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Estimation of Reproductive Potential for Flemish Cap Cod

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Abstract

Traditional measures of spawning stock biomass (SSB) may not provide a good indication of the reproductive potential of a stock. In this paper we calculate alternative estimates of reproductive potential for Flemish Cap cod, successively incorporating annual estimates of proportion mature-at-age, estimates of sex ratio-at-age and of the proportion of females which failed to spawn at each age. While the different indices of reproductive potential produced some change in the stock recruit scatter, there was little difference in the relationship between ln recruitment and ln SSB. Indices reflecting the number of age classes in the SSB and the age diversity were calculated. Multiple regressions showed that including information on the number of age classes and diversity of spawners significantly improved the relationship with recruitment for each of the 3 estimates of SSB. This indicates that the presence of a more diverse age composition of spawners, including older fish, enhances the probability of good recruitment.

Key words: reproductive potential, age composition, age diversity, cod, recruitment

Introduction

The relationship between spawning stock biomass (SSB) and recruitment is an essential element in the understanding of the population dynamics of fish stocks. The stock-recruit relationship underlies the definition of reference points for the precautionary approach. However, for most marine fish stocks the stock-recruit relationship remains poorly defined with large variability around the predicted relationship.

In most stock-recruit relationships SSB is calculated as the sum of the biomass-at-age multiplied by maturity-at-age (often the female maturity-at-age). This assumes that a given SSB will produce the same number of recruits regardless of the characteristics of the fish comprising the spawning stock. There is growing evidence that not all SSBs are created equal. First time spawners may produce eggs of poorer quality than repeat spawners (Solemdal *et al.*, 1995; Kjesbu *et al.*, 1996; Trippel, 1998). Wigley (1999a) showed an improvement in the stock-recruit relationship for Georges Bank haddock (*Melanogrammus aeglefinus*) once first time spawners were removed. Fish in poor condition can have reduced fecundity and/or reproductive success or they can fail to spawn at all (Burton and Idler 1984;Kjesbu *et al.* 1991;Burton *et al.* 1997;Marshall *et al.* 1998;Marteinsdottir and Steinarsson 1998). The age composition of the SSB has also been found to be an important determinant of recruitment (Lambert 1990; Marteinsdottir and Thorarinsson 1998).

The Flemish Cap cod stock has been under moratoria since 1999. It's collapse has been attributed to three factors: overfishing, an increase in catchability and a sustained period of poor recruitment (Vázquez *et al.*, 1999). The most recent assessment indicated that the total biomass and SSB were at the lowest observed levels and that recruitment has been at or near historical lows since 1992 (Cerviño and Vázquez, MS 2004). Substantial changes in the structure of the spawning stock have been noted since 1978. While for the period 1978-1985 the maximum age recorded was 17-19, in the last 5 years it was 7-9. In addition a considerable reduction in age- and size-at-maturity has been reported during the first half of the last decade (Saborido-Rey and Junquera, 1998). There are also indications that skipped spawning has occurred, at least in some years (Walsh *et al*., MS 1986). Given these changes in population size and spawner characteristics it is likely that the reproductive potential of this stock has changed and that the usual measure of SSB may not adequately reflect this change.

In this paper we construct alternative indices of reproductive potential incorporating sex ratio and skipped spawning. In addition we examine the impact of the age diversity of the spawners on recruitment.

Methods

Data were available from Canadian (1978-1985) and EU-Spain (1988-2000). These data were used to estimate female proportion mature-at-age and proportion female-at-age, in each year. During the Canadian surveys there were indications of skip spawning (Walsh *et al.*, MS 1986). From the Canadian data the proportion of mature females that would spawn was also calculated. There was no indication of skip spawning during the period of the surveys conducted by EU-Spain. Because of the gap in the survey series, values for 1986 and 1987 were constructed by interpolation. Population numbers-at-age as well as weights-at-age were taken from Vázquez and Cerviño (MS 2001).

Three indices of spawning stock biomass (SSB) were calculated. The first (SSB) was the sum of the population biomass-at-age multiplied by the female proportion mature-at-age in each year. The second was an index of female SSB (FeSSB) and incorporated sex ratio. FeSSB was calculated as the sum of the population biomass-at-age multiplied by the estimated proportion females that were mature at each age in each year multiplied by the proportion female at age in each year. The third index (NoskipSSB) removed skip spawners during the 1978-1987 period. NoskipSSB was calculated as the sum of the population biomass-at-age multiplied by the estimated proportion females that were mature at each age in each year multiplied by the proportion female at age in each year multiplied by the proportion of adult females that would spawn at each age in each year.

