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Is there any evidence of a stock recruit relationship for Greenland halibut in Subarea 2 + Div. 3KLMNO?

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Abstract

There has been no stock-recruit relationship accepted for Subarea 2+3KLMNO Greenland halibut in past stock assessments. There has been considerable uncertainty about the reproductive biology of the species and in the past the data did not indicate a relationship between the biomass of older fish and recruitment. We re-examine this relationship using data from the last 7 assessments of the stock as well as retrospective analyses of the most recent assessment. We show that there is clearly a relationship between older biomass and recruitment for this stock with implications for recruitment overfishing.

Key words: recruitment, spawning stock biomass, stock-recruit models, Greenland halibut.

Introduction

In the Subarea 2+3KLMNO assessment of Greenland halibut, a stock recruit relationship has not been determined (Healey and Mahé, MS 2006). This is partly related to uncertainty about the reproduction of Greenland halibut. Studies on the maturation and spawning of Greenland halibut have revealed a great deal of variability. The proportion of adult fish at size and age has been found to exhibit a high degree of geographic and temporal variation (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 also appears to be common (Fedorov, 1971; JØrgensen and Boje, MS 1994; Morgan and Bowering, 1997; Skryabin and Smirnov, MS 2008). Greenland halibut may have annual peak and secondary spawning periods 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).

In addition to uncertainties about reproduction in Greenland halibut, concern has been expressed that the XSA does not provide an adequate estimation of older fish in the population despite the use of an age 14+ group, such that SSB calculated from the XSA would not be reflective of the reproductive potential of the population. If this is the case then any stock-recruit relationship that exists may be expected to be obscured.

In 2001, Morgan and Bowering (MS 2001) suggested that it might be advisable to use a single year-invariant maturity ogive, calculated for the entire area, to construct SSB for this stock. This was because of variability of the estimates from the Div. 2J3K area, particularly since the late 1980s, the similarity between estimates from the entire Subarea 2 + Div. 3KLMNO area and those from the Div. 2J3K area, and the lack of any trend in maturity at age or size indicated by the Div 2J3K time series. This single maturity ogive was used in conjunction with the 2003 assessment results to examine S/R at the NAFO Limit Reference Point Study Group (Anon. MS 2004). The result was consistent with the lack of any clear S/R relationship (Fig. 1).

Since that time Morgan and Rideout (MS 2007) re-examined the maturity estimates. They found that for both males and females there is an indication of maturation at a smaller size and younger age for more recent cohorts (Fig. 2). The effect of cohort was significant in all cases. They also examined some of the uncertainties surrounding the maturity estimates for this stock. They compared maturity estimates for females from survey data with those derived from commercial data which have a higher proportion of older fish. They showed that the estimates were very similar from the two data sources for most of the cohorts that could be compared. These results indicate that the old age at maturity estimated from the survey data is not an artifact of very few old fish in the sample. Ageing error has also been suggested as a cause of the large age at maturity. If there is a large ageing error then estimates of maturity at length for fish that are first assigned to a cohort using their age and year should vary substantially from estimates of maturity at length that are simply assigned to a year (i.e. age is not considered). 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. Morgan and Rideout (MS 2007) also found that there may be some retrospective pattern in estimates of maturity by cohort and it may be prudent not to use estimates for cohorts that have not reached 13 years of age, after which the estimation bias is considerably reduced.

A further factor which may obscure any stock-recruit relationship is the treatment of the plus group in the assessment model. XSA calculates the plus group in a given year using the catch in the plus group for that year and the F on the last true age. This method has been called into question, particularly for stocks with a large portion of the population in the plus group (Quinn and Deriso, 1999; Laurec et al., MS 2003).

This paper re-examines the issue of whether or not there is a stock-recruit relationship in SA 2 + Div. 3KLMNO Greenland halibut using the updated maturity estimates and results from assessments dating back to 2001 and retrospective analyses from the 2006 assessment. It also examines the data from the 2007 assessment for evidence of a S/R relationship using different plus group assumptions.

Methods

Plots of recruitment against 10+ biomass were produced for each assessment from 2001 to 2006 (Mahé and Bowering, MS 2001, MS 2002; Darby et al., MS 2003; Darby et al., MS 2004; Healey and Mahé, MS 2005, MS 2006).

The 2002 XSA was not accepted as a basis for projections and there were large changes in model/input formulation introduced in the 2003 assessment (Darby et al., MS 2003, Miller and Shelton, MS 2007). In the 2003 assessment, the Canadian survey series was used as mean numbers per tow rather than abundance, the catch at age data for 2001 were revised, the Canadian spring survey data were included as an index and all indices were shortened to begin in 1995 (1996 for the spring survey). Retrospective results from the 2006 assessment were used to produce plots of recruitment against 10+ biomass using the same model and input formulation for 2001 to 2006 (same formulation also used in 2007).

Maturity-at-age was estimated by cohort using Canadian autumn RV data in Div. 2J3K from 1978 to 2007. The estimation was done using a generalized linear model with a logit link function (Morgan and Rideout, MS 2007). The estimated proportion mature-at-age was applied to the biomass-at-age to produce SSB. A weighted average of the proportions mature from ages 14 to 17 was used for the plus group where the weighting was the commercial catch-at-age from 14 to 17. Only cohorts with a significant model fit to the data and that had reached 13 years of age or more were used in the estimation of SSB. Since the surveys are conducted in the fall and the main spawning is likely the next winter or spring, 1 was added to age and year when applying the maturities to estimate SSB. For cohorts that could not be estimated, the average of the 3 nearest cohorts was used.

