APPENDIX 3

SAW 47 Working Paper 7 (TOR 3) – Life History Parameters

Evaluation of summer flounder life history parameters from NEFSC trawl survey data, 1992 – 2006.

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Background

In 2000, summer flounder stocks were determined to be overfished. Management of the species entered a ten year rebuilding period in order to increase abundance to sufficient levels. Recent stock assessments indicate that, although fishing mortality has decreased substantially and biomass is at the highest level ever recorded, the stock is still only about 50% of the target biomass. As the end of the rebuilding period nears and quotas continue to drop despite the high biomass, there has been growing concern that the stock assessment and/or biological reference points for the species are flawed.

During the 2007 stock assessment update, it was noted that there have been changes in certain biological parameters of the stock over the last few years. Among these are size at age and sex ratio. Changes in these and other parameters could affect population dynamics and rebuilding rates. The purpose of this paper is to review data collected during National Marine Fisheries Service, Northeast Fishery Science Center seasonal trawl surveys in order to investigate key biological parameters and evaluate potential implications on stock rebuilding and management of the species.

Methods

Data were obtained from the NEFSC trawl survey database. Since 1992, NEFSC finfish trawl surveys have occurred three to four times per year, and have recorded lengths, weights, ages, and sex from at least a subsample of summer flounder captured in the survey.

Length and weight at age

Evaluation of sample size at age revealed that sample size at older ages was very low, particularly during early years of the analysis. Data were therefore subset to years and ages that had a sufficient sample size.

Trends of size at age over time were evaluated in two ways. First, sex specific mean size at age was calculated for each year with sufficient sample size. SAS Proc REG (SAS 1990) was used to conduct regressions of size at age over time.

Second, observed data were fit to a von Bertalanffy growth function

$$L_t = L_\infty * (1 - e^{-(k*(t-t_0))})$$

to develop annual sex specific predicted length at age estimates using SAS Proc NLIN (SAS 1989a). For each year, residuals were resampled with replacement to develop 500 bootstrap datasets (Barker 2005), each of which was also fit using the von Bertalanffy growth function. Summary statistics were calculated for the parameter estimates, as well as predicted size at age. SAS Proc REG was used to perform regression analysis of mean predicted length at age over time.

For both methods, slope parameters of length at age over time were evaluated at the $\alpha = 0.10$ level.

Length-weight analysis was also conducted with SAS Proc NLIN using an allometric growth function.

$$W = \alpha L^\beta$$

For each year, residuals between observed and predicted weight at length were calculated and resampled to develop 500 bootstrap datasets which were also fit to the growth function. Summary statistics were calculated for the parameter estimates, as well as predicted weight at length. SAS Proc REG was used to evaluate trends in mean weight at length over time.

Maximum age, sex ratio, and natural mortality

Maximum age by sex was found by analytical review of the raw data, as were overall sex ratios and sex ratios by age. Sex ratio (*i.e.* percent female) at size was analyzed using SAS Proc GENMOD (SAS 1989b) with a normal distribution and a logit link function (*i.e.* a logistic regression).

Natural mortality for each sex was estimated using the approximation of 3 / T_{MAX} (Hoenig 1983). Annual estimates of natural mortality for the stock were determined using a weighted average of sex-specific natural mortality and annual sex ratio.

Fecundity

Individual fecundity was estimated by applying the fecundity:length relationship of Morse (1981) to the mid-year length at age for females.

$$F = 0.0007975 * L^{3.402}$$

Number of mature females by age and year were determined by multiplying the VPA estimated abundance at age by sex ratios at age and the VPA input maturity schedule. These were multiplied by fecundity at age and summed across ages to estimate total theoretical fecundity of the stock.

Results

Length and weight at age

The number of fish observed on trawl surveys was low for some ages and years, particularly during early years of the analysis. Data were therefore subset to years and ages where sample size was generally greater than 50 fish per year (all surveys combined). Prorating ages to the season fish were captured (assuming a January 1 birthdate) as done in earlier drafts resulted in low sample size for some seasons, but fitting equations using ages pooled across surveys in a year resulted in poor or unconverged fits for some years. As a result, length at age calculations (mean and von Bertalanffy) were conducted using samples from the winter survey only. The subset data include years from 1999 to 2006 and ages 0 through 4 for males and 0 through 5 for females. Sample size for these years and ages are generally greater than 40 fish (Table 1).

Mean lengths for males age 1 to 4 show no long term trends between 1999 and 2006 (Table 2, Figure 1), and regression results indicate no significant changes over time (Table 3). Trends in mean length at age for females were similar to males for ages 0 to 4; however, female mean length at age 5 decreased significantly between 1999 and 2006.

Fitting bootstrap data to the von Bertalanffy growth function resulted in unrealistic parameter estimates for males in 2000 and 2006 (Table 4). Bootstrap average maximum length for these years was approximately 100,000 cm. Although the mean estimated parameter values produce unrealistic estimates of length at age, specific bootstrap replicates with large maximum size estimates had correspondingly lower estimates of the growth parameter *k*, such that mean predicted length at age was not erratic for fish less than 8 years old. Regression results for length at ages 0 to 10 (the approximate age range observed in survey data) showed no significant trends (Table 5, Figure 2).

Estimated von Bertalanffy parameters for females were also unrealistic in 2000, though much less so than for males (Table 6). Regression results indicate no significant trend in predicted length at age for ages 0 to 4; however, predicted length at ages five and older decreased significantly between 1999 and 2006 (Table 7, Figure 3). For both males and females, regression results using von Bertalanffy predicted length at age were consistent with results of mean length at age.

Length:weight analysis was conducted on the same subset of years and ages as age:length analysis. As before, sample size was generally above 40 fish (Table 8). No significant trends were observed for weight at length for males (Tables 9 and 10, Figure 4) or females (Tables 11 and 12, Figure 5).

Maximum age, sex ratio, and natural mortality

Between 1985 and 1995, maximum age for males generally varied between age 4 and 5, while female maximum age ranged from age 6 to 8 (Figure 6). By 2000, maximum age of males had increased to between 8 and 9, where it remained stable until 2007 when one 12 year old male was captured. Female maximum age has increased steadily since 1995, with a peak of 14 years in 2005.

From 1992 to 1997 overall sex ratio averaged approximately 54% female (Figure 7). From 1997 to 2000, females increased from 53 to 58% of the stock, where it remained stable for 3 years. In 2003, the ratio dropped to 51% female and has varied widely from 47 to 57% since then.

Natural mortality was estimated as a weighted average of sex ratio and sex-specific natural mortality. Using maximum ages of 12 and 15 for males and females, respectively, sex-specific natural mortality is estimated at 0.25 for males and 0.20 for females. Applying these to overall sex ratios, M has remained relatively stable around 0.223, with a range of 0.221 in 2000 to 0.226 in 2005 (Figure 7).

Sex ratios by age (Figure 8) show a general decrease in percent female at age since the mid 1990s for all ages, although the declines are more evident for ages 2 and above. For example, 3 year old fish have dropped from an average of 75% female during 1992 to 1994 to 56% female in 2004 to 2006. Four year old fish have dropped from 85% female to 62% female over the same time period.

Sex ratio at size data (discussed below) indicate that greater than 90% of fluke can be sexed by 25 cm. Von Bertalanffy estimates indicate that both males and females attain this size by age 1. By age 2 both males and females have recruited to the commercial fishery (36 cm, 14”), so age 1 is the only age where they are large enough to be sexed and experience no harvest pressure. Natural mortality for age 1 fish is generally stable between 0.225 and 0.23 from 1992 to 2002, but has increased to approximately 0.235 in recent years (Figure 9). Even though age 2 fish are exploited, the sex ratio averages approximately 50:50 up to 43 cm (17”, age 3), and both sexes are likely harvested in equal proportions. Natural mortality of age 2 fish shows a gradual increase from 0.216 to 0.23 from 1992 to 2005, before dropping sharply back to 0.224 in 2006. Average M for age 1 and 2 also shows a gradual increase over all years from 0.222 to approximately 0.23.

When data are combined across years, logistic regression of percent female at size shows a 50:50 sex ratio at around 38 cm (15”). Fish smaller than this size are predominantly male, while larger fish are predominantly female (Figure 10). Using annual data, the 50% inflection ranges from 33 cm in 1992 and 1995 to 43 cm in 2003 and 2005 (Figure 11).

Combined data show that greater than 90% of all animals 25 cm and larger can be sexed. Sex ratio for fish 25-35 cm (*i.e.* able to be sexed but less than minimum size) has decreased from an average of 34.5% females for 1992-94 to 29.4% for 2004-06 (Figure 12). Natural mortality for fish in this size range has increased from an average of 0.233 for 1992-94 to 0.235 for 2004-06 (Figure 13). From 35 cm to 43 cm, the sex ratio is approximately 50:50, and fish in this size range are likely exploited in similar proportions. The sex ratio for fish 25 to 43 cm shows a decline from 48.4% female in 1992-1994 to 37.2% in 2004-2006. *M* for this size range has increased from 0.226 to 0.231 over the same time period.

Fecundity

Because of the concerns with sample size for age:length data, fecundity could only be evaluated for the years 1999 to 2006. Theoretical fecundity of the stock increased steadily from approximately 22.3 x 10^{12} eggs in 1999 to a maximum of over 36.5 x 10^{12} eggs in 2004 (Figure 14). Fecundity has decreased in each of the last two years, to approximately 31.0 x 10^{12} eggs in 2006. During this time period, recruitment (VPA output) has remained relatively stable between 28 million and 38 million individuals, except for 2004 where recruitment was estimated at only 17 million. The relationship between fecundity and recruitment is slightly negative, although this appears to be driven primarily by the 2004 data point (highest fecundity and lowest recruitment.

