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Production analysis of southern Gulf of St. Lawrence cod for the identification of biological reference points

Identification de points de référence biologiques par analyse de production pour le stock de morue du sud du Golfe du St-Laurent

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Abstract

Production of the southern Gulf of St. Lawrence cod in relation to spawning stock biomass was investigated to help identify biological reference points. This is a preliminary analysis to examine the feasibility and implications of using production-based arguments in the definition of biological limits. The productivity of this stock has changed through time and is currently at a low level. Based on theoretical growth in biomass in one generation (6 years) and a non-parametric stock-recruit relationship for the stock, the cautious/healthy boundary was estimated to be about 200,000 t. Using this boundary and the generational growth that can be expected under favorable conditions, a preliminary estimate of the critical/cautious boundary for this stock is in the order of 80,000 t.

Résumé

La production du stock de morue du sud du Golfe du Saint-Laurent en fonction de la biomasse reproductrice a été examiné afin d'identifier des points de référence biologiques. Ceci constitue une analyse préliminaire pour étudier la faisabilité et les implications de points de référence basés sur la production du stock. La production de ce stock a changé au cours du temps et se situe présentement à un niveau faible. En se basant sur la croissance théorique de la biomasse sur une période d'une génération (6 ans) pour ce stock et de la relation stock recrue non paramétrique, on estime que la limite entre la zone de prudence et la zone robuste est d'environ 200 000 t. En utilisant cette limite et la croissance au cours d'une génération dans des conditions favorables, un estimé provisoire de la limite entre la zone critique et la zone de prudence est d'environ 80 000 t.

Introduction

In the context of implementing the Canadian precautionary approach for the management of fisheries, recent efforts have focused on determining the spawning stock biomass level below which would result serious or irreversible harm in terms of recruitment overfishing. In this area, Myers et al. (1994) conducted an extensive review of limit reference points (used here synonymously with Biological Reference Points (BRP)) to determine the onset of recruitment overfishing. They examined a variety of approaches to determine this level and concluded that the ones based on the stock size resulting in 50% of the maximum predicted average recruitment were preferred because they were more robust and could be easily understood. As in Myers et al. (1994), Shelton and Rice (2002) suggested examining a variety of approaches as there does not appear to be a single method that can fit all cases.

A national workshop was held in November 2002 to examine this issue in the context of several cod stocks in Atlantic Canada (see Rivard and Rice 2002). Five methods were retained for defining limit reference points in terms of spawning stock biomass(SSB):

1) $B_{recovery}$: the lowest historical biomass level from which the stock has recovered readily (=B_{loss} in ICES)
2) BH50: the level of SSB at which expected average recruitment is one half of the maximum recruitment predicted by assuming an underlying Beverton-Holt stock-recruit relationship (see Myers et al. 1994).
3) RK50: the level of SSB at which expected average recruitment is one half of the maximum recruitment predicted by assuming an underlying Ricker-type stock-recruit relationship (Myers et al. 1994).
4) Sb50/90: the level of SSB corresponding to the intersection of the 50th percentile of the recruitment observations and the replacement line for which 10% of the S-R points are above the line (see Serebryakov 1991; Shepherd 1991).
5) NP50: estimate of the SSB level where the expected mean recruitment is one half of the maximum recruitment calculated by a non-parametric analysis (i.e. loess).

For the southern Gulf of St. Lawrence cod stock, the estimates given by the various methods ranged between 70,000 and 80,000 t (Chouinard et al. 2003). It was concluded that the best estimate of this biological reference point for this stock was 80,000 t. The risk of being below this level of spawning biomass at the end of 2003 was found to be 100%.

One difficulty with this approach was that for several other stocks, the various methods produced a wide range of estimates. The properties of these various estimators were examined through simulations during a workshop held February 10-12, 2004. None of the techniques proved to be without flaws (Rice 2004 (in prep.)) and some (e.g. parametric methods, BH50 and RK50) often behaved poorly. Sissenwine and Shepherd (1987) proposed an alternative method to determining BRP that examines the potential of the parental biomass to replace itself. Analogously, it was suggested that analyses of the production history of each stock may provide indications of biomass levels associated with the boundaries of a precautionary framework for the management of fisheries. The framework considered included three zones: critical, cautious and healthy. In particular, the boundaries of the critical/cautious (conservation limit) and the cautious/healthy (onset limit) zones of such a framework would be of interest to decision makers. This paper describes an analysis for southern Gulf of St. Lawrence (4T-Vn) cod. Similar analyses of production have been also conducted on three other stocks (3Pn 4RS cod, 4VsW cod and 4VW haddock).

One approach suggested at the February 2004 workshop was called “twinning”. It used production analysis in two complementary ways. One manner was to estimate the critical/cautious boundary directly. This point could be defined as the level of spawning stock biomass at which the production had a probability, say at the 50% level, of becoming negative. The other estimate of this boundary used the probable production during a productive period in one generation and the level of the cautious/healthy boundary to calculate the critical/cautious boundary. In other words, if the resource could be expected to double in one generation, the critical/cautious boundary would be at half the biomass of the cautions/healthy. The more conservative of these two would be chosen if both were available.

Data

The data used in this analysis were those used for stock assessment: indices of abundance by age, catch and growth at age information. In the case of southern Gulf of St. Lawrence cod, a 52-year (1950-2002) time-series was available for the analysis. Catch and weights at age, population numbers and fishing mortality trends were from the most recent assessment of the stock (Chouinard et al. 2003). For this stock, a single maturity ogive (derived from sampling in the1990-1995 period) is used to calculate spawning stock biomass. Sinclair (2001) showed that natural mortality (M) increased in the 1980s. Currently, the population model assumes that M was 0.2 before 1986 and 0.4 thereafter for all ages.

Methods

Surplus production was estimated as the annual change in total biomass plus fishery removals. It could be calculated either from survey abundances or VPA. In this work, we used biomass at age estimated from VPA. When production biomass (P/B) ratios are shown they are the production between years t and t+1 divided by the biomass in year t.