Preliminary analyses indicated that a Ricker stock recruit curve might be appropriate for this stock. Therefore, Ricker models were fit for each year for the estimates of SSB using maximum likelihood estimation. The models were fit in R using FLSR, part of the FLR package.

For the Ricker $R = \alpha SSBe^{-\beta SSB}$. The residual sums of squares and akaike information criteria (AIC) were calculated to aid in comparing model fit.

Scatters of recruitment against 10+ biomass and SSB were examined for data from the 2007 assessment (Healey and Mahé, MS 2007) with 3 different methods for handling the plus group. Segmented regression, Beverton-Holt and Ricker stock recruit models were fit to SSB and 10+ biomass produced from each method of calculating the plus group. For the Beverton-Holt *R=(α*SSB/(β+SSB))* and for the segmented regression *R=α*SSB if SSB <β and α*β if SSB ≥β.*

The 3 methods of calculating the plus group were the method used in XSA where the plus group is based on the plus group catch and the *F* from the previous age:

$$N_{14+,y} = \left(\frac{C_{14+,y}}{1 - e^{-(M + F_{13,y})}} \right) \left(\frac{F_{13,y} + M}{F_{13,y}} \right)$$

A 'dynamic pool' method where the plus group is based on F on the last true age as well as F on the plus group in the previous year:

$$N_{14+,y} = N_{13,y-1}.e^{-(M + F_{13,y-1})} + N_{14+,y-1}.e^{-(M + F_{14+,y-1})}$$

A version of the dynamic pool, not relying on any assumption about *F*, but instead removing the catch number for the previous year's plus group (assuming catch occurs halfway through the year – Pope's approximation). i.e.:

$$N_{14+,y} = N_{13,y-1}.e^{-(M + F_{13,y-1})} + \left(N_{14+,y-1}.e^{-\left(\frac{M}{2}\right)} - C_{14+,y-1} \right).e^{-\left(\frac{M}{2}\right)}$$

Results and discussion

There is little indication of a S/R relationship in the 2001 and 2002 assessments (Fig. 3). Starting in 2003, a relationship between recruitment and 10+ biomass begins to appear, and is present in the data from that year forward. The relationship appears to be Ricker in shape, with recruitment first increasing with increasing10+ biomass and then declining at larger biomasses. The fit of the Ricker model to the data becomes much better in 2004 and does not change much between 2004 and 2006 as shown in the plots and indicated by the reduced sums of squares and AIC.

In 2003 a number of changes to the inputs were introduced as pointed out above. There have been some changes since then but they have been relatively minor compared to the revision to the model accepted in 2003. This means that the appearance of the S/R relationship in 2003 could be a result of the changes in the assessment data and formulation. If a retrospective analyses using the same formulation and inputs throughout (but sequentially removing one years data) shows a S/R relationship in each year from 2001 to 2006 then this indicates that the appearance of the S/R relationship in 2003 is the result of the improved assessment formulation used in that year. In the retrospective analyses, there is a clear relationship between recruitment and 10+ biomass in all cases, not just starting in 2003 (Fig. 4). Again the shape is similar to a Ricker curve and fit of the Ricker model to the data becomes much better in 2004 and does not change much between 2004 and 2006.

The S/R relationship is also clearly evident from the beginning of the time series examined (2001) when SSB is the index of reproductive potential used rather than 10+ biomass (Fig. 5). Although model fit is better using SSB for the first 3 years of the time series it is better using 10+ biomass for the last three years, although differences are not marked. The shape of the curve again resembles a Ricker model.

Despite a retrospective issue with the estimates of recruitment (Healey and Mahé, MS 2007) the addition of more data over time does not substantially change the estimates of recruitment derived from Ricker models fit to10+ biomass obtained in 2007 (Fig. 6, Table 1).

Different methods of calculating numbers at age in the plus group result in different relationships between stock and recruits based on population estimates from the 2007 assessment (Fig. 7). However, in most cases there still appears to be a relationship evident except for SSB produced when the plus group does not take F into account (Pope's approximation). In all cases model fit seemed to be better for the Ricker stock/recruit model than for the Beverton-Holt and Segmented regression models (Table 2, Fig. 8).

The above analysis supports the conclusion that there appears to be a relationship between biomass of older fish and recruitment. Although not all of the older fish might be represented in the XSA, it seems that at least a proxy for reproductive potential can be produced from the annual stock assessments that has a significant relationship with recruitment. The shape of that relationship resembles a Ricker curve. Such a S/R relationship can be caused by increasing cannibalism rates with increasing stock size (Ricker 1954). There is some evidence of this for Greenland halibut, with a large increase in the consumption of smaller Greenland halibut by fish above 70-75 cm. Studies have shown that Greenland halibut were one of the most important food items in the diet of Greenland halibut, although less important than capelin in Div. 2J3KL and less important than shrimp in Davis Strait (Bowering and Lilly, 1992; Orr and Bowering, 1997). For SSB, recruitment data are more scattered at higher levels of biomass than they are for10+ biomass. This results in a less steep descending limb at high stock size and contributes to a better model fit for10+ biomass (at least as measured by residual sums of squares). However, 10+ biomass as an index of reproductive potential will not respond to changes in maturity at age that may continue into the future.

