56.89	0.0003

This is in contrast to the study of Morgan and Bowering (MS 2001) that found little indication of a trend in maturation for this population.

Canadian autumn RV surveys tended to sample few fish older than 12, particularly for recent cohorts (Table 1 and 2). This could potentially lead to a bias in the estimated proportion mature at age. Samples from the commercial fishery tended to have more samples of older fish (Table 3). For the cohorts where estimated proportion mature could be compared the average percentage of 6+ that was 12 or older was 22% for the commercial data and only 2.6% from the RV survey data. For cohorts from 1985 to 1994 only 3 female fish were older than 14 in the RV data while 49 were older than 14 in those cohorts in the commercial data. Most fish above age 14 in the commercial data were classed as adults.

A comparison of A50 for females from the two data sources showed that the estimates were very similar for most of the cohorts that could be compared (Fig. 4). Notable exceptions are the 1985 and 1986 cohorts. On average the A50 from the survey was higher than from the commercial sample (12.5 vs 11.6) but for most cohorts the difference was less than one year and for 3 of the 8 cohorts that could be compared the A50 was slightly higher from the commercial data. The low sample size for older fish is reflected in larger fiducial limits for the estimates from the RV survey. When the entire ogive is compared between survey and commercial data, differences appear to be somewhat greater for some cohorts (Fig. 5). One again in some cases maturation was estimated to be younger using the commercial data and sometimes younger using the RV data. The 1985 and 1986 cohorts show the most difference, while the other 6 cohorts that could be compared are very similar. While there are no doubt fish older than those sampled in the commercial fishery, these results indicate that the old age at maturity estimated from the survey data is not an artefact of very few old fish in the sample.

Another source of error could be ageing error. If this is the case then estimates of proportion mature at length by cohort (which are classified into cohorts based on age) could be different from estimates at length by year, where age is not a consideration. Estimates of maturity at length by year were similar to those estimated by cohort for both males and females (Fig. 6). For males the average L50 over the time period was 62 cm when estimated by cohort and 61 cm when estimated by year. For females the L50 was 78 cm when estimated by cohort and the same (78 cm) when estimated by year. This indicates that ageing error is not a factor in estimating that Greenland halibut mature at an old age and a large size in Div. 2J+3K.

A retrospective analysis of the estimated proportion mature at age for female Greenland halibut shows that there can be some change in estimates as more data are added (Fig. 7). There is no change for the 1991 cohort from ages 12 through 14 (no model fit is shown for 2006 as the 1991 cohort was not sampled in the 2006 survey). However, both the 1992 and 1994 cohorts show some change. However, there is little change in estimates for the 1992 cohort after age 13. It might be prudent not to use estimates for the 1994 cohort at this time, as this cohort was only age 12 in 2006 and estimates may change with the addition of more data at older ages.

In summary, there appears to be some decrease in age and size at maturity for both male and female Greenland halibut in Div. 2J+3K in recent cohorts. Estimates from RV survey data are similar to estimates derived from commercial data, indicating that a lack of sampling at older ages is not causing the estimates from RV data to be biased towards larger sizes and older ages. The similarity in length at maturity estimated by year or by cohort indicates that the estimates are not biased by ageing error. There may be some retrospective pattern in estimates by cohort and it may be prudent at this time not to use estimates for cohorts that have not reached 13 years of age.

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Table 1. Number of males from each cohort that were examined for maturity and age from Canadian autumn RV surveys from 1978-2006. I indicates immature and M mature.

Age	Cohort 1965		1966		1967		1968		1969		1970		1971		1972		1973		1974		1975	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0																						
1																						
2																						
3																					142	1
4																			159	3	120	1
5																	138	6	148	19	168	3
6															112	23	127	38	174	9	164	8
7													106	33	62	56	127	35	164	11	129	0
8											57	35	47	26	66	35	91	20	179	6	153	10
9									17	25	21	30	23	21	31	18	104	21	90	27	73	23
10							7	15	10	33	4	15	9	10	42	39	7	14	12	8	36	18
11					6	8	1	19	2	4	2	4	7	31	3	9	1	3	6	3	2	3
12			1	1	0	4	0	3			0	2	1	3			1	1	0	1	0	1
13	0	1	0	2	1	1			1	0	0	1										
14							0	1	0	1												

Table 1. continued…

Age	Cohort 1976		1977		1978		1979		1980		1981		1982		1983		1984		1985		1986	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0					4	0													7	0	3	0
1			6	0	50	0	37	0	56	0	35	0	7	0	26	0	74	0	86	0	25	0
2	84	0	96	0	79	0	124	0	71	0	30	0	75	0	112	0	76	0	80	0	92	0
3	156	1	145	0	154	0	136	0	89	0	97	0	98	0	90	0	138	0	105	0	59	0
4	140	0	158	0	135	0	136	0	138	0	120	0	134	0	115	0	121	0	101	0	98	0
5	189	1	166	0	149	0	185	0	187	0	124	0	121	0	125	0	84	0	71	1	79	0
6	142	0	136	1	117	0	153	0	136	0	144	0	134	1	57	1	61	0	73	0	68	0
7	160	1	114	2	132	2	135	3	154	3	143	6	71	1	72	2	67	0	74	3	51	3
8	123	15	113	9	101	6	141	12	90	12	63	5	47	6	18	1	11	0	23	1	25	2
9	83	14	48	18	60	24	22	10	18	3	8	5	4	2			3	1	3	0		
10	9	10	14	7	4	5	1	0	1	3							0	1			3	0
11			1	2															0	1	0	1
12	0	1																				
13																						
14																						

