Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2019/052

Newfoundland and Labrador Region

Changes in Productivity of Northern Cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL

M. Joanne Morgan

Science Branch
Department of Fisheries and Oceans
PO Box 5667
St. John’s, NL A1C 5X1

October 2019

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Morgan, M.J. 2019. Changes in Productivity of Northern Cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/052. vi + 12 p.

Aussi disponible en français :

Morgan, M.J. 2019. Évolution de la productivité du stock de morues du Nord (Gadus morhua) dans les divisions 2J3KL de l'OPANO. Secr. can. de consult. sci. du MPO. Doc. de rech. 2019/052. vi + 13 p.

TABLE OF CONTENTS

ABSTRACT

An extended period of low productivity could be a signal that a population may not return to productivity conditions that would allow it to grow to historic levels used to set a biomass limit reference point. Length at age, weight at age, condition, spawner per recruit, recruits per spawner, potential population growth rate and surplus production were all examined for evidence that Div. 2J3KL cod has been in an extended period of low productivity. All metrics of productivity showed variation over the time series. Short periods of low (and high) productivity are evident, particularly a low productivity period from the mid 1980s to mid 1990s, including 4 consecutive years with the lowest productivity in the time series. Since the mid 1990s there have been years of both high and low productivity. Overall, there is no evidence that Div. 2J3KL cod is experiencing a prolonged period of low productivity that would indicate that historic levels of biomass cannot be reached in the future under environmental conditions similar to the past.

INTRODUCTION

The productivity of a fish population is the capacity of that population to produce biomass, and is a result of increases due to growth and reproduction, countered by declines due to mortality. The productivity of a fish population determines the level of fishing that can be sustained without a decline in population size. Major components of productivity are recruitment, weight at age, maturity at age and mortality. These components vary over time and therefore, so too does the overall productivity of the population.

The variation in population productivity can have implications for both fishing mortality and biomass limit reference points (B_{lim}). It is clear that variation in productivity affects the level of fishing mortality that a population can sustain (Morgan et al 2014a,b). The implications for biomass limit reference points are less clear. Short term variation in productivity likely has little or no implication for B_{lim}. However, if a population enters an extended period of low productivity from which it may not return to average conditions, then this could mean that historic high biomass levels cannot be reached in the future.

The objective of this study was to examine variation in some of the components of productivity, as well as potential population growth rate, in Div. 2J3KL cod. Specifically the objective was to determine if the population is in an extended period of low productivity.

METHODS

Changes in length at age, weight at age and condition were examined using research vessel data. Length at age and weight at age were calculated for Div. 2J3KL combined, correcting for length stratified sampling. The time series was examined for any patterns. In addition, annual variation in mean weight at age and length at age was examined over ages 3-7 by analyzing deviation from the average as a proportion over the time series for each age. The average mean weight at age or length at age over the time series (1981 to 2015 for length and 1981-2017 for weight) was calculated for each age. Deviation was calculated for each age in each year by subtracting the mean for the age for the time series from the annual observation for that age and then dividing this by the mean for that age.

Relative condition (relative K) was calculated by first fitting a length vs. gutted weight regression for Div. 2K3KL combined. The condition index is then observed condition divided by the condition predicted from the length weight regression for a fish of that length. Relative liver condition (relative LK) was calculated in a similar fashion using a liver weight length regression. Relative K and relative LK for each year were estimated using a generalized linear model with an identity link and a gamma error, with year as a class variable.

Inputs and results from the 2018 assessment of 2J3KL cod were used (Dwyer et al. unpublished report [1]) and from the model extended to 1962 (base xteNCAM (Extension of the Northern Cod Assessment Model) run, Regular unpublished report [2]) in a number of computations to examine changes in population productivity following the methods of Morgan et al (2016).

---

[1] Dwyer, K.S., Brattey, J., Cadigan, N., Healey, B.P., Ings, D.W., Lee, E.M., Mello, L., Morgan, M.J., Regular, P., Rideout, R.M., Rogers, R., and L. Wheeland. 2018. Assessment of the Northern Cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL in 2018. DFO Unpublished Report.

[2] Regular, P.M. 2019. Extension of the Northern Cod (Gadus morhua) State-Space Integrated Assessment Model back to 1962.DFO Unpublished Report.

Annual values of recruits per spawner (*RPS)* were calculated and plotted over time where:

$$RPS_y = \frac{N_{1,Y+1}}{SSB_y}$$

Annual values of spawner per recruit were computed as follows:

$$SPR_y = \sum_{a=1}^{14} N_a e^{-M_{a-1,y}}\ x\ W_{ay}\ x\ P_{ay}$$

where N_a is the number at age starting at 1 fish at age 1, M_{ay} is natural mortality as estimated by the assessment model at age a in year y, W_{ay} is the weight at age a in year y, P_{ay} is the estimated proportion mature at age a in year y. SPR*y* reflects the potential SSB (spawining stock biomass) (kg) produced by one recruit on average over its lifespan in the absence of fishing. The assumption was made that this occurs in a single year rather than over the lifetime of a cohort. Consequently, it is assumed that weight, mortality and proportion mature at age for the year in which the fish is born pertain, rather than values for each subsequent year and age as the recruit ages. The advantage of this approach is that it avoids incomplete cohorts at the beginning and end of the time series and allows SPR to be aliased to a single year and recruitment. This reflects the conditions of the spawners that produce the recruits in that year.