Given the current heavy fishing pressure on this stock, it is important in the context of the Precautionary Approach to determine at what point recruitment overfishing is taking place and to develop a corresponding spawner biomass limit reference point (LRP) based on an index of reproductive potential. Only management strategies that keep a stock above the spawner biomass LRP with high probability and result in rapid rebuilding to the "Safe Zone" for a stock that has been previously depleted, can be considered to be sustainable and consistent with the NAFO PA framework and the requirements under the 1995 UN Fish Stocks Agreement. The application of Management Strategy Evaluation (MSE) to Greenland halibut (Miller et al. MS 2008) requires the identification of performance measures and risk tolerances. Measures related to recruitment overfishing, i.e. the risk of a management strategy resulting in a stock falling below the spawner biomass limit reference point, is a potentially important statistic.

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Table 1. Parameter estimates for the fits of the Ricker model (R=alpha*SSB*exp(-Beta*SSB)) to the recruitment and SSB from the retrospective analyses of the 2006 assessment. Estimates from the 2007 assessment are also given.

Year	alpha	beta	max recruitment estimated
2007	11.46246	3.201786e-05	131614
2006	11.40035	3.265301e-05	128443
2005	12.53609	3.531078e-05	130197
2004	11.83362	3.423834e-05	126780
2003	10.05401	3.106123e-05	119499
2002	11.01349	3.246543e-05	124616
2001	10.77405	3.118046e-05	127265

Table 2. Residual sums of squares from model fits for three different stock recruit curves (segmented regression (segreg), beverton-holt (bevholt), ricker (ricker)) fit to SSB or 10+ biomass with 3 different methods to calculate the numbers in the plus group (see text for equations).

	REGULAR XSA			DYNAMIC POOL			POPES		
	segreg	bevholt	ricker	segreg	bevholt	ricker	segreg	bevholt	ricker
SSB	2.74	2.96	2.34	2.13	2.87	2.03	3.33	4.33	3.85
10+	1.68	2.61	1.25	1.79	2.91	1.40	2.42	3.46	2.14

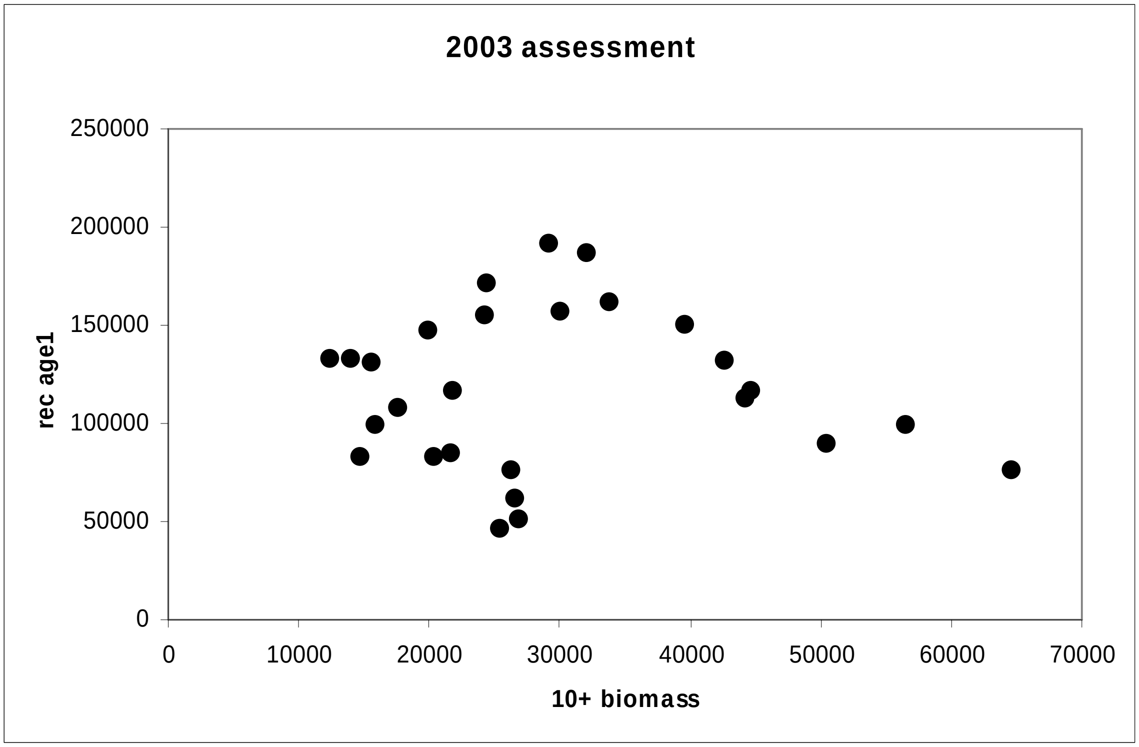

Figure 1. Numbers at age 1 (‘000) of Greenland halibut in SA2+3KLMNO against spawning stock biomass (‘000 t) based on data from the 2003 stock assessment. These data were reviewed in the context of the Precautionary Approach by the NAFO Study Group on Limit Reference Points held in Lorient in 2004. SSB is from population numbers at age, weights at age and a constant maturity ogive at age.

