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Maturity of Female Cod in Divisions 2J+3KL with a Comparison of Fish from Inshore and Offshore Division 3L

M.J. Morgan and J. Brattey
Dept. of Fisheries and Oceans, PO Box 5667
St. John's, Newfoundland, Canada A1C 5X1

Abstract

This study presents the time series for estimates of proportion mature-at-age for Divisions 2J+3KL female cod (*Gadus morhua*) from 1981 to January 1996. The observed proportion mature-at-age are presented in each year for each Division. The proportion of mature fish-at-age has been increasing in all Divisions and in the stock as a whole, with the increase being greatest since the early-1990s. As a result, the estimated age at 50% maturity has decreased from over 6 years to a low of 4.86 years in the most recent 2 years. A comparison of proportion mature-at-age and length in the surveyed area in Div. 3L in autumn 1995 with data from western Trinity Bay does not show a significant difference between the two areas.

Key words: female cod (*Gadus morhua*), maturity-at-age, maturity-at-length

Introduction

The spawning biomass of a stock is a function of the biomass at each age and the proportion of the fish at each age that are mature and will spawn. In recent years there has been an increase in the proportion of mature fish-at-age in the Divisions 2J+3KL cod (*Gadus morhua*) stock as a whole, as well as within each Division separately (Morgan and Shelton, MS 1995; Morgan *et al*. 1994; Xu *et al*. MS 1991). Knife-edge estimates of age at maturity do not take such trends into account. Even small differences in age at maturity can have a significant impact on the estimation of potential yield of a fishery and of population growth rate (Welch and Foucher, 1988). Therefore, the best estimates of proportion mature-at-age should be incorporated into spawning stock biomass estimates. Further, there is a potential for changes in age at maturity to be an indicator of stress in a population so that an examination of the trends themselves may be important (Trippel, 1995).

This study presents the time series for estimates of proportion mature-at-age for Div. 2J+3KL female cod from 1981 to 1 Jan 1996. The observed proportions mature-at-age are also presented in each year for each Division. Also, the proportions mature-at-age and size of females from the autumn bottom trawl survey in Div. 3L are compared with those observed in a similar time period from three fjords in western Trinity Bay.

Methods

Maturity data of female cod from autumn surveys in Div. 2J+3KL (Fig. 1) from 1981 to 1995 were used in the analyses with the exception of Div. 3L in 1984 when the survey ended 2 months before the starting date in any other year. Fish were assigned to the category 'mature' or 'immature' based on the criteria of Templeman *et al*. (1978). The first stage in this scheme is classed as immature and all other stages show some evidence of maturing to spawn or of having spawned, and are classed as mature in this study. The 'other' or 'unknown' category was excluded from analyses. Because of the length stratified collection of otoliths, the calculation of proportion mature-at-age included a weighting by the female population number-at-length (Morgan and Hoenig, MS 1993). Estimates of proportion mature-at-age and of age at 50% maturity (A_{50}) were produced for each year using Probit analyses with a logit link function (SAS Institute Inc., 1989). Since the fish sampled in the autumn will not spawn until the following year, the proportion mature-at-age was assumed to be for 1 January of the year following the survey (e.g. 1 January 1996 for the autumn 1995 survey) and a year was added to each age (e.g. age 5 fish in the autumn survey would become age 6).

Two studies were conducted in the southwest arm area of western Trinity Bay, the first in December 1995 and the second in April 1996. Fish were assigned to mature and immature categories as above. For the December study, ages were available and the observed proportion mature-at-age was calculated. These data were not collected in a length stratified manner so there was no weighting by the length frequency. For the April study, only lengths were available and proportion mature-at-length was calculated. The effect of area (western Trinity Bay *vs* bottom trawl survey in 3L) on