Discussion

Summer flounder biomass has increased substantially during the rebuilding period, yet managers continue to cut annual quotas in an attempt to reach established biomass reference points. This has led many managers and industry stakeholders to question the accuracy of the reference point targets. In recent months, evidence has been presented that summer flounder stocks may be experiencing changes in life history parameters, such as size at age and sex ratios. In addition, there have been implications that management measures themselves are impeding stock rebuilding by selectively harvesting larger individuals which are primarily female. This paper was undertaken to evaluate certain life history parameters and the implications they have on stock rebuilding.

Dery 1988 found males reached a maximum age of 7 years and females 12 years. This is generally consistent with maximum ages observed in NEFSC trawl surveys from 1992 to 2000. Since then, maximum ages of both males and females captured in the NEFSC trawl surveys have approximately doubled, likely as a result of reduced fishing mortality allowing fish to survive to older ages. Trawl data indicate that maximum ages of 12 for males and 15 for females may be more appropriate. As maximum ages for both sexes were observed in recent years, additional years of reduced fishing pressure may result in even older maximum ages. In addition, maximum ages may be confounded with survey catchability at size.

As identified by Terceiro (pers. comm.) length and weight at age do appear to have decreased in recent years. For males, decreases in length at age are not yet statistically significant, but may become so if the trend continues. For females, significant decreases in length at age have been observed for ages 5 and older. Although length:weight relationships have not changed, decreased length at age results in lower weight at age, which may result in slower than anticipated rebuilding rates.

In recent months, many fishermen have expressed concern regarding the finding of the NEAMAP trawl survey that most fluke greater than 41 cm (16”) are female. These findings are not new (*e.g.* Murawski and Figley 1977, Morse 1981), but this sexual dimorphism has greater implications for management and stock rebuilding as minimum size limits increase in an effort to reduce harvest. There does appear to be a general decline in the ratio of females to males observed in the trawl survey. However, for many ages this decline has been observed over 15 years, much longer than states have required large minimum sizes.

Natural mortality for summer flounder is generally approximated as $M = 0.2$ based on longevity information. Because summer flounder males and females appear to have different maximum ages, the sex ratio of the population could affect the overall stock natural mortality rate. The shift in sex ratio towards more males in recent years has led to a slight increase in natural mortality for the stock, but the increase does not appear substantial enough to affect rebuilding. However, estimates based on current data indicate that $M = 0.22$ might be a more appropriate estimate of overall natural mortality. A higher natural mortality rate would result in a higher F_{Target} and lower SSB_{Target} than currently estimated. Although this analysis provides evidence for a higher M, additional analyses should be conducted. The Hoenig (1983) approximation used in this paper is often criticized as being inadequate (*e.g.* Pascual and Iribarne 1993, Hewitt and Hoenig 2005). In addition, maximum ages captured by trawl in a stock that is undergoing rebuilding may be underestimated.

Morse (1981) found that length was the best indicator of fecundity in fluke. Changes in female length at age and management strategies directing effort to large females could affect fecundity of the stock. In general, however, increases in total abundance have outpaced any decreases in fecundity, resulting in theoretical stock fecundity increasing more than 50% from 1999 to 2004. Fecundity declined in 2005 and 2006, coincident with slower stock growth. However, additional years of data are necessary to determine if there is a causal relationship.

Conclusions

Review of NEFSC trawl survey data do indicate that certain life history parameters have changed since 1992. Length at age has decreased significantly for older females. Maximum ages have approximately doubled since 2000. Sex ratios have shifted towards higher proportions of males. Natural mortality based on longevity and sex ratio has increased slightly. Despite decreases in fecundity at age, overall theoretical stock fecundity was higher in 2006 than in 1999. The implications of these patterns in biological parameters should be reviewed and considered when evaluating potential management strategies for stock rebuilding.

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Table 1. Sample size by age and year from the winter survey. Cells in bold italics indicate the years and ages used in the age:length analysis. A) Males, B) Females

A)

Year	Age 1	2	3	4	5	6	7	8+
1992	150	75	14	1				
1993	113	144	5		1			
1994	102	185	19	6				
1995	92	155	3	1				
1996	229	145	18	2				
1997	106	152	27	22	4			
1998	67	92	71	7	2			1
1999	***46***	***161***	***101***	***15***	6			
2000	***18***	***164***	***122***	***72***	13	5	1	2
2001	***70***	***186***	***160***	***81***	23	10		2
2002	***75***	***239***	***172***	***75***	17	6	1	1
2003	***127***	***161***	***117***	***45***	12	3	1	1
2004	***51***	***221***	***112***	***46***	17	7	3	3
2005	***76***	***127***	***77***	***38***	19	8	2	2
2006	***72***	***148***	***78***	***50***	22	9	5	5

B)

Year	Age 1	2	3	4	5	6	7	8+
1992	138	175	17	3	1	3		
1993	88	242	30	5	1	2		
1994	67	285	63	22			1	
1995	145	195	28	3				
1996	221	263	51	10	2			
1997	140	247	69	23	12	4		
1998	46	133	140	62	16	2		
1999	***48***	***135***	***151***	***92***	***35***	9	5	3
2000	***24***	***155***	***176***	***169***	***86***	18	10	3
2001	***113***	***149***	***279***	***146***	***74***	43	12	10
2002	***101***	***273***	***201***	***148***	***94***	43	14	4
2003	***83***	***145***	***134***	***99***	***59***	28	24	15
2004	***55***	***201***	***166***	***110***	***51***	45	24	31
2005	***45***	***89***	***103***	***54***	***37***	21	13	25
2006	***46***	***179***	***102***	***89***	***72***	36	18	43

Table 2. Results of mean length (cm) at age.

Sex	Age		Year 1999	2000	2001	2002	2003	2004	2005	2006
Males	1	**Mean**	27.15	27.67	28.20	28.91	29.83	28.53	27.66	29.75
Males	1	**Std Dev**	3.47	2.22	2.39	2.96	3.39	2.79	2.91	3.54
Males	2	**Mean**	36.36	34.37	36.18	36.85	37.64	36.62	36.42	34.99
Males	2	**Std Dev**	3.30	2.56	2.91	2.79	3.05	3.09	3.16	2.91
Males	3	**Mean**	42.27	39.98	41.11	42.94	44.01	42.59	42.14	39.86
Males	3	**Std Dev**	2.98	2.95	3.00	2.93	3.39	2.90	2.90	3.52
Males	4	**Mean**	47.47	45.74	46.99	48.19	48.51	47.72	45.82	44.36
Males	4	**Std Dev**	3.64	3.18	3.21	3.36	3.45	2.79	3.14	3.08
Females	1	**Mean**	28.98	28.29	28.27	30.00	31.27	28.84	28.09	29.83
Females	1	**Std Dev**	3.18	2.93	2.83	3.33	3.16	3.30	2.98	3.97
Females	2	**Mean**	38.78	37.51	38.79	40.24	41.12	40.32	39.02	38.94
Females	2	**Std Dev**	3.58	4.18	3.76	3.35	3.48	3.52	3.50	3.40
Females	3	**Mean**	46.97	44.23	46.19	48.10	48.94	47.49	46.27	43.34
Females	3	**Std Dev**	2.87	4.11	3.79	3.94	3.66	3.08	3.28	4.13
Females	4	**Mean**	53.10	52.41	54.47	54.61	55.58	53.75	52.09	49.52
Females	4	**Std Dev**	3.03	3.70	4.29	3.65	3.63	3.38	3.12	3.76
Females	5	**Mean**	60.49	57.98	59.49	60.30	58.59	57.65	56.95	53.32
Females	5	**Std Dev**	3.74	3.25	4.16	3.57	4.60	3.51	3.12	3.01

Table 3. Regression results for the slope of mean length at age over time. Rows in bold italics are significant at 0.05 level.

Sex	Age	RMSE	Estimate	Std Err	T value	P Value	Lo 95 CI	Up 95 CI
Male	1	0.8577	0.2388	0.1324	1.8041	0.1213	-0.0851	0.5626
Male	2	1.1190	0.0334	0.1727	0.1936	0.8529	-0.3891	0.4559
Male	3	1.5629	-0.0065	0.2412	-0.0270	0.9794	-0.5966	0.5836
Male	4	1.4199	-0.2242	0.2191	-1.0234	0.3456	-0.7603	0.3119
Female	1	1.1565	0.0936	0.1785	0.5247	0.6186	-0.3430	0.5303
Female	2	1.1513	0.1691	0.1776	0.9521	0.3778	-0.2656	0.6038
Female	3	2.0131	-0.1241	0.3106	-0.3995	0.7034	-0.8842	0.6360
Female	4	1.8421	-0.3315	0.2842	-1.1663	0.2878	-1.0270	0.3640
Female	***5***	***1.5172***	***-0.7445***	***0.2341***	***-3.1803***	***0.0191***	***-1.3174***	***-0.1717***

**Table 4. Results of von Bertalanffy growth analysis using bootstrap data for males.
A) Parameter estimates, B) Predicted length at age. Lengths are in cm.**

A)

Param		Year 1999	2000	2001	2002	2003	2004	2005	2006
L_inf	Mean	57.69	105879.36	73.02	69.65	66.93	66.29	52.88	99089.26
L_inf	Std Err	0.24	15286.72	0.79	0.31	0.33	0.32	0.10	13789.90
k	Mean	0.37	0.07	0.19	0.22	0.25	0.25	0.43	0.08
k	Std Err	3.69E-03	2.59E-03	2.42E-03	2.02E-03	2.44E-03	2.51E-03	2.71E-03	2.87E-03
t0	Mean	-0.82	-2.87	-1.77	-1.51	-1.45	-1.40	-0.73	-3.67
t0	Std Err	1.15E-02	3.30E-02	1.67E-02	1.14E-02	1.22E-02	1.34E-02	7.46E-03	4.30E-02