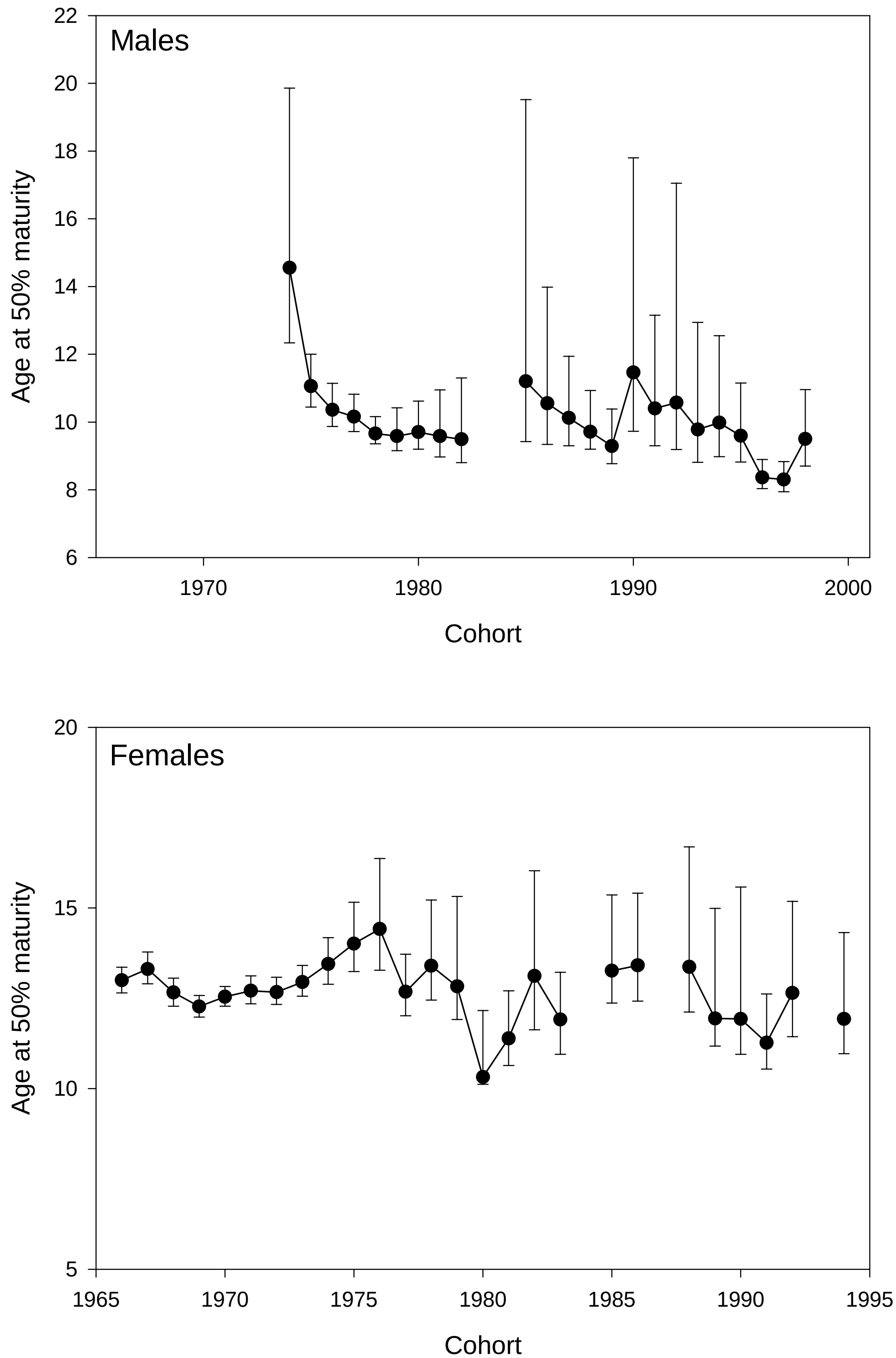

Figure 2. Age at 50% maturity (± 95% fiducial limits) for male and female Greenland halibut in Divs. 2J3K by cohort. Data are from Canadian autumn surveys. (Morgan and Rideout MS 2007)