For much of this work, the approach of Sissenwine and Shepherd (1987) has been adapted to do a moving window analysis. The Sissenwine-Shepherd approach is an equilibrium analysis of production which uses an age structured population. It may be thought of as a linkage of yield per recruit analysis and stock-recruit analysis. Like yield per recruit, it uses a range of fishing mortalities and at each calculates the equilibrium population and yield. Among its outputs are maximum yield (MSY) and the biomass at that maximum (BMSY). Our analysis used moving 10-year data windows. Ten-year windows were arbitrarily chosen as containing enough data to form realistic estimates while being short enough to give some temporal resolution.

Results and Discussion

The biological reference points described in the introduction were recalculated using the 2003 assessment results (Chouinard et al. 2003) to estimate the point where serious or irreversible harm could occur. The analysis used recruitment at age 2. The results of the BRP calculations are in Figure 1 and show that three of the reference points (RK50, Sb9050 and $B_{recovery}$) fell in the 60,000 to 80,000 t range while the BH50 suggested a much lower SSB level of 43,000 t.

Surplus production (estimated annual change in total biomass plus fishery removals) showed that the production pattern for southern Gulf cod splits into 2 distinct periods: a relatively productive period from 1950 to 1985 and a less productive period from 1986 to the present (Figure 2a)). The main difference between these two periods is the increased natural mortality in the latter. The increased natural mortality period also coincides with a period when weights-at-age have been at their lowest. Thus, SSB does not provide a good indicator of productivity for this stock. The period from the late 1980s clearly follows a lower path (Figure 2a). Another way of displaying the same data is to convert the production into a production/biomass (P/B) ratio. In this instance, it is surplus production divided by the total biomass. The cloud of points before 1990 has a negative slope which shows the compensation of the resource as the biomass falls (Figure 2b). On an individual basis the mid-1970s were very productive. The break from these compensatory dynamics in 1990 is clear. This type of display contrasts a productive period when biomass is good with a situation in which the environment is productive, but the biomass is low.

Estimates of Maximum Sustainable Yield (MSY) were obtained using data contained in 10 year moving windows. These showed a wide variation with recent values of MSY being extremely low (Figure 3). Moving average estimates of B_{MSY} indicated that the spawning stock biomass associated with MSY in recent years would be in the range of about 60,000 t. (Figure 4). MSY plotted against SSB also showed that the period starting in the late 1980s was distinct from the previous period (Figure 5).

The moving window MSY was most affected by changes in the number of recruits produced, natural mortality and growth (Figure 6). Currently, all 3 factors are in a state (low SSB, high M and low growth) that makes production low compared to the historical pattern. In the late 1970s and early 1980s, the numbers of recruits produced per unit of biomass were high. During this period, the high number of recruits per unit biomass compensated to some degree for the decline in growth and increase in M. It should be noted that a constant maturity ogive was used to calculate SSB throughout the time period hence data do not exist to examine the effect of changes in maturity on MSY. Changes in fishing practice as estimated by partial recruitment did not affect the MSY as much as the other components (Figure 6, lower panel).

The change in the moving window MSY and production appears to be linked, at least to some extent, to changes in the temperature of the environment (Figure 7a and b), approximated by the mean temperature of the cold intermediate layer (CIL -30-100 m) in the Gulf of St. Lawrence (Dutil et al. 1999). A similar observation was made for the 4VsW cod production when compared to the Misaine Bank bottom temperatures (R. Mohn, unpublished data). This requires further investigation. However, the link between growth and temperature for this and other cod populations is well documented (Brander 1995; Campana et al. 1995; Swain et al. 2003). Temperature has also been linked with the recruitment portion of production in some cod populations (O'Brien et al. 2000; Ottersen et al. 1994; Planque and Fredou 1999).

In order to estimate the potential growth of biomass in one generation, the reconstructed population from the most recent assessment (Chouinard et al. 2003) was divided into either SSB windows or into time windows. Within a data window the standing population in a year, recruitment and natural mortality were all independently sampled with replacement. The weight-at-age and partial recruitment were averaged over the data window. A standard stock projection was run in the absence of fishing for one generation, (for this stock, average generation time is 6 years, Smedbol et al. 2002) using re-sampled or averaged values. The percentage change in total biomass over one generation was estimated for each of 5000 replicates. The percentage change for biomass ranges of SSB (0-100, 100-200 and 200 +) and for different periods (1950-1978; 1979-1989; 1990-2002) showed little difference for different biomass ranges but larger differences depending on the period from which the input data were chosen. In particular, if conditions during the decade starting in 1990 persist, the simulation suggested that little increase in SSB can be expected in one generation (Figure 8). The distributions of SSB increases were also integrated and the 50^{th}, 75^{th}, 90^{th} and 95^{th} percentiles estimated and summarized in the following table.

		Percentiles			
	% change	0.50	0.75	0.90	0.95
Biomass Range	0-100	48.20	75.45	103.95	123.66
	100-200	95.50	126.43	156.21	172.18
	200+	97.60	124.27	149.13	163.80
Periods	1950-1977	112.61	176.97	239.25	269.25
	1978-1989	127.78	171.61	221.70	250.91
	1990-2002	6.64	2.16	10.15	14.36

The objective was to assess potential growth under the most favorable conditions. Therefore, the 90% level (e.g. the top 10% of growth) for SSB was chosen. At this level, the highest generational growth using data over the entire time series is about 150% (shaded cells in table above). A growth of 150% means that after one generation the SSB would be 2.5 times larger the original level. Therefore, if the cautious/healthy boundary is divided by 2.5, it will approximate the critical/cautious boundary. For southern Gulf of St. Lawrence cod, there is no obvious break for the cautious/healthy zone based on the production plot (Figure 2). However, the frequency distributions of generational change (Figure 9) show that, while the proportional change in biomass tends to level off at about 150,000 t, there are gains in biomass to be made until biomass reaches 200,000 to 250,000 t. In addition, 200,000 t appears to be the level where the non-parametric stock-recruit relationship declines rapidly (see Figure 1, dashed line). Using the value of 200,000 t would give an approximate critical/cautious boundary of 80,000 t.