To determine potential population (SSB) growth rate (*G*) I used a standard age-structured population model (Quinn and Deriso 1999) to simulate *G* in the absence of fishing once a stable age composition had been achieved. The age-structured simulation model was fully determined by the following equations:

$$N_{a+1,y+1} = N_{ay} + e^{-M_{ay}}$$

With

$$N_{1,y+1} = RPS_y\ x\ SSB_y$$

where N_{ay} is the number at age *a* in year *y*, RPS_y is the recruits per spawner in year y and M_{ay} is the natural mortality at age a in year y, estimated in the assessment model. The maximum potential SSB growth rate was simply calculated as

$$G = \frac{SSB_{y+1} - SSB_y}{SSB_y}$$

where F=0 and the stock is below the break point of the hockey stick s/r and has a stable age composition.

Basic surplus production was also calculated where:

$$P_y = SSB_{y+1} - SSB_y + C_y$$

P_y is surplus production in a year and C_y is catch as estimated by NCAM(Northern Cod Assessment Model). Surplus production rate was calculated as $\frac{P_y}{SSB_y}$.

RESULTS

Mean length at age for Div. 2J3KL cod decreased from the beginning of the time series in 1981 (Figures 1 and 2) to about 1985 or 1986. Mean length at age remained low until the mid-1990s after which it increased. Since the mid-2000s mean length at age has been similar to the levels seen at the beginning of the time series, except for a large decline in 2012. Mean length at age has been above the average of the time series in most years since 1997.

Mean weight at age declined from the beginning of the time series to the early 1990s, before starting to increase (Figures 3 and 4). It remained below average until about 1997. Mean weight at age has been above average and at levels similar to the beginning of the time series in most years from 1997 to 2014. However, there has been a steady decline since 2013, and in 2017 weight at age was well below average.

Relative gutted condition decreased from the beginning of the time series to about 1985 and was also low from 1990 to 1994 (Figure 5). Since then it has been at or above average in almost every year, although there was a steady decline from 2011-16, increasing to near average in 2017. Relative liver condition (Figure 5) declined for the first few years of the time series but has been at or above average in most years since. As with relative gutted condition, relative liver condition showed a steady decline from 2011-16, but was above average in 2017.

The amount of spawner biomass (Kg) per recruit (SPR) has fluctuated over the time series (Figure 6). Results from both models (NCAM starting in 1983 or 1962) were near zero from 1991-1994. Since 2004, SPR has generally been above average, although it was very low in 2009 and 2010. SPR was very high in 1980-82 in the model that extends back to 1962.

Recruits per spawner (RPS) increased to very high levels in the mid-1990s (Figure 7). It remained at these high levels until 2002, after which it declined to just below average. RPS for the most recent year classes are well below average, similar to the levels of the 1980s.

Using the results of the NCAM model starting in 1983, potential population growth rate varied from a low of -0.69 to a high of 0.44 (Figure 8). It was negative and at its lowest from 1990-94 when the population was collapsing. Potential population growth rate was negative again from 2000-03 and again in 2009 and 2010. In most of the years since 1995 (17 of 21 years) potential population growth rate was positive, ranging from 4 to 42 percent, somewhat higher than the pre 1990 years. Results using the NCAM model starting in 1962 are similar. Potential population growth rate was negative from 1990-94, 2001-03, and also in the early part of the time series in 1970-74. Although potential growth was not negative in 2009 and 2010, it was very low. Results from the extended model show that potential population growth rate was positive in all but 3 years since 1995, with many years equal or greater than the levels of the early part of the time series. In this model potential population growth rate ranged from -0.64 to 0.42.

Surplus production derived from the two formulations of the NCAM model were similar (Figure 9). Both showed lower surplus production at SSB below the average of the 1980s and a period of negative surplus production in the early 1990s. The model with the longer time period showed a steady decline in surplus production from the late 1960s to the mid1970s, and generally higher surplus production at SSB higher than the average of the 1980s.

Despite some interannual variability surplus production rate was similar across a broad range of SSB, except for those years of negative production (Figure 10). There are more years of near zero surplus production since 1995 than earlier in the time series, but no indication of an overall decrease in production rate, with many years having a surplus production rate similar to the pre collapse period.

DISCUSSION

Length at age, weight at age and relative gutted condition, all indicated reduced productivity in the late 1980s, early 1990s when the stock was collapsing. These results are consistent with those of Morgan et al. (2018), who examined these metrics by division and life stage. They concluded that by 2006 these indices of productivity were mainly back to the levels observed prior to stock collapse.

This study does not examine changes in maturity and natural mortality directly, but these components of productivity are included in SPR, RPS and potential population growth rate. All of these metrics indicated reduced productivity during the period in which the population was collapsing in the late 1980s, early 1990s. They have all varied since with some periods of below average RPS and SPR and negative potential population growth rate. However, there is no indication of any extended period of low productivity.

Based on the analyses of potential population growth, the maximum population growth rate that can be expected for northern cod appears to be 42-44%. This is reasonably consistent with the analyses of Morgan et al (2016) based on output from a previous population model of northern cod. They found the maximum population potential growth rate to be 30%.

Surplus production is lower in recent years when SSB has been below the levels of the 1980s. However, surplus production rate is similar to the pre collapse period, indicating that productivity is also similar.

Overall, there is no evidence that Div. 2J3KL cod is experiencing a prolonged period of low productivity that would indicate that historic levels of biomass cannot be reached in the future if environmental conditions are similar.

REFERENCES CITED

Morgan, M. J., Shelton, P.A., and R.M. Rideout. 2014a. An evaluation of fishing mortality reference points under varying levels of population productivity in three Atlantic cod (Gadus morhua) stocks. ICES J. Mar. Sci. 71:1407-1416.

Morgan, M. J., Shelton, P.A., and R.M. Rideout. 2014b. Varying components of productivity and their impact on fishing mortality reference points for Grand Bank Atlantic cod and American plaice. Fisheries Research 155:64-73.