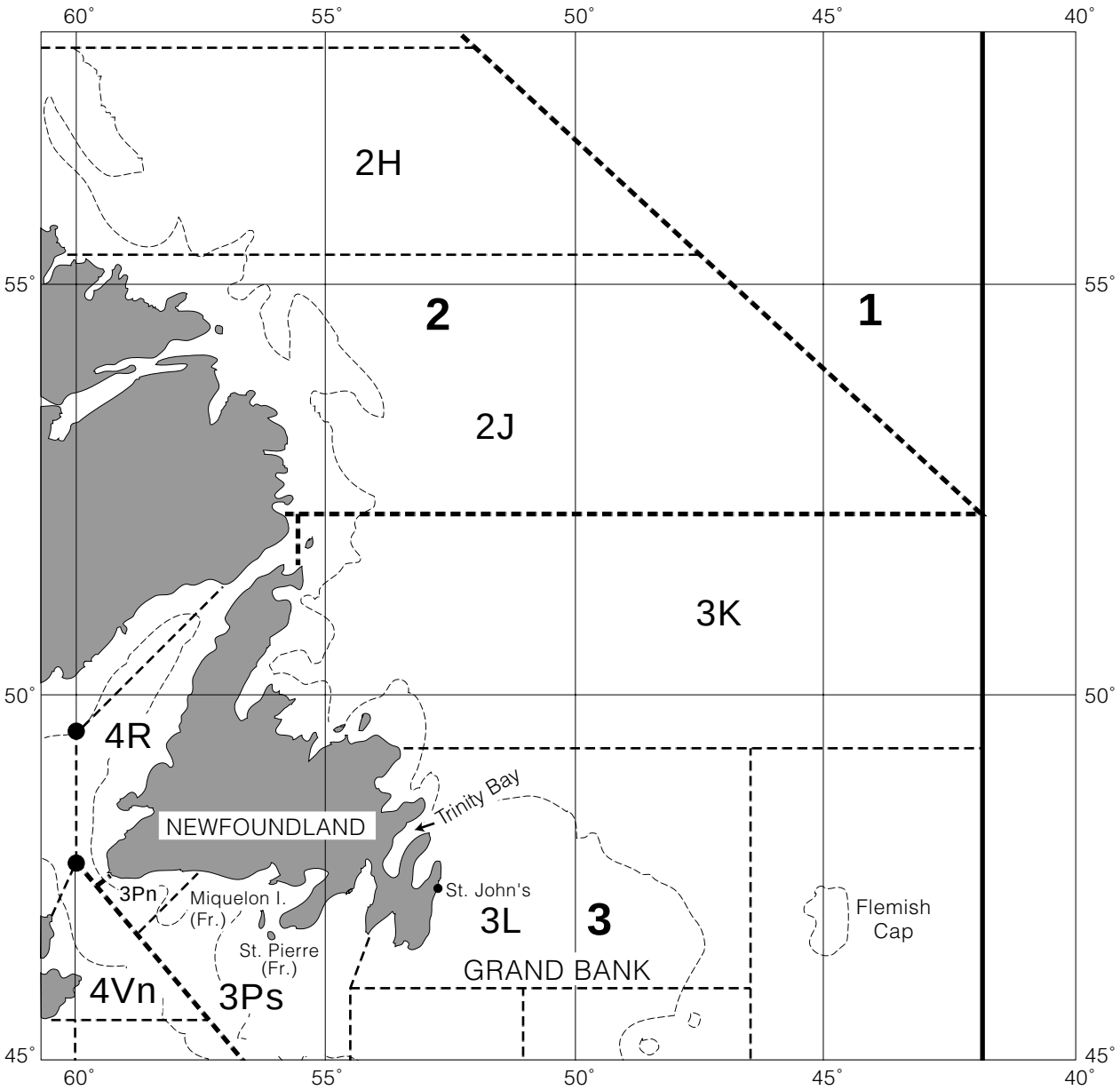

Fig. 1. Map showing area of study mentioned in the text.

proportion mature-at-age and -length was examined using a generalized linear model with a binomial error distribution and a logit link function, to determine if the addition of an area term significantly decreased the deviance of the model (McCullagh and Nelder, 1983; SAS Institute Inc.,1993).