The "twin" estimate defined as the biomass at which negative production becomes probable does not exist in this case, as there was only a small probability of negative production as a function of biomass. The production as a function of the time period selected was a bit more pessimistic and would have implications on the speed of recovery. The 80,000 t estimate is close to the $B_{recovery}$ for this stock of about 77,000 t. A graph of the production to biomass (P/B) ratio and SSB for the stock also suggests that below this level most of the values of the P/B ratio are below average (Figure 2b). It should be noted that the P/B ratio is generally lower at very high biomass levels suggesting some density-dependent mechanism. This level of 80,000 t is higher than the Ricker and Beverton-Holt SSB at 50% maximum recruitment as well as the Serebyakov SB9050 (see Figure 1). The latter values are either below levels of SSB that have been observed or at levels where recovery has not been observed in the history of the stock, and may therefore, not be precautionary.

Using production instead of only the stock and recruit relationship as a consideration for setting biological reference points provides a wider view. Furthermore, our approach allows the decomposition of the potential yield into its functional determinants (growth, survivorship, reproduction…). This in turn allows for an analysis of the various contributors to yield, some insight into their history and the possibility of linking them to oceanographic or other exogenous events.

References

Brander, K.M. 1995. The effect of temperature on growth of Atlantic cod (*Gadus morhua* L.). ICES J. Mar. Sci. 52:1-10.

Campana, S.E., R.K. Mohn, S.J. Smith and G.A. Chouinard. 1995. Spatial implications of a temperature-based growth model for Atlantic cod (*Gadus morhua*) off the eastern coast of Canada. Can. J. Fish. Aquat. Sci., 52:2445-2456.

Chouinard, G.A., D.P. Swain, L. Currie, G.A. Poirier, A. Rondeau, H. Benoit, T. Hurlbut and D. Daigle. 2003. Assessment of the southern Gulf of St. Lawrence cod stock, February 2003/ Évaluation du stock de morue du sud du Golfe du St-Laurent, février 2003. CSAS. Res. Doc. 2003/015, 116 p.

Dutil, J.-D., M. Castonguay, D. Gilbert, and D. Gascon. 1999. Growth, condition, and environmental relationships in Atlantic cod (*Gadus morhua*) in the northern Gulf of St. Lawrence and implications for management strategies in the Northwest Atlantic. Can. J. Fish. Aquat. Sci., Vol. 56: 1818-1831.

Myers, R.A., A.A. Rosenberg, P.M. Mace, N. Barrowman and V.R. Restrepo. 1994. In search of thresholds for recruitment overfishing. ICES J. Mar. Sci., 51:191-205.

O'Brien, C.M., C.J. Fox, B. Planque, and J. Casey.2000. Climate Variability and North Sea cod. Nature 404:142-142.

Ottersen,G., H. Loeng., and A. Raknes. 1994. Influence of temperature variability on recruitment of cod in the Barents Sea. ICES Mar. Sci. Symp. 198: 471-481.

Planque B. and T. Fredou. 1999. Temperature and the recruitment of Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci., 56:2069-2077.

Rice, J.C. 2004. Proceedings of the Precautionary Approach Workshop, Ottawa, February 10-12, 2004. CSAS Proceedings 2004/003 (in prep).

Rivard, D. and J. Rice (co-chairs). 2002. National workshop on reference points for gadoids. CSAS Proc. Ser. 2002/033: 21 p.

Serebryakov, V.P. 1991. Predicting year-class strength under uncertainties related to survival in the early life history of some North Atlantic commercial fish. NAFO Sci. Counc. Studies, 16:49-55

Shelton, P. A. and J. C. Rice. 2002. Limits to overfishing: reference points in the context of the Canadian perspective on the precautionary approach. CSAS Res. Doc. 2002/084.

Shepherd, J. 1991. Report of Special session. NAFO Sci. Counc. Studies, 16:7-12.

Sinclair, A.F. 2001. Natural mortality of cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. ICES J. Mar. Sci. 58: 1-10.

Sissenwine, M.P. and J.G. Shepherd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44:913-918.

Smedbol, R. K., P. A. Shelton, D. P. Swain, A. Fréchet, and G. A. Chouinard. 2002. Review of population structure, distribution and abundance of cod (*Gadus morhua*) in Atlantic Canada in a species-at-risk context. CSAS Res. Doc. 2002/082.

Swain, D.P., A.F. Sinclair, M. Castonguay, G.A. Chouinard, K.F. Drinkwater, L.P. Fanning and D.S. Clark. 2003. Density- versus temperature-dependent growth of Atlantic cod (*Gadus morhua*) in the Gulf of St. Lawrence and on the Scotian Shelf. Fish. Res., 59: 327-341.

