Fisheries and Oceans Canada
Pêches et Océans Canada

Canadian Stock Assessment Secretariat
Research Document 98/08

Secrétariat canadien pour l'évaluation des stocks
Document de recherche 98/08

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Assessment of Cod in the Southern Gulf of St. Lawrence, January 1998

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ISSN 1480-4883
Ottawa, 1998
Canada

Abstract

The southern Gulf of St. Lawrence cod stock was in a state of rapid decline in abundance and biomass in the early 1990s, and this decline was halted by the closure of the commercial fishery in September 1993. Since then, population biomass has remained low, close to the lowest seen since 1950. Recruitment has been well below the historical average and there is no sign of improvement. While there is a significant standing stock, its rate of production is very low due mainly to the paucity of recruitment. Post moratorium estimates of total mortality from research survey results indicate that the natural mortality rate of this stock is in the range of 0.4 - 0.5, more than twice that traditionally assumed. Goodness of fit tests of an SPA calibration and changes in size at age indicate that M may have increased in the mid-1980s. Catch projections based on population estimates assuming the traditional value of natural mortality (0.2) indicate that the spawning stock biomass may increase by about 5% if there is no catch in 1998. However, if natural mortality is as high as the survey results suggest, the stock may decline even if there is no catch in 1998. Improved recruitment is essential for this stock to recover. At present there is no evidence to suggest that this is happening. Given that recruitment estimates are available for age 2 cod, that they recruit to the fishable population at age 5, and that it will take a few good year-classes to fuel a recovery, the indications are that commercial stock abundance (age 5+) will not recover for several years.

Résumé

Tant l'effectif que la biomasse du stock de morue du sud du golfe du Saint-Laurent déclinaient rapidement au début des années 1990 et ce déclin a été stoppé par la fermeture de la pêche commerciale en septembre 1993. Depuis lors, la biomasse est demeurée faible, se rapprochant de la valeur la plus faible notée depuis 1950. Le recrutement a été bien en deçà de la moyenne historique et il y a absence d'indice d'amélioration. Bien que le stock actuel soit appréciable, son taux de production est très faible, surtout à cause de la pauvreté du recrutement. Les estimations, faites après le moratoire, de la mortalité totale à partir des résultats des relevés de recherche indiquent une mortalité naturelle de l'ordre de 0,4 - 0,5, soit plus que le double de la valeur antérieurement supposée. La validité de l'ajustement d'un étalonnage par ASP et les variations de taille selon l'âge indiquent que la valeur de M a pu s'accroître au milieu des années 1980. Les projections des captures basées sur des estimations de population fondées sur la valeur antérieurement utilisée pour la mortalité naturelle (0,2) montrent que la biomasse du stock de géniteurs pourrait s'accroître de 5 % environ en l'absence de captures en 1998. Mais si la mortalité naturelle est aussi élevée que le laissent supposer les résultats du relevé, le stock pourrait bien diminuer même en l'absence de pêche en 1998. L'augmentation du recrutement est essentielle au rétablissement de ce stock. Nous ne disposons actuellement d'aucun indice d'une telle situation. Comme nous possédons des estimations du recrutement pour les morues d'âge 2, que ces poissons peuvent être capturés à l'âge 5 et qu'il faudra quelques bonnes classes d'âge pour alimenter un rétablissement, il apparaît que le stock commercial (âge 5+) ne sera pas rétabli avant plusieurs années.

1. Introduction

Southern Gulf of St. Lawrence cod are highly migratory. Spawning occurs in the Shediac Valley and around the Magdalen Islands from late April to early July. During the summer, the cod are widely distributed in the southern Gulf while they feed heavily on krill, shrimp, and small fish, primarily herring, American plaice, and capelin. The fall migration begins in late October with cod first leaving the areas off Gaspé and Chaleur Bay, becoming concentrated off western Cape Breton and then moving into 4Vn in mid-November. The stock overwinters in 4Vn and northern 4Vs, along the edge of the Laurentian Channel. The return migration begins in mid-April, although in some years (1991-1992) this was delayed by the late breakup of the winter ice. The management unit for this stock originally included all of 4T and catches in 4Vn during January-April. However, it was recently recognized that a substantial part of the stock migrates into 4Vn in November and that by January significant catches were being made in northern 4Vs. As a result the management unit and the stock assessment data were modified to include all of 4T, catches in 4Vn during November-April, and some catches in 4Vs in January-April (Sinclair et al. 1994).

Southern Gulf of St. Lawrence cod are relatively long lived, and may reach ages of 20 or more when mortality is low. They begin to reach commercial size at age 4, and are fully available to the commercial fishery by age 7. They mature sexually at a size slightly below the commercial size of 41 cm.

The stock has been exploited since the 16th century. Landings varied between 20,000 - 40,000 t annually between 1917-1940, and then increased to a peak of over 100,000 t in 1958 (Fig. 1). The fishery was primarily prosecuted with hook and line until the late 1940s, when a ban on otter trawling was lifted. Landings remained relatively high in the 1960s and early 1970s, in the range of 60,000 t. TACs were first imposed in 1974, and these became restrictive as the stock declined in the mid-1970s. The stock recovered somewhat, and landings returned to the 60,000 t range during the 1980s. During the 1980s, the fixed gear fishery declined drastically, and the fishery was mainly prosecuted by mobile gear until it was closed in September 1993, due to low abundance.

2. Description of the 1997 Fishery

Directed commercial fishing of the 4TVn (N-A) cod stock continued to be prohibited in 1997. Although fisheries for American plaice, witch flounder, winter flounder, yellowtail and dogfish were permitted in NAFO Division 4T, these were subject to a number of management measures designed to limit cod by-catch. Provisions were made for a 4TVn (N-A) cod catch of up to 2000 t in 1997. A recreational fishery using hook and line gear was allowed. The sentinel survey, which is conducted under a scientific protocol and designed to obtain additional indices of abundance of the stock, was expanded. Experimental fisheries, comprised of all gear types except handlines, were also carried out in 1997. In this section, a summary of landings, management measures and input from industry on the status of the southern Gulf of St. Lawrence cod stock in 1997 is provided.

2.1 Landings by gear, area, season, fishery type

The estimated total landings of southern Gulf cod in 1997 was 1591 t (Table 1). This includes 445 t of by-catch from other commercial fisheries, 290 t reported from experimental fisheries in quota reports, 538 t estimated by fisheries observers in the sentinel surveys, plus 318 t from recreational fisheries, an estimate obtained from fishery officers and compiled by the DFO Fisheries Management Branch (G. Bernard, pers. com.). The by-catch, experimental, and sentinel survey catches are supported by purchase slip and observer reports. Unfortunately, the landings by sentinel survey vessels are not yet incorporated in the DFO catch and effort statistics from all regions, thus necessitating the use of observer estimates. There is very little hard evidence to support the estimated recreational catch and steps need to be taken to get a better idea of the removals from this sector. In addition, the recreational catch estimate was received too late to incorporate into the data used in the analytical assessment (i.e. catch at age). Consequently, the recreational catch estimates are not included in the landings tables or catch at age tables presented in this document while the by-catch, experimental and sentinel survey catches are.

The 1997 total landings were higher than that reported for 1996 (1142 t), but represents one of the lowest catches on record for this stock (Figure 1). Landings were entirely from NAFO Division 4T except for 12 kg reported from 4Vn in the period of January - April. Landings increased in 1997 for all gear types except otter trawls which indicated a 52 t decrease (Table 2). Although Table 2 would suggest a decline in handline catches, it does not include the recreational fisheries, noted above. It should be noted that these are preliminary statistics which will be updated when final estimates are available.

Monthly landings peaked in August due in part to the sentinel surveys. This trend is contrary to the traditional pattern with peaks in January (in 4Vn), April and November (in 4T). Landings by fixed gears occurred predominantly in August and September.

2.2 Management measures

The Fisheries Resource Conservation Council (FRCC) recommended that the southern Gulf cod fishery be reopened in 1997 with a TAC of 6000 t (FRCC.96.R.2, October 1996). During subsequent consultative meetings it became apparent that there were concerns within the fishing industry that a 6000 t TAC might adversely affect stock recovery and there was also considerable disagreement among the fleet sectors on how the TAC would be shared. Following these meetings and discussions, the Minister of Fisheries and Oceans announced that the southern Gulf cod fishery would not reopen but a precautionary quota of 2000 t was set to cover by-catch, sentinel surveys, and experimental projects (Press Release, NR-HQ-97-22).

There were some modifications to management measures in 1997, partially in response to the 2000 t quota. DFO maintained the by-catch limits of cod in fisheries directed toward other species, but the limit was increased from 10% to 25% by weight in order to allow the fleets to take their by-catch allocations. The minimum mesh size for American plaice was increased to 155 mm square. Small fish protocols were maintained whereby fishing was closed if the percentage of small fish caught exceeded specific thresholds. The minimum fish sizes agreed to by the industry were the following:

- 30 cm for American plaice
- 45 cm for white hake
- 25 cm for winter flounder and yellowtail
- 41 cm for cod

As in previous years, a fleet sector would be closed if it exceeded its by-catch or small fish protocols. An optional provision was made to close individual vessels if their fishing activities appeared particularly abusive. The number of fishery closures in 1997 was much lower than in previous years, mainly due to the increased by-catch limits and increased mesh size.

2.3 Input from industry

The pre-assessment consultation comprised a series of Science Workshops, designed to obtain the views of industry on the status of the stocks. These were held throughout the southern Gulf of St. Lawrence in November 1997. The meetings were held in Grande Rivière, Cap-aux-Meules, Caraquet, Charlottetown, and Port Hawkesbury. Scientists presented a preliminary description of the 1997 fishery, results of the September 1997 fall groundfish survey, and results from sentinel surveys. Fishers were then invited to provide comments on these data and indicate whether or not this was consistent with their view of the stocks.

In Port Hawkesbury, fishers were of the opinion that cod abundance was high; however, attendance at the meeting was poor. The P.E.I. fishers felt that the abundance of cod was very high, especially on the north shore of the island. There was a split in opinion on the Magdalen Islands, with one-half of the participants indicating favorable cod abundance and the other half, low abundance. In Caraquet, the participants felt that there had been a slight increase in abundance in 1997; conversely, the Gaspé fishers all agreed that the abundance was at a low point.

2.4 End of season telephone survey

A telephone survey of fishers active in the 1997 groundfish fishery in the southern Gulf was conducted from Nov. 17 to Dec. 19, 1997 (Hurlbut and Stevens 1998). The primary purpose of the survey was to obtain their views and opinions on groundfish abundance for inclusion in stock assessments.