Table 1. continued…

Age	Cohort																					
	1987		1988		1989		1990		1991		1992		1993		1994		1995		1996		1997	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0			10	0	2	0					5	0	5	0	48	0	42	0	3	0	14	0
1	72	0	33	0	6	0	80	0	22	0	14	0	57	0	72	0	128	0	87	0	110	0
2	52	0	31	0	50	0	65	0	68	0	59	0	109	0	136	0	118	0	118	0	126	0
3	48	0	50	0	63	0	88	0	62	0	73	0	99	0	100	0	127	0	57	0	63	0
4	85	0	108	0	81	0	81	1	58	0	82	0	106	0	119	0	111	0	77	0	94	0
5	68	0	79	0	75	0	93	0	92	0	115	0	95	0	114	0	104	0	107	0	164	2
6	61	2	57	0	60	0	75	0	111	5	103	1	89	5	93	1	123	3	106	1	82	1
7	65	1	21	1	50	4	97	11	90	13	86	8	77	3	108	6	50	4	58	5	61	27
8	3	0	25	4	38	18	52	4	47	13	32	2	45	5	12	3	20	3	23	18	23	14
9	12	6	16	8	10	3	8	2	6	0	6	2	1	1	2	2	6	1	2	2	5	5
10	3	1	1	3	1	0			2	0			1	0	1	0	0	2	1	0		
11															1	0						
12																						
13																						
14																						

Table 1. continued...

Age	Cohort																	
	1998		1999		2000		2001		2002		2003		2004		2005		2006	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0			13	0	8	0	10	0	37	0	10	0	14	0	14	0	10	0
1	61	0	90	0	132	0	155	0	107	0	92	0	88	0	121	0		
2	92	0	94	0	149	0	107	0	97	0	112	0	100	0				
3	88	0	98	0	60	0	54	0	58	0	57	0						
4	149	0	86	0	80	5	102	5	104	0								
5	94	0	89	11	116	7	135	0										
6	67	17	101	6	125	3												
7	73	20	109	4														
8	49	9																
9																		
10																		
11																		
12																		
13																		
14																		

Table 2. Number of females from each cohort that were examined for maturity and age from Canadian autumn RV surveys from 1978-2006. I indicates immature and M mature.

Age	Cohort																					
	1958		1960		1961		1962		1963		1964		1965		1966		1967		1968		1969	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
8																						
9																					83	4
10																			71	12	74	12
11																	68	22	58	13	71	30
12															45	29	63	13	32	41	24	43
13													22	30	45	24	24	27	8	31	52	31
14											6	12	14	22	6	27	1	18	41	45	5	44
15									0	13	8	15	3	13	1	10	21	44	4	22	4	28
16							1	8	6	18	0	9	0	2	1	30	1	6	1	20	1	17
17					0	7	0	9	0	2			0	5			1	8	3	15	0	3
18					0	4					0	2	1	2			0	6			0	1
19			0	3											0	1						
20	0	1																	0	1		

Table 2. continued…

Age	Cohort																					
	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0																	1	0				
1															10	0	48	0	58	0	64	0
2													73	0	121	0	104	0	153	0	71	0
3											145	0	121	0	148	0	151	0	149	0	122	0
4									154	0	129	0	134	0	160	0	169	0	134	0	124	0
5							168	1	186	0	163	1	166	0	157	0	148	0	186	0	178	0
6					156	0	186	0	178	6	190	0	127	0	137	0	121	0	154	0	146	0
7			137	1	134	0	167	9	168	0	144	0	157	1	138	0	134	0	126	0	157	0
8	110	2	94	2	105	13	157	3	172	1	164	3	128	4	124	0	117	0	142	0	120	0
9	68	2	71	13	152	10	148	2	145	7	109	13	94	5	83	3	126	3	70	1	52	0
10	68	11	97	36	112	5	94	9	81	42	109	15	61	0	63	5	31	4	26	0	23	5
11	81	44	101	13	77	24	46	35	79	17	64	1	47	8	19	6	22	0	24	5	2	3
12	95	27	48	40	20	49	58	37	51	9	53	10	14	2	4	1	13	4	5	0		
13	26	42	17	44	22	27	34	11	26	13	9	12	1	0	5	7	2	1			0	1
14	4	57	15	38	23	13	12	20	7	9	2	0	5	5	1	0	0	1	0	1		
15	5	29	16	21	3	17	1	13	1	1	1	2										
16	5	16	3	9	0	9	0	3	0	3	1	0										
17	0	8	0	5																		
18	0	1																				
19																						
20																						

Table 2. continued…

Age	Cohort																					
	1981		1982		1983		1984		1985		1986		1987		1988		1989		1990		1991	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0									1	0	1	0			5	0	2	0				
1	35	0	12	0	28	0	61	0	81	0	37	0	73	0	44	0	8	0	75	0	22	0
2	48	0	66	0	110	0	89	0	86	0	97	0	57	0	50	0	47	0	61	0	73	0
3	114	0	112	0	112	0	149	0	131	0	53	0	51	0	45	0	63	0	79	0	50	0
4	119	0	137	0	116	0	114	0	96	0	98	0	83	0	113	0	96	0	85	0	60	0
5	124	0	108	0	115	0	82	0	72	0	79	0	71	0	73	0	96	0	114	0	95	0
6	142	0	115	0	54	0	62	0	86	0	76	0	59	0	61	0	53	0	90	0	123	0
7	171	0	73	0	72	1	54	0	74	0	54	0	61	0	28	0	69	0	104	0	112	0
8	74	1	62	1	52	0	22	0	33	0	48	0	14	0	24	1	71	0	71	0	65	0
9	47	2	20	0	5	2	6	0	10	0	4	0	31	2	37	0	24	0	31	1	14	0
10	9	4	2	1	1	0	3	0	1	0	8	2	12	0	14	0	13	1	10	0	7	1
11	1	0			2	0	0	1	6	1	8	3	14	0	9	1	5	1	5	1	1	1
12	2	3	1	0			2	5	5	4	7	0	2	0	1	1	1	1			1	2
13	1	0			1	7	0	5	6	1	4	3			3	1	0	1	0	1	0	2
14			1	2	0	2	0	1	0	1	1	1	1	0							0	1
15																			0	1		
16			0	1											0	1						
17																						
18																						
19											0	1										
20																						