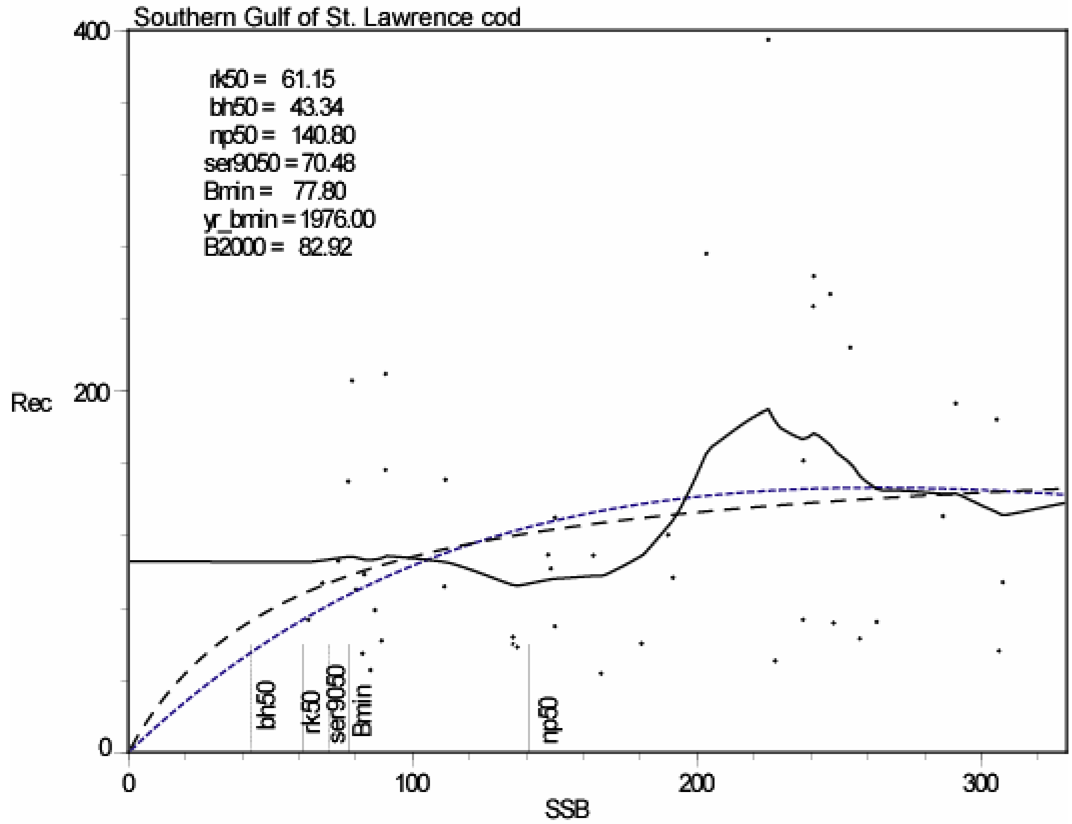

Figure 1. Plot of recruitment at age 2 versus spawning stock biomass and biological reference points for southern Gulf of St. Lawrence cod. The dashed lines show the Ricker (long dash) and Beverton Holt (short dash) stock-recruit relationships. The solid line is the non-parametric fit. Reference points are described in the text.

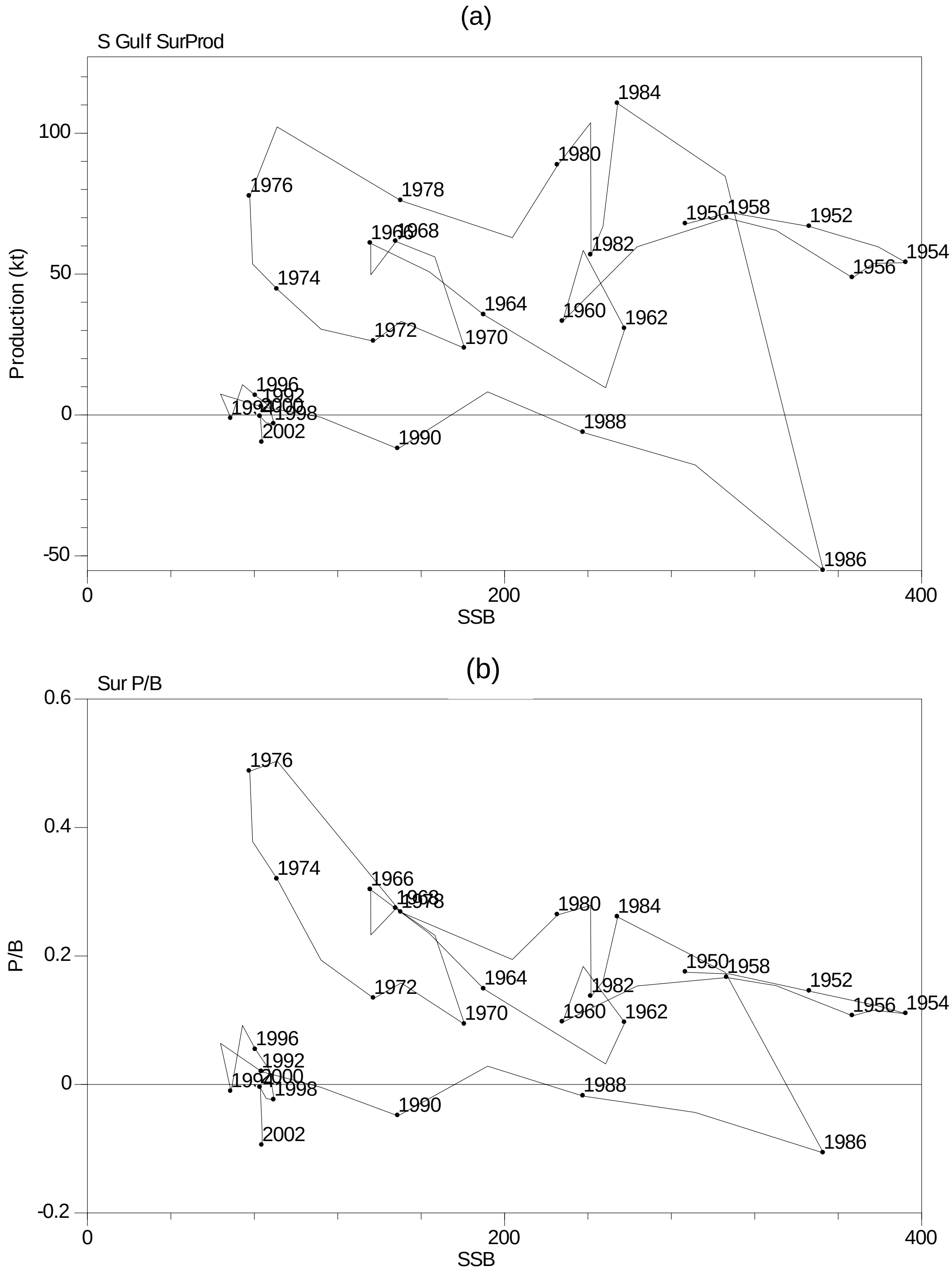

Figure 2. Production of southern Gulf of St. Lawrence cod and spawning stock biomass. The upper plot (a) is the annual surplus production. The lower panel (b) is a plot of the P/B ratio (ratio of surplus production to total biomass) and spawning stock biomass. The 2002 P/B point is an approximation using the 2001 change in biomass and the 2002 yield.