B)

Age		Year 1999	2000	2001	2002	2003	2004	2005	2006
0	Mean	14.17	21.13	19.74	19.15	19.62	18.49	14.06	23.98
0	Std Err	0.10	0.06	0.05	0.05	0.05	0.06	0.07	0.04
1	Mean	27.26	27.95	28.53	28.95	29.80	28.66	27.67	29.75
1	Std Err	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02
2	Mean	36.26	34.27	35.74	36.79	37.70	36.56	36.45	35.03
2	Std Err	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	Mean	42.49	40.14	41.67	43.06	43.84	42.73	42.13	39.88
3	Std Err	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	Mean	46.83	45.61	46.56	48.09	48.64	47.56	45.82	44.35
4	Std Err	0.03	0.01	0.01	0.01	0.02	0.02	0.02	0.02
5	Mean	49.88	50.73	50.61	52.13	52.39	51.35	48.23	48.50
5	Std Err	0.06	0.04	0.03	0.03	0.04	0.04	0.03	0.04
6	Mean	52.04	55.53	53.97	55.39	55.34	54.34	49.80	52.35
6	Std Err	0.08	0.07	0.06	0.05	0.06	0.06	0.05	0.07
7	Mean	53.57	60.05	56.77	58.01	57.66	56.70	50.84	55.95
7	Std Err	0.11	0.11	0.09	0.07	0.09	0.08	0.06	0.11
8	Mean	54.66	64.31	59.10	60.14	59.49	58.57	51.52	59.32
8	Std Err	0.13	0.16	0.11	0.09	0.11	0.11	0.07	0.16
9	Mean	55.45	68.35	61.06	61.86	60.94	60.06	51.97	62.49
9	Std Err	0.15	0.21	0.14	0.12	0.13	0.13	0.08	0.21
10	Mean	56.03	72.18	62.70	63.26	62.09	61.24	52.27	65.48
10	Std Err	0.16	0.27	0.17	0.14	0.15	0.15	0.08	0.27

Table 5. Regression results for the slope of male predicted length at age over time.

Age	RMSE	Estimate	Std Err	T value	P Value	Lo 95 CI	Up 95 CI
0	3.4782	0.3580	0.5367	0.6671	0.5295	-0.9552	1.6713
1	0.8369	0.2059	0.1291	1.5940	0.1620	-0.1101	0.5219
2	1.1417	0.0678	0.1762	0.3851	0.7135	-0.3632	0.4989
3	1.4866	-0.0515	0.2294	-0.2243	0.8300	-0.6128	0.5099
4	1.4686	-0.1516	0.2266	-0.6691	0.5283	-0.7061	0.4029
5	1.5410	-0.2343	0.2378	-0.9851	0.3626	-0.8161	0.3476
6	2.0495	-0.3016	0.3162	-0.9538	0.3770	-1.0754	0.4722
7	2.9216	-0.3561	0.4508	-0.7900	0.4596	-1.4592	0.7469
8	3.9818	-0.4000	0.6144	-0.6511	0.5391	-1.9034	1.1033
9	5.1309	-0.4353	0.7917	-0.5498	0.6023	-2.3725	1.5020
10	6.3189	-0.4635	0.9750	-0.4753	0.6514	-2.8493	1.9223

Table 6. Results of von Bertalanffy growth analysis using bootstrap data for females. A) Parameter estimates, B) Predicted length at age. Lengths are in cm.

A)

Param		Year 1999	2000	2001	2002	2003	2004	2005	2006
L_inf	Mean	98.94	175.38	95.32	83.70	72.92	68.16	70.01	68.25
L_inf	Std Err	0.55	21.38	0.35	0.19	0.13	0.09	0.15	0.22
k	Mean	0.15	0.09	0.16	0.21	0.28	0.33	0.29	0.24
k	Std Err	1.39E-03	1.60E-03	1.07E-03	9.93E-04	1.31E-03	1.36E-03	1.58E-03	1.90E-03
t0	Mean	-1.40	-1.87	-1.22	-1.17	-0.98	-0.70	-0.82	-1.58
t0	Std Err	9.69E-03	1.71E-02	6.70E-03	5.92E-03	5.94E-03	5.43E-03	6.54E-03	1.37E-02

B)

Age		Year 1999	2000	2001	2002	2003	2004	2005	2006
0	Mean	18.21	19.38	16.81	17.86	17.46	13.87	14.44	20.67
0	Std Err	0.05	0.07	0.04	0.04	0.05	0.06	0.06	0.07
1	Mean	29.22	28.68	28.42	30.13	31.08	29.11	28.31	30.55
1	Std Err	0.02	0.03	0.02	0.01	0.02	0.02	0.02	0.02
2	Mean	38.67	37.15	38.28	40.10	41.33	40.05	38.68	38.32
2	Std Err	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	Mean	46.79	44.85	46.66	48.19	49.05	47.90	46.44	44.44
3	Std Err	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	Mean	53.77	51.88	53.79	54.76	54.86	53.55	52.25	49.28
4	Std Err	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	Mean	59.78	58.29	59.85	60.11	59.25	57.61	56.62	53.10
5	Std Err	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02
6	Mean	64.96	64.15	65.01	64.46	62.56	60.54	59.90	56.13
6	Std Err	0.04	0.04	0.03	0.02	0.03	0.03	0.04	0.03
7	Mean	69.42	69.52	69.40	68.00	65.07	62.64	62.36	58.54
7	Std Err	0.06	0.07	0.05	0.04	0.04	0.04	0.05	0.05
8	Mean	73.27	74.43	73.15	70.88	66.96	64.17	64.22	60.45
8	Std Err	0.09	0.10	0.07	0.05	0.05	0.05	0.06	0.06
9	Mean	76.60	78.94	76.34	73.22	68.39	65.26	65.62	61.98
9	Std Err	0.11	0.14	0.09	0.06	0.06	0.06	0.08	0.08
10	Mean	79.48	83.08	79.06	75.14	69.48	66.06	66.68	63.19
10	Std Err	0.14	0.18	0.11	0.08	0.07	0.06	0.09	0.10

Table 7. Regression results for the slope of female predicted length at age over time. Rows in bold italics are significant at the 0.05 level.

Age	RMSE	Estimate	Std Err	T value	P Value	Lo 95 CI	Up 95 CI
0	2.4271	-0.1979	0.3745	-0.5284	0.6162	-1.1143	0.7185
1	1.0632	0.1244	0.1641	0.7584	0.4770	-0.2770	0.5258
2	1.3838	0.1393	0.2135	0.6525	0.5383	-0.3832	0.6618
3	1.7126	-0.0470	0.2643	-0.1778	0.8648	-0.6936	0.5997
4	1.7485	-0.3597	0.2698	-1.3330	0.2309	-1.0198	0.3005
5	***1.5973***	***-0.7464***	***0.2465***	***-3.0283***	***0.0232***	***-1.3494***	***-0.1433***
6	***1.4044***	***-1.1709***	***0.2167***	***-5.4032***	***0.0017***	***-1.7012***	***-0.6407***
7	***1.3408***	***-1.6087***	***0.2069***	***-7.7758***	***0.0002***	***-2.1149***	***-1.1025***
8	***1.5285***	***-2.0433***	***0.2359***	***-8.6636***	***0.0001***	***-2.6204***	***-1.4662***
9	***1.9350***	***-2.4642***	***0.2986***	***-8.2531***	***0.0002***	***-3.1948***	***-1.7336***
10	***2.4627***	***-2.8649***	***0.3800***	***-7.5389***	***0.0003***	***-3.7947***	***-1.9350***

Table 8. **Sample size of weights by age and year from the winter survey. Cells in bold italics indicate the years and ages used in the age:length analysis. A) Males, B) Females**

A)	**AGE**							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1992								
1993	113	144	5		1			0
1994	99	184	19	6				0
1995	92	155	3	1				0
1996	229	144	18	2				0
1997	106	151	26	22	4			0
1998	67	92	71	7	2			1
1999	***46***	***159***	***101***	***15***	6			0
2000	***18***	***164***	***122***	***72***	13	5	1	2
2001	***70***	***186***	***160***	***81***	23	10		2
2002	***75***	***239***	***172***	***75***	17	6	1	1
2003	***127***	***161***	***117***	***45***	12	3	1	1
2004	***51***	***221***	***112***	***46***	17	7	3	3
2005	***76***	***127***	***77***	***38***	19	8	2	2
2006	***72***	***148***	***78***	***50***	22	9	5	5

B)	**AGE**							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1992								
1993	88	242	30	5	1	2		0
1994	67	285	63	22			1	0
1995	141	191	28	3				0
1996	219	263	51	10	2			0
1997	140	246	69	23	12	4		0
1998	46	133	139	62	16	2		0
1999	***48***	***135***	***151***	***92***	***35***	9	5	3
2000	***24***	***155***	***176***	***169***	***86***	18	10	3
2001	***113***	***149***	***279***	***146***	***74***	43	12	10
2002	***101***	***272***	***201***	***148***	***94***	43	14	4
2003	***83***	***145***	***134***	***99***	***59***	28	24	15
2004	***55***	***201***	***166***	***110***	***51***	45	24	31
2005	***45***	***89***	***103***	***54***	***37***	21	13	25
2006	***46***	***179***	***102***	***89***	***72***	36	18	43

Table 9. Results of length:weight analysis using bootstrap data for males. A) Parameter estimates, B) Predicted length at age. Weights are in kg.