Table 2. continued…

Age	Cohort																					
	1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002	
	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M	I	M
0	2	0	1	0	23	0	43	0	1	0	7	0			12	0	9	0	1	0	45	0
1	18	0	60	0	79	0	129	0	96	0	104	0	64	0	76	0	133	0	156	0	108	0
2	54	0	112	0	143	0	119	0	131	0	120	0	86	0	121	0	144	0	104	0	105	0
3	73	0	100	0	96	0	121	0	76	0	71	0	71	0	106	0	55	0	56	0	62	0
4	77	0	99	0	106	0	92	0	81	0	104	0	138	0	76	0	82	0	91	0	109	0
5	110	0	108	0	109	0	87	0	102	0	170	0	105	0	106	0	137	0	117	0		
6	97	0	100	0	103	0	119	0	101	0	76	0	81	0	104	0	122	0				
7	99	0	65	0	101	0	66	0	66	0	80	0	123	0	122	1						
8	43	1	68	0	29	0	39	0	54	1	53	3	86	0								
9	19	2	13	0	9	0	18	0	28	0	35	1										
10	5	0	6	0	8	2	9	0	8	0												
11	2	3	2	0	4	1	8	0														
12	2	0	2	1	2	1																
13	2	0																				
14	0	1																				

Table 2. continued…

Age	2003 I	2003 M	2004 I	2004 M	2005 I	2005 M	2006 I	2006 M
	Cohort							
0	7	0	6	0	7	0	5	0
1	93	0	88	0	121	0		
2	109	0	89	0				
3	53	0						
4								

Table 3. Number of females from each cohort that were examined for maturity and age from commercial sampling. I indicates immature and M mature.

Age	1985 I	1985 M	1986 I	1986 M	1987 I	1987 M	1988 I	1988 M	1989 I	1989 M	1990 I	1990 M	1991 I	1991 M	1992 I	1992 M	1993 I	1993 M	1994 I	1994 M
	Cohort																			
0																				
1																				
2																				
3																	3	0		
4															18	0	5	0		
5													50	0	35	0	11	0	25	0
6			1	0					6	0	90	0	103	0	74	0	119	0	70	0
7	13	0					1	3	60	0	121	0	81	0	83	0	41	0	106	0
8					1	6	53	4	89	5	72	1	44	1	31	2	54	0	34	9
9			0	5	25	3	48	4	57	1	39	2	20	2	21	0	25	10	51	5
10	1	5	12	2	35	24	37	0	31	7	8	5	18	1	13	12	33	20	10	29
11	3	6	8	23	27	14	13	16	3	2	13	4	1	12	14	22	5	17	9	28
12	3	31	3	25	6	20	2	12	8	6	1	11	3	19	1	20	6	34		
13	3	15	0	21	1	8	2	7	0	7	2	16	0	14	4	31				
14	1	13	0	7	1	3	0	2	0	18	0	7	1	20						
15	0	2	0	1			0	6	0	7	2	12								
16					0	4	0	1	0	8										
17							0	4												
18			0	2	0	1														
19																				
20																				