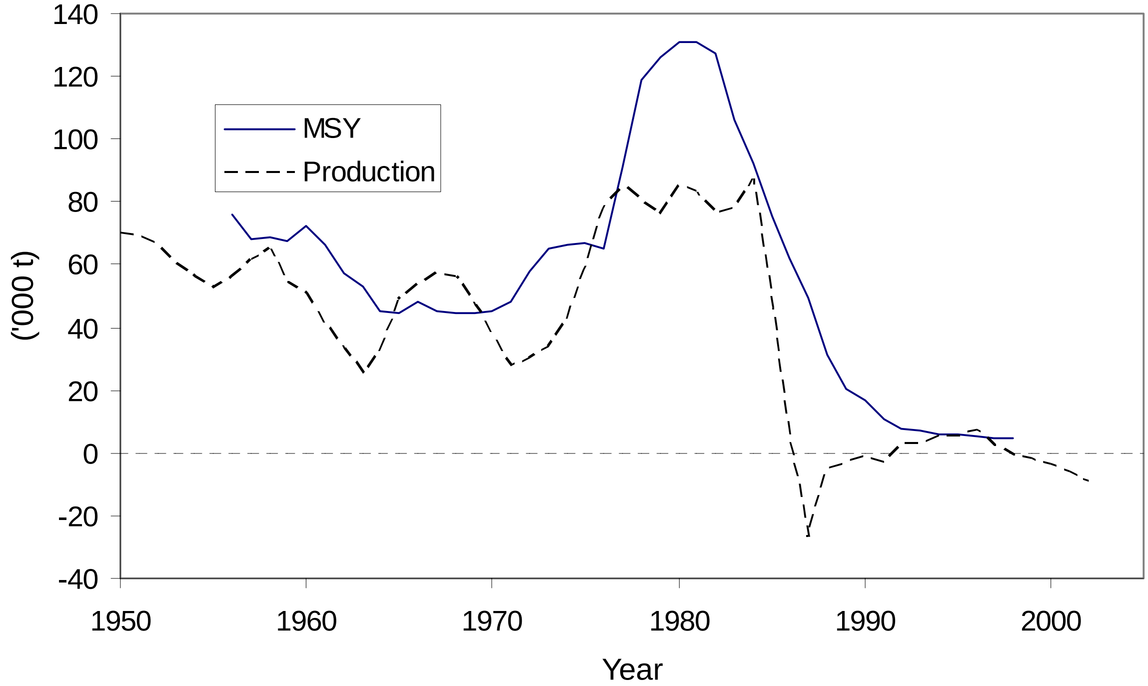

Figure 3. Time series of production (smoothed using moving average) and moving window (10 years - shorter line) Maximum Sustainable Yield (MSY) for southern Gulf of St. Lawrence cod. The step to higher M in 1986 is responsible for the sharp drop in the productivity.

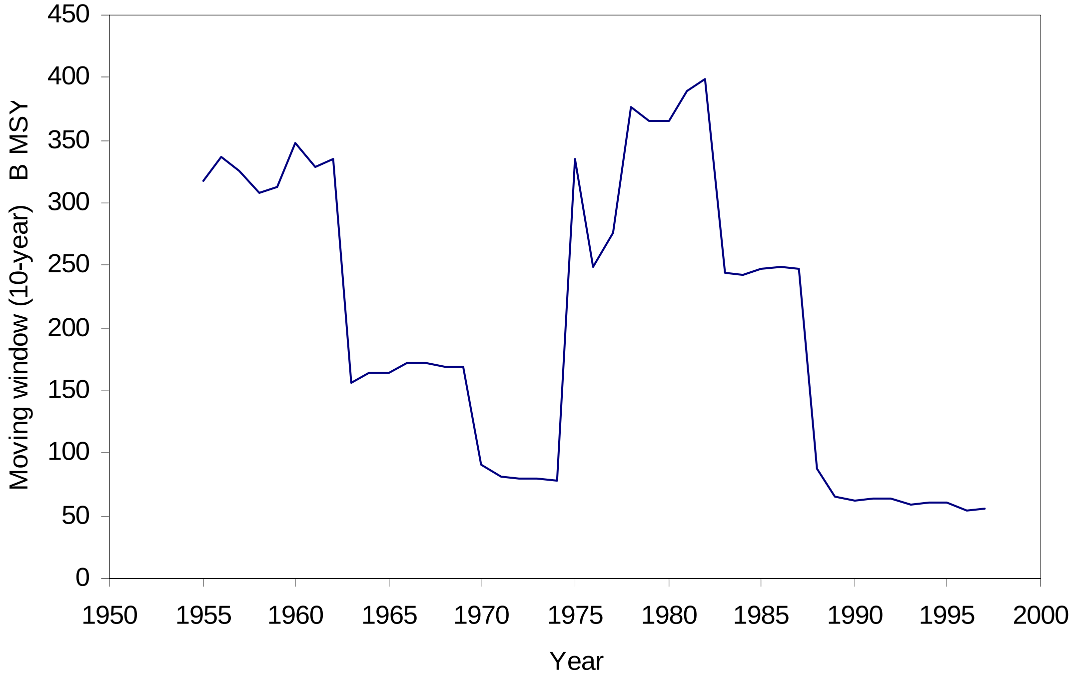

Figure 4. Moving window B_{MSY} for southern Gulf of St. Lawrence cod.