Interview subjects were selected from a list of all southern Gulf purchase slips received and processed by Nov. 1, 1997 (328 fishers were identified from New Brunswick, Nova Scotia, Prince Edward Island and Quebec). Of these, 172 were successfully interviewed. Twenty-eight respondents directed for cod in 1997 to some extent (i.e., first, second or third priority), with 13 fishers indicating cod as their first priority (nine participated in the 1997 sentinel fishery). As well, seven respondents directing for cod fished in the recreational fishery. The 28 respondents who fished for cod 'most of the time' in 1997 were distributed on the Gaspé Peninsula (12), northern NB (3), PEI (2), Gulf shore of Cape Breton (5) and the Magdalen Islands (6). The majority fished with fixed gears (11 gillnets, 11 longlines, 3 seines, 3 otter trawls).

When asked for their opinion concerning the abundance of cod in the southern Gulf in 1997, the respondents indicated conditions were somewhat better than average. Eight of the 28 fishers indicated abundance to be low or very low, seven felt it was average, and 13 considered it to be high or very high. The 13 respondents who identified cod as their first priority in 1997 were asked to compare its abundance in 1997 to that of 1996, and to all previous years. Five fishers described the 1997 cod abundance as higher or much higher than in 1996, three indicated it was the same, and two felt the abundance was the same or lower (three respondents did not fish cod in 1996). In comparing the abundance of cod in 1997 to that of all the years they had fished for cod, eight of the 13 fishers stated cod abundance was higher or much higher, one thought it was the same, and four were of the opinion that the 1997 abundance was lower or much lower.

3. Age Determination

Consistency of age determinations was verified by regular blind readings of a reference otolith collection. Tests were performed after each 1000 fish had been aged. The level of agreement with the reference collection was high with no bias detected (see below).

Date	% agreement	direction of bias
Reader # 1		
970716	84	0
970801	84	0
971104	84	0
971114	81	0
971204	85	0
Reader #2		
980109	88	0

Nevertheless, comparisons of readings by the 2 agers revealed a difference in interpretation of otoliths from age 0-2 cod from the September survey. Re-calibration tests were performed and it was decided that these otoliths should be re-read by reader 2 because of a closer agreement with the reference collection and with historical size at age data for these ages.

4. Commercial Fisheries Data

4.1 Catch at Age

The calculation of the 1997 commercial catch at age was complicated by the limited fishery, which has been the case since 1994, and the fact that not all landings and samples for the fourth quarter were available. Due to time constraints, only fish caught in the second and third quarter sentinel, observer and port samples were aged. Assuming that the age composition is the same for fish caught in the fourth quarter, the calculated catch at age was prorated to include the fourth quarter landings. The recreational fishery catch estimate was received too late to incorporate into the catch at age.

Similar to last year, it was necessary to use aging material collected during the sentinel surveys to augment the commercial and observer samples. Catch at age was estimated separately for the sentinel survey and commercial landings because of differences in fishing gear, seasons, and areas. We included all second and third quarter observer commercial length frequencies collected by the Gulf and Quebec region observer programs to estimate the size composition of commercial landings. Observer samples are collected on a set-by-set basis while commercial port samples are collected on a trip-by-trip basis. The set-by-set observer samples were weighted to the catch in the set, then combined within trips and weighted to the observer estimate of trip catch. Observer and port sample trips were combined and weighted to the total landings in the period/gear. A summary of the sampling data used in constructing the 1997 catch at age is given in Table 3.

The following length (L in cm)-weight (W in grams) relationship was obtained from the September 1997 research vessel survey and was used to calculate mean weights at age

$$W = 0.004607 * L^{3.1759}$$

The numbers landed, mean weights at age, and mean lengths at age for each age-length key are presented in Tables 4 to 6.

The total number of fish landed in 1997 was the lowest on record (Table 7). The modal age in the 1997 landings was 9 (1988 year-class) but relatively large numbers of age 5 - 10 were landed. Commercial weights at age have increased moderately since the early 1990s, but are still low relative to the historical time series (Table 8 and Fig. 2). The commercial weights at age have been somewhat higher than those in the research vessel survey since the closure in 1993. This is likely the result of a higher proportion of the landings coming from fixed gears which tend to catch larger fish at age (see also Table 5).

5. .Research Data

5.1 September 1997 survey

A stratified random groundfish survey of the southern Gulf of St. Lawrence has been conducted annually in September since 1971. Three survey vessels have been used, the *E.E. Prince* from 1971-1985, the *Lady Hammond* from 1985 - 1991, and the *Alfred Neeedler* from 1992 to the present. The *E.E. Prince* fished 12-hour days and used a Yankee 36 trawl, while the other 2 vessels fished 24-hour days and used a Western IIA trawl. Comparative fishing experiments were conducted each time the vessel changed and conversion factors have been applied where necessary (Nielsen 1989, Nielsen 1994, Swain et al. 1995). Catches by the *E.E. Prince* were multiplied by 1.3 to make them comparable with the rest of the time series and there was a depth-dependent correction applied to the results of the *Lady Hammond* missions. In addition, a series of 13 fixed stations were occupied between 1971 - 1987. These have been incorporated into the time series, along with the comparative fishing stations occupied during the 1985 survey (Nielsen 1995). When the survey was conducted aboard the *E.E. Prince*, 61 to 70 stations were occupied each year. Now, with 24-hour fishing operations, between 180 to 230 fishing sets can be made. The original survey design included 24 strata which cover over 95% of the southern Gulf. Three inshore strata were added in 1985 (strata 401, 402, and 403) to increase coverage of white hake and inshore flounder habitat. Catches of cod in these strata are small and the results are not included in the abundance index.

The 1997 survey was conducted from September 3-26 (Chouinard et al. 1997). A total of 214 successful fishing sets were made (Fig. 3). The stratified mean numbers per tow for all ages (0+) was 52.85 (Fig. 4) which is the lowest value observed since 1975. This index of population abundance has remained at a very low level since 1992. The catch rate in mean weight per tow also declined from 57 kg/tow in 1996 to 44 kg/tow in 1997. This index is also low compared to the historical time series. Both the mean numbers and mean weight per tow indices suggest the stock is at a level comparable to the early 1970s, at a time when the stock was considered to be in a severely depressed status.

The age-based indices presented here are preliminary. The otolith collection had to be subsampled, due to time constraints. Random samples up to a maximum of 25 otoliths per 1 cm length interval were taken. This resulted in approximately one third of the otoliths being read in time for the assessment. Aging will be completed and revised estimates of the mean catch per tow at age will be presented in the subsequent assessment. The total mean numbers per tow and mean weight per tow will not be affected by this subsampling procedure.

A qualitative examination of the mean numbers per tow at age in the 1997 survey indicates that abundance is low at all ages, comparable to that of year-classes spawned in the early 1970s (Table 9). Age 5 (the 1992 year-class) was the modal age in the survey, and the age range was relatively broad. Coefficients of variation of the estimated mean numbers per tow at ages 5+ have usually been below 20% (Table 10). The values for 1997 were higher than 20% due mainly to a large catch close to the edge of the Laurentian Channel.

A comparison of the length frequency distributions of cod shows that recent year-classes are much smaller than those that promoted the last recovery of the stock (1977 - 1981, Fig. 5). The stock was at very low abundance in 1977; however, there were two modes less than 40 cm in the length frequency distribution, indicating good recruitment. This was followed by another good year-class at age 2 in 1979, and these led to an increase in adult fish abundance. In contrast, data from 1993-1997, since the fishery closure, show no strong modes at lengths less than 40 cm, and adult abundance remains low. These results indicate that recruitment to the stock remains low and is probably inadequate to rebuild the stock.

Weights at age estimated during the 1997 survey are at the low end of the range observed since 1960; however, there appears to be an increasing trend over the recent past for ages 4-9 (Table 11, Fig. 2). RV lengths at age are given in Table 12 and these show similar trends to the weights at age in the survey. However, there appears to have been a greater increase in the commercial weights at age. This is probably due to the commercial catches being dominated by fixed gear catches to a greater extent than before the moratorium. Fixed gears tend to catch larger fish at age than mobile gear.

5.2 Cod condition

5.2.1 Seasonal index

Cod condition in the southern Gulf of St. Lawrence has been monitored on a regular basis since September 1991. Ideally, samples were to be collected on a monthly basis; however, since the fishery closed in September 1993, samples have not always been available. Nevertheless, it has been possible to collect sufficient samples to be able to characterize the annual cycle of cod condition.

Sampling for monitoring cod condition consists of 130 fish (5 fish/cm for fish 35 to 60 cm). For the stock, the fish were collected from the main areas of concentration. Because of the migratory nature of the southern Gulf cod stock, samples were taken in 4Vn during winter, in 4Tfg (western Cape Breton shore) in early spring and late fall, and from 4Tklm (Gaspé coast - eastern N.B.) during June to September. The fish were kept on ice and/or temporarily frozen and then dissected in the laboratory where individual body components (liver, stomach, gonad, intestinal track, etc.) were weighed.

For the seasonal monitoring, the Fulton's condition factor (K) is used:

$$K = \alpha \frac{W}{L^3}$$

where W = carcass weight (g) which is defined as the total weight less stomach and gonad,
L = fork length (cm)
α = 100, a scaling factor to control the number of decimals

Dutil et al. (1995) showed that Fulton's condition factor can be dependent on fish size for southern Gulf cod. For example, in September 1997 (Fig. 6) , smaller cod less than 40 cm tended to have a lower condition index. As well, larger cod (>60 cm) tended to have a higher condition index. Previous analyses indicated that for the most part, condition of fish in the 40-50 cm range is independent of size and consequently only fish in this length range were used in the calculation of the condition index. Samples were length-stratified and this resulted in samples of up to 55 fish uniformly distributed over the length interval. Dutil et al. (1995) suggested that samples of 30 fish are desirable to monitor condition.

During 1997, samples were obtained for the months of January, February and June to November. Laboratory analysis is ongoing but has been completed for samples collected up to August.

A distinct seasonal cycle is evident in the Fulton's condition index (K), being low in the spring, before and during spawning, and reaching a maximum in the late fall (Fig. 7). Generally, the condition of cod in the fall is 25- 40% higher than that in the spring. Condition was lowest in 1992, as well as during the winter and spring of 1997 for the period examined. Although condition was low until June in 1997, condition increased markedly in both July and August. Condition of cod in August 1997 was comparable to that of previous years.