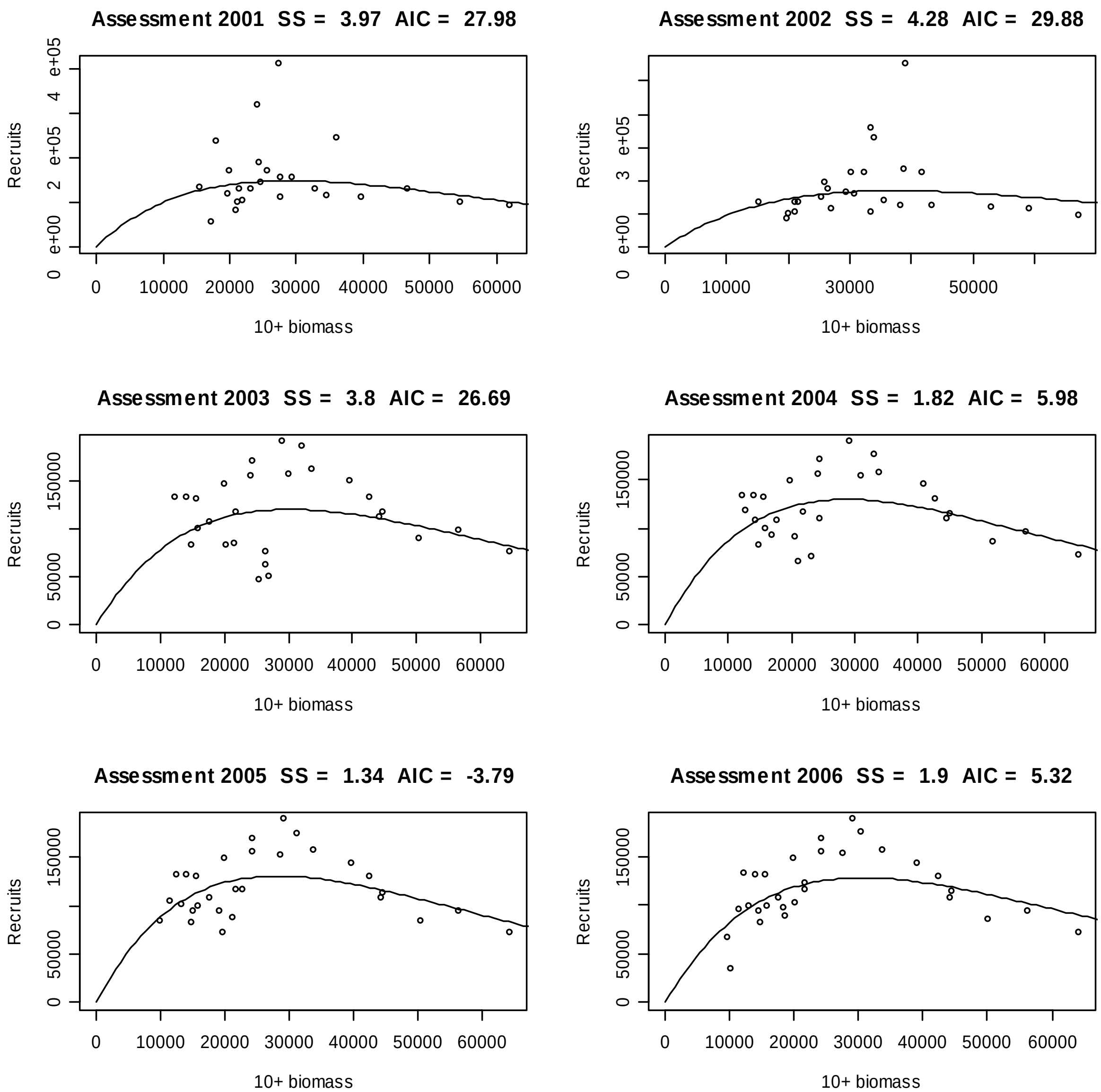

Figure 3. Numbers at age 1 ('000) of Greenland halibut in SA2+3KLMNO against 10+ biomass (tons). Results are from the last 6 assessments of the stock. The lines are the predicted recruitment from a Ricker model fit to the data. SS is the residual sums of squares for the model fits, AIC is the Akaike information criterion.