Morgan, M.J., Shelton, P.A, González-Costas, F., and D. González –Troncoso. 2016. Compensation potential from six depleted groundfish stocks from the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 73: 257-269.

Morgan, M.J., Koen-Alonso, M., Rideout, R.M., Buren, A.D., and D. Maddock Parsons. 2018. Growth and condition in relation to the lack of recovery of northern cod. ICES J. Mar. Sci. 75:631-641.

Quinn, T.J., II, and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford UniversityPress, New York. 560p.

FIGURES

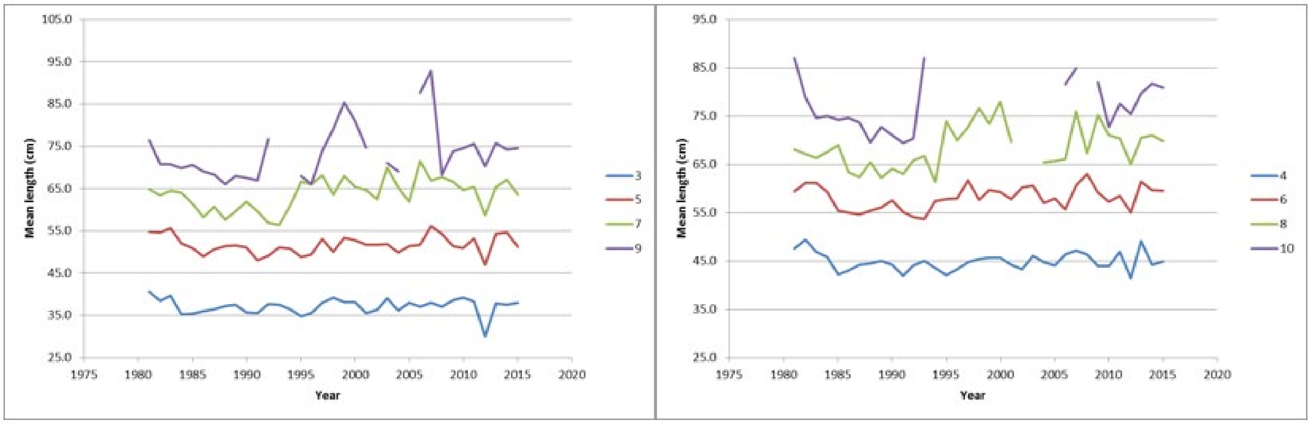


Figure 1. Mean length at age (cm) for Div. 2J3KL cod ages 3-10 from research vessel data.

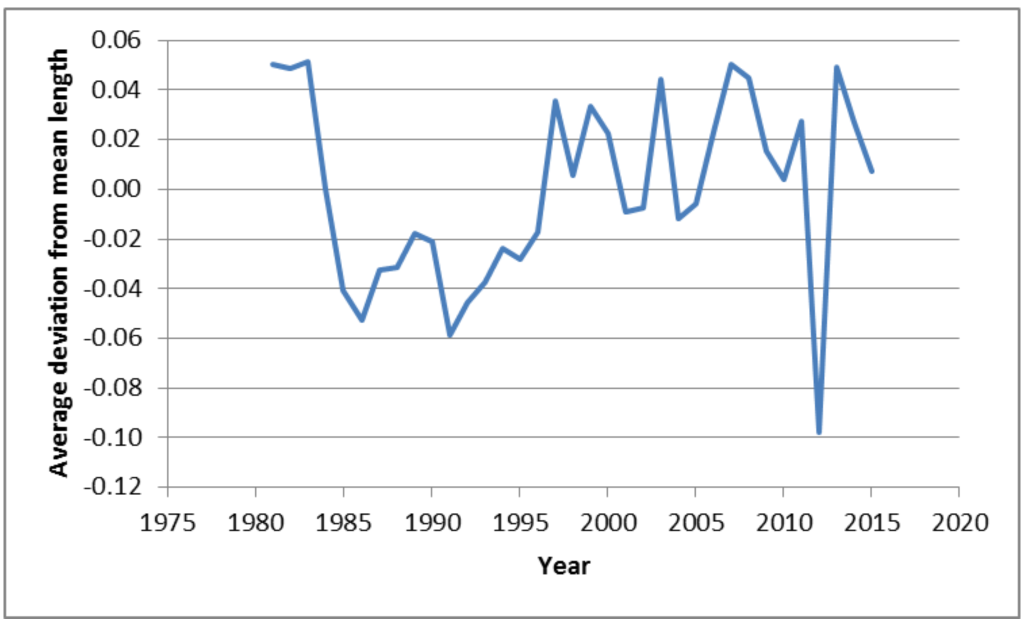


Figure 2. Average deviation (as a proportion) from the mean length at age for ages 3-7 for Div. 2J3KL cod.

