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# Background information on the southern Gulf of St. Lawrence cod stock for the Fisheries Oceanography Committee workshop on the cod recruitment dilemma.

D. P. Swain and G. A. Chouinard

Department of Fisheries and Oceans, Gulf Fisheries Centre,
P.O. Box 5030, Moncton, NB, E1C 9B6

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**Abstract**

Spawning stock biomass (SSB) of southern Gulf of St. Lawrence cod declined to low levels in the mid 1970s and the early 1990s. Recovery was rapid from the earlier decline but has been slow from the recent decline. Both survey data and SPA estimates indicate that the rate of recruitment (R/SSB, where R is abundance of age-3 cod) was remarkably high during the low abundance period of the mid 1970s. Recruitment rate estimates for the recent period depend on the SPA assumptions and calibration methods. However, neither the survey data nor the SPA estimates (regardless of the assumptions or calibration methods used) indicate that recruitment rate has been unusually low during the recent period of low abundance. Instead, estimates of recruitment rates in recent years range from average levels typical of the 1950s, 1960s and early 1970s to relatively high levels. Changes in SSB depend on rates of adult growth and adult mortality as well as recruitment. Adult growth rates have been unusually low since the mid 1980s and adult natural mortality appears to be currently unusually high. The rapid recovery in the mid 1970s resulted from unusually high recruitment rates combined with high adult growth rates and average (apparently) natural mortality rates of adults. Recovery has not occurred in the 1990s despite low fishing mortality and average to high recruitment rates. The lack of recovery in the 1990s appears to be the result of unusually low growth rates and unusually high adult natural mortality rates.

**Résumé**

La biomasse du stock reproducteur (BSS) de morue dans le sud du golfe du Saint-Laurent a chuté au milieu des années 70 et à nouveau au début des années 90 pour se rétablir rapidement dans le premier cas, mais pas dans le second. Les données de relevé et les estimations issues de l'Analyse séquentielle de population (ASP) indiquent que le taux de recrutement (R/BSS, où R représente l'abondance de morues d'âge 3) était remarquablement élevé pendant la période de faible abondance du milieu des années 70. Bien que les estimations récentes du taux de recrutement dépendent des hypothèses de l'ASP et des méthodes d'étalonnage, ni les données de relevé ni les estimations issues de l'ASP (indépendamment des hypothèses ou des méthodes d'étalonnage utilisées) indiquent que le taux de recrutement a été anormalement faible pendant cette période de faible abondance. Les estimations des taux de recrutement au cours des dernières années varient plutôt de niveaux moyens typiques des années 50 et 60 et du début des années 70 à des niveaux relativement élevés. Les fluctuations de la BSS dépendent des taux de croissance et de mortalité des adultes, ainsi que du recrutement. Ainsi, les taux de croissance des adultes ont été anormalement bas depuis le milieu des années 80 tandis que le taux de mortalité naturelle des adultes semble anormalement élevé à l'heure actuelle. Le rétablissement rapide au milieu des années 70 était le résultat de taux de recrutement exceptionnellement élevés combinés à des taux de croissance élevés et des taux moyens (selon toute apparence) de mortalité naturelle des adultes. Par contre, la BSS n'a pas augmenté dans les années 90 malgré un faible taux de mortalité par pêche et un taux de recrutement allant de moyen à élevé. Le manque de rétablissement au cours des années 90 semble être le résultat de taux de croissance anormalement bas et de taux de mortalité naturelle anormalement élevés des adultes.

## Introduction

Abundance of many Northwest Atlantic cod populations declined to low levels in the early 1990s, resulting in moratoria on directed fishing for these stocks. Recovery from these low levels of abundance has been slow despite severe restrictions on fishing pressure. In contrast to this lack of recovery from the recent declines, these cod populations recovered rapidly from declines to low abundance in the mid 1970s. The earlier period of decline and rapid recovery was characterized by rapid growth rates and strong recruitment while the recent collapse and slow recovery has been in a period of slow growth and weak recruitment. In recent reports, the Fisheries Resource Conservation Council has identified this “recruitment dilemma”, the failure of depressed cod stocks to recover despite restricted fishing mortality, as a research priority. Consequently, DFO’s Fisheries Oceanography Committee convened a workshop to address this issue at its annual meeting in February 2000.

In preparation for this workshop, background information on recruitment and other population parameters (e.g., mortality rates, size at age) was assembled for each cod stock. The purpose of this document is to present this information for the southern Gulf of St. Lawrence cod stock.