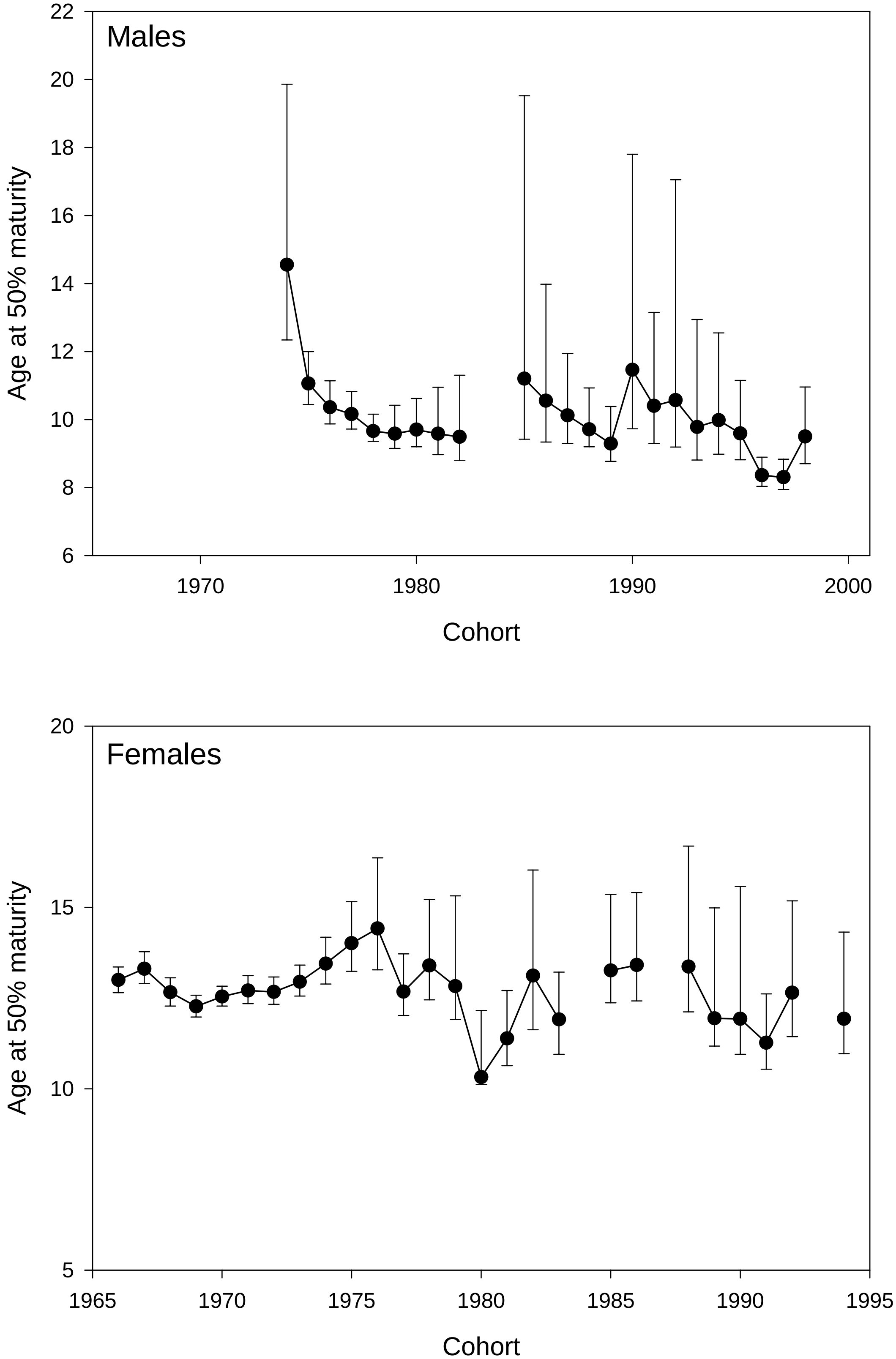


Figure 1. Age at 50% maturity (± 95% fiducial limits) for male and female Greenland halibut in NAFO Divs. 2J3K by cohort. Data are from Canadian fall surveys.