For each index of SSB, the relationship with recruitment was explored. In each case recruitment was taken as the number of 1 year olds from the VPA. Regressions of Log_e recruitment against Log_e SSB were conducted to compare the strength of the relationship between SSB and recruitment for each case.

Two indices of age composition were constructed. The first was simply the number of ages in the SSB. This was derived from the number of ages in the survey for which there were estimates to be mature females. This index was the same for all measures of SSB. The second was an index of age diversity as calculated by Marteinsdottir and Thorarinsson (1998). This index (H, Hfe, Hnoskip for each of the three indices of SSB respectively) was calculated for each index of SSB.

To determine if age composition of the SSB was important to the level of recruitment, multiple linear regressions were conducted. All values in these regressions were logged before the regressions were run.

Results and Discussion

All three indices of SSB showed the same general trends over the time period but there were some differences between them (Fig. 1). For example there is a decline in FeSSB and NoskipSSB between 1994 and 1995, while SSB increased. The degree of difference between the first year of the series (1978) and the peak in 1989 is greater for NoskipSSB than for the other two indices. This index also decreases between 1984 and 1985 while the other two increase. There is no difference between FeSSB and NoskipSSB after 1987. This is because skip spawners were not removed after that year as there was no indication of this phenomenon during the EU Spain surveys.

Stock recruit scatters were very similar among the three indices of SSB (Fig. 2). The best fit of the linear regression was for SSB. The fact that the stock recruit scatters were similar is not surprising since the trends in indices of the spawning stock were quite similar.

The number of year-classes comprising the spawning stock has shown quite a steady decline over the years and has decreased from 14-17 down to about 7 (Fig. 3). The age diversity of the spawning stock was very similar for the three indices (Fig. 4). In all cases diversity was lower at the beginning and end of the time series.

Multiple regressions indicated that the age composition of the spawning stock had a significant impact on recruitment. In all cases, both the number of year-classes and the diversity index had a significant impact (Table 1). This indicates that the presence of a more diverse age composition of spawners, including older fish, enhances the probability of good recruitment. Predicted recruitment from multiple regressions for all three indices of spawning stock had a similar relationship with observed recruitment (Fig. 5).

While age diversity and number of year-classes were both significant in their effect on recruitment, their impact may not be the same at all spawning stock sizes. For example in the early part of the time series age diversity was low, while number of age classes and spawning stock size were high. However recruitment during this period was poor. In the most recent part of the time series the number of age classes, age diversity, spawning stock size and recruitment were all low. Other studies have found the impact of age diversity to vary with spawning stock size or environmental conditions (Marteinsdottir and Thorarinsson, 1988; Cardinale and Arrhenius, 2000). This aspect needs to be explored further.

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Table 1. Results of multiple linear regressions for 3 indices of spawning stock size: SSB, FeSSB, and NoskipSSB. Included in the multiple regressions are indices of age diversity (LnH, LnHfe, LnHnoskip) and number of year-classes in the SSB (Lnnyrclass).

Parameter	Estimate	Model r-square	P value
SSB			
Intercept	-7.32		0.05
LnSSB	1.53	0.53	0.001
LnH	3.66	0.64	0.007
Lnnyrclass	2.02	0.72	0.03
FeSSB			
Intercept	-6.42		0.08
LnFeSSB	1.45	0.43	0.004
LnHfe	4.31	0.57	0.003
Lnnyrclass	2.58	0.70	0.01
NoskipSSB			
Intercept	-7.37		0.06
LnNoskipSSB	1.44	0.38	0.004
LnHnoskip	4.08	0.51	0.004
Lnnyrclass	3.10	0.69	0.002