## Methods

Data were taken from recent stock assessment documents (Chouinard et. al. 1999, in most cases). Unless otherwise indicated, sequential population analysis (SPA) estimates of abundance use the formulation accepted by Chouinard et al. (1999), updated to include 1999 data.

Spawning stock biomass (SSB) was calculated as:

$$SSB_i = \sum_{j=3}^{15} N_{ij} W_{ij} P_j$$

where $N_{ij}$ is the abundance at age $j$ in year $i$ estimated by SPA or the mean number per tow at age $j$ in the research survey in year $i$, $W_{ij}$ is the mean weight at age $j$ in year $i$ and $P_j$ is the proportion of females mature at age $j$ (note that the same maturity ogive, calculated from data collected in July 1991-1995, is used in all years).

Recruitment $R$ was defined as the abundance of 3-yr old cod estimated by SPA or the mean number of 3-yr old cod per tow in the research survey. The rate of recruitment was calculated by dividing the number of recruits by the spawning stock biomass that produced them. This is often referred to as an index of pre-recruit survival, though we recognize that variation in this recruitment rate could reflect variation in characteristics of the spawning stock related to egg production (see Swain and Chouinard 2000) as well as variation in pre-recruit survival (see Swain et al. 2000). We also examined effects of SPA assumptions and calibration indices on the estimates of recruitment rate. SPA based on alternate assumptions are described by Sinclair et al. (1998).

The instantaneous rate of total mortality *Z* was estimated for moving 4-yr blocks using a modified catch curve analysis (Chouinard et al. 1999). This technique used analysis of covariance with *ln* survey catch rate as the dependent variable, yearclass as a class variable and age (7-11 yr) as a covariate The covariate slope provided the estimate of *Z*. SPA estimates of the instantaneous rate of fishing mortality *F*, averaged over ages 7-11 yr for the same 4-yr blocks, were also calculated to provide an indication of variation in fishing mortality.

Weight at age 6 yr was taken from Chouinard et al. (1999) to provide an indication of variation in growth rates. For 1960-1999, these weights were based on data from September research surveys. Annual length-weight relationships were estimated and applied to the length distributions at age 6 yr in each year. For earlier years, these weights were based on catches in the fishery.

## Results and Discussion

### *Trends in Spawning Stock Biomass, SSB*

Survey- and SPA-based trends in SSB correspond closely (Fig. 1). SSB collapsed to very low biomass in the mid-1970s, followed by a rapid recovery, despite continued fishing (minimum landing 26884 t in 1977). SSB declined again beginning in the late 1980s. Biomass reached very low levels in early 1990s, comparable to the levels seen in the mid-1970s. There has been little recovery from the recent collapse, despite a moratorium on directed fishing from September 1993 to the opening of a small ‘index’ fishery in 1998 (total landings of 2588 t in 1998).

### *Recruitment, R*

Both the survey and the SPA indicate a period of high recruitment from the mid 1970s to the mid 1980s (Fig. 2). The survey indicates that the 1985-1987 yearclasses were stronger than is estimated by the SPA. It is believed that these yearclasses were heavily discarded (Sinclair et al. 1996). This would lead SPA to underestimate their strength. Both the survey and the SPA indicate a decline to low levels of recruitment since the late 1980s.

### *Recruitment Rate, R/SSB*

The high levels of recruitment in the mid 1970s were produced by very low levels of SSB. Both the survey and the SPA indicate a period of remarkably high rates of recruitment in the mid to late 1970s (Fig. 3).

The survey indicates a decline in recruitment rate in the late 1970s to the level observed in the early 1970s. The survey estimates of recruitment rate have fluctuated around this level since then and do not currently appear to be unusually low, remaining in the range seen in the early 1970s and the 1980s.

The SPA (using the accepted formulation from Chouinard et al. 1999) indicates that recruitment rates remained high until the early 1980s when they declined to levels typical of those seen throughout the 1950s, 1960s and early 1970s. The SPA indicates a return to high recruitment rates in the 1990s, though not as high as the exceptional rates of the mid 1970s.