Results and Discussion

The annual observed proportion mature at each age in each Division from 1982 to 1996 is shown in Tables 1 to 3. Each Division shows an increase in observed proportion mature-at-age for younger ages in recent years, particularly ages 5 and 6 years. In the early portion of the time series, less than 10% of the fish at age 5 were mature. In most recent years, 40 to 85% of age 5 fish were mature. The proportion mature at age 6 had increased from 30 to 50% in the first years of the time series to nearly 100% in recent years.

For the stock as a whole, estimated proportion mature-at-age also showed an increase over the time period (Table 4, Fig. 2). This increase was par-

TABLE 1. Observed proportion mature-at-age for female cod on 1 January in NAFO Div. 2J. A dot indicates that no fish at that age in that year.

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
2	.	0	0	0	0	0	0	0	0	0	0	.	.	.	0
3	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0
4	0	0	0	0	0.03	0	0	0	0	0	0	0.02	0	0.14	0.01
5	0	0.03	0.06	0.07	0.03	0	0.11	0	0.09	0.3	0.25	0.33	0.82	0.73	0.74
6	0.3	0.5	0.49	0.71	0.49	0.52	0.49	0.52	0.58	0.52	0.64	0.75	1	1	0.95
7	0.83	0.88	0.85	0.96	0.93	0.9	1	0.9	1	0.95	1	1	1	1	1
8	0.91	1	0.9	1	1	1	0.9	0.96	1	1	0.93	1	1	1	.
9	0.99	1	1	1	1	1	1	1	1	1	1	.	.	.	.
10	1	1	1	0.98	1	1	1	1	1	1	1	.	.	.	.
11	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
12	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
13	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
14	1	1	1	1	.	1	1	1	.	1	.	.	.	.	.
15	1	1	1	.	.	1	1	1	.	.	.	.	.	.	.

TABLE 2. Observed proportion mature-at-age for female cod on 1 January in NAFO Div. 3K. A dot indicates that no fish at that age were sampled in that year.

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.
2	0	0	0	0	.	0	0	0	0	0	0	0	.	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0.02
5	0	0.02	0.06	0.08	0.06	0.06	0.17	0.12	0.12	0.15	0.36	0.53	0.57	0.43	0.49
6	0.61	0.36	0.55	0.7	0.56	0.53	0.48	0.75	0.74	0.54	0.77	0.92	1	1	0.82
7	0.96	0.98	0.85	0.93	0.97	0.95	0.76	0.9	0.85	0.88	0.97	0.93	1	1	.
8	1	0.96	1	1	1	1	1	1	1	0.94	1	1	1	1	.
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	.
10	1	1	1	1	1	1	1	1	1	1	1	1	.	.	.
11	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
12	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
13	1	1	1	1	1	1	1	1	1	1	1	.	.	.	.
14	1	1	.	1	1	1	1	.	1	.	1	.	.	.	.
15	1	1	1	1	1	.	1	1	1	.	.	.	.	.	.

TABLE 3. Observed proportion mature for female cod on 1 January in NAFO Div. 3L. Data for 1985 are not included as the autumn 1984 survey was several months early. A dot indicates that no fish of that age were sampled in that year.

Age	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	
1	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.
2	0	0	0	0	0	0	0	.	.	0	.	.	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0.02	0	0	0	0.02	0.05	0.11	0	
5	0.03	0.09	0.03	0.03	0	0	0.12	0.12	0.07	0.11	0.26	0.51	0.61	0.85	
6	0.43	0.55	0.4	0.29	0.16	0.17	0.73	0.65	0.31	0.23	0.83	0.87	1	0.84	
7	0.78	0.96	0.78	0.63	0.67	0.8	0.9	0.98	0.87	0.51	0.82	0.97	1	0.77	
8	1	1	0.91	1	0.75	1	1	0.93	1	0.95	1	1	.	1	
9	1	1	1	1	0.92	1	1	1	1	1	1	1	.	.	
10	1	1	1	1	1	1	1	1	1	1	1	.	.	.	
11	1	1	1	1	1	1	1	1	0.69	1	1	1	.	.	
12	1	1	1	1	1	1	1	1	1	1	1	.	.	.	
13	1	1	1	1	1	1	1	1	1	1	.	.	.	.	
14	1	1	1	1	1	1	1	1	1	1	.	.	.	.	
15	.	1	1	1	1	1	1	1	1	.	.	.	.	.	