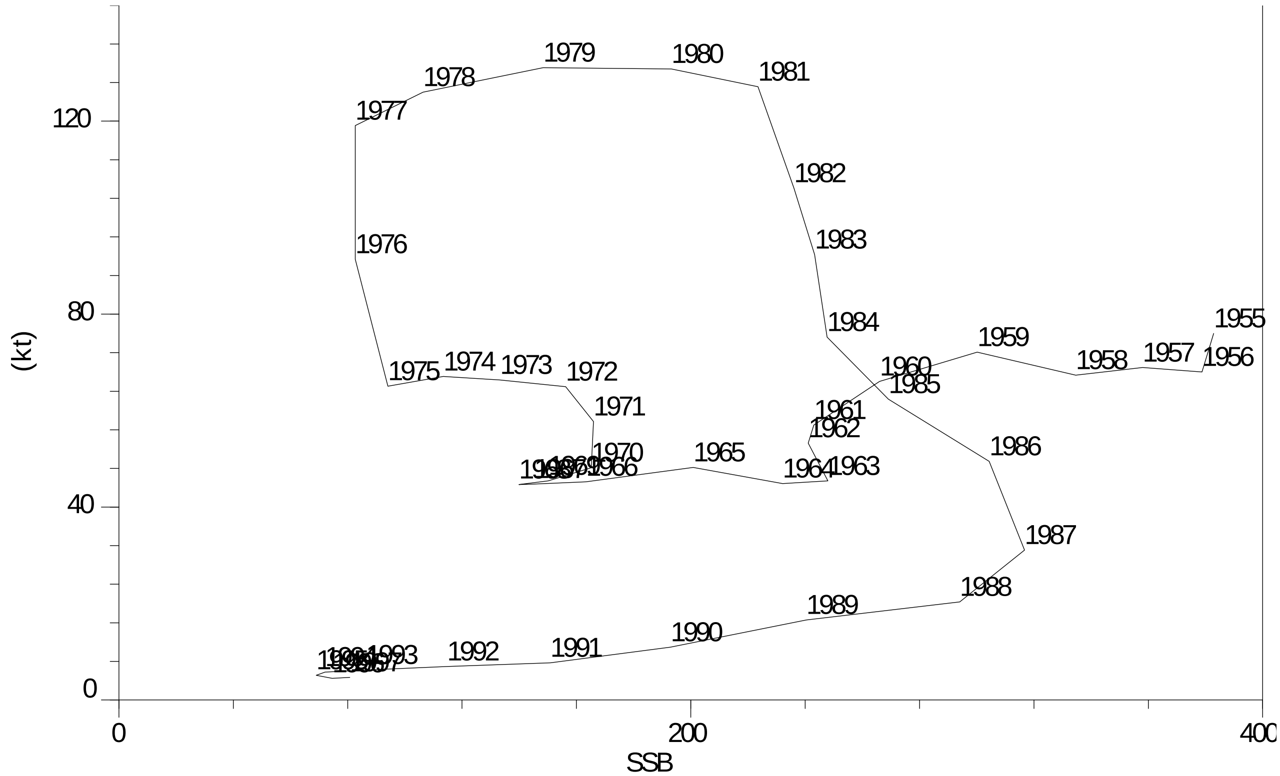

Figure 5. Phase plot of the estimate of Maximum Sustainable Yield (MSY) using 10-year time windows (each year represent the mid-point in the period) as a function of spawning stock biomass (SSB).

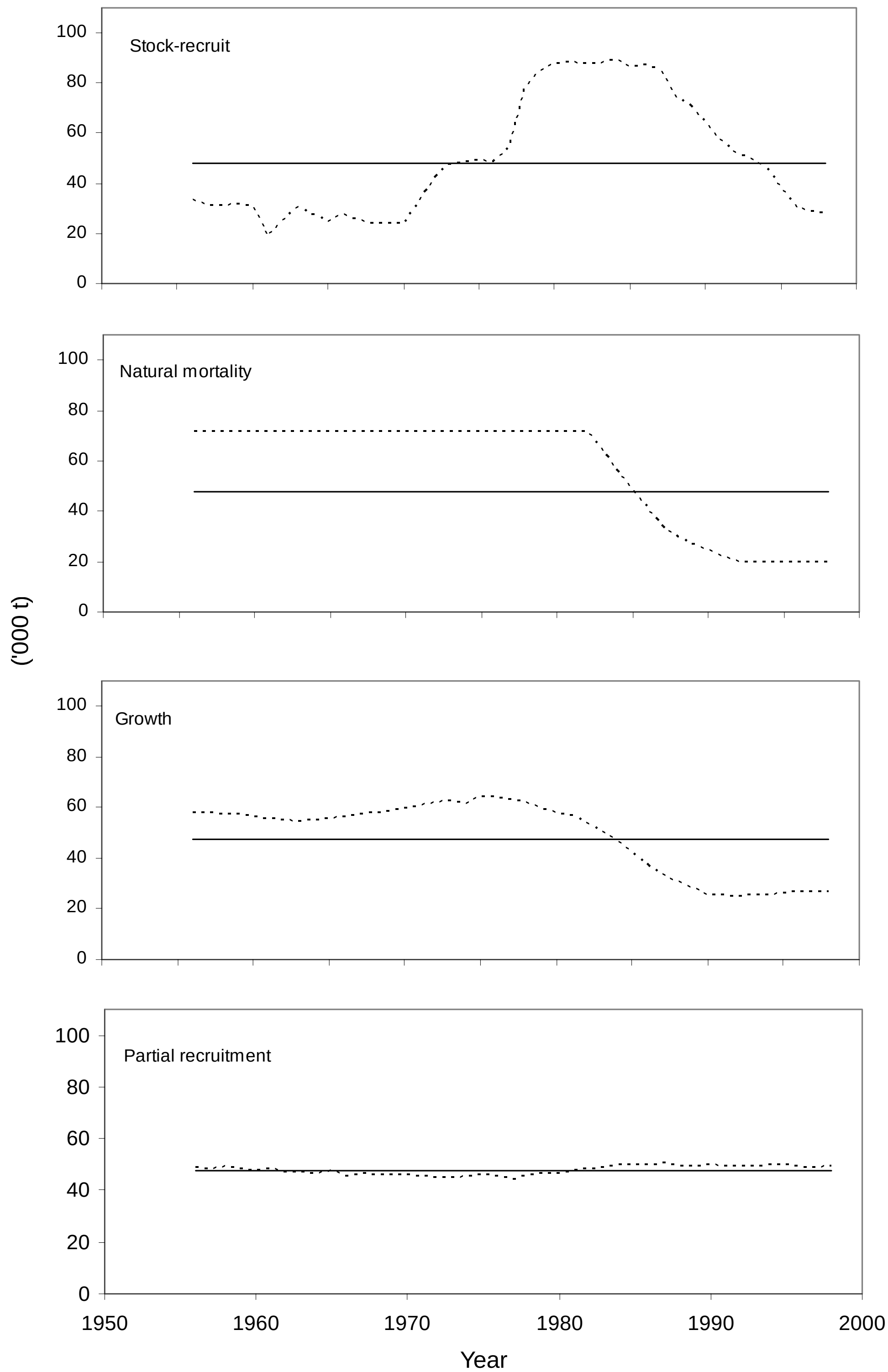

Figure 6. Sensitivity of moving window MSY to stock-recruit, natural mortality, growth and partial recruitment. The long-term average MSY is indicated as reference (solid line).