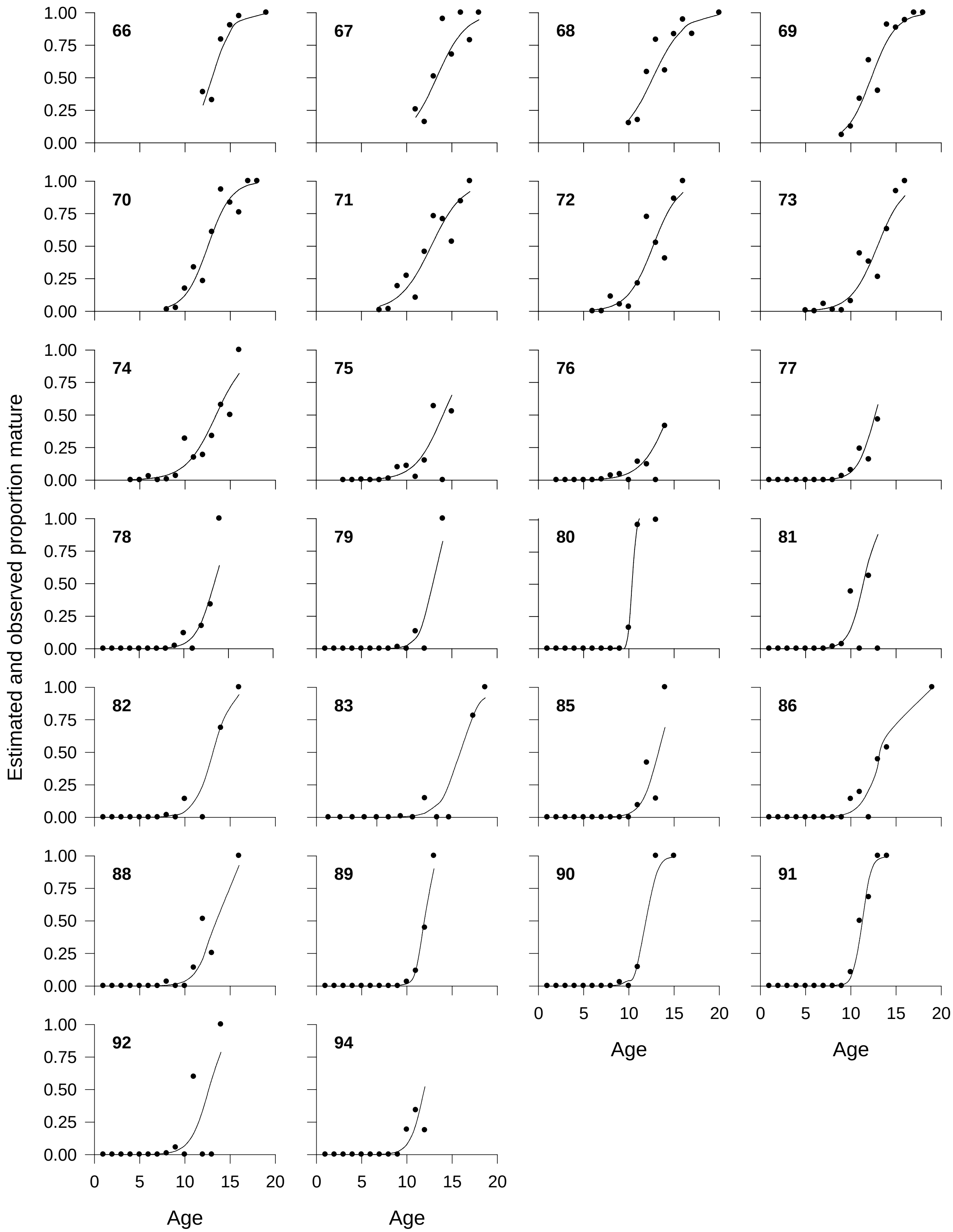
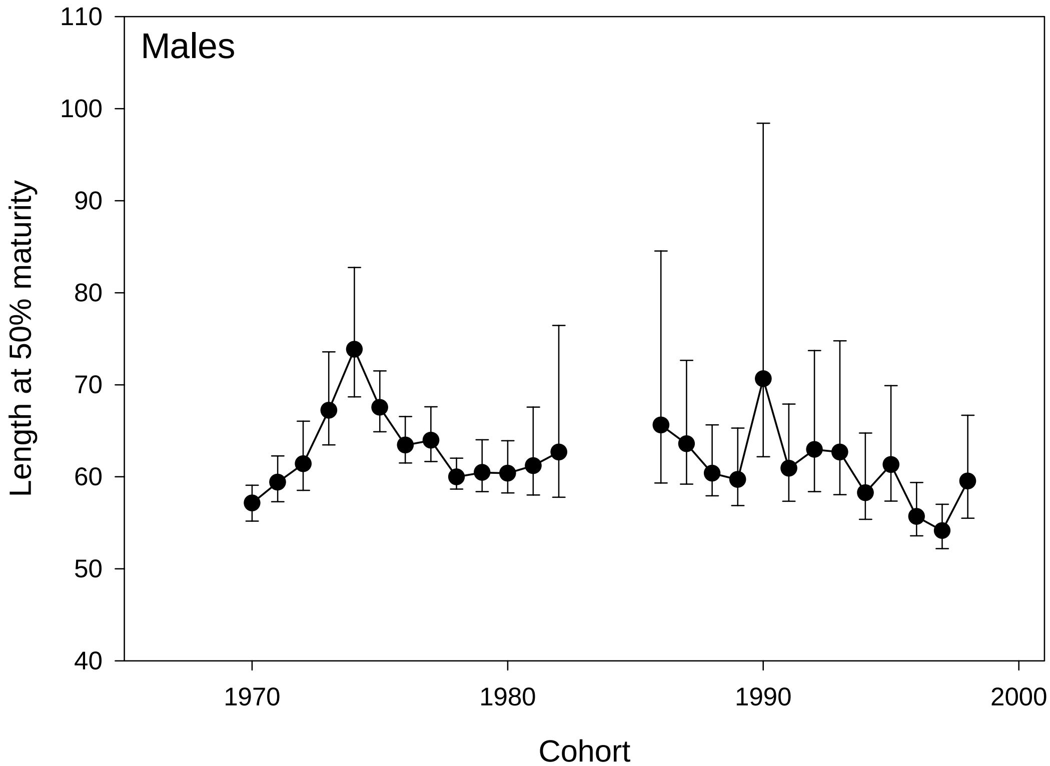


Figure 2. Estimated (line) and observed (dots) proportion mature at age for female Greenland halibut. Only ages occurring in the data are shown and only cohorts with a significant model fit.