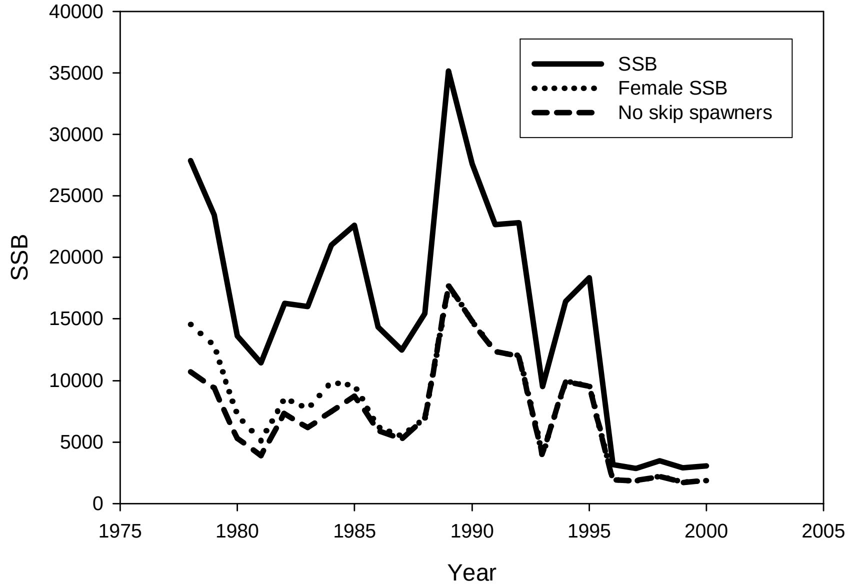

Fig. 1. Indices of spawning stock size produced for Flemish Cap cod.

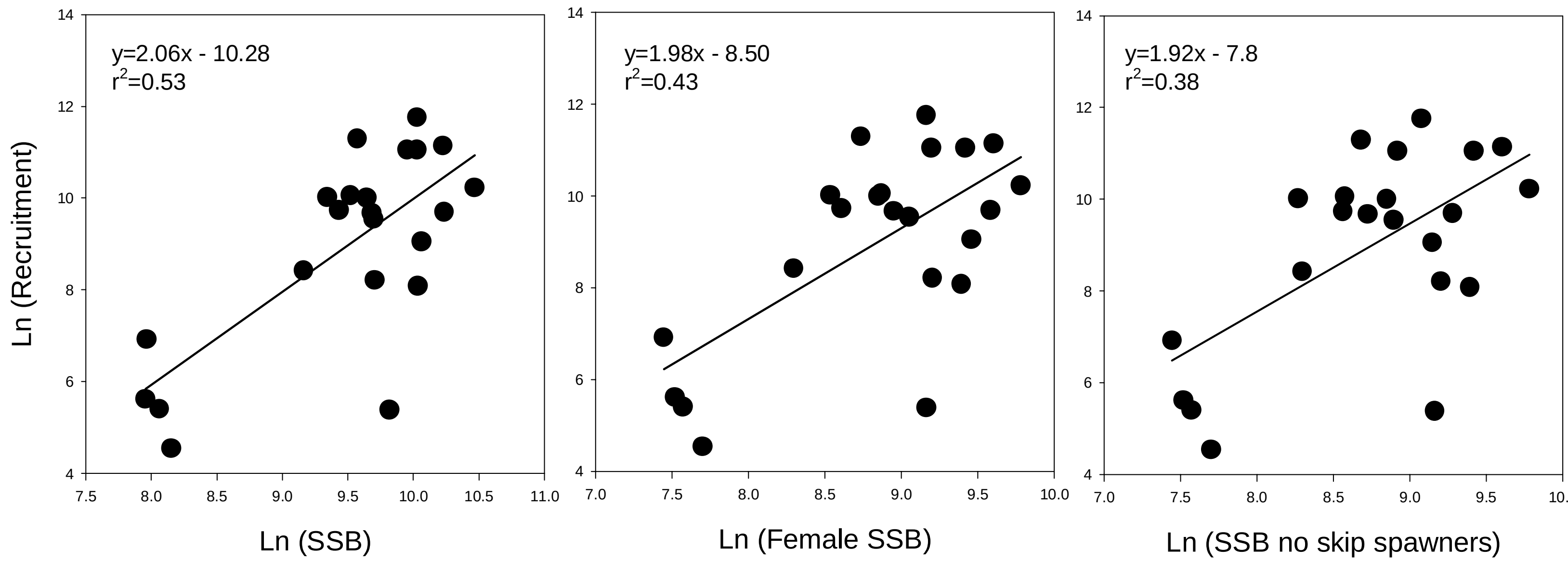

Fig. 2. Stock recruit scatters for each index of spawning stock size. The lines are the predicted recruitment from linear regressions of Log_e recruitment against Log_e index of spawning stock size. The regression equation and r^2 are also given.

Fig. 3. Number of year-classes comprising the SSB in each year.