TABLE 4. Estimated proportion mature-at-age for female cod in NAFO Div. 2J+3KL on 1 January. No estimate was produced for 1985 because of the timing of the autumn survey in Div. 3L in 1984. Age at 50% maturity (A_{50}) for the population is also given for each year. A dot indicates that no fish at that age was sampled in that year. n is the number of otoliths examined.

Age	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	0	0	0	.	.	.	.	0	.	.	.	.	.	0
2	0	0	0	0	0	0	0	0	0.001	0.003	0.001	.	0	0
3	0.001	0	0.001	0	0.001	0.001	0.002	0.001	0.006	0.013	0.007	0.006	0.002	0.001
4	0.005	0.004	0.009	0.004	0.007	0.008	0.016	0.011	0.03	0.059	0.053	0.073	0.051	0.046
5	0.051	0.052	0.075	0.049	0.066	0.07	0.123	0.118	0.13	0.24	0.292	0.494	0.612	0.625
6	0.35	0.45	0.428	0.381	0.401	0.409	0.551	0.615	0.423	0.611	0.753	0.924	0.979	0.983
7	0.844	0.924	0.873	0.88	0.864	0.864	0.915	0.95	0.782	0.887	0.958	0.993	0.999	1
8	0.982	0.995	0.984	0.989	0.984	0.983	0.989	0.996	0.946	0.975	0.994	0.999	1	1
9	0.998	1	0.998	0.999	0.998	0.998	0.999	1	0.989	0.995	0.999	1	1	.
10	1	1	1	1	1	1	1	1	0.998	0.999	1	.	.	.
11	1	1	1	1	1	1	1	1	1	1	1	1	.	.
12	1	1	1	1	1	1	1	1	1	1	1	.	.	.
13	1	1	1	1	1	1	1	1	1	1	.	.	.	.
14	1	1	1	1	1	1	1	1	1	1	.	.	.	.
15	1	1	1	1	1	1	1	1	1	.	.	.	.	.
A_{50}	6.27	6.07	6.13	6.2	6.18	6.16	5.91	5.81	6.19	5.72	5.44	5.01	4.86	4.86
n	1028	1354	1202	1260	1037	1146	1386	1422	1361	1045	697	489	139	561

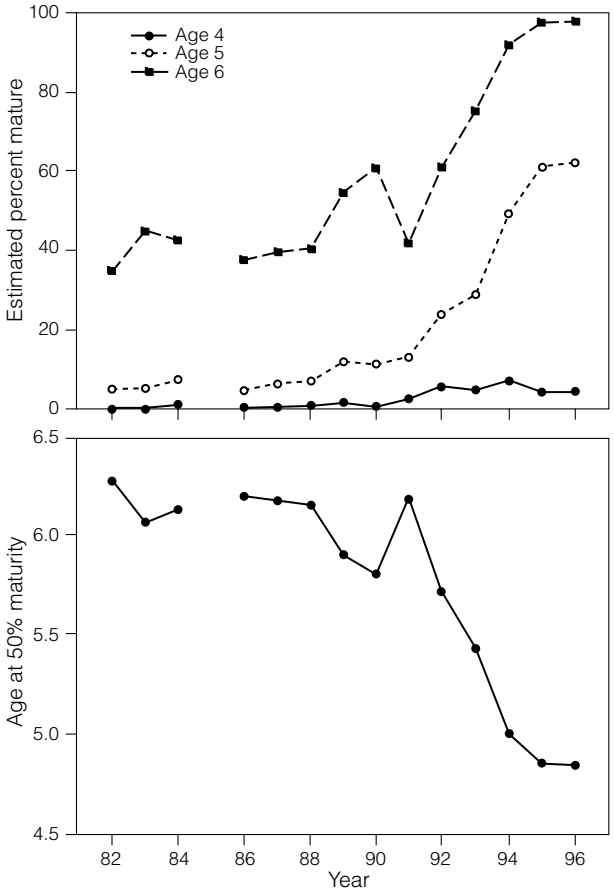

Fig. 2. Estimated proportion mature at ages 4, 5, and 6 for female cod in NAFO Div. 2J+3KL for 1 January 1982 to 1996 (top). Age at 50% maturity over the same time period is shown in the bottom panel.

ticularly evident since the early-1990s. As a result, the age at 50% maturity declined from over 6 years to less than 5 years.