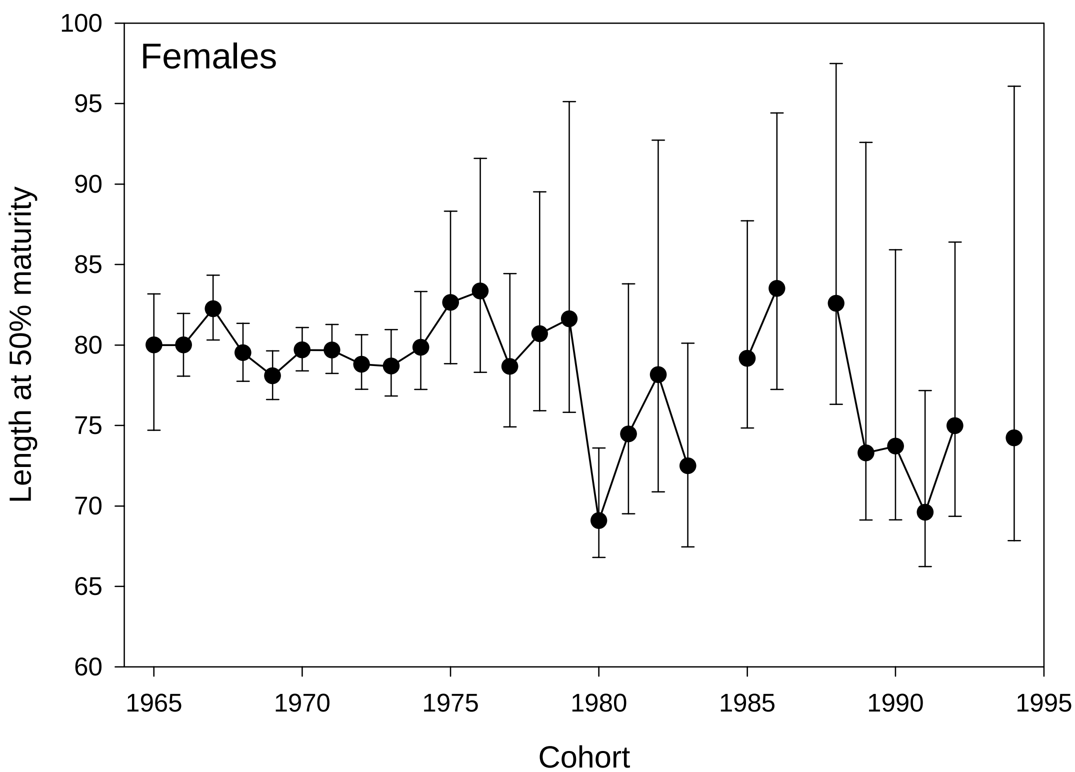


Figure 3. Length at 50% maturity (± 95% fiducial limits) for male and female Greenland halibut in NAFO Divs. 2J3K by cohort. Data are from Canadian fall surveys.

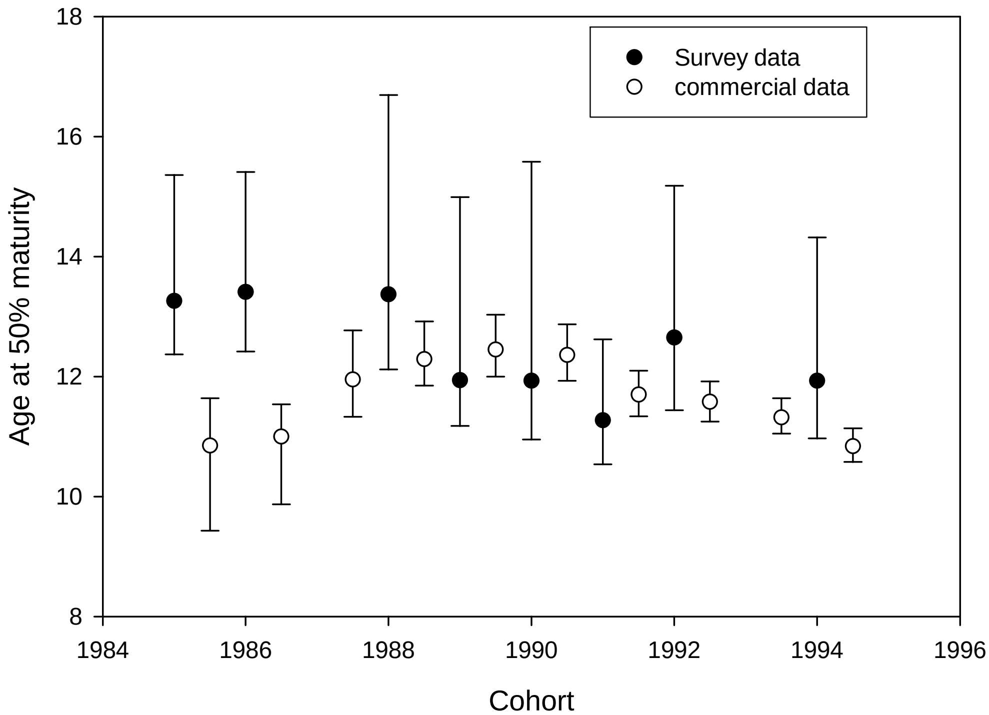


Figure 4. Age at 50% maturity (± 95% fiducial limits) for female Greenland halibut from autumn RV surveys and from sampling of the commercial fishery for cohorts from 1985 to 1994. The 1987 and 1993 cohorts did not have a significant model fit to the survey data.