The SPA-based estimates of recent recruitment rates depend on the assumptions and calibration indices (Fig. 4). Traditionally, *M*, the instantaneous rate of natural mortality, has been assumed to be 0.2. The SPA making this assumption (1998 M02; Sinclair et al. 1998) yields a time trend in recruitment rate that is more like that obtained from the survey data. However, *M* appears to have been near 0.4 in recent years (see below). An SPA assuming an increase in *M* from 0.2 to 0.4 in 1986 (1998 Mup; Sinclair et al. 1998) suggests high recruitment rates in the early 1980s (unlike the survey data), but like the ‘traditional’ SPA and the survey does not indicate unusually high rates in recent years. Updating this model to 1999 (2000 Mup in Fig. 4) suggests that rate of recruitment has been moderately high throughout the 1990s, slightly above the maximum values seen in the 1950s and 1960s. Estimates of recent recruitment rates increase markedly if sentinel survey indices are included in the SPA calibration in addition to the research survey index (2000 SPA; *M* assumed to increase to 0.4 in 1986). In summary, both the survey-based analysis and all the SPA-based analyses indicate that the rate of recruitment was remarkably high in the mid-1970s and typical to high in recent years.

Most stock-recruit models assume that compensatory mechanisms result in reduced rates of recruitment (R/SSB) at high spawning stock biomass. Recruitment of southern Gulf cod appears to conform to this model (Fig. 5).

*Adult Mortality*

Chouinard et al. (1999) estimated *Z*, the instantaneous rate of total mortality, for ages 7-11 yr in moving 4-yr blocks. *Z* appeared to be relatively low in the mid 1970s and increased rapidly in the late 1980s as the fishery for southern Gulf cod intensified (Fig. 6). *Z* declined sharply in the early 1990s with the closure of the cod fishery. However, even though fishing mortality has been reduced to levels near zero, total mortality has remained unexpectedly high in recent years. This suggests that natural mortality of adult cod is currently at a high level. *M* appears to have been near 0.4 in recent years, double the value traditionally assumed for adult cod in the Northwest Atlantic, and much higher than the values that must have prevailed throughout the 1970s (given the estimates of *Z* and *F* for this period).

*Growth Rates*

Size at age has varied widely for southern Gulf cod (e.g., Fig. 7). Mean weight of 6-yr-old cod was high in the 1950s, but declined to relatively low levels in the early 1960s. Weight at age 6 returned to high levels from the late 1960s to the late 1970s. Then weight at age 6 declined steeply to a record low level by 1985. It has remained near this record low level since then.

*Conclusions*

The recruitment rate of southern Gulf cod has not been unusually low in recent years. Instead, it appeared to be remarkably high during the previous collapse of this stock in the mid1970s. The period of high recruitment in the mid 1970s coincided with the collapse of herring and mackerel stocks in the southern Gulf, and the high rate of recruitment during this period can be explained by a negative effect of these pelagic fishes (potential predators of cod eggs and larvae) on cod pre-recruit survival (Swain et al. 2000).

Although much lower than the remarkable recruitment rates that fueled the rapid recovery in the 1970s, recruitment rates appear to be currently near or above the levels that persisted throughout the 1950s, 1960s and early 1970s. Why then has recovery been so slow? Changes in spawning stock biomass also depend on growth rates and adult mortality rates. These appear to have differed between the collapses of the 1970s and 1990s. Growth rates were fast in the 1970s and slow in the 1990s. Natural mortality of adult cod in the 1990s appears to be double the 1970s rate. Given the current slow rates of growth, it appears that 'average' rates of recruitment are only able to replace the biomass removed by the current high rate of natural mortality.

The relative effects of the differences in rates of recruitment, growth and adult mortality on the difference in recovery rate between the 1970s and the 1990s can be demonstrated by a simple simulation (Fig. 8). We simulated changes in SSB assuming (1) the weights at age from either the mid 1970s or the early 1990s, (2) a recruitment rate (R/SSB) of either 2.0 (the peak in the mid 1970s) or 0.5 (near estimates for the early 1990s and above the average between 1950 and 1970), and (3) a natural mortality rate of either 0.2 (rate assumed for the 1970s) or 0.4 (near the apparent rate in the 1990s). Increases in recruitment rates or in adult growth rates or decreases in $M$ to the levels seen in the mid1970s would all result in similar growth in SSB (Fig. 8). At the current slow growth rate, an average rate of recruitment can only replace the spawning stock biomass lost to natural mortality with $M$ at a high level of 0.4 (Fig. 8).