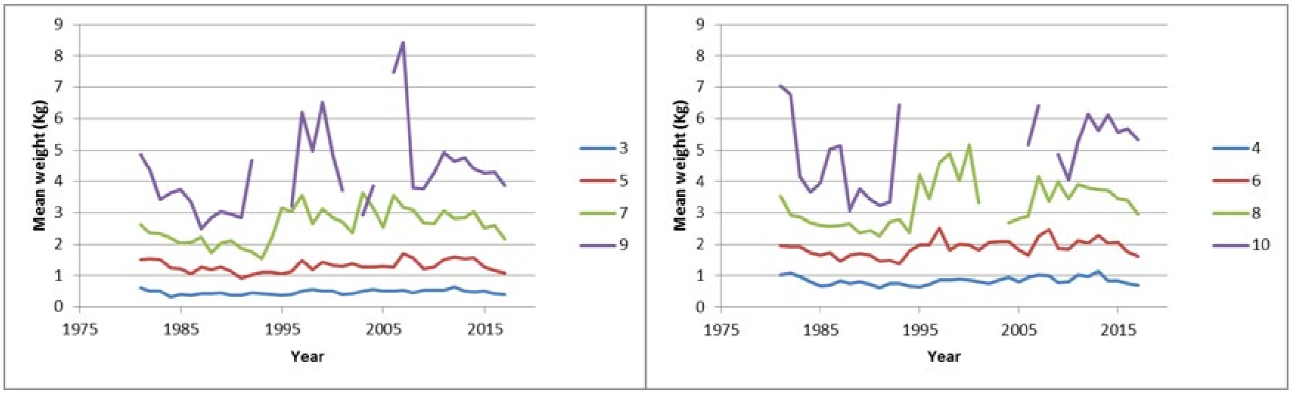


Figure 3. Mean weight at age (Kg) for Div. 2J3KL cod ages 3-10 from research vessel data.

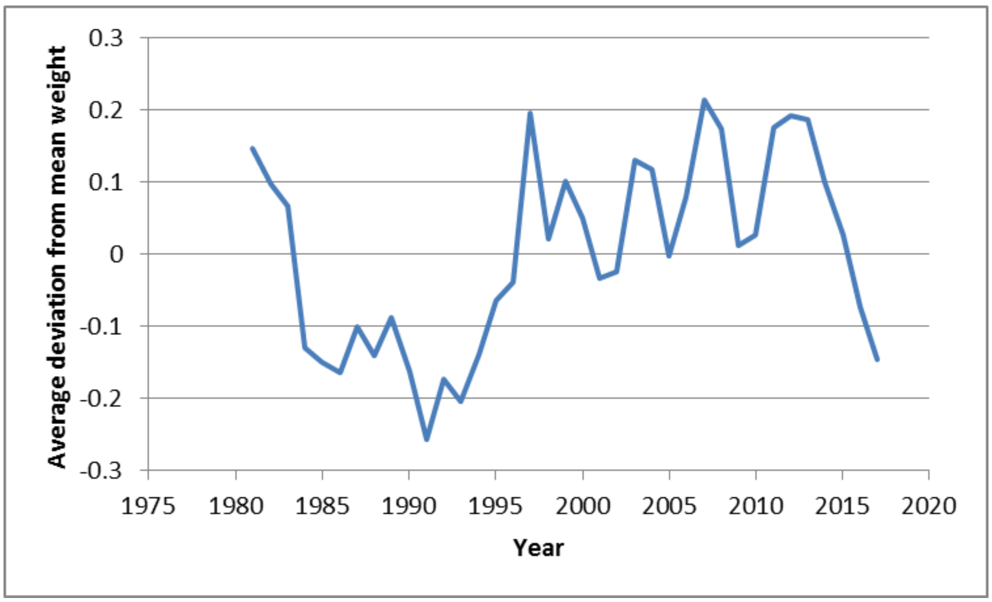
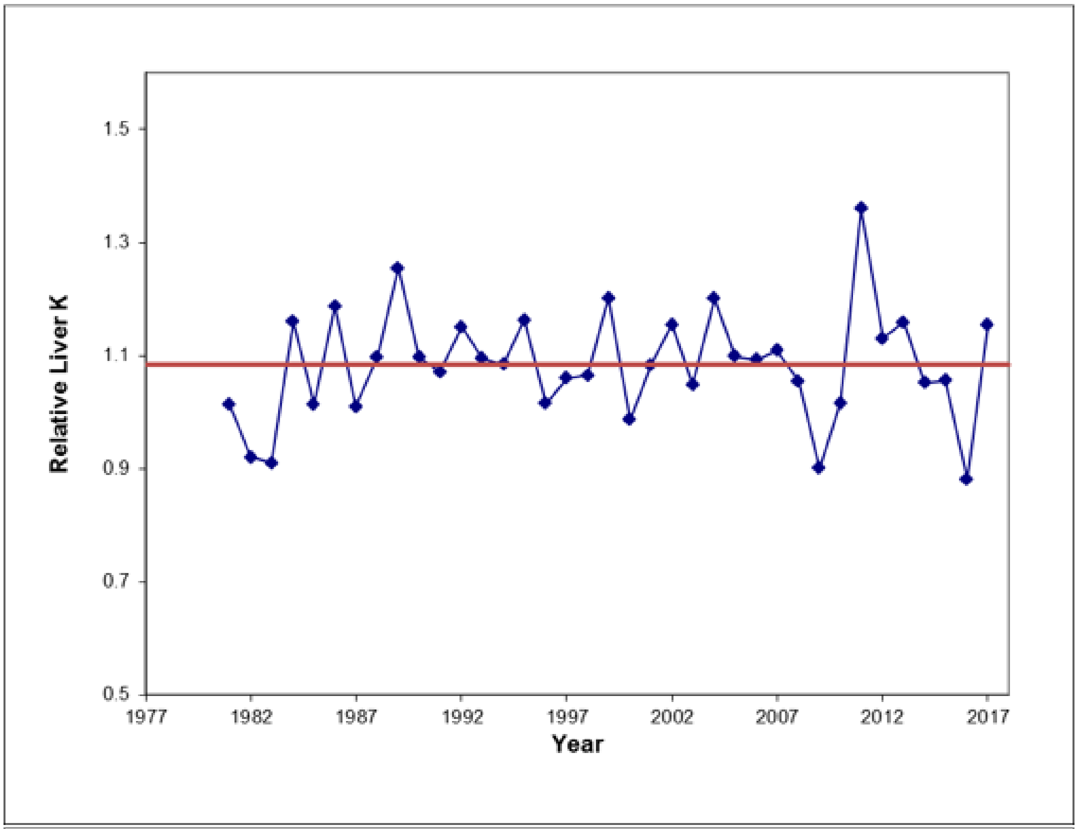


Figure 4. Average deviation (as a proportion) from the mean weight at age for ages 3-7 for Div. 2J3KL cod.