A)

Param		Year 1999	2000	2001	2002	2003	2004	2005	2006
a	Mean	5.27E-06	6.73E-06	3.61E-06	5.67E-06	4.10E-06	4.61E-06	3.25E-06	9.14E-06
a	Std Err	2.66E-08	2.98E-08	1.87E-08	2.09E-08	1.88E-08	2.46E-08	1.63E-08	4.81E-08
b	Mean	3.18	3.11	3.28	3.15	3.24	3.21	3.31	3.03
b	Std Err	1.35E-03	1.17E-03	1.38E-03	9.75E-04	1.20E-03	1.43E-03	1.35E-03	1.42E-03

B)

Length (cm)		Year 1999	2000	2001	2002	2003	2004	2005	2006
10	Mean	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	Std Err	1.52E-05	1.49E-05	1.38E-05	1.17E-05	1.29E-05	1.55E-05	1.28E-05	1.93E-05
20	Mean	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08
20	Std Err	7.17E-05	6.85E-05	7.12E-05	5.61E-05	6.59E-05	7.65E-05	6.68E-05	8.07E-05
30	Mean	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.27
30	Std Err	1.23E-04	1.20E-04	1.34E-04	1.03E-04	1.27E-04	1.39E-04	1.24E-04	1.26E-04
40	Mean	0.64	0.65	0.64	0.63	0.64	0.64	0.65	0.64
40	Std Err	1.11E-04	1.20E-04	1.37E-04	9.86E-05	1.35E-04	1.33E-04	1.27E-04	1.16E-04
50	Mean	1.30	1.30	1.32	1.27	1.31	1.31	1.35	1.26
50	Std Err	3.68E-04	3.07E-04	3.59E-04	1.95E-04	2.81E-04	3.62E-04	3.87E-04	4.26E-04
60	Mean	2.32	2.29	2.40	2.25	2.37	2.35	2.47	2.18
60	Std Err	1.17E-03	9.56E-04	1.17E-03	6.87E-04	9.26E-04	1.18E-03	1.24E-03	1.25E-03
70	Mean	3.78	3.69	3.98	3.66	3.91	3.85	4.12	3.48
70	Std Err	2.66E-03	2.17E-03	2.75E-03	1.64E-03	2.20E-03	2.75E-03	2.88E-03	2.73E-03
80	Mean	5.78	5.59	6.16	5.57	6.04	5.91	6.40	5.21
80	Std Err	5.09E-03	4.14E-03	5.36E-03	3.21E-03	4.33E-03	5.33E-03	5.60E-03	5.06E-03
90	Mean	8.40	8.07	9.07	8.07	8.84	8.63	9.46	7.44
90	Std Err	8.71E-03	7.06E-03	9.35E-03	5.56E-03	7.56E-03	9.22E-03	9.74E-03	8.46E-03

Table 10. Regression results for the slope of male predicted weight at length over time.

Length (cm)	RMSE	Estimate	Std Err	T value	P Value	Lo 95 CI	Up 95 CI
10	0.0011	4.00E-05	1.70E-04	0.2363	0.8211	-0.0004	0.0005
20	0.0049	1.40E-04	7.60E-04	0.1901	0.8555	-0.0017	0.0020
30	0.0077	2.10E-04	1.18E-03	0.1798	0.8633	-0.0027	0.0031
40	0.0067	1.40E-04	1.03E-03	0.1357	0.8965	-0.0024	0.0027
50	0.0328	-1.50E-04	5.06E-03	-0.0300	0.9771	-0.0125	0.0122
60	0.0985	-7.00E-04	1.52E-02	-0.0459	0.9649	-0.0379	0.0365
70	0.2176	-1.50E-03	3.36E-02	-0.0446	0.9659	-0.0837	0.0807
80	0.4086	-2.50E-03	6.31E-02	-0.0396	0.9697	-0.1568	0.1518
90	0.6919	-3.61E-03	1.07E-01	-0.0338	0.9741	-0.2649	0.2576

Table 11. Results of length:weight analysis using bootstrap data for females. A) Parameter estimates, B) Predicted length at age. Weights are in kg.

A)

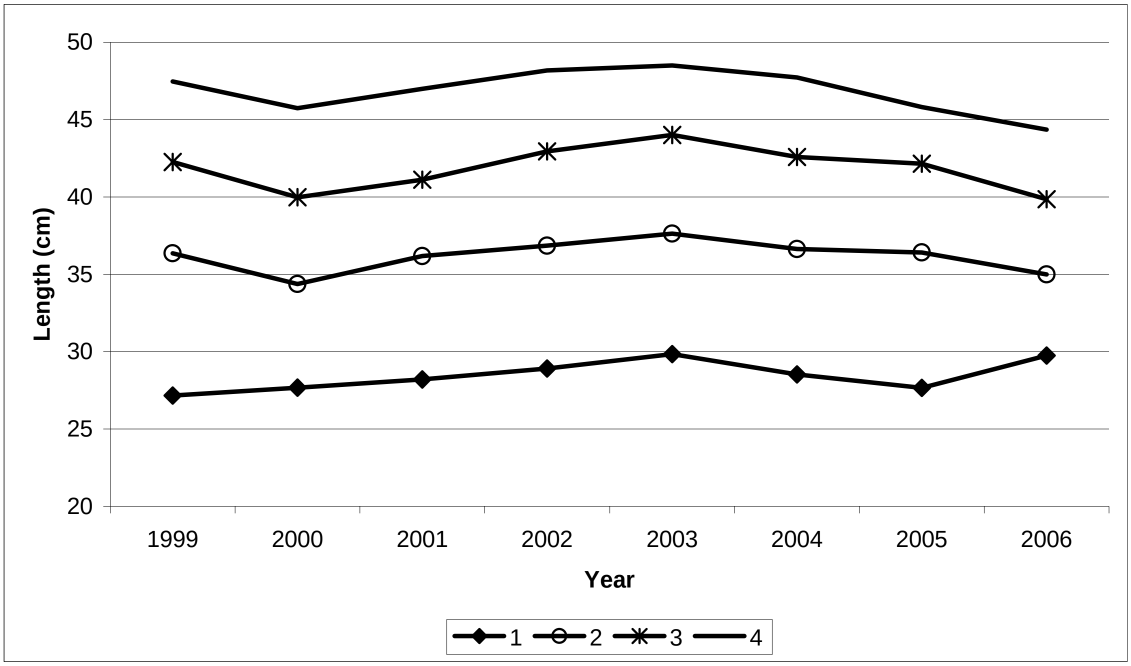
Param		Year 1999	2000	2001	2002	2003	2004	2005	2006
a	Mean	2.65E-06	4.60E-06	2.84E-06	4.83E-06	4.00E-06	4.61E-06	3.24E-06	5.12E-06
a	Std Err	1.20E-08	2.20E-08	1.11E-08	1.80E-08	1.92E-08	2.17E-08	2.14E-08	3.85E-08
b	Mean	3.35	3.21	3.33	3.19	3.24	3.21	3.30	3.18
b	Std Err	1.14E-03	1.20E-03	9.68E-04	9.33E-04	1.20E-03	1.18E-03	1.67E-03	1.89E-03

B)

Length (cm)		Year 1999	2000	2001	2002	2003	2004	2005	2006
10	Mean	0.0060	0.0074	0.0061	0.0075	0.0069	0.0074	0.0064	0.0077
10	Std Err	1.14E-05	1.49E-05	1.01E-05	1.19E-05	1.42E-05	1.46E-05	1.77E-05	2.35E-05
20	Mean	0.0611	0.0682	0.0612	0.0680	0.0655	0.0681	0.0633	0.0696
20	Std Err	6.91E-05	8.15E-05	6.11E-05	6.48E-05	8.01E-05	7.91E-05	1.01E-04	1.21E-04
30	Mean	0.2381	0.2504	0.2361	0.2478	0.2437	0.2496	0.2413	0.2525
30	Std Err	1.62E-04	1.80E-04	1.44E-04	1.44E-04	1.81E-04	1.72E-04	2.23E-04	2.49E-04
40	Mean	0.6250	0.6299	0.6156	0.6203	0.6189	0.6278	0.6236	0.6304
40	Std Err	2.30E-04	2.44E-04	2.13E-04	2.01E-04	2.55E-04	2.30E-04	2.90E-04	2.99E-04
50	Mean	1.3212	1.2885	1.2948	1.2639	1.2756	1.2840	1.3027	1.2819
50	Std Err	2.33E-04	2.23E-04	2.19E-04	1.92E-04	2.44E-04	2.14E-04	2.58E-04	3.12E-04
60	Mean	2.4357	2.3124	2.3768	2.2609	2.3031	2.3037	2.3783	2.2896
60	Std Err	4.91E-04	4.46E-04	3.68E-04	3.26E-04	4.24E-04	4.85E-04	7.58E-04	9.96E-04
70	Mean	4.0852	3.7914	3.9723	3.6969	3.7957	3.7765	3.9564	3.7389
70	Std Err	1.39E-03	1.30E-03	1.04E-03	9.35E-04	1.24E-03	1.37E-03	2.17E-03	2.61E-03
80	Mean	6.3940	5.8186	6.1982	5.6602	5.8512	5.7948	6.1487	5.7181
80	Std Err	3.07E-03	2.86E-03	2.34E-03	2.08E-03	2.77E-03	2.95E-03	4.69E-03	5.36E-03
90	Mean	9.4927	8.4900	9.1770	8.2416	8.5711	8.4540	9.0718	8.3180
90	Std Err	5.77E-03	5.33E-03	4.46E-03	3.89E-03	5.22E-03	5.44E-03	8.66E-03	9.61E-03

Table 12. Regression results for the slope of female predicted weight at length over time.