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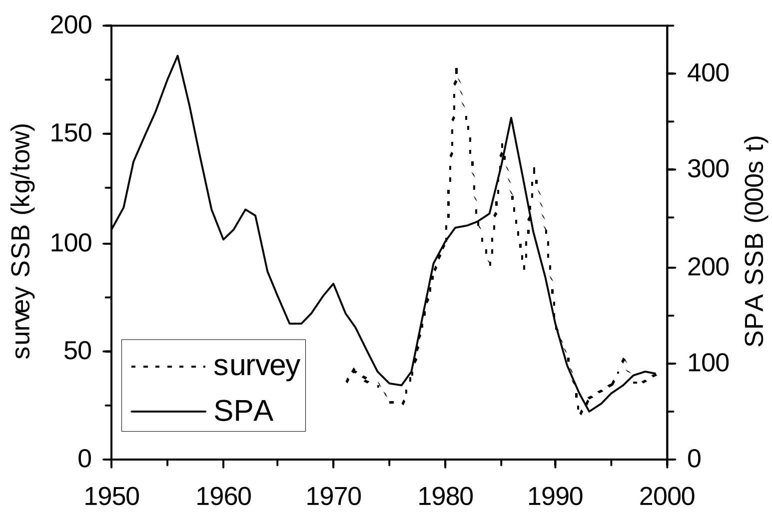


Figure 1. Trends in spawning stock biomass (SSB) for southern Gulf of St. Lawrence cod, based either on catch rates in the annual research survey or on SPA estimates of abundance.

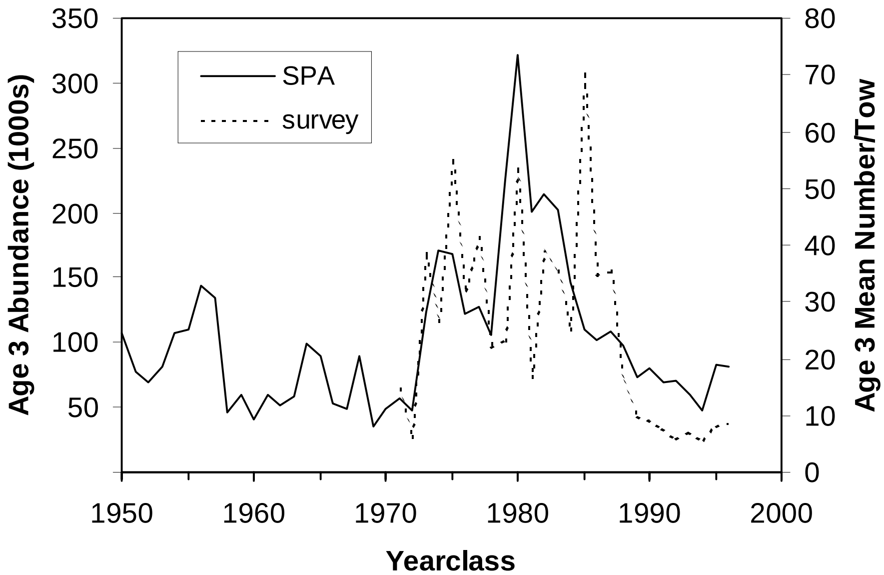


Figure 2. Recruitment of southern Gulf of St. Lawrence cod, based either on catch rates in the annual research survey or on SPA estimates of abundance.

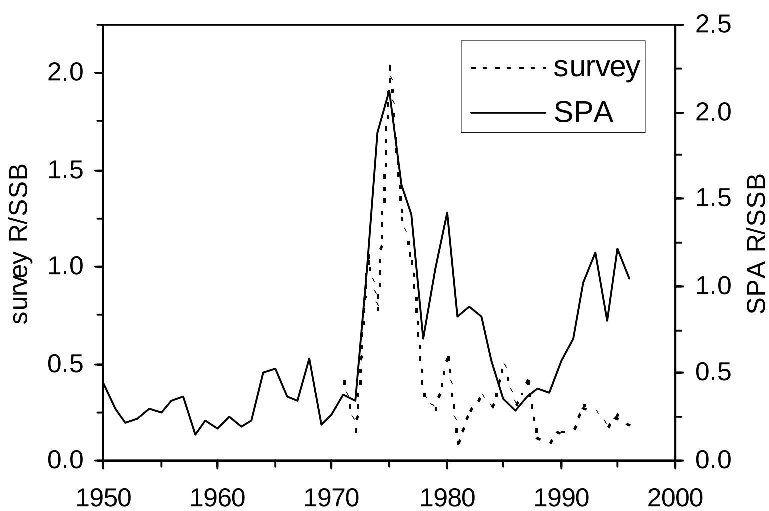


Figure 3. Recruitment rate of southern Gulf of St. Lawrence cod, based either on catch rates in the annual research survey or on SPA estimates of abundance. The SPA is based on the model in Chouinard et al. (1999), updated to include 1999 data.