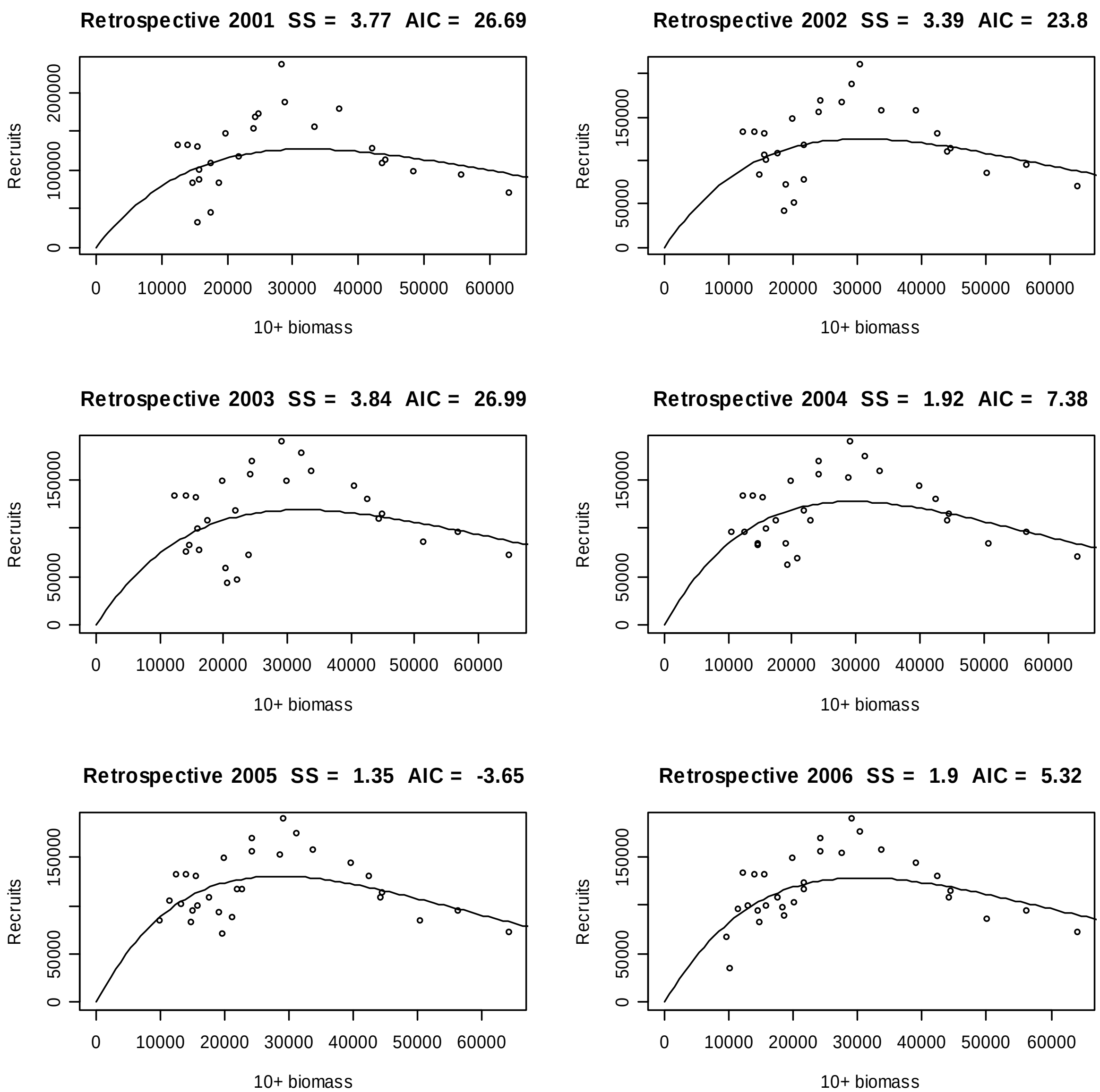

Figure 4. Numbers at age 1 ('000) of Greenland halibut in SA2+3KLMNO against 10+ biomass (tons). Results are from 6 years of retrospective analyses from the 2006 assessment of the stock. The lines are the predicted recruitment from a Ricker model fit to the data. SS is the residual sums of squares for the model fits, AIC is the Akaike information criterion.

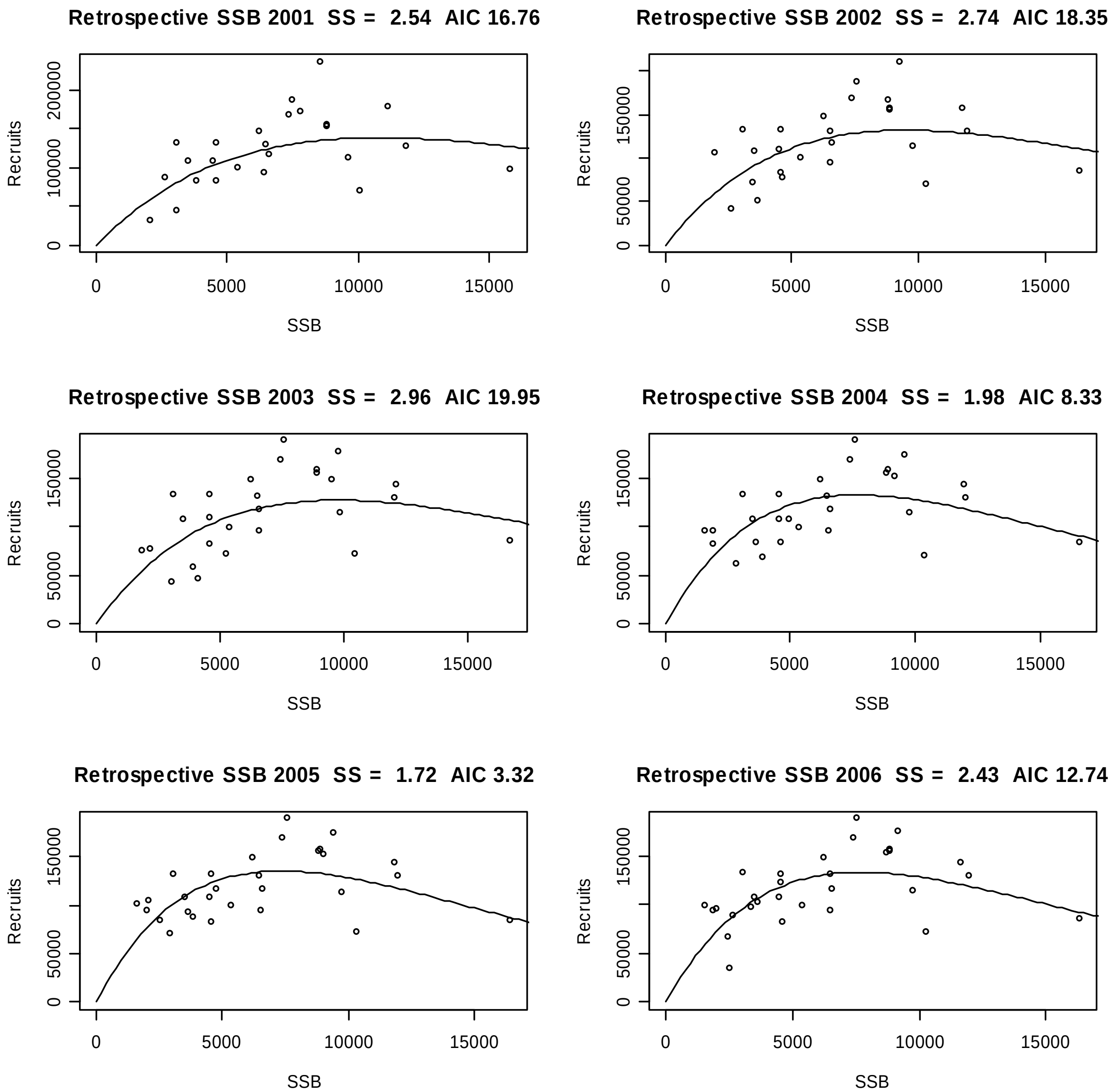

Figure 5. Numbers at age 1 (‘000) of Greenland halibut in SA2+3KLMNO against spawning stock biomass (tons). Results are from 6 years of retrospective analyses from the 2006 assessment of the stock. The lines are the predicted recruitment from a Ricker model fit to the data. SS is the residual sums of squares for the model fits.