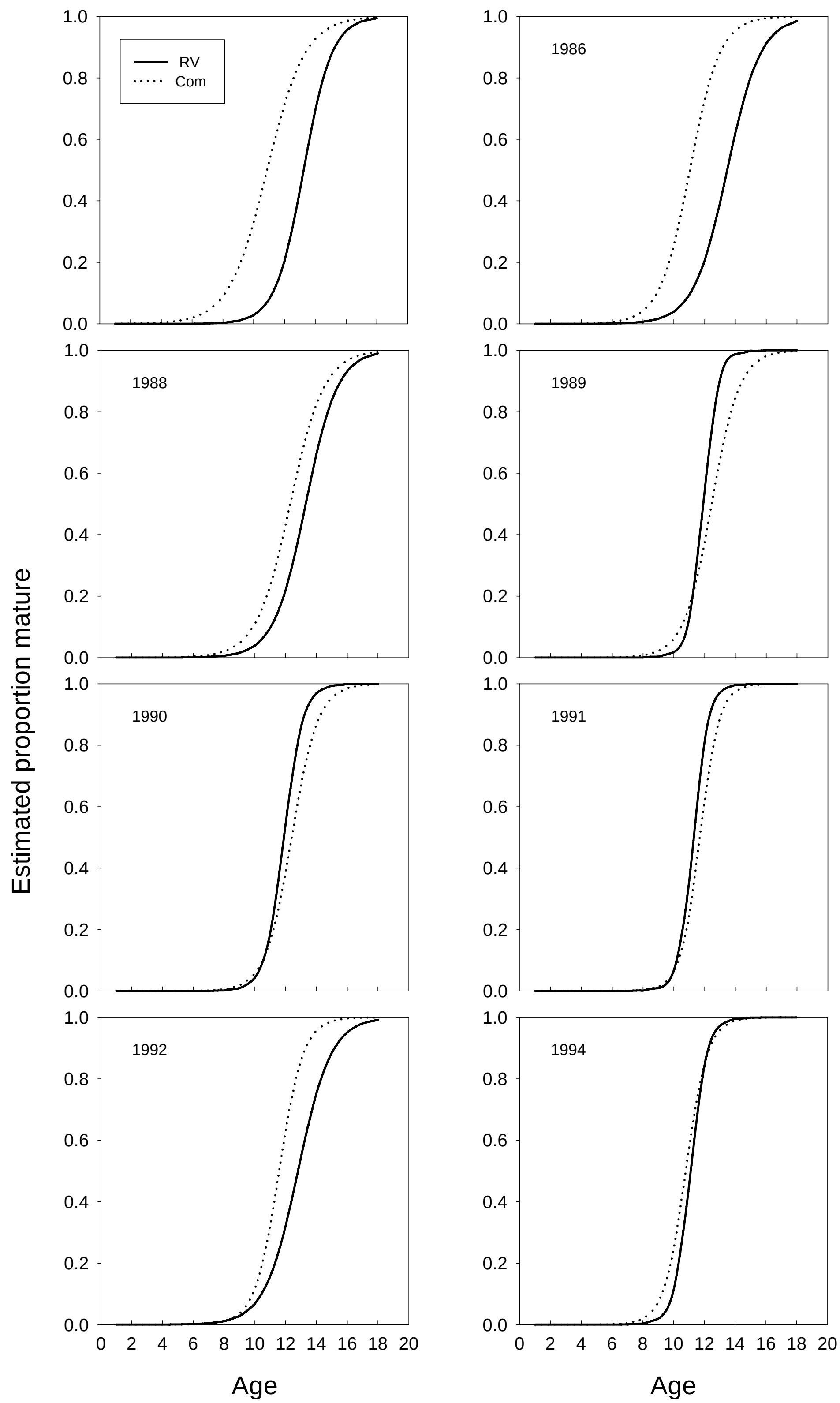
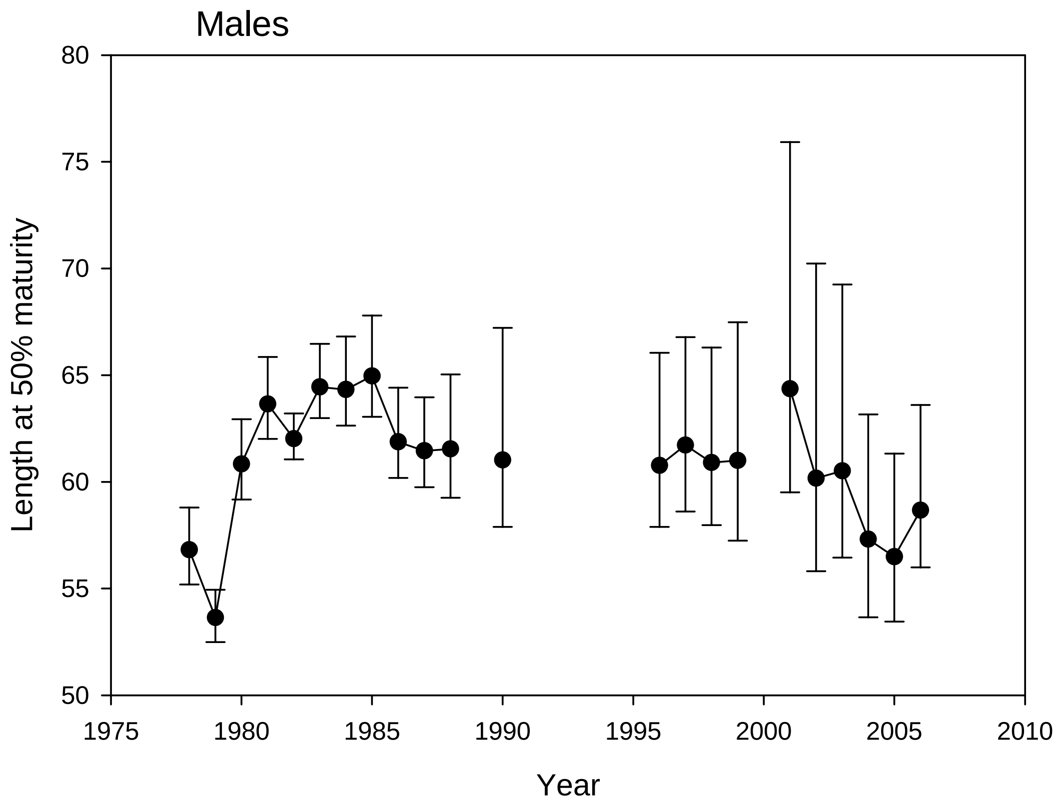


Figure 5. Estimated proportion mature at age for female Greenland halibut from autumn survey data (RV) and data collected from the commerical fishery (com)