Length (cm)	RMSE	Estimate	Std Err	T value	P Value	Lo 95 CI	Up 95 CI
10	0.0006	1.30E-04	1.00E-04	1.2622	0.2537	-0.0001	0.0004
20	0.0032	6.30E-04	5.00E-04	1.2579	0.2552	-0.0006	0.0019
30	0.0059	1.09E-03	9.00E-04	1.2101	0.2717	-0.0011	0.0033
40	0.0056	5.00E-04	8.70E-04	0.5741	0.5868	-0.0016	0.0026
50	0.0176	-2.67E-03	2.71E-03	-0.9873	0.3616	-0.0093	0.0040
60	0.0567	-1.04E-02	8.74E-03	-1.1845	0.2810	-0.0318	0.0110
70	0.1312	-2.49E-02	2.02E-02	-1.2280	0.2655	-0.0744	0.0247
80	0.2540	-4.88E-02	3.92E-02	-1.2453	0.2594	-0.1447	0.0471
90	0.4399	-8.52E-02	6.79E-02	-1.2546	0.2563	-0.2513	0.0809



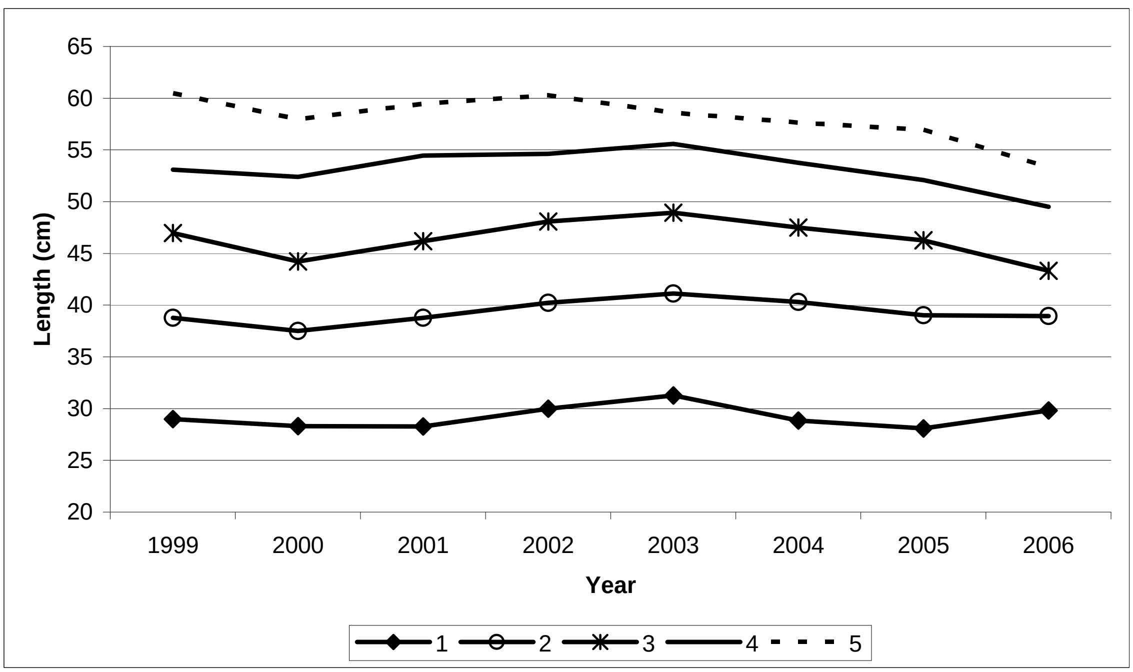


Figure 1. Mean length at age for males age 1 to 4 (top) and females age 1 to 5.

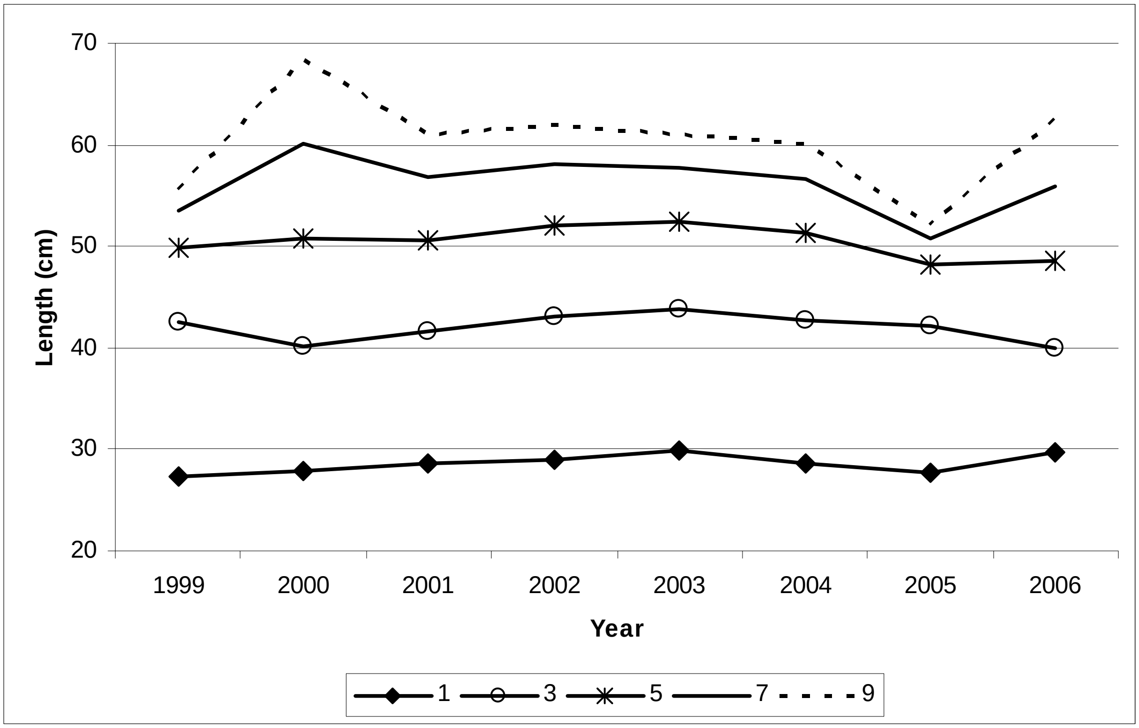


Figure 2. Mean predicted length at age for selected ages of males.

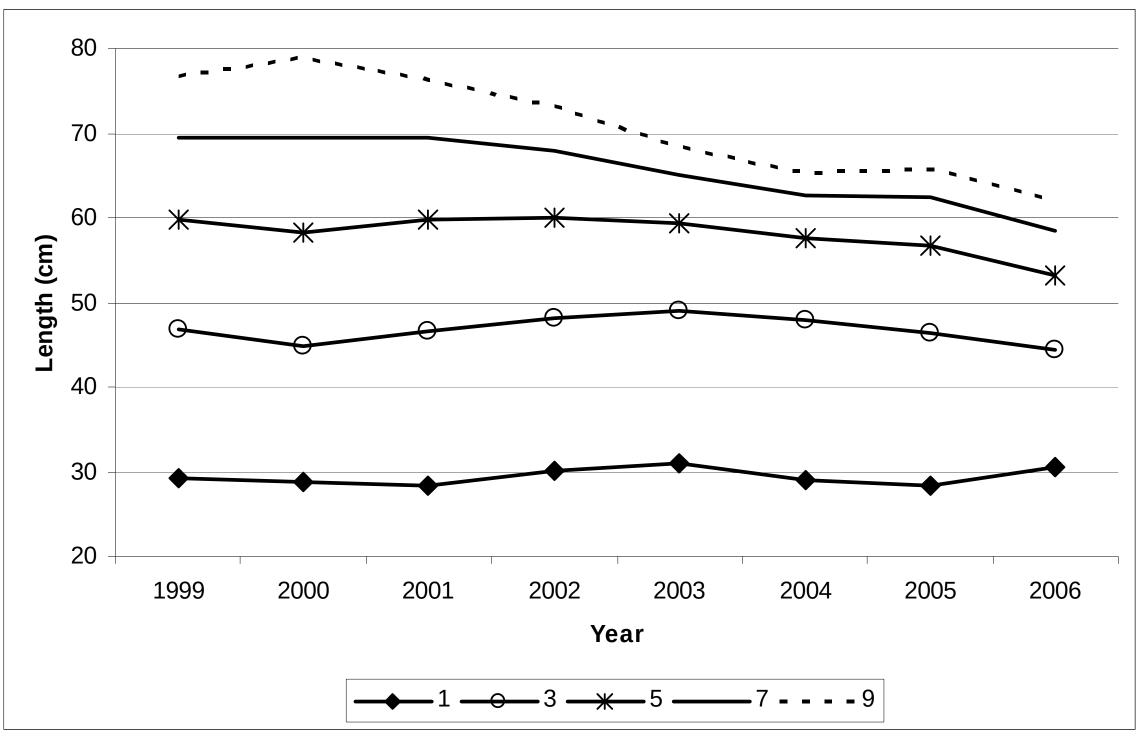


Figure 3. Mean predicted length at age for selected ages of females.