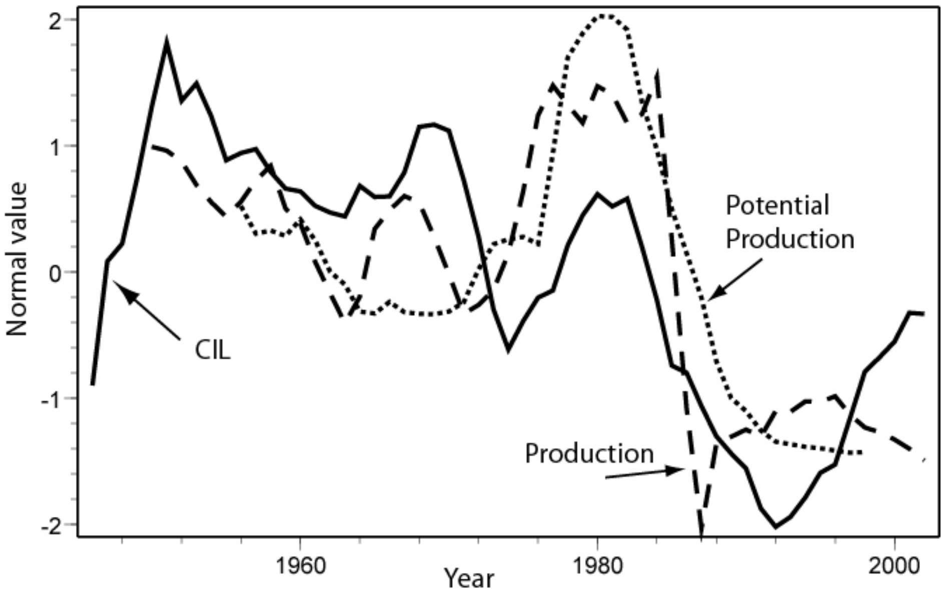

Figure 7a. Moving window MSY (dotted line), production (dashed line) and Gulf of St. Lawrence mean temperature of the cold intermediate layer (solid line - CIL; 30-100 m, Dutil et al. 1999).

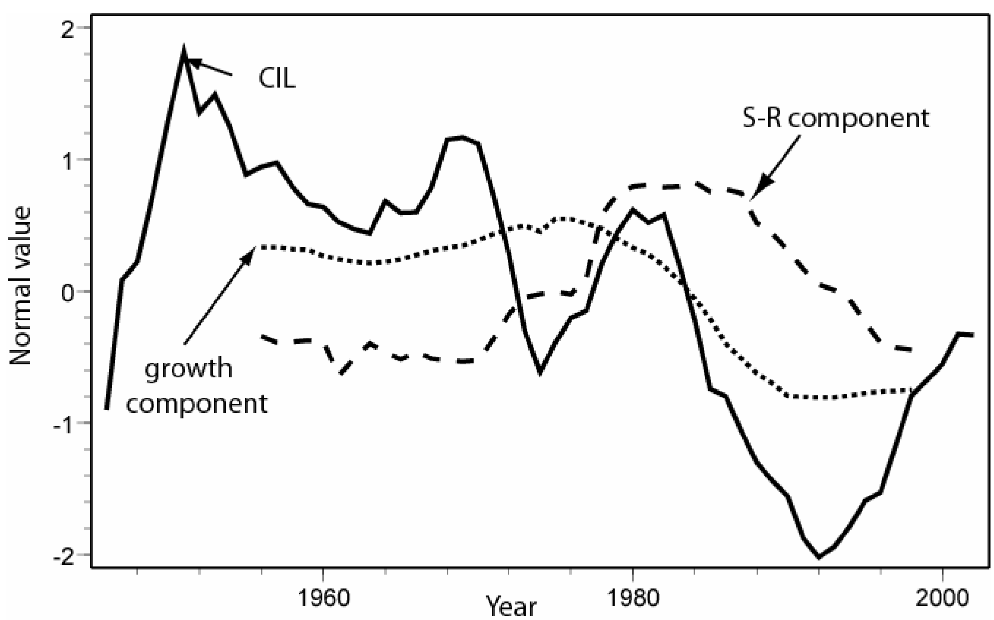

Figure 7b. Moving window MSY influence from changes in growth (dotted line), and changes in stock-recruit relationship.(dashed line) and Gulf of St. Lawrence mean temperature of the cold intermediate layer (solid line - CIL; 30-100 m, Dutil et al. 1999).