5.2.2 Annual Index

Monitoring condition using one annual value can present problems of aliasing (see Dutil et al. 1995) and as such may not be reliable for detecting trends in condition. Despite this potential problem, cod condition has also been calculated on an annual basis from data collected during the annual groundfish research vessel survey. In this index, round weight for cod 40 to 50 cm are used in the calculations of K using the equation presented previously.

Another measure of annual condition is the predicted weight of a 45 cm cod calculated from annual length-weight relationships derived from the research vessel data:

$$W_{45} = aL^b$$

where W_{45} = predicted weight for a 45 cm fish
a and b = parameters of the length-weight relationship
L = length of fish (here 45 cm)

These two condition indices suggest relatively similar trends since 1971(Fig. 8). It would appear from this information that cod condition was higher in the early 1970s, declined to lower levels in the late 1970s and early 1980s and is presently at intermediate levels over the time series. As indicated previously, because of potential aliasing these results should be viewed with caution.

6. Analysis Methods and Results

6.1 Analysis of RV Data

We have been developing analytical methods that can be used on the research vessel survey results alone over the past several years. Traditional analytical stock assessments have used the RV indices to calibrate sequential population analyses (SPA) of commercial catch at age data; essentially, the survey results were given less weight in the assessment than the commercial data. However, in the late 1980s, SPAs were considered problematic due to apparent biasing of the results as shown by worrisome retrospective patterns (Sinclair et al. 1991). Possible causes for these patterns are changes in the rate of catch reporting, non-stationarity in the survey catchability, and changes in natural mortality. This prompted us to develop analytical methods which could be used on survey results alone, and be less subject to errors because of incorrect assumptions.

6.1.1 Multiplicative Analyses

The RV mean numbers per tow at age were analyzed with a multiplicative model to obtain information on relative year-class abundance and trends in total mortality in the pre-recruit ages. The model was

$$\ln A_{ij} = \beta_0 + \beta_1 \mathbf{I} + \beta_2 \mathbf{J} + \varepsilon$$

where A_{ij} = the RV index at age i and year-class j
$\mathbf{I}$ = a matrix of 0 and 1 indicating age
$\mathbf{J}$ = a matrix of 0 and 1 indicating year-class

Sinclair et al. (1995) reported that the southern Gulf RV survey gave consistent estimates of relative year-class strength for cod beginning at age 2 and continuing to age 12. Survey results for two groups of ages, 2-3 (pre-recruit ages) and 4-6 (recruiting ages) were analyzed separately. The analyses did not include one large set in 1995 (set 127) in which about 6600 small cod were taken. Previous analyses indicated that this result was anomalous and produced an unreliable estimate of year-class abundance (Sinclair et al. 1997). The main effect vector for year-class (β_2) was interpreted as an index of relative year-class strength. The difference between the year-class effects estimated for the two age groups was interpreted as an index of total mortality of the respective year-classes. Inter-year-class differences in the mortality index were interpreted as differences in total mortality (see Sinclair et al. 1995 for details).

The main effects in the two analyses were statistically significant (Table 13) and the assumption of normal distribution of residuals was not violated.

The trend in relative year-class strength from the age 2-3 and age 4-6 analyses indicates similar patterns in recruitment (Fig. 9). The year-classes in the early 1970s were of low abundance. The estimates then increased to high values in the late-1970s reaching a maximum for the 1980 year-class. Recruitment indices remained high through the mid-1980s, then declined to low values in the 1990s. The age 2-3 index in 1997 (the 1995 year-class) was somewhat higher than others from the 1990s, suggesting a modest increase in recruitment. However, the value is still well below average. The main difference between the two analyses was in the estimates for the 1985-1987 year-classes. The age 2-3 indices suggested these year-classes were above average in abundance, and similar to those from the early 1980s and late 1970s. The age 4-6 indices, however, suggested that these year-classes were about average.

The trend in total mortality between ages 2-3 and 4-6 is similar to that reported last year. The estimate of relative Z for the 1992 year-class is the lowest in the time series (Fig. 10). This is now followed by a relatively high value for the 1993 year-class, the new observation this year. This trend might change as more information on the year-class is collected at age 5 in 1998, and age 6 in 1999. The difference in the relative Z indicates that the 1985-1987 year-classes experienced, on average, a total mortality 1.75 times greater than the three previous and four following year-classes. In the normal scale, this suggests that only half as many of them survived the recruitment phase as did the year-classes before and after. This trend is likely due to high fishing mortality and discarding of undersized fish, and is unlikely to reflect adverse environmental conditions or predation by seals (Sinclair et al. 1995).

6.1.2 Direct Estimates of Relative F

Sinclair (1998) described a new method for examining trends in fishing mortality using a relative index obtained from the ratio of catch at age divided by the RV population estimates at age. Provided that the survey index is taken close to when the population is at its average abundance for the year, these relative fishing mortality estimates are not affected by changes in natural mortality. The trends are affected, however, by changes in the rate of catch reporting and changes in survey catchability. The analysis was repeated here with the current data.

The relative fishing mortalities were high in the early 1970s, followed by a decline at the time of extended fisheries jurisdiction in 1977 (Fig. 11). The relative F was stable in most of the 1980s, but increased beginning in 1988 until a peak in 1992. With the closure of the cod fishery in September 1993 the relative F dropped to the lowest level previously seen and with the continuance of the closure, the relative F declined further in 1994 and 1995, and remained low in 1996.

6.1.3 Total mortality

The closure of the cod fishery in the southern Gulf of St. Lawrence, and the fact that there is a reliable research vessel (RV) survey of the stock, has provided a unique opportunity to directly estimate the instantaneous rate of natural mortality (M) of a commercial cod stock. The fishery was closed in September 1993, and there have been 5 abundance surveys since then. The survey covers over 95% of cod habitat in the area, has relatively low annual CVs and high correlations in year-class estimates among years. During this same period, annual catches of cod in other fisheries (either commercial fisheries for other species, the cod sentinel survey, experimental or recreational fisheries) have been restricted to below 1,600 t, compared to annual landings in excess of 40,000 t prior to the closure. This, and the pattern of relative F shown above, indicate that F has been negligible and most of the post moratorium total mortality may be attributed to natural causes.

A modified catch curve analysis was used to estimate total mortality using RV survey results. The model was an analysis of covariance;

$$\ln A_{ij} = \beta_0 + \beta_1 \mathbf{Y} + \beta_2 I + \varepsilon$$

where Aij = the stratified mean catch per tow of age i in year j
Y = a matrix of 0 and 1 indicating year-class Y
I = the covariate age

The slope parameter, β_2, is an estimate of total mortality. The inclusion of **Y** is to account for variation in year-class strengths, and the parameters $\boldsymbol{\beta}_1$ are separate intercepts for the year-classes. Separate analyses were performed on a 4-year moving window. Ages 7 - 11 were selected based on examination of residual patterns from preliminary analyses. The criterion for selecting the age range was to minimize the variation of residuals with respect to age. A convex pattern would indicate that not all ages were experiencing the same level of total mortality. The time trend in total mortality was not affected by the selected age range. Within a 4-year window, only year-classes which had 2 or more estimates were included. These analyses are not independent, of course, given that there are 3 years of data overlap between adjacent windows.

The trend in total mortality corresponds to the fishing history of this stock. Total mortality started out at a relatively high value in the early 1970s when it is thought that the stock was heavily exploited by Canadian and foreign fisheries. With the extension of fisheries jurisdiction in 1977, the rate of fishing declined and this is reflected in the total mortality estimates which reached a minimum of close to 0.25 in the periods 1975-1978 and 1976-1979 (Fig. 12). Total mortality increased subsequently and varied between 0.6 - 0.8 throughout the mid-1980s. There was then a rapid increase in total mortality as the fishery intensified in the late 1980s and early 1990s. Total mortality then declined sharply when the fishery was closed, however, not to as low a level as in the mid-1970s.

The last two periods of the analysis comprise years since the fishery closure. The estimates of total mortality for these periods were 0.44 and 0.57, respectively. Allowing for the fact that there have been limited catches of cod since the closure, this indicates that natural mortality has been in the range of 0.4 to 0.5 in these years. That recent values of total mortality have been higher than those in the mid-1970s indicates that natural mortality may have increased. This is also indicated by changes in size at age, where year-classes produced since 1973 have lower L_∞ and higher k values than those produced before (A. Sinclair, unpublished data).

6.1.4 Trends in spawning stock biomass and recruitment

The groundfish surveys provide fishery independent indices of spawning stock biomass and recruitment. These are presented here and may be compared to similar estimates from SPA. Recruitment estimates were obtained from the re-transformed ln estimates from the multiplicative analysis of ages 2 and 3 survey results (earlier section). Spawning stock biomass was estimated from the survey estimates of mean weight (kg) per tow at age multiplied by a single maturity ogive obtained from July surveys conducted in 1990-1995 (Table 21). While it is preferable to use annual maturity ogives, these were not available for this assessment. Examination of the maturity determinations from the September surveys revealed difficulties in distinguishing resting spawners from immature fish at that time of year (Trippel et al. 1997). July is closer to the spawning period and provides more reliable maturity determinations.

The scatter of spawning biomass and recruitment suggests a weak relationship, albeit with some exceptions (Fig. 13). The 1975 and 1977 year-classes were the second and third largest in the time series, but were produced from a relatively low spawning biomass. Similarly, the 1988 and 1989 year-classes were small, but came from relatively large spawning biomass. With the exception of these 4 points, all year-classes produced from a spawning biomass index of 75 kg/tow or greater (9) were larger than all year-classes produced from a lower spawning biomass index (12).

The ratio of recruits divided by spawning biomass has been used as an indication of conditions affecting spawning success and juvenile survival. The year-classes produced in the mid-1970s, which drove the recovery of the stock from a previous period of low abundance, had the highest R/S ratios. The year-classes produced in the mid-1980s, which should have supported the fishery in the early 1990s when the fishery was closed, had average ratios of R/S. Subsequent year-classes have had below-average R/S ratios.

Summary of RV analysis

1) The stock is currently of low abundance, biomass and recruitment.
2) The recovery of the stock in the late 1970s was driven by a period of above-average juvenile survival.
3) Year-classes that should have supported the fishery in the early 1990s experienced average juvenile survival (R/S). Their low abundance in 1993 occurred as a result of high mortality after age 3.
4) Juvenile survival in the late 1980s and early 1990s has been below average.