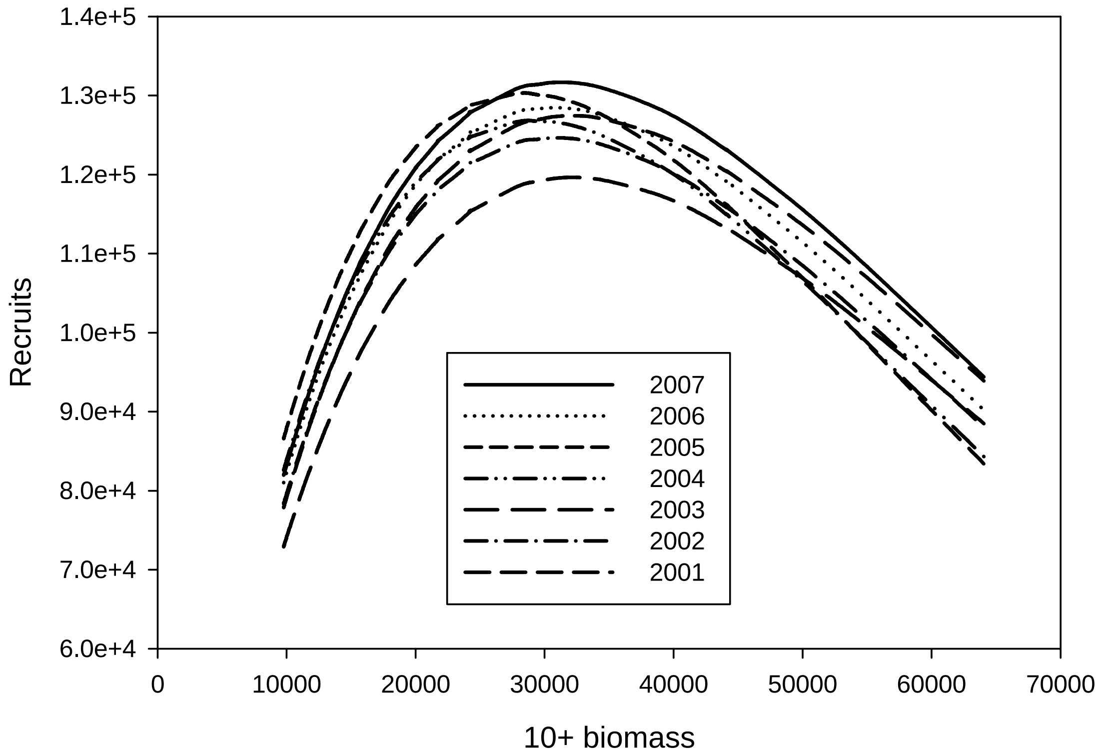

Figure 6, Estimated recruitment from Ricker model fit to retrospective analyses from the 2007 assessment.