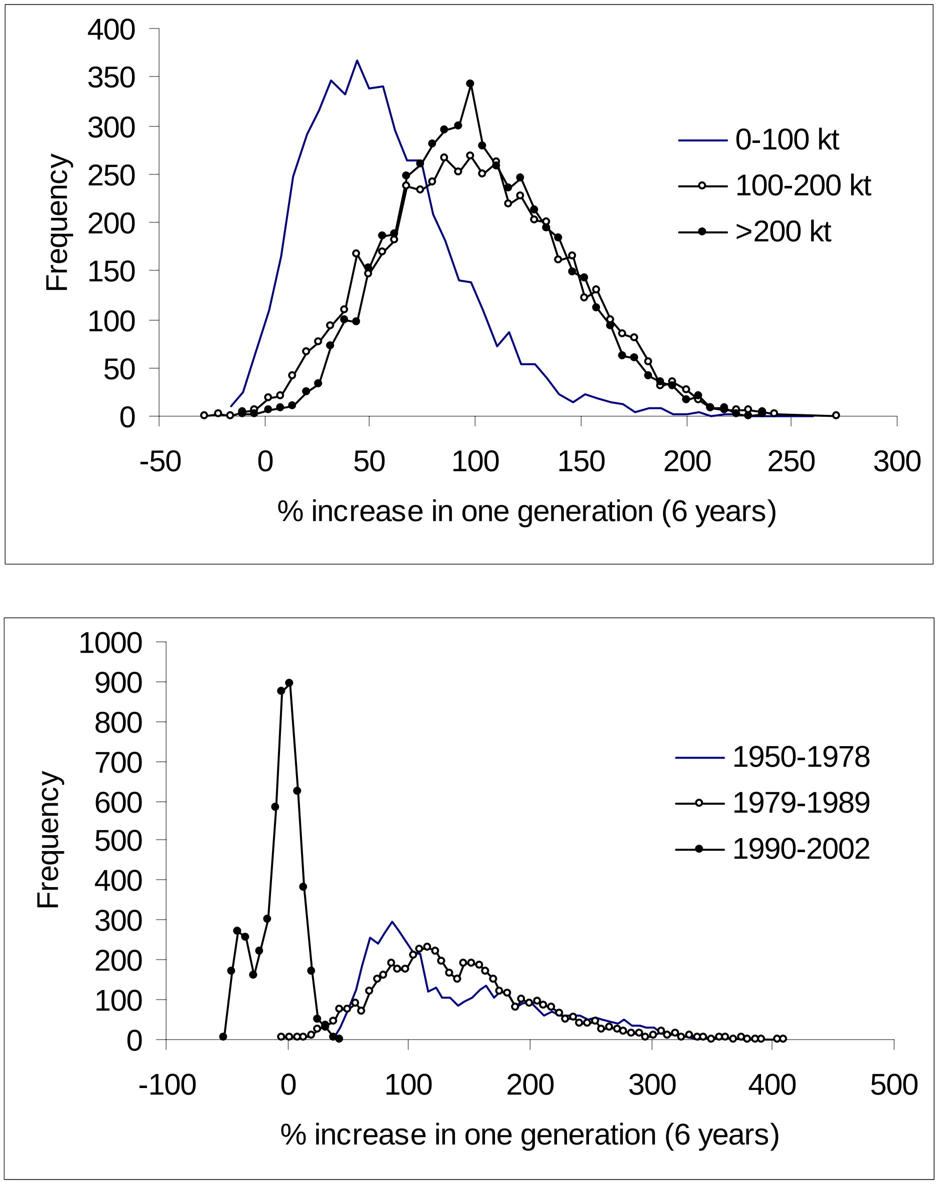

Figure 8. Frequency of the percent change in biomass expected in one generation (6 years) for a range of spawning stock biomass (top) and for different periods (bottom) from 5000 replicates. Note: 100% represents a doubling of biomass in one generation.

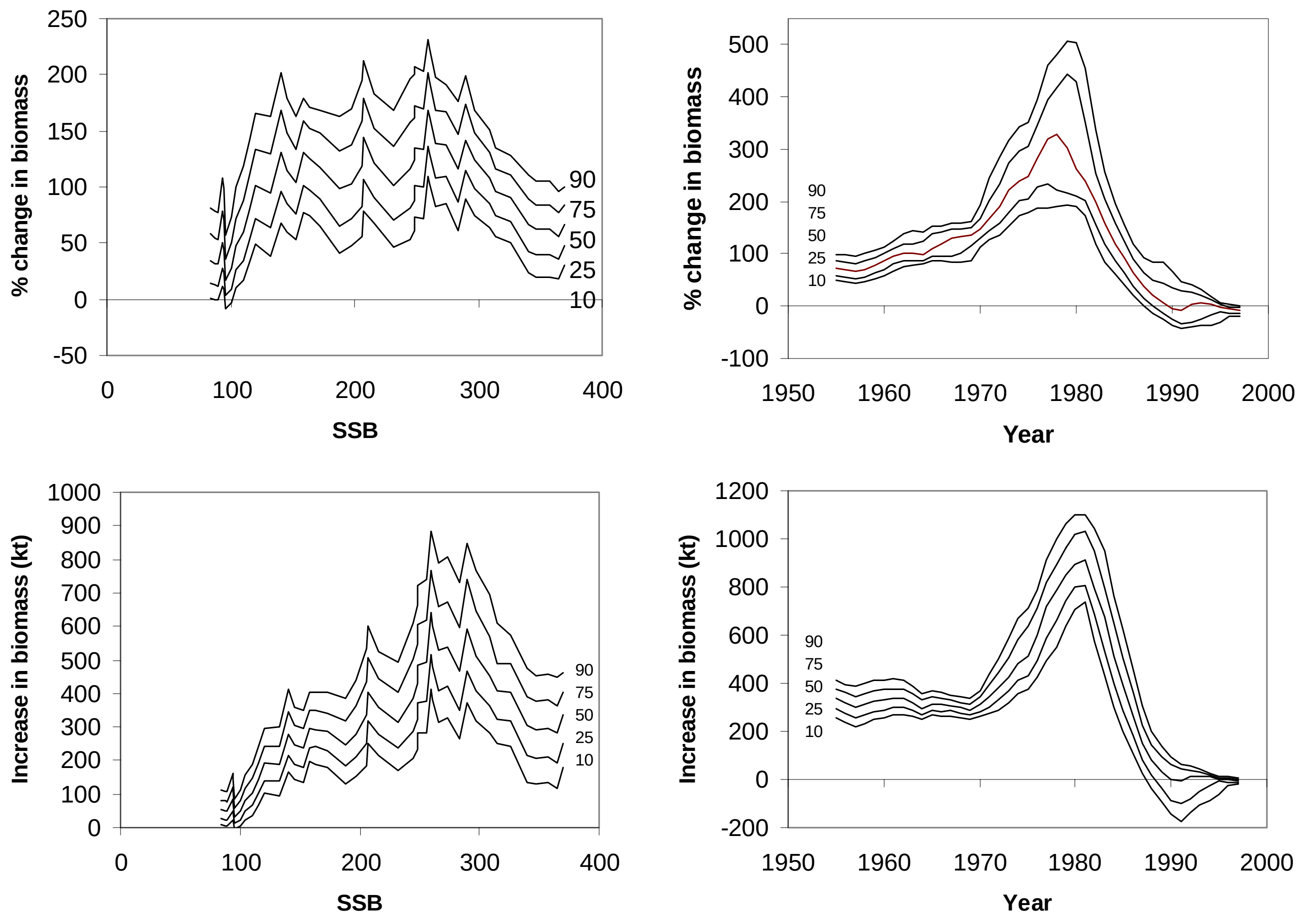

Figure 9. Distribution of generational change in percentage (top) and total biomass (bottom) plotted against SSB (left) and time (right).