6.2 Sequential population analysis

Sequential population analysis (SPA) uses commercial fishery catch at age data to estimate stock size and fishing mortality. Starting parameters, in terms of stock abundance in the final year, are determined by calibration with an independent index of stock size, in this case the RV estimates of relative stock abundance. Several assumptions need to be made: what is the natural mortality rate; what is the functional form of the calibration relationship; how does one estimate the abundance of year-classes at the oldest ages in the analysis? The following section deals with the SPA of southern Gulf cod.

6.2.1 Choice of natural mortality

Natural mortality has traditionally been assumed to be fixed across ages and years at 0.2. This is based on earlier work by Dickie (1963), Beverton (1965), Pinhorn (1975), and Myers and Doyle (1983). All of these studies produced estimates of M of 0.2 or lower, but all were based on data collected in the 1970s or earlier. The post moratorium total mortality estimates described above suggest that M for this stock is currently 0.4 or higher. It is thus possible that M may have increased sometime in the last 20 years. Changes in growth characteristics, from high to low values of L_{∞}, the occurrence of extreme environmental conditions in recent years, and the possible increased predation by seals, may have caused such an increase in M.

The feasibility of a change in M was investigated here by examining changes in the residual mean square error (rmse) of the SPA calibration in response to a change in M. Normally, M is assumed to be fixed at age and year. However, if M in fact changed at some point during the time period for which SPA data are available, but it was assumed to have been constant, then the fit of the calibration model to the data would deteriorate resulting in a higher rmse (all other things being equal). It follows that by varying M systematically, either by year or year-class, the rmse should reach a minimum where the assumed M equals the true M. Following the example of Mohn (1998), M was varied by year and year-class between values of 0.2 or 0.4, according to

$$M_y = \begin{cases} M_1 \ for \ y <= i \\ M_2 \ for \ y > i \end{cases}$$

where y = year or year-class
M_1 is one level of M, M_2 is the other
evaluated for I = 1971 - 1997

Two M scenarios were contrasted: $M_1 = 0.2$, $M_2 = 0.4$; and $M_1 = 0.4$, $M_2 = 0.2$. The former is supported by previous and current estimates of M (i.e. that current M is higher than former). The scale of the change in M is consistent with what was used in the past and the current estimates. The ADAPT calibration procedure was used (Gavaris 1988) with a proportional calibration relationship between the RV and SPA estimates.

This analysis supports the hypothesis that M increased during the assessment period. It is not consistent with a decrease in M. It favors a year-dependent change in M as opposed to a year-class dependent change. The lowest rmse was found for a year-dependent increase in M, with the increase occurring between 1988-1989 (Fig. 14). The rmse values varied little for a change in M between 1981-1988. For the increasing M scenario, the rmse increased and was much higher than for a decrease in M. It was interesting to note that the SPA calibration made virtually no distinction between fixed Ms of 0.2 and 0.4 as the rmse was similar for cases where M was constant at either 0.2 or 0.4 for the entire period.

Other factors may produce a similar effect on the calibration, including an increase in the rate of catch underreporting in the late 1980s, or an increase in survey catchability in recent years. In terms of changes in survey catchability, comparative fishing experiments were performed with each change in survey vessel, and conversion factors were applied where indicated. Cod mean size at age also changed during the assessment period, being above average in the late 1970s, then declining to below average values by the mid-1980s. It is possible that a reduction in size at age could lead to a decline in survey catchability at age due to selection by the gear. However, examination of the calibration residuals from an SPA with M = 0.2 and the mean length at age measured in the annual surveys revealed the opposite trend (Fig. 15), i.e. residuals (catchability) were highest when length at age was lowest. Thus, if there was a change in catchability as a result of the change in size at age, it was overwhelmed by other processes occurring at the same time. Catch misreporting was known to have occurred, however, the main problem was in discarding of undersized fish. While discarding will affect SPA estimates of young fish (ages 3-4 in SPA) abundance, and their associated residuals, it will not affect estimates of older fish.

The next step was to examine retrospective plots from different scenarios of M. The base run, with M fixed at 0.2, produced a severe retrospective pattern for calibrations ending in 1983 - 1992 (Fig. 16). It was notable that the pattern disappeared the year in which the fishery closed, perhaps indicating the interannual consistency of the RV survey. The retrospective pattern improved slightly when an M change was introduced in 1989 (Fig. 17). However, the stock size was overestimated, relative to the full dataset, in analyses ending in 1983 - 1992. The best retrospective pattern was obtained when M changed in 1986 (Fig. 18) The annual deviations in average F and population biomass were the smallest, and the differences were more balanced. Moving the M change to 1982 seemed to produce more of an opposite retrospective pattern (Fig. 19). This led us to accept the M change in 1986 as possibly the best guess when such a change might have occurred.

6.2.2 Calibration

The last analytical assessment of this stock used a density dependent calibration relationship between the SPA estimates of population abundance and the RV indices. This was based on work by Swain and Wade (1993) and Swain et al. (1994) who found density dependent changes in cod distribution, with cod moving offshore in years of high abundance. This may cause changes in survey catchability. Model fits at the time were better with a density dependent relationship in the form

$$A_{ij} = a_i N_{ij}^{b_i}$$

where a and b are parameters describing the density dependent relationship. Results of these calibrations were compared to those obtained using a simpler proportional model

$$A_{ij} = k_i N_{ij}$$

Note that the first relationship has two parameters per age group where the second has only one.

We compared the rmse from the two calibration models to see if one outperformed the other (Fig. 20). There was little to choose between the two, but the proportional model had marginally higher rmse but fewer parameters. Based on these comparisons and in the interest of parsimony, we elected to use the proportional relationship in the SPA calibrations.

The ADAPT formulation was:

Parameters

- Terminal N estimates:
  - $N_{i,1997}$, i=3 to 10
- Calibration coefficients:
  - k_i i=3 to 10
- Structure Imposed:
  - Error in catch at age assumed negligible
  - PR on ages 11 - 15 in 1997 = 1.0
  - F on oldest age equal to average at ages 9-10
  - run M = 0.2, M = 0.2 for all years and ages
  - run Mup, M = 0.2 for 1971-1985 and M = 0.4 for 1986-1997
- Input:
  - C_{ik} i=3 to 15, k=1971-1997
  - A_{ik} i=3 to 10, k=1971-1997
- Objective function:
  - Minimize sum of squared ln residuals
- Summary:
  - Number of observations:
    - 216 from RV
  - Number of Parameters
    - 16

6.2.3 Variance estimation and bias correction.

Bootstrapping was used to estimate the parameter variance and adjust for bias. The procedure was as follows. First, a base run of the calibration was run to obtain an initial set of parameter estimates, predicted survey values, and residuals. The residuals were sampled by age, with replacement, and these were added to the original run predicted values to obtain pseudo replicate indices. These were used in subsequent calibrations. The pseudo population estimates from 250 replicates were saved. The bias of the estimator was estimated as the difference between the mean of the bootstrap population estimates and the original estimates. The variance of the bootstraps was used to estimate the variance of the original estimate. The bias corrected population estimate was obtained as the original estimate less the bias. The bootstrap estimates were also retained for catch projection and risk analysis, and this procedure is described later.

6.2.4 Parameter Estimates

The parameter estimates from calibrations for the two scenarios of M are compared in Table 14. The population estimates in the terminal year were lower for ages 3-6, and higher for ages 7-10 under the M=0.2 assumption than with the Mup assumption. Survey catchability estimates were higher for the low M assumption. The coefficients of variation of the population estimates were higher for the low M assumption. The relative bias was low in both cases, except for age 3 in 1997. Population estimates, F, and residuals from the increase in M calibration are given in Tables 15-17 and for the M = 0.2 calibration in Tables 18-20.

6.2.5 Population Biomass

SPA estimates of spawning stock biomass diverge in the early 1980s between the two calibration scenarios (Fig. 21). Using Cohort analysis for SPA, the abundance of any cohort at age (a) = b is estimated as the sum of two components, its abundance at the maximum age in the data (N_s), and the sum of the annual catches (C) of the cohort, both adjusted for the instantaneous rate of natural mortality (M).

$$N_b = N_s e^{M(s-b)} + \sum_{a=s-1}^{b} C_a e^{M/2}$$

The SSB estimate in the mid-1980s under the Mup scenario was considerably higher than under the M = 0.2 scenario. This would be expected because the SPA estimates of population abundance in those years was almost entirely from the M-adjusted catch at age. The magnitude of the M-adjustment is considerably higher for M = 0.4 than M = 0.2. However, in the most recent years, the estimates are comparable. The main difference between the two scenarios in recent years, is that under the M=0.2 scenario there was an increase in spawning biomass since the fishery closed, while in the Mup scenario, there was little change.

6.2.6 Recruitment

Both M scenarios indicate that recruitment has fallen steadily from the early 1980s to the present (Fig. 22). In the M=0.2 scenario, the year-class strengths in the 1990s have been the lowest on record. Under the Mup scenario the most recent year-classes have been slightly larger than the lowest observed. No improvement in recruitment is forecast in either scenario.

6.2.7 Fishing mortality

The trend in fishing mortality was similar in the two M scenarios (Fig. 23). There was an early peak in 1975 followed by a decline to 1977. F varied between 0.5 and 0.7 for most of the 1980s. The estimates were higher for the M=0.2 scenario. In both cases, there was an increase in fishing mortality in the late 1980s to a peak in 1992. This was followed by a sharp decline when the fishery was closed, and it has been very low since.

6.2.8 Spawning stock and recruitment

The SPA time series for this stock begins in 1950 and provides a relatively long historical record of stock and recruitment. Spawning stock biomass was estimated as the product of the beginning of year population numbers from SPA, the beginning of year RV estimates of population weight at age, and a fixed maturity ogive (Trippel et al. 1997, Table 21). Recruitment estimates were taken from the age 3 SPA population estimates.

The scatter of spawning biomass and recruitment points from the 1980s to the present varies depending on the assumed values of M (Fig. 24). With M increasing in 1986, the estimated abundance of the 1979 - 1989 year-classes is considerably higher than when M is assumed constant. Similarly, the estimated spawning biomass in the early to mid-1980s is also higher. Other than that, the patterns are quite similar. The 1973 to 1977 year-classes were estimated to be large relative to the spawning biomass that produced them. In both cases, the most recent spawning biomass and recruitment estimates are the lowest in the time series.