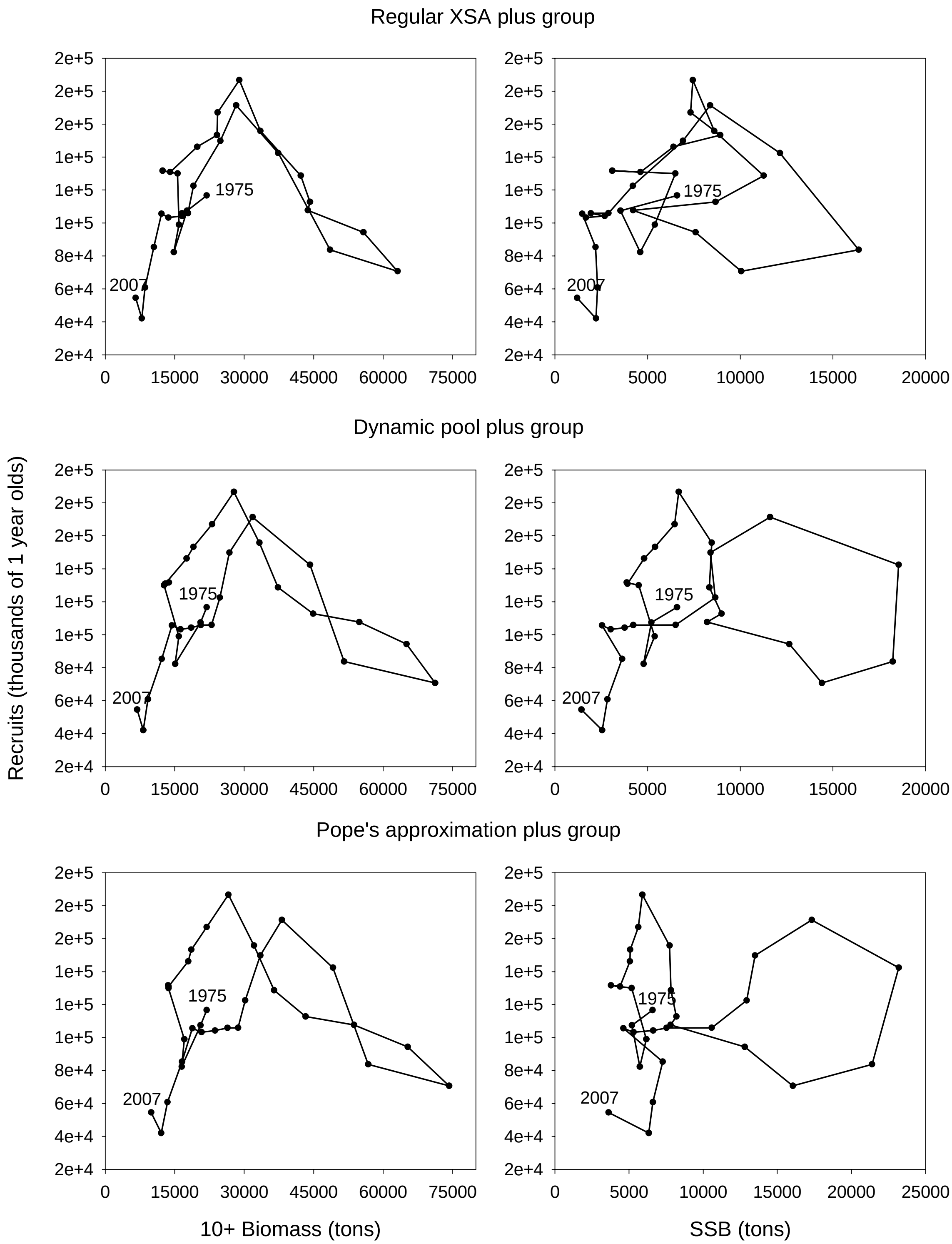

Figure 7. Scatters of recruitment (thousands of 1 year olds) against 10+ biomass (tons) and SSB (tons) for 3 different methods of calculating numbers in the plus group based on population estimates from the 2007 assessment.

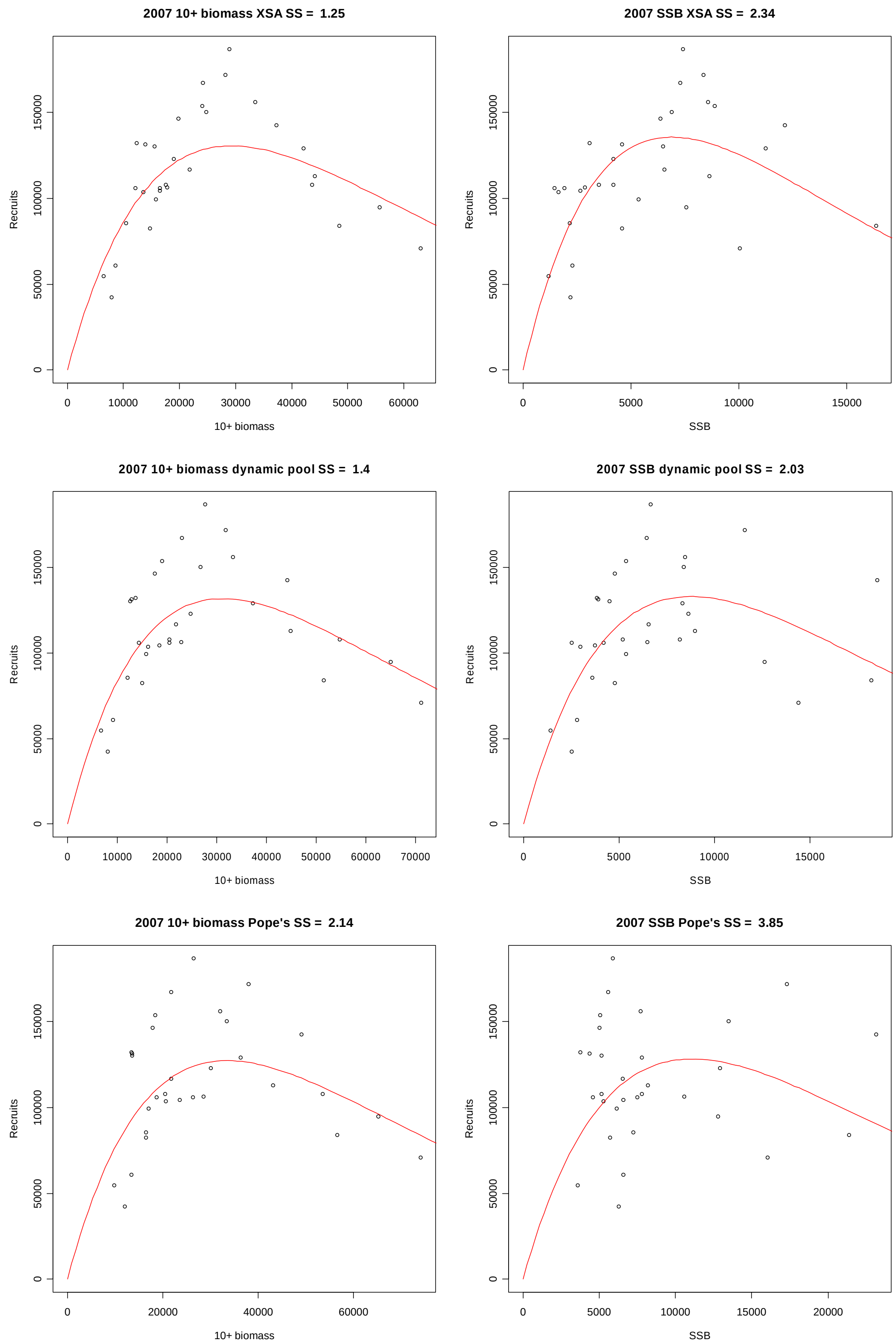

Figure 8. Ricker curves fit to stock recruit data for 10+ biomass or SSB produced from 3 different methods for calculating the numbers in the plus group based on population estimates from the 2007 assessment.