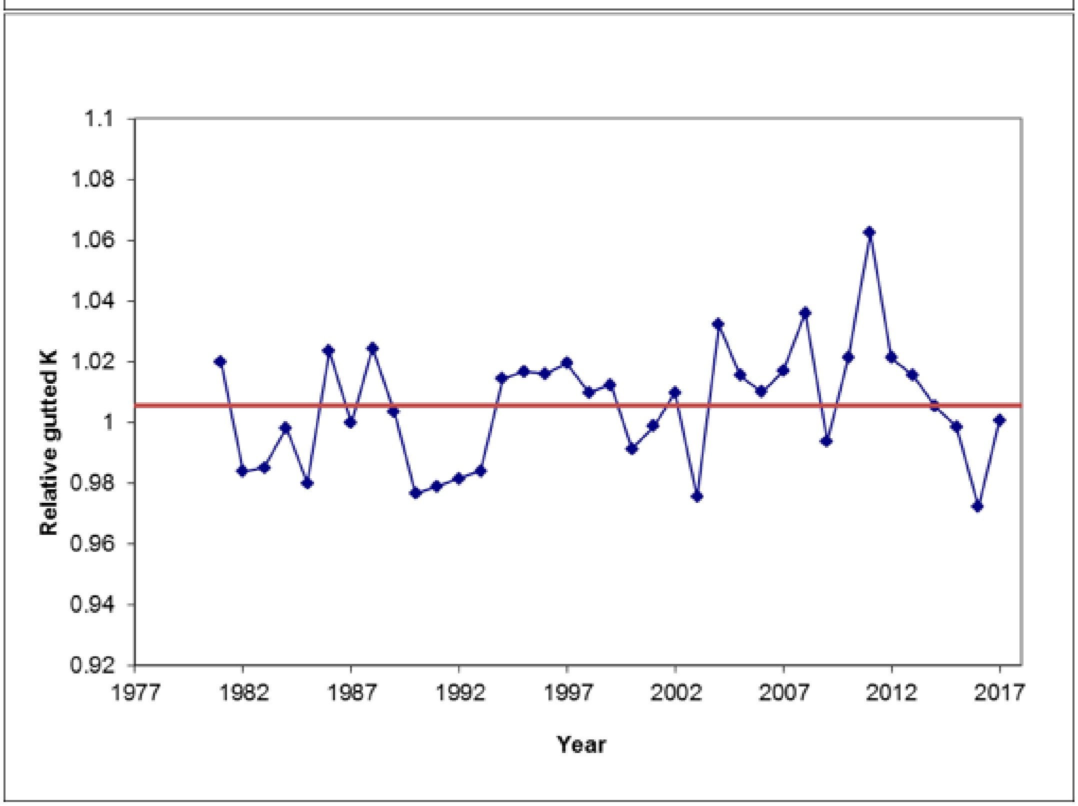


Figure 5. Relative gutted condition (top) and relative liver condition (bottom) for Div. 2J3KL cod. The horizontal line indicates the average year effect estimate.