The ratio of SPA recruitment estimates divided by spawning biomass indicates that juvenile survival in the mid to late 1970s was very high, similar to the pattern seen from RV estimates (Fig. 25). This distinction is more pronounced in the SPA time series which contains estimates from as far back as 1950. Indeed, most of the ratios from the 1970s to the present tended to be higher than those from the 1950s and 1960s. The year-classes produced in the mid-1970s drove the recovery of the stock at that time. The year-classes produced in the mid-1980s, which should have supported the fishery in the early 1990s when the fishery was closed, had below average ratios of R/S compared to the period 1970 to the present. However, these were comparable to the long term average for the case where M was assumed to increase in 1986, and below the long term average where M was assumed to be constant. The SPA results suggest the following:

1) The recovery of the stock in the late 1970s was driven by a period of above average juvenile survival.
2) Year-classes that should have supported the fishery in the early 1990s (i.e. those produced in the mid-1980s) experienced below average juvenile survival.
3) Juvenile survival in the late 1980s and early 1990s has been below average compared to the more recent period (i.e. since 1970), but closer to the long term average.

7. Assessment Results

7.1 Natural mortality

The closure of the fishery for this stock in 1993 and the existence of a relatively precise groundfish survey which covers almost all of the stock habitat have made it possible to estimate the recent rate of natural mortality of the stock. The results indicate that total mortality has been in the range of 0.45 to 0.57 since the fishery was closed. Allowing for a small amount of fishing mortality, this suggests that M may currently be in the range of 0.40 - 0.50. It is also suggested that M may have increased to this relatively high level sometime in the mid-1980s. The causes of this increase would include all sources of unaccounted mortality such as those from harsh environmental conditions, seal predation, unreported catches and changes in life history characteristics. The relative contributions of each is currently unknown. Nevertheless, future management options should include consideration of such a high rate of natural mortality.

7.2 Population biomass

There are three separate estimates of trends in stock size: the RV survey (1971 - 1997), an SPA assuming M constant at 0.2 from 1950 - 1997, and an SPA assuming M = 0.2 for 1950 - 1985 followed by M = 0.4 from 1986 to the present. The spawning biomass estimates were the same for the two SPAs for 1950 - 1970 and they indicated that spawning biomass increased from 1950 to a maximum in the time series in 1959 of slightly over 400,000 t. The biomass then declined through the 1960s to a minimum in 1976. The SPA and RV results indicate that there was a rapid recovery in biomass in the late 1970s. The SPA with an increase in M indicated that this increase continued to 1986, while the RV and SPA with a fixed M indicated stability in biomass. This period of high biomass was followed by a rapid decline in the late 1980s to 1993. All three estimates indicate that spawning biomass has increased since the fishery closure; the largest increase in the SPA with fixed M and a slower increase in the other two. These patterns are quite similar with the exception of the high biomass estimates in the mid-1980s from the SPA with an increase in M. This may simply be an artifact of introducing this change in a knife-edged manner.

7.3 Recruitment

Recruitment estimates from SPA varied between 50 - 150 million fish at age 3 throughout the 1950s and 1960s. Recruitment increased in the 1970s, with the 1974, 1975, 1979, and 1980 year-classes estimated to be over 150 million at age 3. Recruitment estimates from SPA then declined throughout the 1980s while the RV estimates were about average until 1987. This is the main difference between the RV and SPA estimates. Previous studies suggest that the difference may be due to discarding of catches of undersized cod in the late 1980s and early 1990s, when fishing effort was at its maximum. For this reason, it is considered that the recruitment trend from the RV results is more reliable than that from SPA for the period 1985 - 1990. Recent recruitment estimates are the lowest on record with no indication of recovery since the fishery was closed.

8. Management Alternatives

Catch projections based on the results of the two SPAs with different M scenarios are presented here in an analysis of management alternatives. The section begins with the estimation of biological reference points relevant to the different levels of M. Deterministic catch projections based on the SPA point estimates of stock size are then presented. This is followed by a risk analysis of TAC options using bootstrap estimates of population abundance.

8.1 Biological reference points

Biological reference points used to set TACs depend on the assumed M of the fish stock. Given the recent evidence that M may have increased, separate reference points were estimated for M = 0.2 and M = 0.4. At this point, it is difficult to say which M may be more appropriate for the long term. Thus, this section is meant only to illustrate the sensitivity of reference point estimates to assumptions about M.

Yield per recruit models have been used traditionally to estimate reference points for eastern Canadian cod fisheries. These models estimate the average total yield expected from one recruit throughout its life. Inputs include M at age, fishery weight at age, and the distribution of F at age (referred to as partial recruitment). Yield per recruit (Y/R) is estimated in relation to F. The traditional reference point used in east coast fisheries is $F_{0.1}$, the fishing mortality at which the marginal increase in Y/R is one tenth that at an F of 0. The Y/R model does not consider any explicit relationship between stock size and recruitment and therefore it cannot be used to estimate the expected total yield from a fishery in relation to F. Y/R was estimated using the method described in Rivard (1982).

Stock production models have also been used to estimate reference points. This type of model can provide reference points relevant to the Precautionary Approach to Fisheries Management which contains explicit reference to maximum sustainable yield (MSY) and the F associated with MSY. An age structured production model was used to estimate stock production curves (Sinclair 1997, Cook et al. 1997). This approach includes fitting a stock/recruitment curve, and using these parameters in conjunction with Y/R analysis to estimate equilibrium stock yield, recruitment and spawning biomass in relation to fishing mortality.

8.1.1 Yield per Recruit

Inputs for Y/R analysis were obtained as follows. The same catch weight at age vector was used for both analyses and was taken as the average observed commercial weight at age for the past 3 years. The distribution of fishing mortality at age was determined from the final 3 years of the respective SPA calibrations and the fully recruited F was the average of ages 7-12. Natural mortality was assumed to be 0.2 and 0.4 respectively. The input data are given in Table 21.

The Y/R curve for the M = 0.2 analysis had a distinct maximum (Fig. 26). $F_{0.1}$, F_{max} and the Y/R at $F_{0.1}$ were estimated to be 0.22, 0.40, and 0.45 kg respectively. The Y/R curve for M = 0.4 was flat-topped and did not reach a maximum for a reasonable range of F. $F_{0.1}$ and the Y/R at $F_{0.1}$ were estimated to be 0.50 and 0.20 kg respectively. In essence, the Y/R analysis says: 'fish harder if M is higher in order to catch the fish before they die naturally'.

8.1.2 Stock Production

The main objective of presenting stock production analysis is to compare its reference points with those from Y/R analysis. Inputs for the age structured production model included the same elements as for Y/R analysis plus mean weights at age from RV surveys to represent the population mean weight at age (adjusted to beginning of the year (Rivard 1982)), the spawning stock biomass and recruitment series from the SPAs run at the two different values of M. Separate Ricker stock/recruitment curves were fit to these data (assuming lognormal error) and it was assumed that the same relationship held for the respective M scenario. The relationship used was

$$R_j = \alpha S_j e^{-\beta S_j}$$

where R_j = the abundance of year-class born in year j
S_j = the spawning biomass in year j
α and β are the S/R parameters.

MSY, F_{msy} and F_{crash}, the unsustainable fishing mortality, were estimated.

The yield curve for an M of 0.4 was much lower than that for an M of 0.2 (Fig. 27). MSY, F_{msy}, and F_{crash} were 3,000 t , 0.08, and 0.18, respectively, for an M of 0.4. For an M of 0.2, these same parameters were 33,000 t, 0.18 and 0.47, respectively. Thus, reference points estimated using production analysis reacted differently to a change in M than did those estimated with a Y/R model. The production model essentially says: 'fish less at high M in order to ensure the stock can replace itself'.

8.2 Yield projections

Deterministic yield projections were run for 1998 using population estimates for the two M scenarios. In this case, the ADAPT population estimates are treated as point estimates (no error). The catch mean weights (mid-year), population mean weights (beginning of year), F at age, and maturity at age were the same as used in the reference point calculations. 1998 beginning of year population numbers were taken from the respective ADAPT calibrations. Recruitment at age 3 in 1998 was estimated as the average in the recent past (1993 - 1997). The results are presented in terms of F and change in spawning stock biomass as a function of the 1998 total catch.

For the SPA where M was assumed to be fixed at 0.2, the spawning biomass was projected to increase by about 6% if there was no catch in 1998 (Fig. 28). A catch of 8,000 t in 1998 resulted in no change in spawning biomass. The $F_{0.1}$ = 0.25 projected catch was 21,500 t and, if this catch was taken, the spawning biomass declined by 10%. If M was assumed to increase from 0.2 to 0.4 in 1986, the projection results were quite different. The spawning biomass was projected to decline by 5% if there was no catch (Fig. 29). The $F_{0.1} = 0.5$ projected catch was 25,000 t with a predicted 30% decline in spawning biomass.

8.3 Risk analysis

A risk analysis was performed to determine the probability of specific stock targets not being achieved as a result of a management action (in this case the total catch in 1998). A bootstrap procedure, described above, was used to estimate the variance and distribution of the population estimates as input to the risk analysis. A total of 250 bootstrap population estimates were obtained. Recruitment at age 3 in 1998 was estimated as the average in the recent past (1993 - 1997). A catch projection was performed with each population estimate. The estimated population numbers were first adjusted for the estimated bias of the estimator (- 2* bias). A range of 1998 catches from 0 - 30,000 t was used for each population estimate. A tally of the number of times the spawning population biomass declined and the spawning biomass did not increase by 10% was made for each catch and M scenario. These tallies were used to estimate the probability of a decline in biomass and of the biomass not increasing by 10% respectively. These risk analyses do not include uncertainties in all components of the stock assessment, including weight at age, partial recruitment, and catch at age, but provide guidelines for decision making.

The risk analyses re-emphasize the results of the deterministic projections in terms of the main difference between the SPAs using different M assumptions. The stock is projected to have a limited potential for growth in biomass if M is 0.2, but it is likely to decline further, even if there is no fishing, if M is 0.4. Under the M=0.2 scenario, there is only a 10% probability that spawning biomass will decline for a 1998 catch of 5,000 t, while for the M = 0.4 scenario there is a 93% probability that the biomass will decline if the 1998 catch is 0 (Fig. 30). In both cases, there is an extremely high probability (>90%) that the biomass will not increase by 10%.

9. Acknowledgements

We'd like to thank Bob Mohn, Jerry Black, and Stratis Gavaris for their assistance in the SPA calibrations.

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11. Tables

Table 1: Landings (t) of southern Gulf of St. Lawrence cod, 1965-97, by area and time period relevant to the management unit. The column "stock" indicates the landings used in the analytical assessment, and is the total for 4T, 4Vn (J-A), 4Vn (N-D), and 4Vs. The TAC applies to the traditional management unit, 4TVn (J-A). Landings given for 1997 do not include 318 t estimated as being taken in the recreational fishery (Section 1.1).