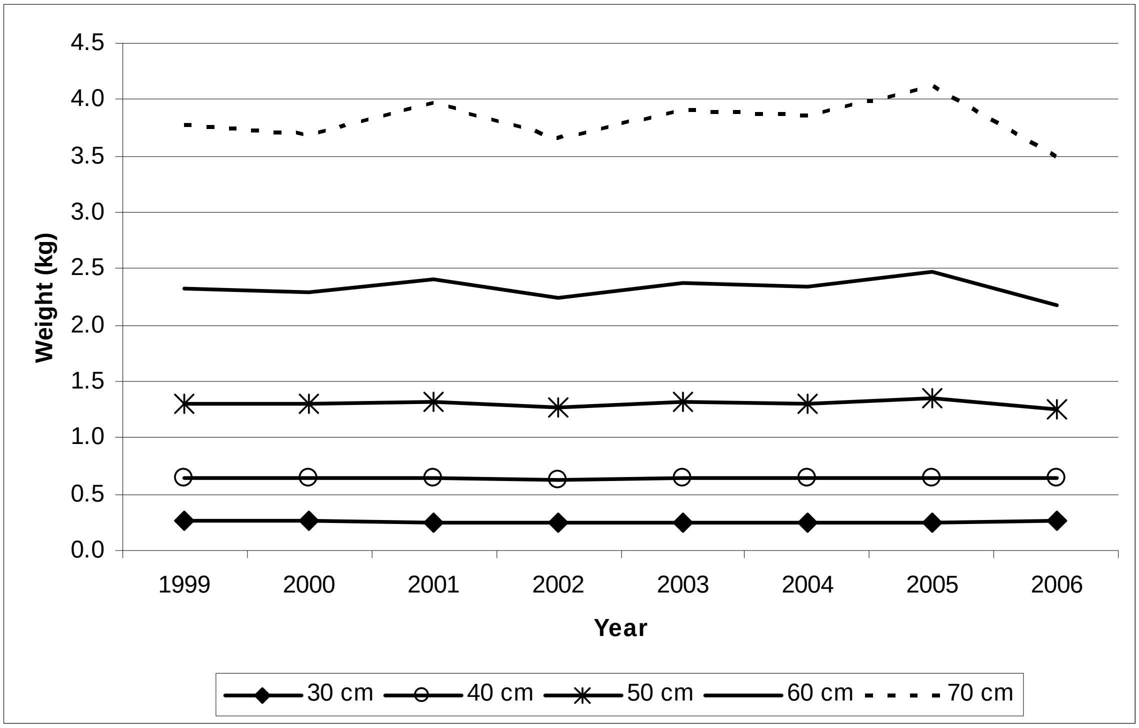


Figure 4. Mean predicted weight at length for selected lengths of males.

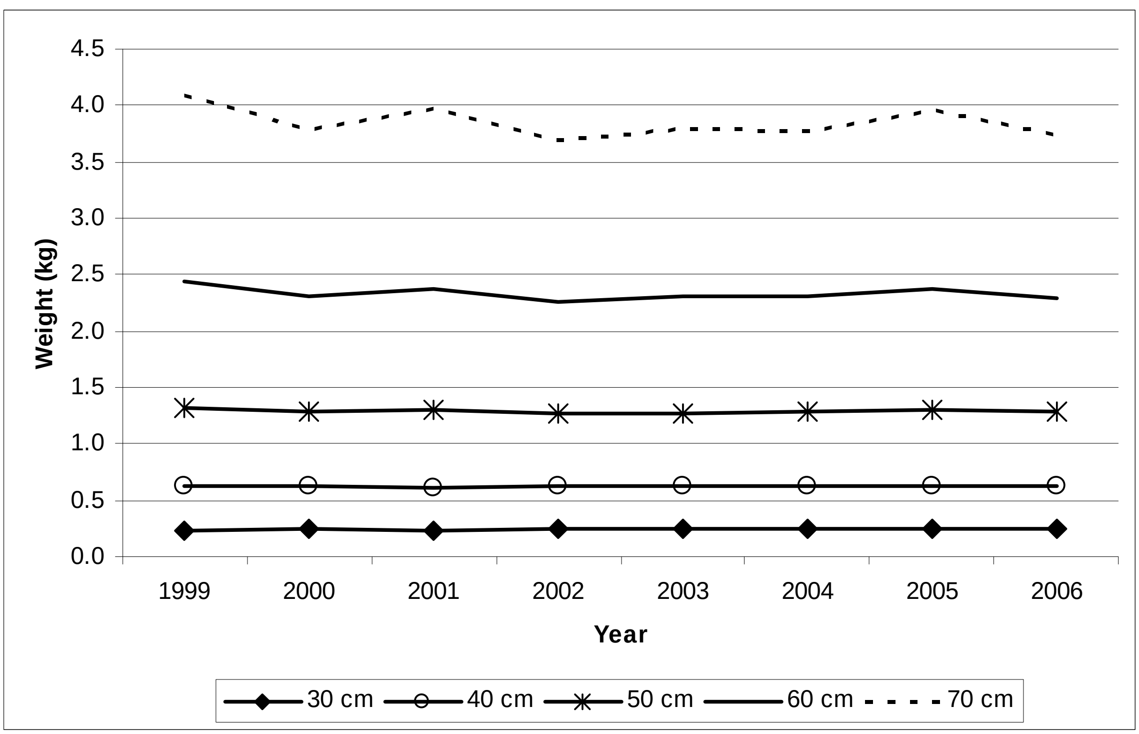


Figure 5. Mean predicted weight at length for selected lengths of females.

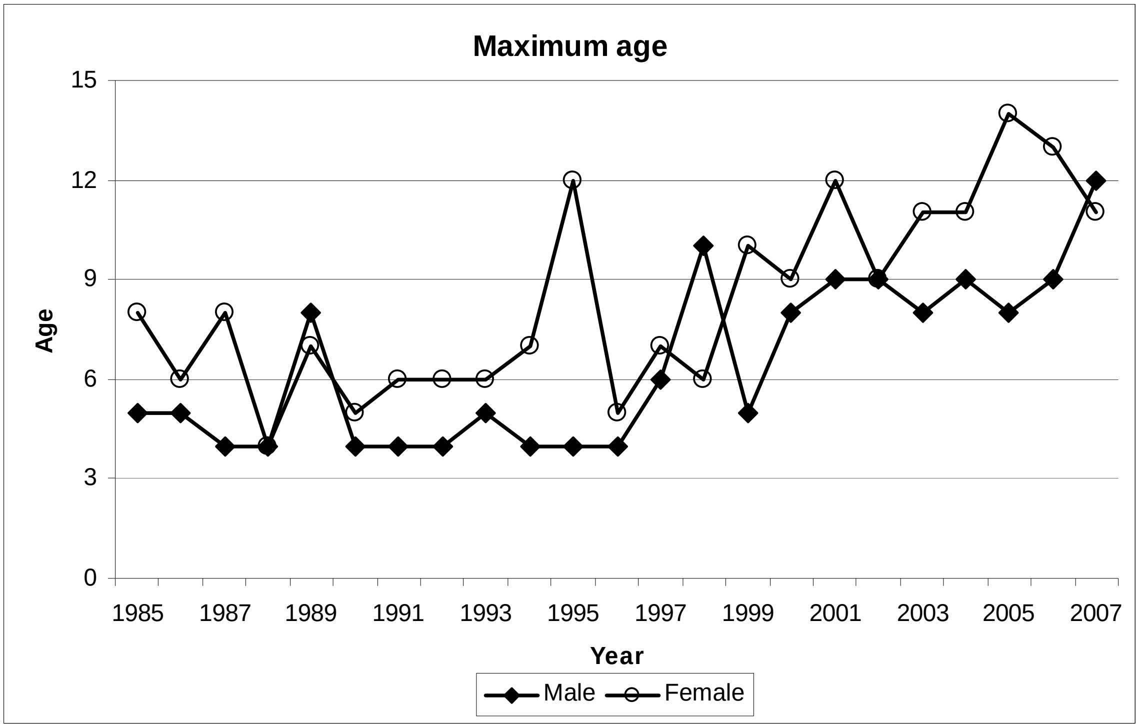


Figure 6. Observed maximum age by sex in NEFSC trawl surveys.

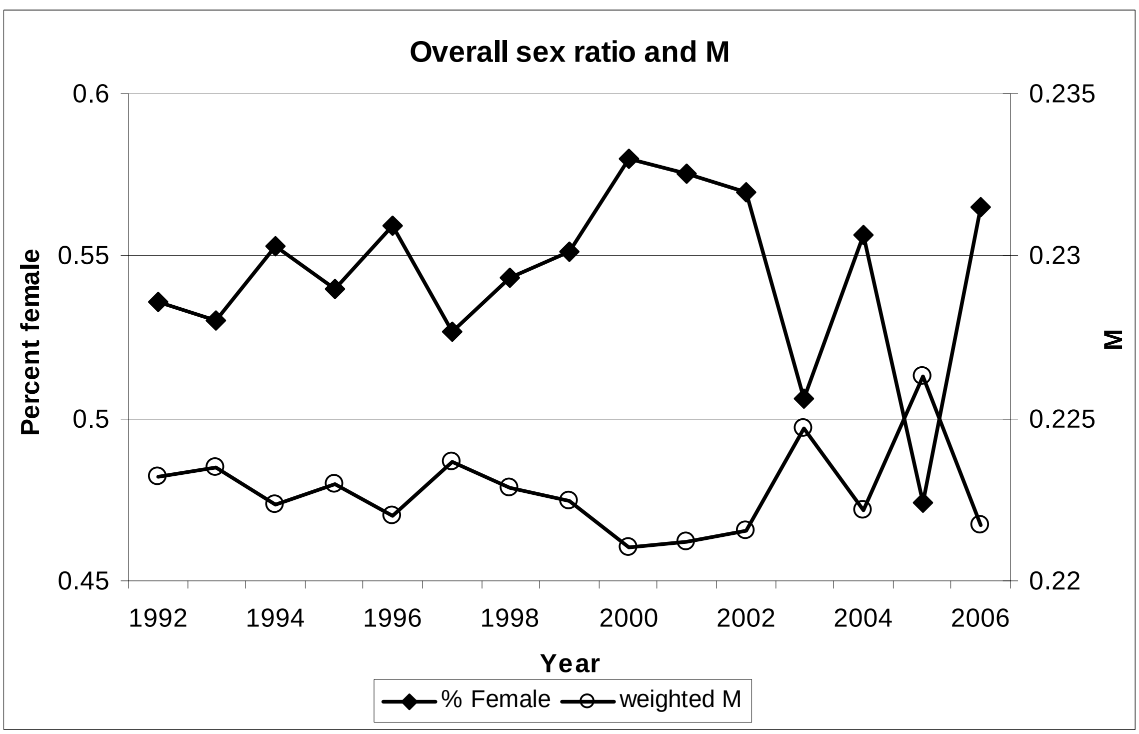


Figure 7. Sex ratio and natural mortality estimate by year across all ages.