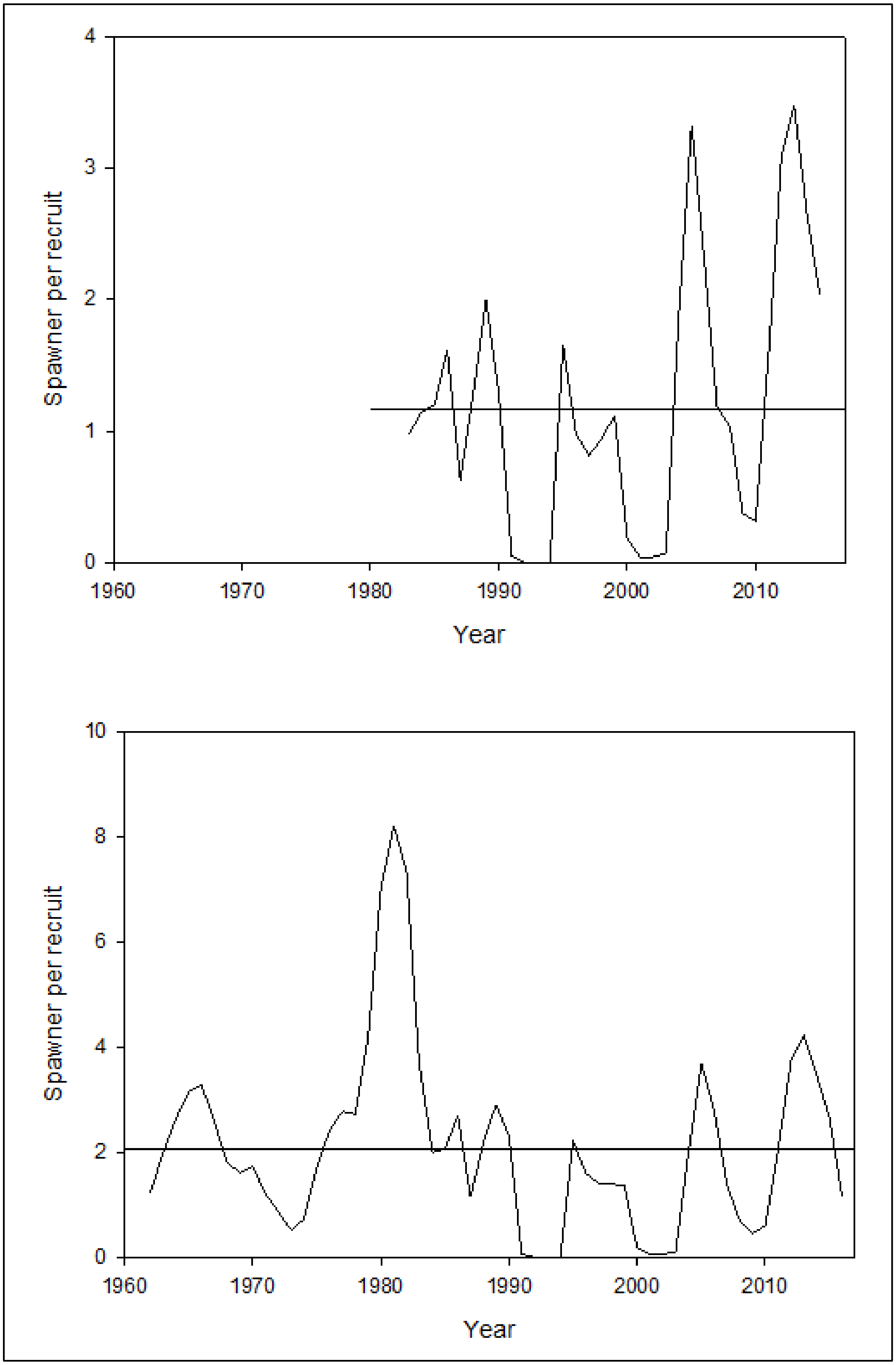


Figure 6. Spawner per recruit for Div. 2J3KL cod derived from the results of NCAM starting in 1983 (top) and 1962 (bottom). The horizontal line gives the average of each time series.

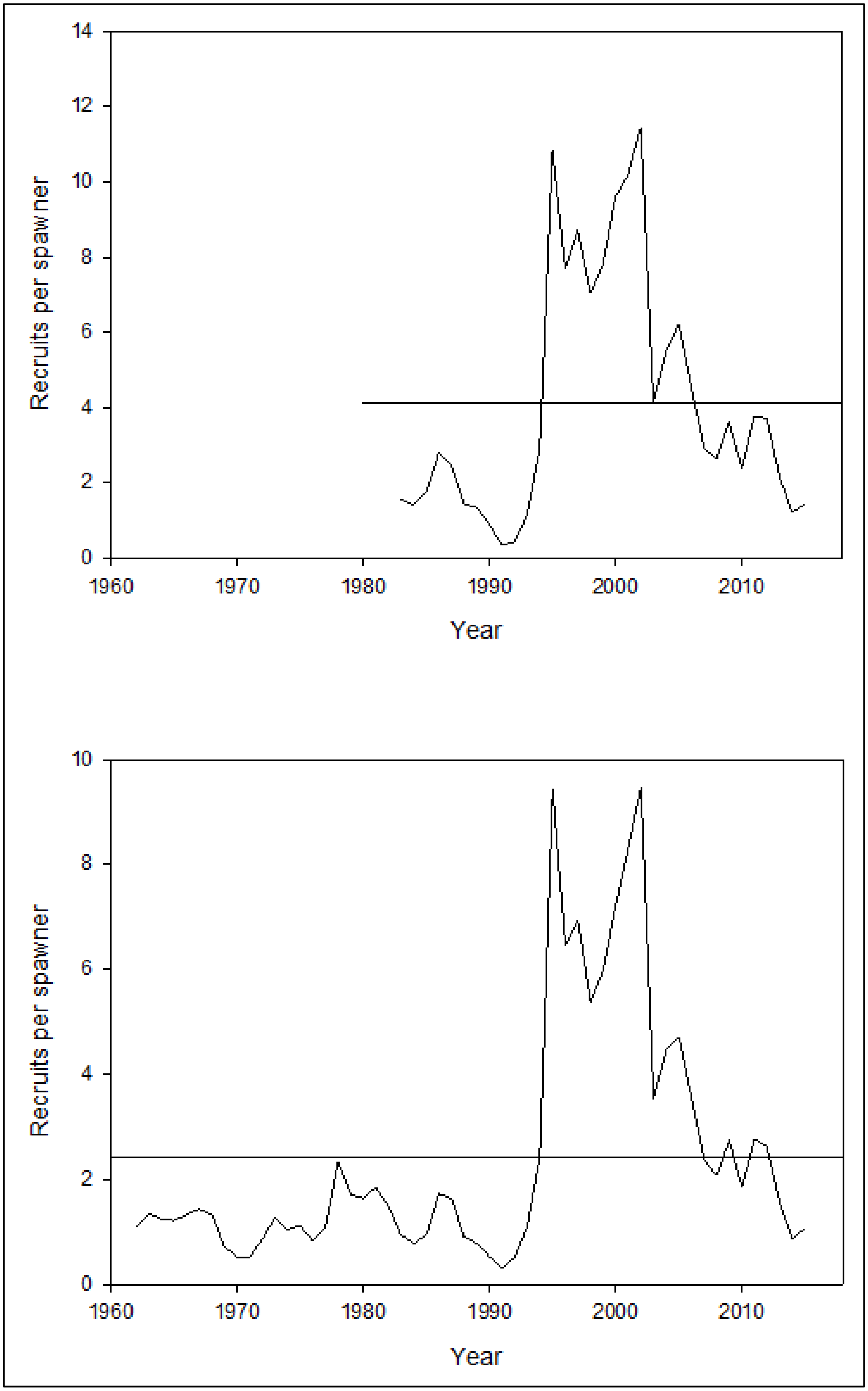


Figure 7. Recruits per spawner for Div. 2J3KL cod derived from the results of NCAM starting in 1983 (top) and 1962 (bottom). The horizontal line gives the average of each time series.