Year	4T	4Vn(J-A)	4Vn(N-D)	4Vs	Stock	4TVn(J-A)	TAC
65	46471	16556	2077		65104	63027	
66	38282	16603	2196		57081	54885	
67	34245	7071	2096		43412	41316	
68	37910	8641	2440		48991	46551	
69	40905	6914	2442		50261	47819	
70	43410	21055	1523		65988	64465	
71	40669	15706	1556		57931	56375	
72	42096	25704	1517		69317	67800	
73	25756	24879	1308		51943	50635	
74	28580	20167	1832		50579	48747	63000
75	28853	13618	795		43266	42471	50000
76	17600	15815	3928		37343	33415	30000
77	19536	2683	4665		26884	22219	15000
78	25453	12439	1128		39020	37892	38000
79	46695	9301	1700		57696	55996	46000
80	36157	18477	2592		57226	54634	54000
81	48132	17045	1970		67147	65177	53000
82	43418	14775	3476		61669	58193	60000
83	48222	13073	2695		63990	61295	62000
84	40652	14712	2200		57564	55364	67000
85	47819	14319	1835		63973	62138	67000
86	48066	15709	1444	3463	68682	63775	60000
87	43571	7555	1437	2029	54592	51126	45200
88	44616	7442	1165	2496	55719	52058	54000
89	43617	9191	1887	2574	57269	52808	54000
90	41552	9688	2031	4606	57877	51240	53000
91	31938	6781	1830	8911	49460	38719	48000
92	27899	6782	2282	4164	41127	34681	43000
93	4121	1161	55		5337	5282	13000
94	1190	139	1		1330	1329	0
95	1032		4		1036		0
96	1140		2		1142		0
97	1273	0			1273		0

Table 2: Landings (t) by gear of the southern Gulf of St. Lawrence cod stock, 1965-97. Landings given for 1997 do not include 318 t estimated as being taken in the recreational fishery (Section 1.1).

Year	Otter trawl	Seines	Gillnets	Longlines	Handlines	Misc.	Total
1965	48854	2735	3571	4713	0	5231	65104
1966	37023	2444	9414	3062	0	5138	57081
1967	24823	2293	9948	2536	2469	1343	43412
1968	29553	1064	12933	1344	2942	1155	48991
1969	28131	1234	9581	5014	5066	1235	50261
1970	43652	1798	9786	6258	3205	1289	65988
1971	36338	2267	9676	3600	4011	2039	57931
1972	50615	2121	7896	1792	2103	4790	69317
1973	36467	2137	8223	925	2135	2056	51943
1974	35815	1768	6141	1352	1292	4211	50579
1975	29080	1983	6330	245	3530	2098	43266
1976	28928	1384	4459	163	1191	1218	37343
1977	14695	3269	5931	692	1299	998	26884
1978	22669	4504	8929	1015	1449	454	39020
1979	31727	8845	12022	1622	1957	1523	57696
1980	32698	10095	4260	2827	1562	5784	57226
1981	34509	12563	4053	7017	1061	7944	67147
1982	32242	11360	4205	5481	916	7465	61669
1983	32880	13857	3010	4754	1286	8203	63990
1984	32316	10732	6891	5058	1903	664	57564
1985	40177	11935	5287	4261	2078	235	63973
1986	41653	15380	4328	5314	1975	32	68682
1987	31961	9759	4792	5926	2106	48	54592
1988	34055	12017	3936	4074	1602	35	55719
1989	34260	15492	2796	3396	1190	135	57269
1990	37354	14094	1962	3289	1048	130	57877
1991	35216	9282	1679	2502	778	3	49460
1992	28408	8660	1263	1890	875	31	41127
1993	2143	328	1313	842	705	6	5337
1994	213	404	302	103	153	155	1330
1995	110	379	101	78	101	267	1036
1996	269	398	134	127	214		1142
1997	217	560	254	224	17	1	1273

Table 3: Age-length keys used in the calculation of the 1997 catch at age for southern Gulf of St. Lawrence cod.

KEY	FISHERY	SAMPLES	SAMPLE SIZE	LANDINGS (t)
1	OTB APR-JUN	APR-JUN OTB LENGTHS	95	0.528
		APR-JUN OTB & SNU AGES	547	
2	OTB JUL-SEP	JUL-SEP OTB LENGTHS	6953	29.296
		JUL-SEP OTB & SNU SENTINEL AGES	824	
3	SNU APR-JUN	APR-JUN SNU LENGTHS	2012	92.847
		APR-JUN OTB & SNU AGES	547	
4	SNU JUL-SEP	JUL-SEP SNU LENGTHS	11621	141.378
		JUL-SEP OTB & SNU SENTINEL AGES	824	
5	GNS JUL-SEP	JUL-SEP GNS LENGTHS	1785	167.534
		JUL-SEP GNS & LLS SENTINEL AGES	792	
6	LLS APR-JUN	APR-JUNE LLS LENGTHS	523	24.994
		APR-JUNE LLS AGES	98	
7	LLS JUL-SEP	JUL-SEP LLS LENGTHS	1018	51.656
		JUL-SEP GNS & LLS SENTINEL AGES	792	
8	LHP JUL-SEP	JUL-SEP LHP LENGTHS	4760	9.810
		JUL-SEP GNS & LLS SENTINEL AGES	792	
9	MOBILE SENTINEL JUL-SEP	JUL-SEP OTB & SNU SENTINEL LENGTHS	82571	192.614
		JUL-SEP OTB & SNU SENTINEL AGES	824	
10	FIXED SENTINEL JUL-SEP	JUL-SEP GNS & LLS SENTINEL LENGTHS	59947	145.988
		JUL-SEP GNS & LLS SENTINEL AGES	792	
	UNSAMPLED			416.242
	TOTAL LANDINGS			1272.887

Table 4: Landings (numbers) at age by gear and time period, 1997. The age-key numbers correspond with Table 3.

KEY	1	2	3	4	5	6	7	8	9	10		
GEAR	OTB	OTB	SNU	SNU	GNS	LLS	LLS	LHP	MOB	FIX	Unsamp	TOTAL
QUARTER	2	3	2	3	3	2	3	3	3	3		
Age												
2				34					7011		3361	10406
3		63		660	23				14185	126	7184	22240
4		538	141	5844	319		11	7	18471	1230	12672	39232
5	4	1799	892	15454	986	177	273	168	30597	3656	25766	79771
6	15	4360	2067	25413	3363	480	1191	519	37143	6876	38849	120274
7	29	3841	3687	19260	7855	1378	2772	860	27371	10908	37196	115157
8	64	3850	8719	17241	12944	1580	4181	954	22618	12890	40574	125614
9	63	4178	9526	17746	18145	1736	5808	1224	21882	17343	46590	144240
10	33	2082	4708	8081	11749	2234	3525	692	10210	10088	25478	78878
11	13	623	2797	2515	4709	954	1335	224	3084	3517	9432	29201
12	3	105	490	533	1565	269	486	75	535	1184	2502	7745
13	1	55	154	202	321	419	105	15	225	255	836	2589
14	1	14	309	118	380	182	114	13	116	250	714	2212
15					207	16	54	12		172	220	680
16+	0		68		39		16	1		22	70	215
TOTAL 3+	224	21508	33558	113066	62603	9425	19868	4762	186437	68516	248081	768049

Table 5: Mean weight (kg) at age by gear and time period, 1997. The age-key numbers correspond with Table 3.

KEY	1	2	3	4	5	6	7	8	9	10	
GEAR	OTB	OTB	SNU	SNU	GNS	LLS	LLS	LHP	MOB	FIX	AVERAGE
QUARTER	2	3	2	3	3	2	3	3	3	3	
Age											
2				0.16					0.14		0.14
3		0.37		0.38	0.51				0.22	0.40	0.23
4		0.62	0.40	0.58	0.65		0.75	0.74	0.49	0.66	0.52
5	0.98	0.83	0.80	0.76	1.18	0.85	1.40	1.26	0.68	1.00	0.75
6	1.27	1.14	1.25	1.03	1.90	2.00	1.76	1.52	1.00	1.47	1.12
7	1.64	1.26	1.70	1.17	2.20	2.33	2.14	1.76	1.11	1.81	1.44
8	2.26	1.48	2.66	1.46	2.70	2.88	2.59	2.12	1.37	2.29	1.97
9	2.46	1.61	2.95	1.67	2.79	2.49	2.72	2.16	1.58	2.37	2.19
10	3.15	1.78	3.57	1.86	2.88	2.81	2.90	2.30	1.76	2.51	2.45
11	3.36	1.73	4.01	2.00	3.22	2.86	2.94	2.44	1.75	2.85	2.79
12	2.40	2.38	3.08	2.58	3.17	3.87	3.16	2.74	2.55	2.97	3.01
13	3.49	1.98	5.42	2.28	3.09	2.70	3.29	2.64	2.11	3.07	2.95
14	2.22	2.62	3.85	3.07	3.59	2.96	3.54	2.96	2.93	3.36	3.42
15					2.12	6.24	2.12	2.12		2.12	2.26
16+	3.51		4.93		4.48		4.48	4.48		4.48	4.69
ALL 3+	2.35	1.36	2.77	1.25	2.68	2.65	2.60	2.02	0.99	2.13	1.65

Table 6: Mean length (cm) at age by gear and time period, 1997. The age-key numbers correspond with Table 3.