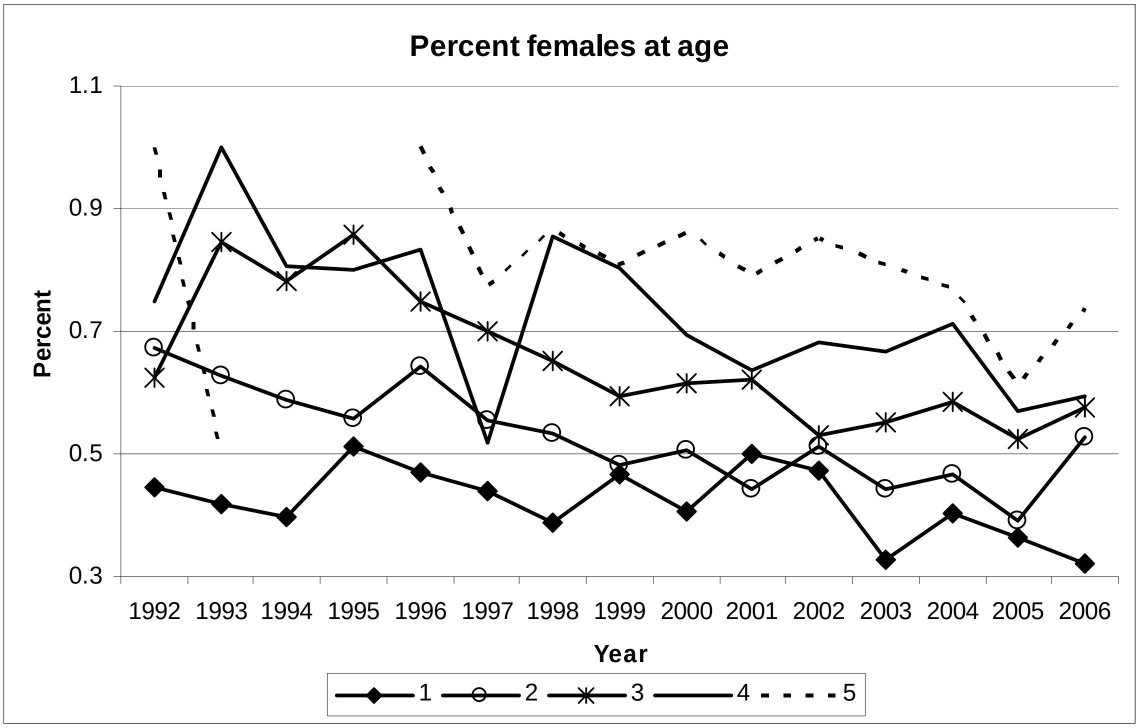


Figure 8. Percent female at age for selected ages.

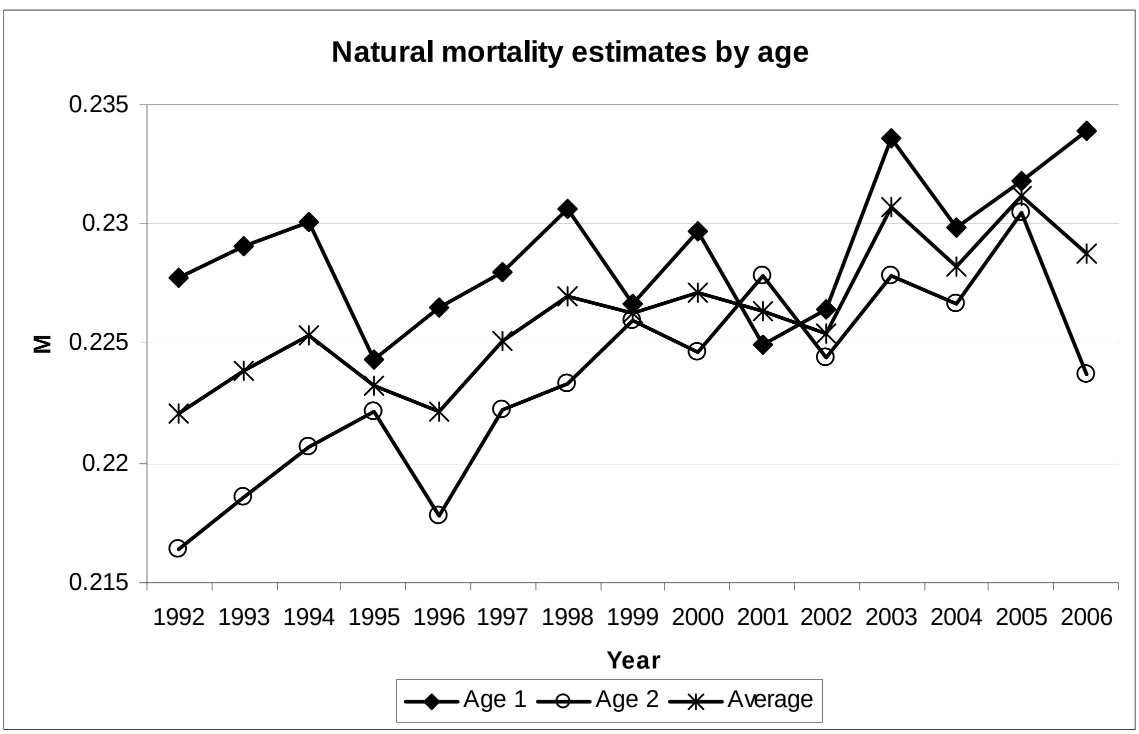


Figure 9. Natural mortality estimates by age for 1 and 2 year old fish

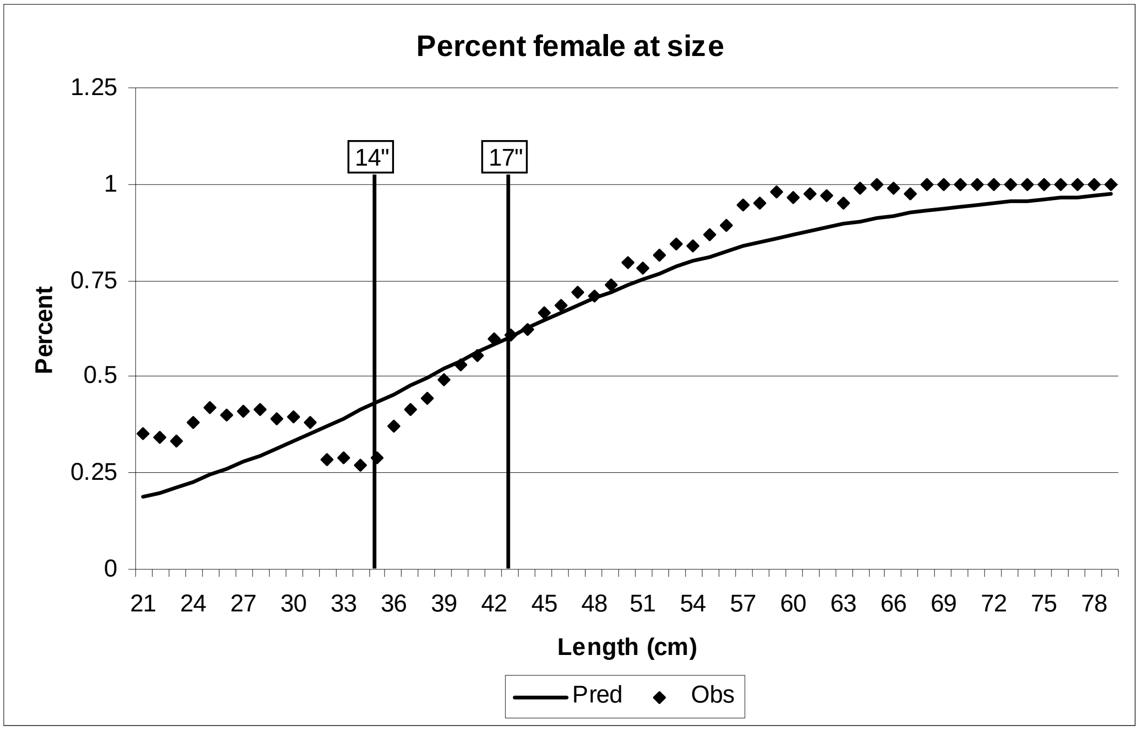


Figure 10. Logistic regression of percent female at size for all years combined.