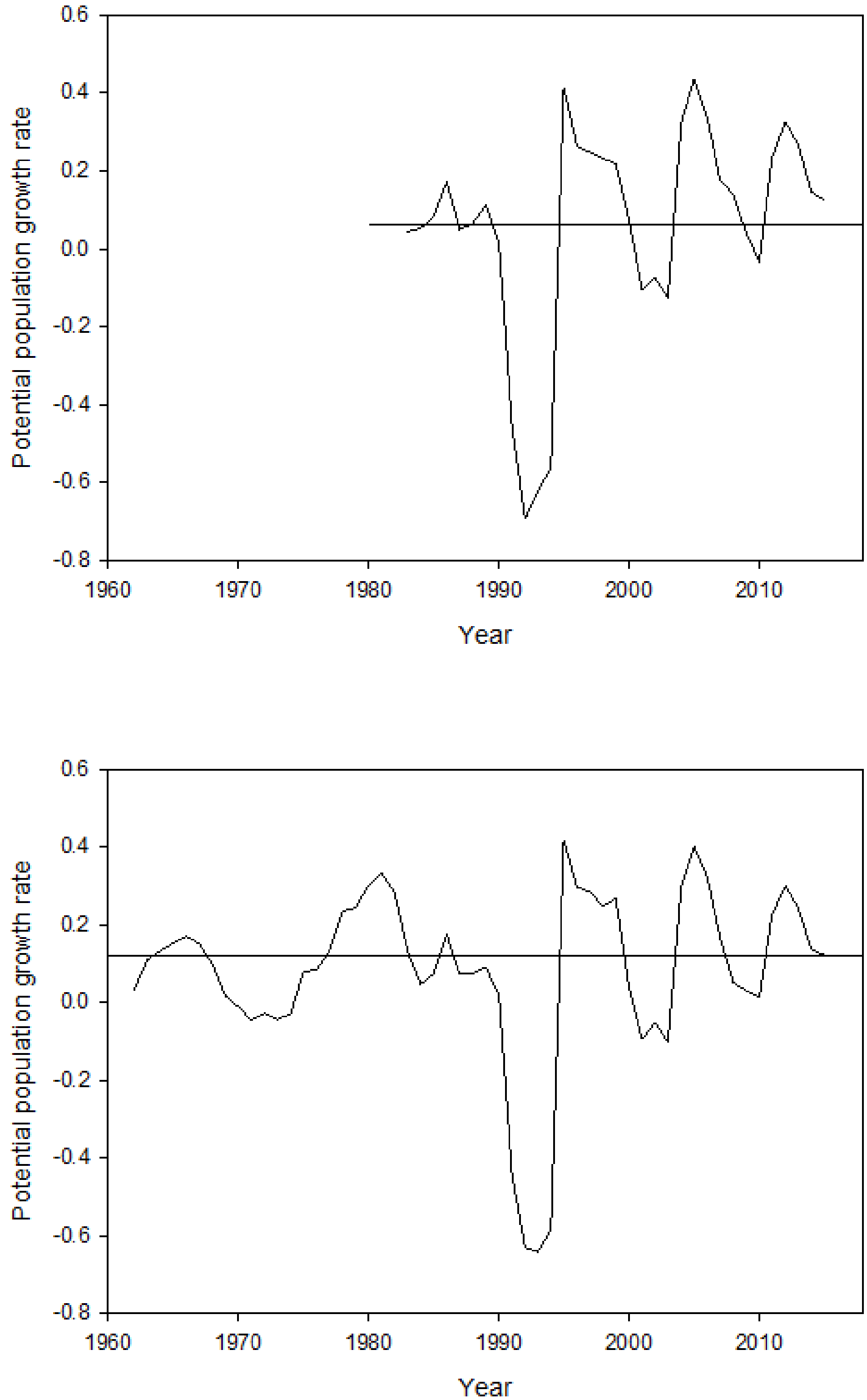


Figure 8. Potential population growth rate as proportion growth in SSB for Div. 2J3KL cod using results of NCAM starting in 1983 (top) and 1962 (bottom).