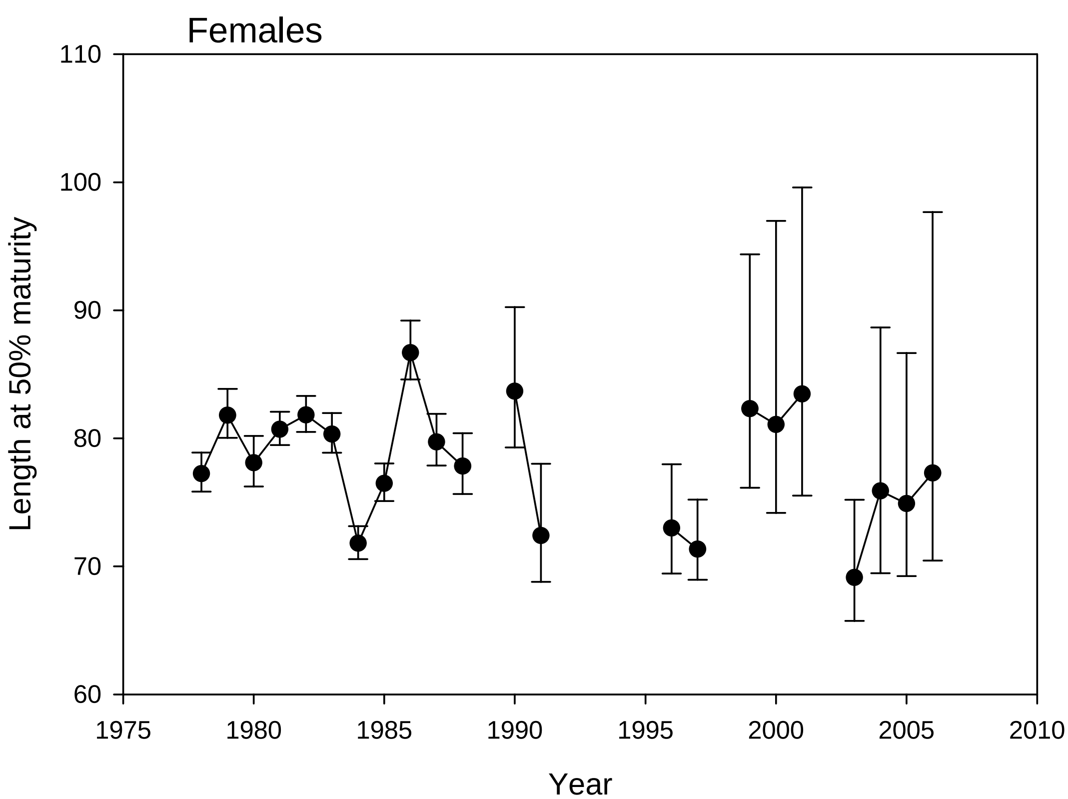


Figure 6. Estimated proportion mature at length for male and female Greenland halibut by year from Canadian autumn RV surveys.

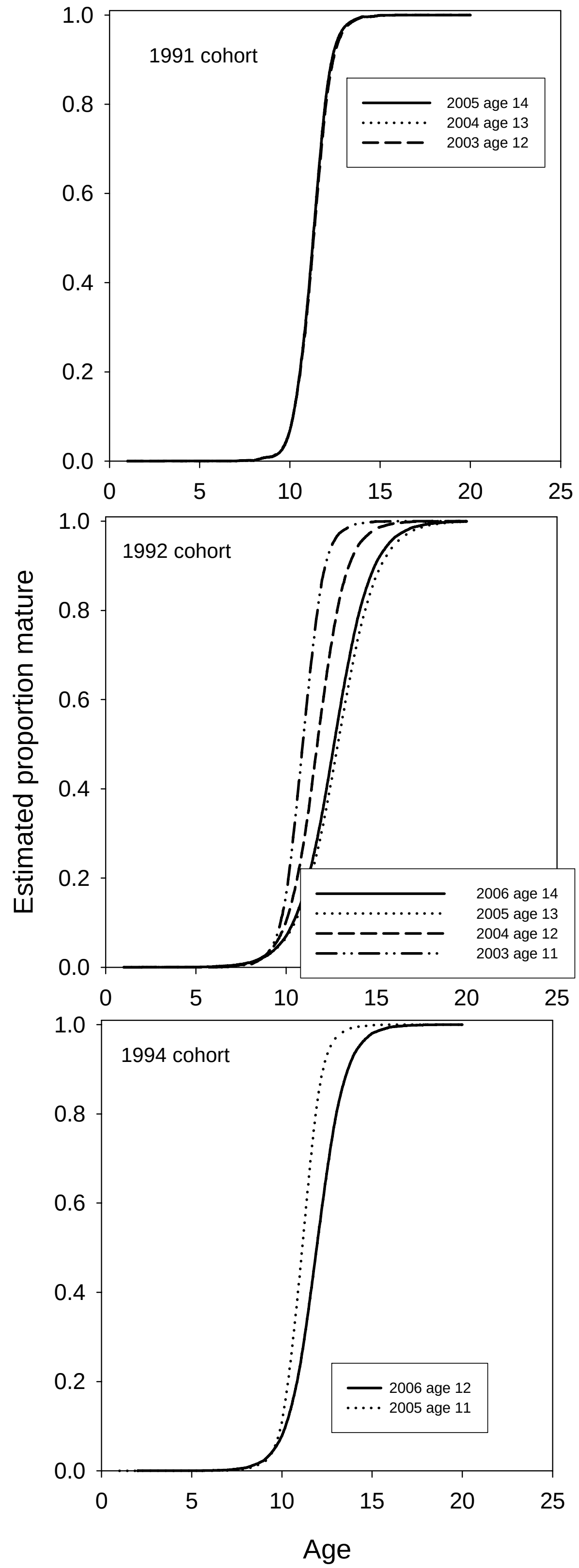


Figure 7. Estimated proportion mature at age for 3 cohorts using one less year of data in each case. For each line the last year of data and the age of the cohort in that year is indicated in the legend.