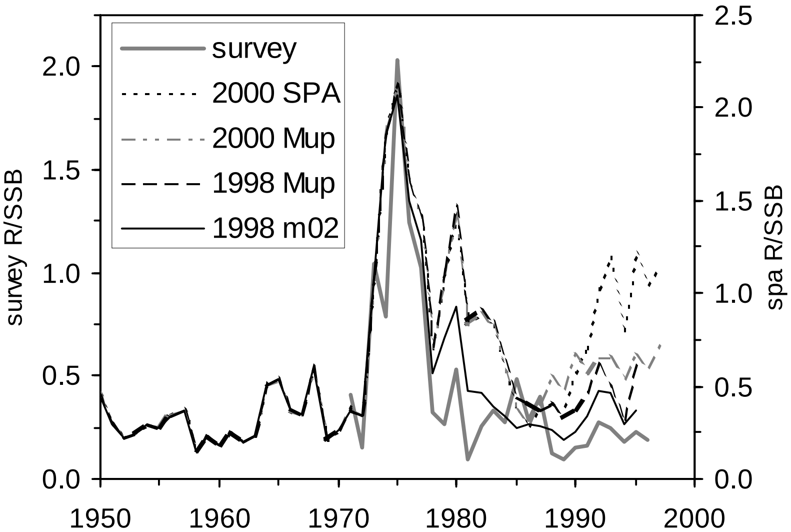


Figure 4. Recruitment rate of southern Gulf of St. Lawrence cod, based either on catch rates in the annual research survey or on SPA estimates of abundance. Results are shown for different SPA models: 1998 m02 – *M*=0.2 in all years, calibrated with research survey catch rates (from Sinclair et al. 1998); 1998 Mup – *M* increases from 0.2 to 0.4 in 1986 (from Sinclair et al. 1998); 2000 Mup – same as previous but updated to 1999; 2000 SPA – same as previous but calibrated with sentinel survey and fishery catch rates as well as with the research survey (see Chouinard et al. 1999).

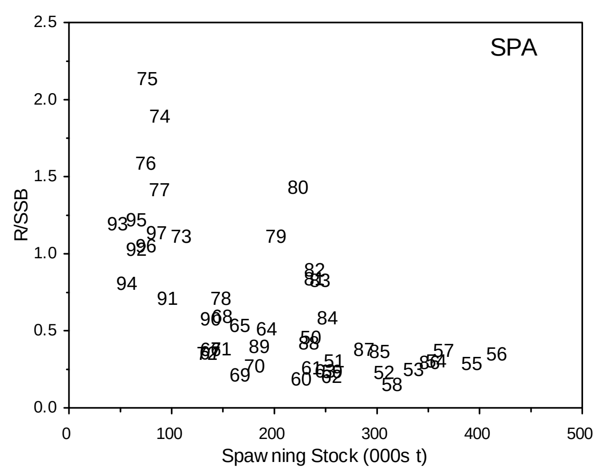


Figure 5. Relationship between spawning stock biomass and recruitment rate of southern Gulf cod. Data from SPA (following the model in Chouinard et al. 1999).

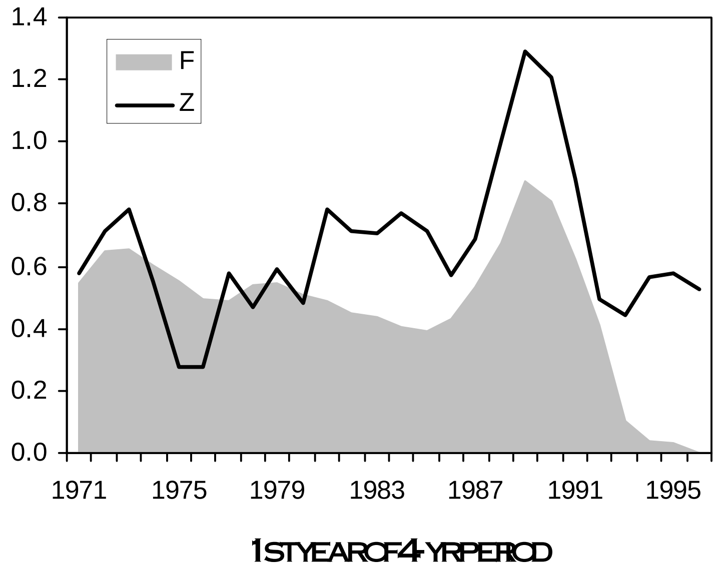


Figure 6. Rates of total (*Z*) and fishing (*F*) mortality estimated in 4-yr moving blocks for southern Gulf cod aged 7-11 yr. *Z* is estimated from research survey data as described by Couinard et al. (1999). *F* is from SPA.