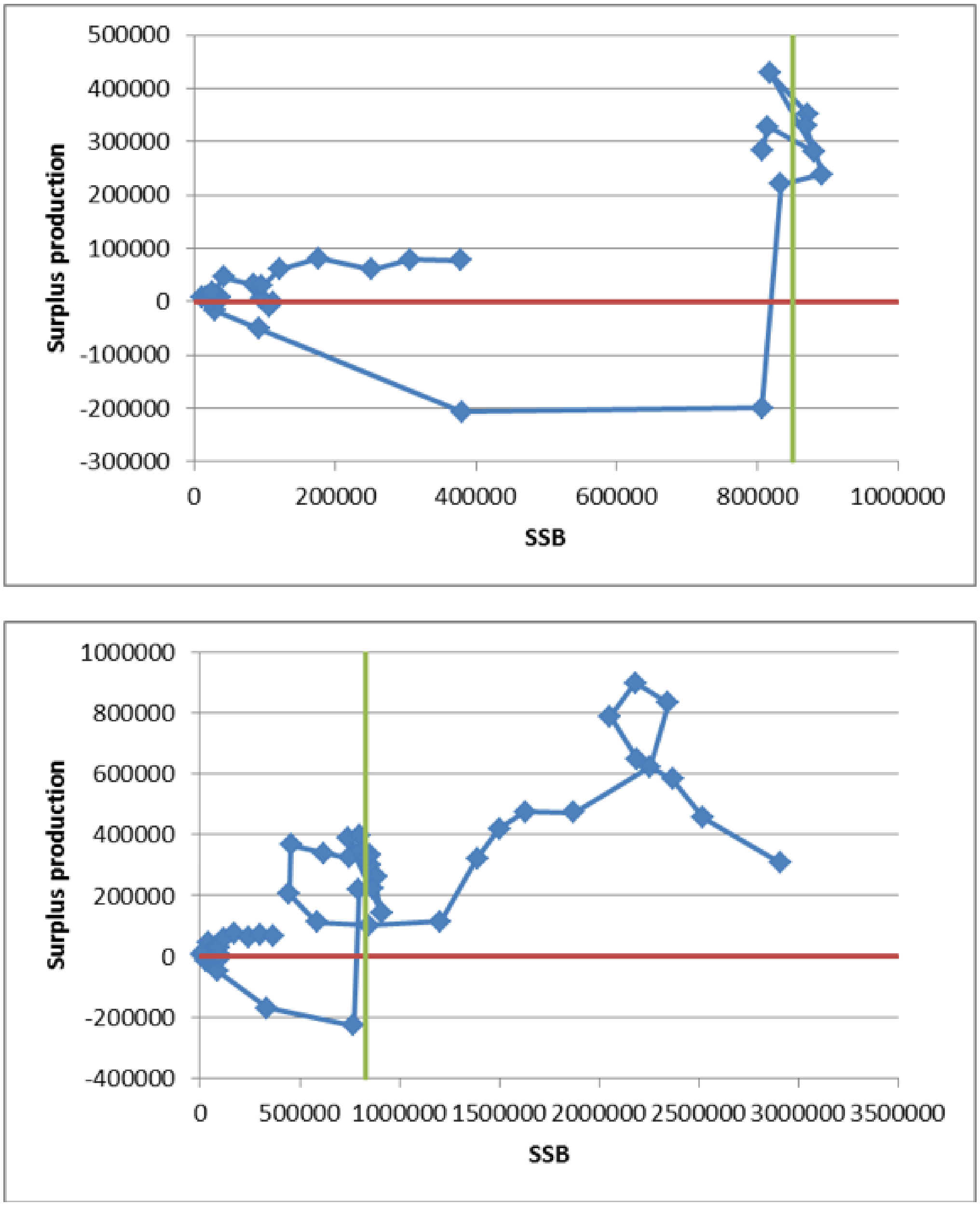


Figure 9. Surplus production from the results of NCAM starting in 1983 (top) and 1962 (bottom). In each plot the horizontal line is zero and the vertical line is the average SSB of the 1980s.

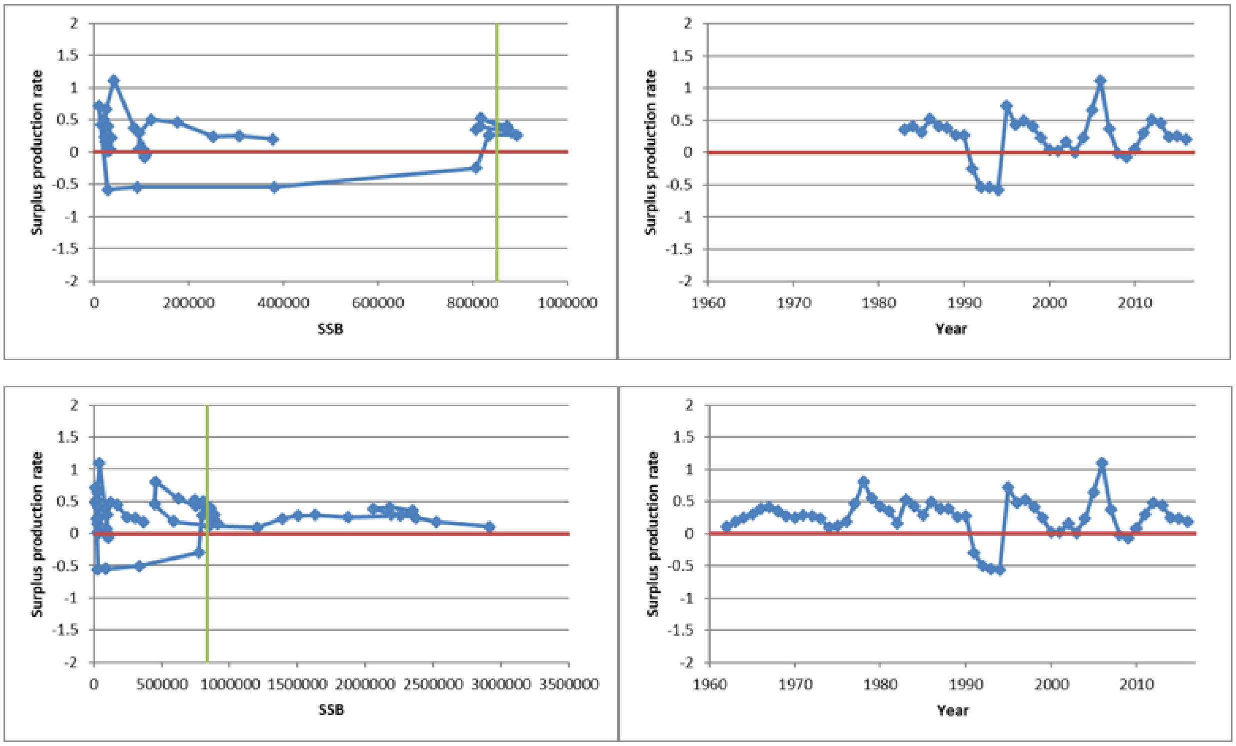


Figure 10. Surplus production rate from the results of NCAM starting in 1983 (top) and 1962 (bottom). The left hand panels shows surplus production rate against SSB and the right hand panels shows the rate over time. In each plot the horizontal line is zero and in the left hand panels the vertical line is the average SSB of the 1980s.