The observed proportion mature-at-length and -age for western Trinity Bay and the surveyed area of Div. 3L are shown in Tables 5 and 6. Although it appears that proportion mature-at-length increased more steeply in the survey, the addition of an area term to the model did not significantly decrease the deviance over a model including the effect of length

TABLE 5. Proportion mature-at-length from Shamook 251 (inshore) and 1995 autumn survey in Div. 3L (offshore). Adjacent 3 cm length categories have been combined to increase sample size.

Length	Shamook	Survey
14.5	.	0
20.5	0	0
26.5	0	0
32.5	0	0
38.5	0.06	0
44.5	0.2	0.23
50.5	0.76	0.91
56.5	0.87	0.8
62.5	0.85	1
68.5	0.78	1
74.5	0.95	.
80.5	0.67	.
85	1	.
97	1	.
130	1	.

TABLE 6. Proportion mature-at-age from Shamook 250 (inshore) and 1995 autumn survey in Div. 3L (offshore). Ages are as of 1 January.

Age	Shamook	Survey
2	0	0
3	.	0
4	0.2	0
5	0.56	0.85
6	0.81	0.84
7	0.88	0.77
8	1	1
9	1	.

alone (Δ deviance for length term = 274.3 df =1 p = 0.0001; Δ deviance for area term = 2.4 df = 1 p = 0.119). The same result was seen for the proportion mature-at-age, where age had a significant effect on the proportion mature (Δ deviance =145.5 df =1 p = 0.0001) but the addition of an area term did not significantly decrease the deviance of the model (Δ deviance = 0.22 df =1 p = 0.637). These results do not indicate a difference in the maturity schedule in the two areas in the 1995/96 spawning season.

These estimates of proportion mature depend on an accurate classification of cod as juvenile or adult fish. In the southwest arm region of western Trinity Bay in April 1996, several large (>60 cm) fish were sampled which had gonads that appeared to be immature. An alternative explanation is that these fish were adults but were going to skip this spawning season. Non-spawning adult cod have been observed previously, and hypothesised to be fish that were not in good condition (Walsh *et al.*, 1986). It may be possible to distinguish such fish from juveniles by examining the otoliths for spawning checks and/or by histological examination of the gonad (Walsh *et al.*, 1986; Kjesbu, 1991).

Another important consideration with respect to the maturity categories used in the Newfoundland Region is the accurate determination of the location and timing of spawning. Cod are batch spawners and will not move sequentially through the maturity categories devised by Templeman *et al.* (1978). Rather, they will cycle between the stages labelled MatBP (up to 50% clear eggs) and MatAP (eggs visible to the naked eye but no clear eggs) as each batch is hydrated and released (Kjesbu, 1989; 1991; and Kjesbu, pers. comm., Inst. of Marine Research, Norway). MatCP (50% or more clear eggs) probably represents the formation of the last batch to be spawned for that fish in a season. It is unclear where the partly spent (PSP) category (ovary not as full as MatCP) fits in this cycle but the fish are definitely spawning. This means that all fish which have any clear eggs in the ovary are spawning, as well as some fish which appear to be in the MatAP stage. This MatAP stage must be verified by the careful examination of the oviduct and the inside of the ovary for the presence of a few clear eggs from a previous batch which would indicate spawning (Kjesbu, 1991). A 'spawning' category would include MatBP, MatCP, PSP and any MatAP with clear eggs and this 'spawning' category is what should be used to determine spawning time and location.

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