KEY	1	2	3	4	5	6	7	8	9	10	
GEAR	OTB	OTB	SNU	SNU	GNS	LLS	LLS	LHP	MOB	FIX	AVERAGE
QUARTER	2	3	2	3	3	2	3	3	3	3	
Age											
2				26.01					24.59		24.60
3		34.19		34.20	38.26				28.43	35.01	28.78
4		40.03	34.78	39.46	41.20		43.28	43.07	37.21	41.30	37.99
5	47.13	44.40	43.75	43.28	49.20	45.07	52.88	51.10	41.55	47.03	42.79
6	51.12	49.35	51.00	47.76	58.35	59.51	56.97	54.30	47.23	53.42	48.85
7	55.43	50.96	55.77	49.56	61.29	61.80	60.61	56.81	48.75	57.15	52.57
8	61.21	53.60	64.30	52.99	65.18	66.28	64.34	60.22	52.02	61.60	57.97
9	62.74	55.07	66.26	55.24	65.84	62.84	65.34	60.59	54.34	62.19	60.12
10	67.67	56.88	70.47	57.24	66.44	65.83	66.48	61.96	56.22	63.56	62.45
11	68.89	56.17	73.24	58.00	68.73	66.23	66.96	63.35	56.08	66.14	64.87
12	63.18	63.22	67.58	64.78	69.03	73.01	68.84	66.00	64.44	67.51	67.67
13	70.84	59.52	79.12	61.91	68.29	64.64	69.35	65.45	60.56	68.06	66.37
14	61.55	65.44	73.26	67.80	71.99	66.73	71.64	67.93	67.07	70.48	70.52
15					61.00	87.00	61.00	61.00		61.00	61.89
16+	72.00		79.12		78.00		78.00	78.00		78.00	78.52
ALL 3+	61.49	51.85	64.27	49.94	64.79	64.30	64.24	59.24	44.56	59.71	53.59

Table 7: Landings at age ('000) of southern Gulf of St. Lawrence cod, 1971-97.
The table includes landings in 4T, 4Vn (Nov.-Apr.), and 4Vs (Jan.-Apr.).

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1971	6	2099	7272	9262	5916	2331	1251	520	130	354	75	120	154	68	29558
1972	3179	22247	12018	6666	7561	3551	952	547	372	120	51	14	47	38	57361
1973	1374	6999	14498	5325	3720	2800	1861	557	338	100	69	47	12	24	37723
1974	2993	5400	5033	9690	3102	1854	1772	1054	260	198	81	29	6	19	31490
1975	1567	8910	6933	2540	3297	1319	1119	801	680	151	53	76	7	67	27519
1976	508	4093	9996	6975	1708	1257	478	285	148	145	47	17	12	10	25679
1977	659	4960	5899	3320	1773	400	284	182	114	50	53	10	4	5	17712
1978	548	10037	10897	4596	2681	1108	244	248	110	72	44	5	13	6	30610
1979	148	5138	15913	11251	3509	1724	865	295	253	66	33	17	16	8	39235
1980	295	1920	14674	14142	9789	1522	808	404	143	30	18	8	14	26	43793
1981	98	3829	7380	19144	13116	6200	913	463	203	71	89	2	14	4	51526
1982	518	1621	10671	8700	12539	7663	2533	444	142	76	5	2	2	1	44917
1983	42	1147	6311	12124	11936	7646	5379	2668	139	51	18	10	5	5	47481
1984	30	1319	4210	7410	9085	6949	5173	2937	942	151	52	7	5	9	38278
1985	175	1561	10307	17163	8342	6094	3975	2277	971	353	26	6	8	6	51265
1986	136	3546	8295	23645	9739	4069	3041	2372	1197	803	159	19	3	2	57027
1987	80	1029	7400	10851	18933	7011	2250	1684	700	417	132	112	14	13	50627
1988	111	1725	5241	11259	9072	12151	6813	1818	970	466	202	51	44	8	49931
1989	71	1658	6065	12398	10714	7316	7628	5171	990	465	153	49	37	15	52730
1990	540	2973	7508	10613	10207	6983	4468	4644	2066	385	122	37	30	29	50605
1991	286	5178	10371	9586	8416	4735	3173	1754	955	587	91	25	16	9	45184
1992	487	3437	12511	9912	5290	3453	2059	910	510	375	112	12	5	9	39081
1993	53	262	904	1174	946	499	223	135	74	36	31	7	9	2	4353
1994	28	53	96	208	279	154	70	27	19	8	4	2	0	0	949
1995	68	132	143	129	222	133	59	24	13	5	2	1	0	0	931
1996	39	80	129	145	127	174	92	34	11	7	3	1	0	0	842
1997	22	39	80	120	115	126	144	79	29	8	3	2	1	0	768

Table 8: Average weights at age (kg) from the commercial fishery for the southern Gulf of St. Lawrence cod stock, 1971-1997.

AGE	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Ave.
1971	0.76	0.82	1.11	1.40	2.15	3.67	3.83	5.25	6.00	4.78	6.85	7.42	7.96	17.72	1.96
1972	0.36	0.56	0.91	1.33	1.52	2.55	4.82	5.97	7.13	8.08	8.85	10.25	5.65	11.23	1.16
1973	0.46	0.67	0.92	1.28	1.69	2.31	3.59	5.51	6.03	7.95	6.16	6.72	8.86	6.12	1.37
1974	0.60	0.78	1.09	1.49	1.96	2.68	2.89	4.11	5.97	7.07	8.30	6.87	9.84	12.65	1.61
1975	0.48	0.74	1.15	1.76	2.36	2.75	3.22	3.70	4.46	6.95	9.20	6.30	8.39	6.19	1.57
1976	0.46	0.78	1.11	1.54	2.19	2.84	3.23	3.79	4.62	5.09	6.19	9.87	10.45	15.05	1.45
1977	0.52	0.81	1.27	1.79	2.42	3.51	4.27	4.31	5.10	5.57	6.45	8.61	12.56	9.88	1.52
1978	0.40	0.68	1.03	1.66	2.27	2.81	4.33	4.63	6.37	6.46	6.23	5.09	11.56	10.17	1.27
1979	0.51	0.71	1.01	1.42	2.22	3.31	4.07	7.14	6.96	6.69	4.70	8.79	15.52	17.34	1.47
1980	0.58	0.69	0.92	1.22	1.50	2.78	3.08	4.00	7.83	6.01	9.98	5.81	9.13	9.35	1.30
1981	0.50	0.68	0.85	1.13	1.39	1.84	3.19	4.17	4.47	5.60	6.11	7.08	3.49	8.35	1.30
1982	0.75	0.76	0.97	1.16	1.45	1.72	2.27	3.27	4.01	4.14	6.46	6.92	4.18	11.10	1.37
1983	0.33	0.61	0.89	1.14	1.31	1.58	1.73	2.01	4.84	7.63	8.55	10.51	12.09	14.76	1.35
1984	0.45	0.65	0.79	1.09	1.38	1.61	2.07	2.27	3.05	4.93	5.66	8.61	11.74	13.23	1.50
1985	0.44	0.57	0.76	0.99	1.42	1.67	1.83	2.14	2.41	2.89	8.33	5.71	11.41	12.97	1.24
1986	0.43	0.60	0.81	1.01	1.29	1.75	1.98	1.89	2.64	2.23	3.07	4.83	15.36	13.55	1.20
1987	0.27	0.49	0.70	0.86	0.99	1.25	1.85	2.16	2.24	3.15	3.57	4.03	12.41	14.21	1.08
1988	0.40	0.60	0.77	0.92	1.04	1.13	1.29	1.90	2.23	2.72	3.52	5.67	5.92	14.32	1.12
1989	0.53	0.63	0.77	0.90	1.07	1.19	1.22	1.40	1.94	2.15	2.55	3.49	3.41	2.76	1.09
1990	0.56	0.72	0.85	1.03	1.17	1.28	1.36	1.41	1.50	1.84	2.59	3.36	2.81	7.98	1.14
1991	0.53	0.65	0.85	1.01	1.22	1.41	1.51	1.60	1.63	1.73	2.20	2.50	3.08	3.80	1.09
1992	0.55	0.65	0.81	1.00	1.22	1.45	1.61	1.85	1.88	1.91	2.27	5.52	6.58	9.88	1.05
1993	0.41	0.56	0.70	1.00	1.40	1.81	1.93	2.21	2.29	2.09	2.04	3.00	5.84	13.18	1.23
1994	0.36	0.57	0.79	1.04	1.46	1.87	2.26	2.18	2.50	2.41	2.04	2.31	2.38	13.52	1.40
1995	0.25	0.49	0.67	0.90	1.18	1.49	2.12	2.52	2.98	3.39	4.87	4.94	4.19	10.16	1.09
1996	0.36	0.47	0.81	0.99	1.35	1.69	2.05	2.64	3.23	2.88	3.58	4.82	5.95	5.36	1.32
1997	0.23	0.52	0.75	1.12	1.44	1.97	2.19	2.45	2.79	3.01	2.95	3.42	2.26	4.69	1.65

Table 9: Mean numbers per tow at age of southern Gulf of St. Lawrence cod from the annual research vessel surveys, 1971-97. Line 1995a contains set 127, a very large set where approximately 6600 age 1-3 cod were caught. This set is considered anomalous and has not been included in the index (see Sinclair et al. 1997)