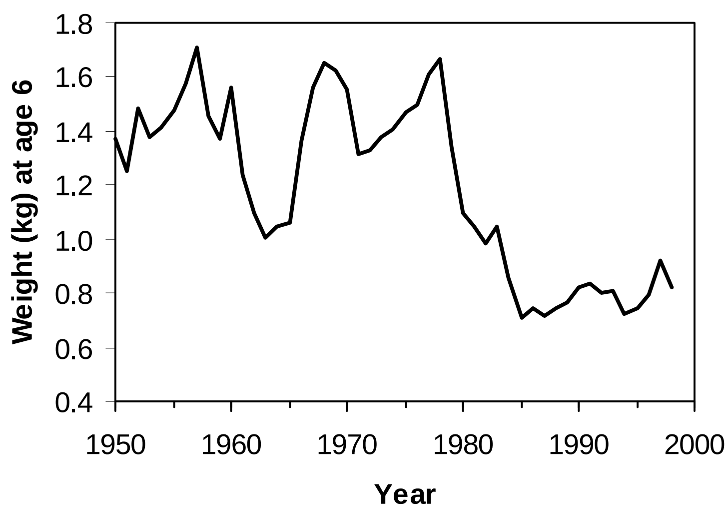


Figure 7. Mean weight of 6-yr-old cod in the southern Gulf of St. Lawrence.

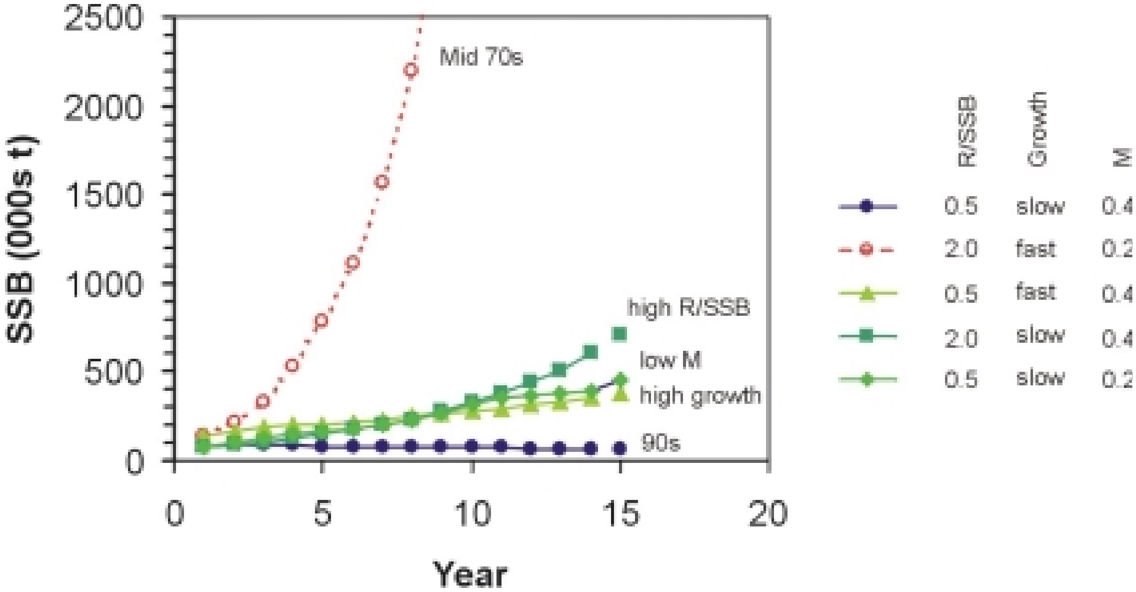


Figure 8. Simulated changes in spawning stock biomass, assuming rates of recruitment, growth and adult natural mortality like those in the mid 1970s (R/SSB=2.0, growth=fast, $M$=0.2) or the early 1990s (R/SSB=0.5, growth=slow, $M$=0.4).