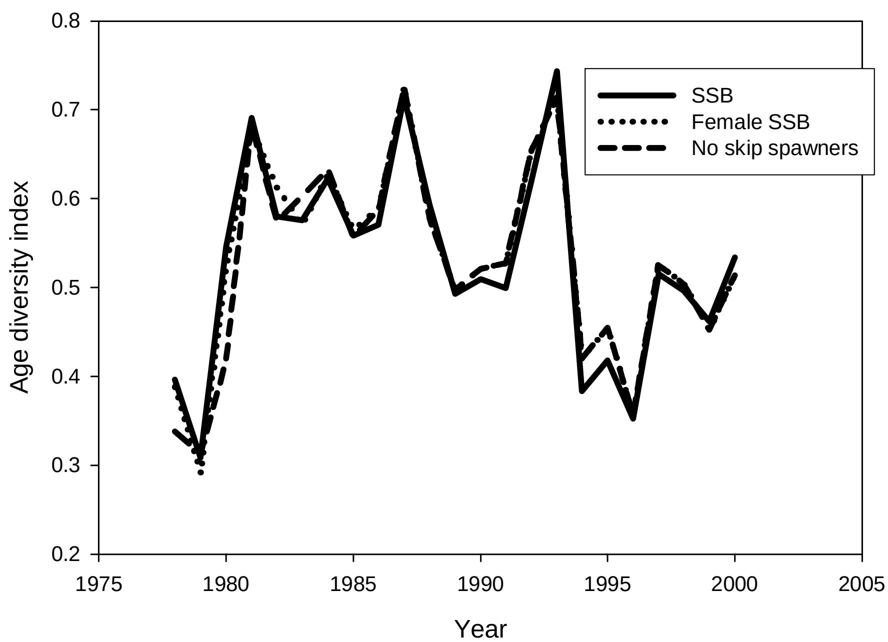

Fig. 4. Index of age diversity calculated for each index of spawning stock size in each year.

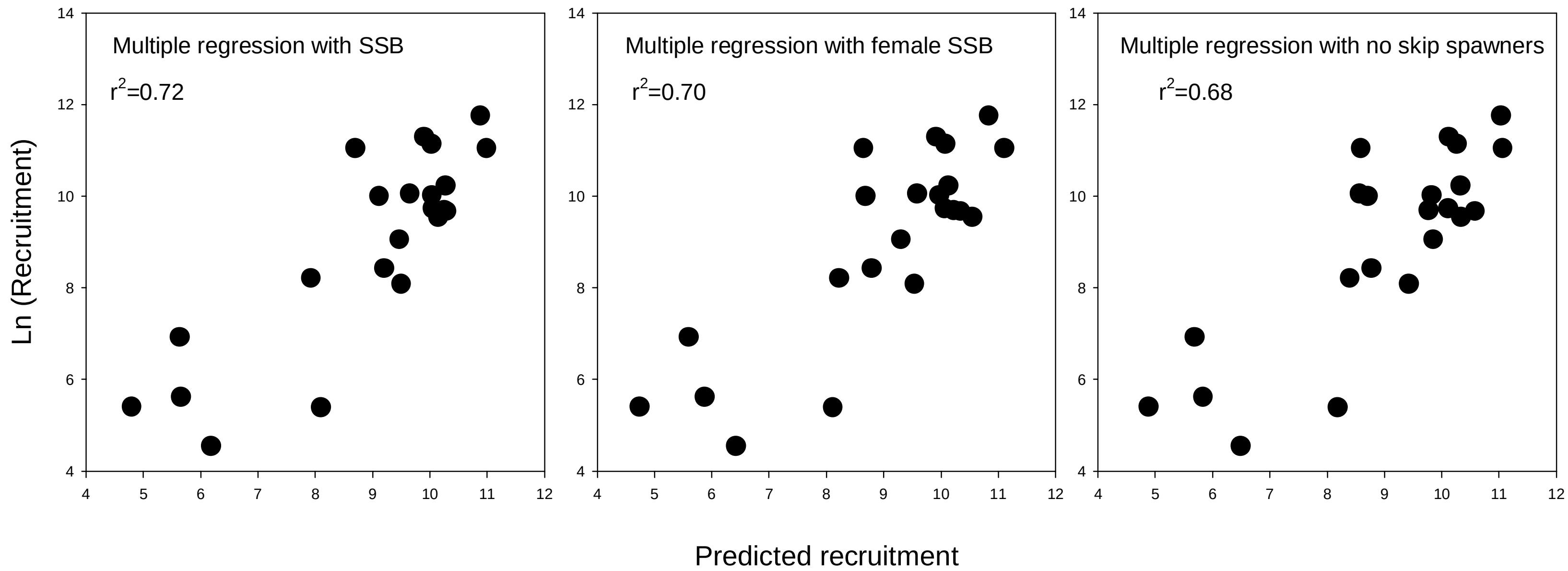

Fig. 5. Log_e recruitment against predicted recruitment from multiple linear regressions for each index of spawning stock size. In each case the multiple regression included the index of spawning stock size, number of year-classes in SSB and the age diversity index. The r^2 are from Pearson correlations.