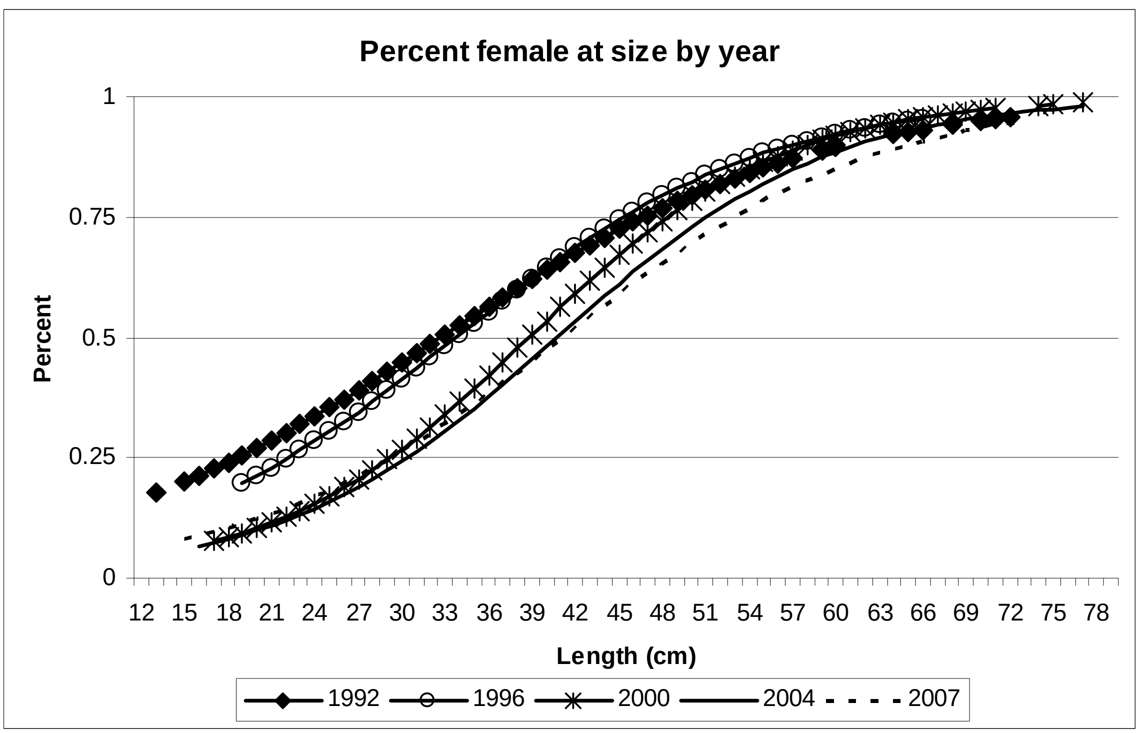


Figure 11. Logistic regression of percent female at size by year for selected years.

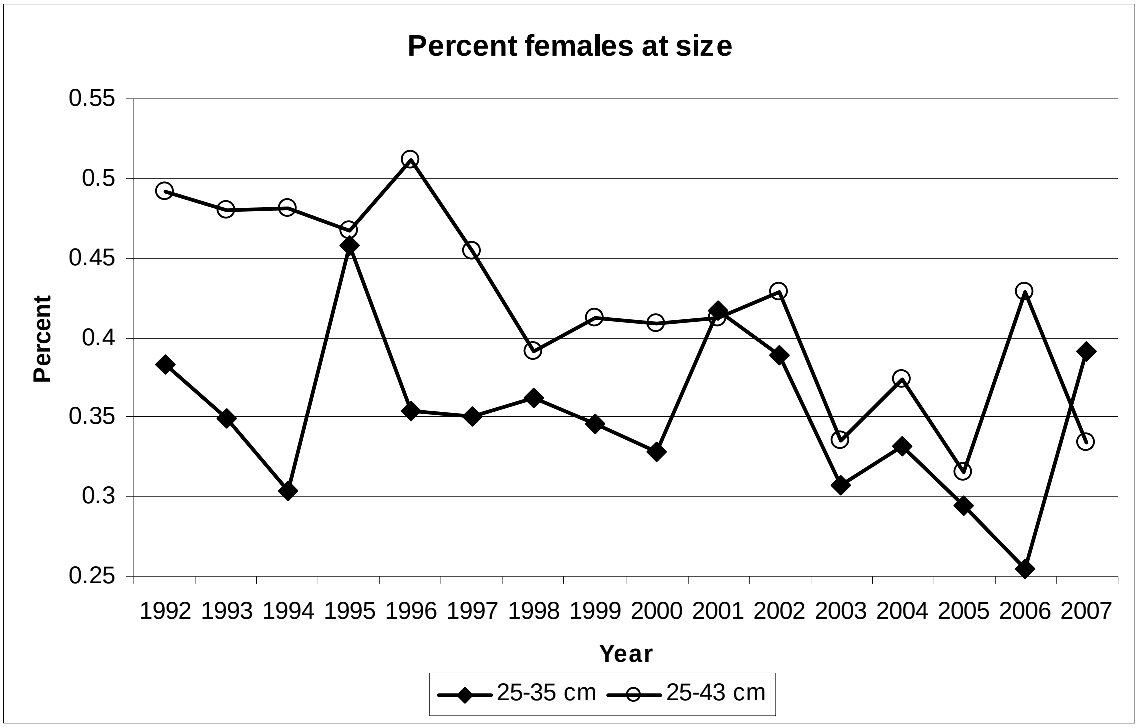


Figure 12. Percent female by year for two different size classes.

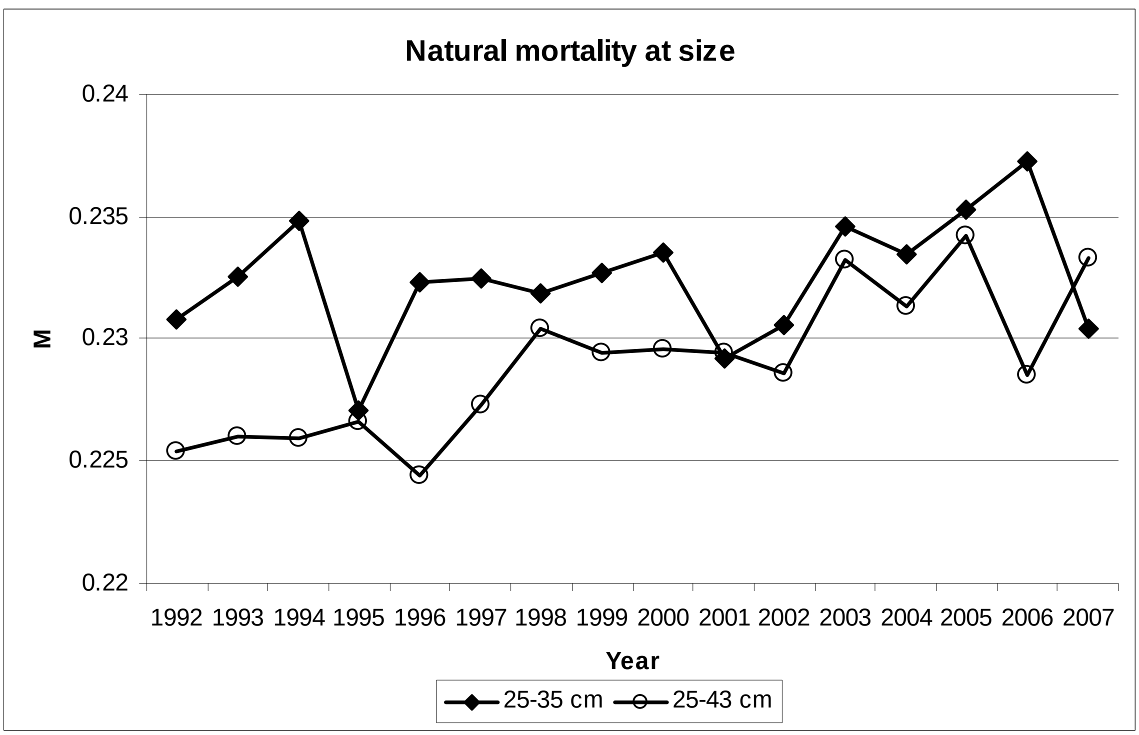


Figure 13. Natural mortality estimates for two different size groups.

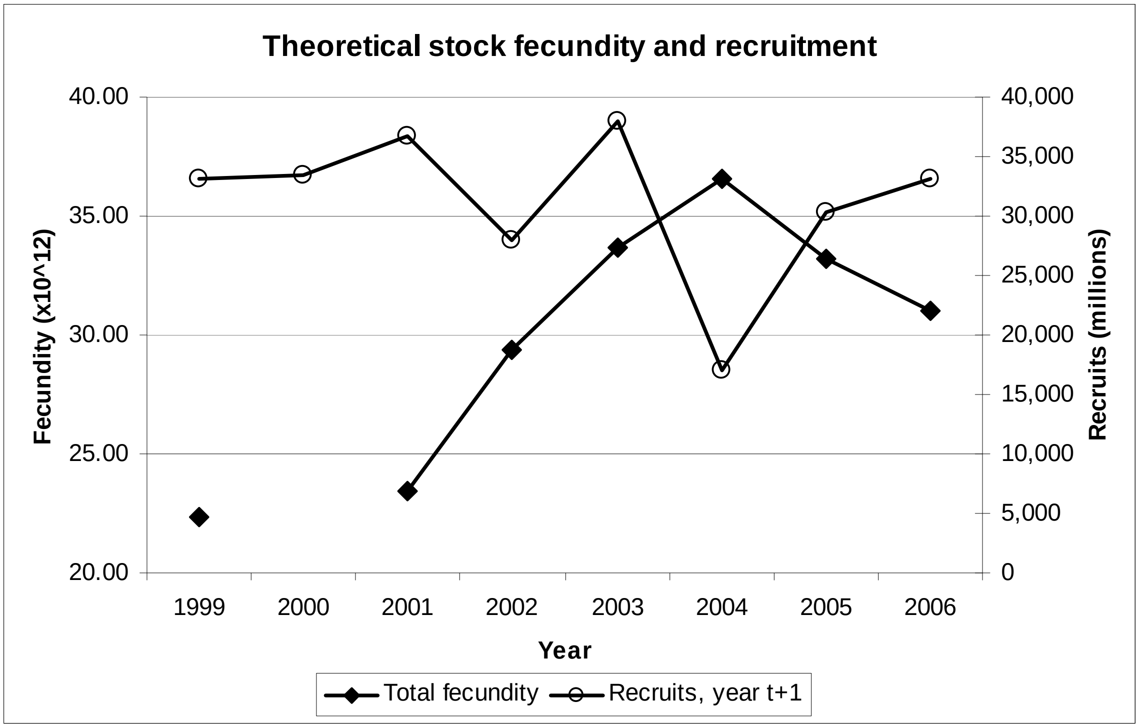


Figure 14. Overall fecundity and recruitment.