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	0+	3+	5+
1971		0.10	0.73	8.72	8.84	7.90	6.09	3.99	1.24	0.32	0.35	0.25	0.11	0.02	0.11	0.13	0.28	39.16	38.34	20.78
1972		0.53	3.60	7.85	18.02	6.84	5.77	3.97	2.40	0.49	0.40	0.44	0.14	0.06	0.05	0.05	0.08	50.70	46.56	20.70
1973	0.03	0.12	6.20	12.24	5.79	9.25	4.32	3.07	2.25	1.43	0.38	0.11	0.27	0.04	0.07	0.02	0.19	45.77	39.42	21.40
1974		0.14	3.55	14.51	11.03	4.73	5.67	2.12	1.44	1.46	0.49	0.19	0.10	0.24		0.04	0.13	45.83	42.13	16.59
1975		0.54	8.19	6.27	9.24	7.24	2.46	1.73	1.14	0.51	0.35	0.43	0.11	0.05	0.01	0.01	0.00	38.27	29.54	14.03
1976		4.30	9.85	38.38	9.91	7.45	3.36	0.92	0.64	0.34	0.31	0.27	0.09	0.05	0.02	0.03	0.03	75.95	61.80	13.51
1977	0.01	1.05	30.26	26.55	19.01	7.08	3.69	1.91	0.91	0.64	0.41	0.34	0.33	0.32		0.06	0.10	92.66	61.33	15.77
1978		1.23	9.29	54.73	40.86	19.72	5.55	3.21	1.01	0.43	0.54	0.64	0.11		0.15	0.05	0.00	137.50	126.99	31.40
1979	0.19	0.18	32.52	31.85	65.04	39.17	15.98	4.14	1.71	0.82	0.26	0.26	0.21	0.07	0.06	0.04	0.02	192.51	159.63	62.74
1980	0.32	1.41	6.73	41.14	30.51	53.54	26.39	9.50	1.65	0.80	0.34	0.11	0.04	0.03	0.05	0.02	0.02	172.60	164.14	92.48
1981	0.28	5.34	21.91	21.92	67.15	56.53	55.54	23.42	12.72	1.77	0.74	0.36	0.14	0.06	0.06	0.10	0.14	268.18	240.66	151.59
1982	0.34	4.74	38.42	23.22	27.50	31.90	50.82	26.51	12.83	4.05	0.47	0.20	0.13	0.07	0.02		0.03	221.25	177.75	127.03
1983	0.01	7.57	24.58	52.76	47.60	25.97	18.45	15.91	10.59	5.01	3.26	0.85	0.17	0.45	0.05	0.07	0.00	213.30	181.15	80.79
1984		1.91	11.27	16.62	36.99	49.10	17.53	9.87	10.31	4.70	2.10	0.79	0.09	0.04	0.09	0.02	0.02	161.44	148.26	94.65
1985	4.31	9.71	15.28	38.64	41.88	67.91	70.29	15.69	6.65	4.60	2.19	1.61	0.52	0.17			0.07	279.51	250.21	169.69
1986	2.06	7.11	24.68	35.22	36.62	36.86	43.97	31.77	9.47	2.01	2.75	1.11	0.78	0.22	0.14		0.06	234.82	200.98	129.14
1987	0.44	0.91	12.71	24.91	23.04	31.69	23.94	31.03	11.11	2.49	1.77	0.66	0.53	0.23	0.11	0.03	0.02	165.60	151.54	103.59
1988	1.70	3.89	19.05	70.02	64.56	51.26	35.86	19.36	20.94	12.18	2.38	0.55	0.32	0.27	0.10	0.11	0.00	302.55	277.91	143.33
1989	0.28	12.78	27.01	34.63	32.49	29.46	30.93	16.98	10.84	10.62	6.99	1.33	0.43	0.23	0.18	0.05	0.12	215.35	175.27	108.16
1990	0.20	2.07	6.62	35.40	26.35	19.31	13.64	9.41	5.31	3.13	3.61	1.69	0.34	0.06	0.09	0.02	0.01	127.26	118.38	56.63
1991	1.47	2.74	7.70	15.89	33.24	26.37	10.18	5.85	3.97	1.66	1.05	1.08	0.63	0.08	0.02	0.01	0.01	111.95	100.05	50.91
1992	0.61	1.92	4.69	9.81	13.78	12.24	6.58	2.55	1.20	0.75	0.32	0.20	0.10	0.06	0.01		0.01	54.83	47.61	24.02
1993	0.66	0.60	6.51	9.17	14.01	16.45	10.80	4.94	1.61	0.65	0.37	0.11	0.05	0.12	0.02	0.02	0.01	66.09	58.31	35.14
1994	1.25	0.66	1.79	7.61	9.07	9.73	12.03	7.76	2.79	1.12	0.41	0.30	0.08	0.04	0.02		0.01	54.67	50.97	34.29
1995	8.25	1.12	4.17	5.86	10.23	10.11	8.01	10.39	4.82	1.82	0.57	0.30	0.12	0.03	0.03	0.02	0.00	65.84	52.29	36.21
1995a	8.10	13.58	16.91	13.43	11.09	10.16	7.94	10.24	4.63	1.75	.56	.29	.12	.03	.03	.02		98.88	60.29	35.77
1996	0.78	2.73	2.21	7.25	12.61	11.16	9.81	7.50	8.14	3.84	1.12	0.38	0.11	0.10	0.01	0.01	0.03	67.78	62.07	42.20
1997	2.36	2.58	5.97	4.33	5.05	10.96	7.46	5.34	3.03	3.76	1.50	0.37	0.09	0.04	0.01		0.01	52.85	41.94	32.56

Table 10: Coefficients of variation of mean numbers per tow at age from research vessel surveys, 1971-1997.

Age	1	2	3	4	5	6	7	8	9	10	11	12
1971	47.0	22.9	12.3	15.1	17.6	16.5	14.1	16.0	20.7	25.3	22.9	17.0
1972	49.0	26.0	19.0	13.4	13.2	12.8	12.1	13.1	13.9	17.5	22.5	30.0
1973	46.7	21.8	18.8	19.3	19.1	17.7	17.3	15.5	16.2	19.8	27.2	39.7
1974	43.4	22.6	12.4	13.3	19.7	21.4	17.4	19.7	18.9	17.2	23.5	27.8
1975	64.3	37.8	31.3	26.3	22.3	23.1	23.2	23.3	22.7	24.5	28.5	30.6
1976	27.7	15.5	15.0	14.8	21.6	24.4	27.4	25.2	30.8	27.6	32.6	36.8
1977	25.8	31.8	19.7	15.6	13.6	15.1	17.2	25.9	21.3	26.8	27.8	31.1
1978	48.2	20.7	29.0	32.3	35.7	29.7	26.5	22.4	42.8	37.7	71.0	51.4
1979	47.4	22.1	14.5	11.8	10.7	9.0	8.3	9.8	12.3	32.1	22.7	22.9
1980	32.9	18.6	26.2	16.4	14.0	13.0	11.2	13.1	16.5	21.2	21.1	28.8
1981	25.5	33.0	16.3	16.4	16.8	16.4	15.3	14.2	13.2	14.9	15.3	24.1
1982	24.5	28.2	24.2	18.8	21.6	22.2	18.6	16.0	13.9	24.8	32.1	51.1
1983	21.1	13.0	11.9	14.1	12.9	9.9	10.2	10.6	13.3	11.8	18.3	36.8
1984	16.6	16.1	13.6	14.7	15.8	10.5	7.9	7.7	8.3	8.0	10.1	22.7
1985	57.6	21.1	13.8	21.0	26.5	28.7	25.8	20.2	19.6	19.2	15.4	41.6
1986	43.7	28.6	23.4	15.7	13.9	12.6	12.2	12.0	9.6	11.5	11.8	12.3
1987	37.3	20.4	14.8	12.1	11.5	10.9	12.3	14.8	15.5	18.7	19.1	17.5
1988	59.2	42.4	38.9	26.0	18.7	14.5	13.4	12.6	12.8	14.5	19.8	18.0
1989	60.0	28.7	20.2	14.6	11.7	11.4	11.3	11.3	11.5	12.4	12.2	13.5
1990	20.2	19.8	14.4	12.4	11.1	10.3	10.1	9.8	10.1	10.0	10.0	12.0
1991	32.4	18.7	22.0	24.5	21.3	15.0	12.3	11.1	10.4	11.0	10.1	11.0
1992	31.3	24.7	16.6	13.7	13.6	12.9	13.0	12.9	12.7	13.3	16.3	11.9
1993	22.7	20.3	18.3	12.7	9.3	9.3	9.6	10.2	10.2	12.3	11.7	16.7
1994	25.1	18.3	17.2	13.7	11.0	10.0	10.1	11.2	13.0	13.4	15.3	24.8
1995	30.8	24.3	16.5	14.3	12.5	11.8	11.0	10.4	10.8	15.2	17.1	18.4
1996	16.0	24.5	26.2	23.8	19.1	16.3	15.6	15.0	15.4	16.5	18.0	22.5
1997	32.7	25.0	15.0	22.6	24.4	22.0	21.9	21.9	21.7	20.4	20.2	28.8

Table 11: Mean weights (kg) at age of southern Gulf cod from research vessel surveys, 1960-1997.

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
1960	0.35	0.67	1.12	1.72	2.00	2.77	3.57	3.25	3.71	3.31	4.29	12.85	5.98
1961	0.31	0.55	0.90	1.36	2.08	2.75	3.41	4.83	6.51	6.87	7.56	9.01	14.86
1962	0.36	0.65	0.93	1.33	1.96	2.86	5.64	7.22	7.90	11.03		14.86	
1963	0.38	0.61	0.92	1.09	1.46	2.00	2.79	4.91	2.99	8.15	9.04	5.98	
1964	0.40	0.58	0.91	1.20	1.35	1.95	2.55	4.28	6.71	8.99		4.53	
1965	0.40	0.69	1.18	1.24	1.66	2.01	2.52	2.88	4.93		8.31		9.38
1966	0.39	0.79	1.29	1.58	1.91	2.26	2.43	3.36	4.75	6.53	7.82	9.95	
1967	0.45	0.70	1.45	1.88	2.38	2.46	2.86	4.14	4.62	6.17	8.00	10.19	11.18
1968	0.41	0.79	1.34	1.88	2.64	3.85	2.58	3.08	3.90	5.61	6.41	10.22	10.60
1969	0.44	0.85	1.40	1.96	2.63	3.51	4.23	2.84	7.19	6.73	6.82	7.04	10.77
1970	0.42	0.75	1.22	1.73	2.49	3.30	4.44	4.77	3.70	4.25	5.29	4.96	8.62
1971	0.41	0.75	1.15	1.42	2.00	3.03	4.59	5.49	6.31	4.43	3.56	4.26	6.61
1972	0.39	0.73	1.22	1.55	1.95	2.72	3.92	4.61	6.00	6.30	5.08	10.77	6.13
1973	0.34	0.75	1.18	1.56	1.94	2.39	2.84	4.97	5.29	8.78	3.58	2.98	4.89
1974	0.46	0.74	1.20	1.67	2.13	2.31	2.42	3.51	4.39	5.66	11.03		4.31
1975	0.30	0.74	1.20	1.80	2.39	2.87	3.22	4.29	4.81	5.99	10.04	11.35	13.88
1976	0.26	0.73	1.32	1.87	2.50	3.04	3.06	4.07	5.31	4.41	6.97	4.90	3.37
1977	0.34	0.66	1.35	1.95	2.70	4.33	3.88	5.38	4.92	5.87	8.75		14.96
1978	0.33	0.74	1.22	2.06	2.49	3.63	5.40	6.57	9.46	9.03		7.37	10.47
1979	0.26	0.59	0.97	1.48	2.18	2.81	3.65	6.94	7.37	6.41	11.97	4.84	13.29
1980	0.35	0.61	0.94	1.24	1.64	3.05	3.79	4.61	5.16	6.45	9.35	10.22	7.77
1981	0.30	0.65	0.87	1.18	1.42	1.78	3.09	3.89	4.58	7.67	11.49	9.52	11.67
1982	0.28	0.60	0.94	1.13	1.43	1.67	2.18	4.03	5.77	9.91	7.61	13.10	
1983	0.26	0.43	0.74	1.17	1.29	1.54	1.97	1.98	4.92	6.15	12.66	3.95	9.42
1984	0.27	0.42	0.60	1.00	1.37	1.45	1.92	2.23	3.46	11.62	7.45	11.62	7.45
1985	0.32	0.50	0.69	0.84	1.16	1.76	1.78	2.05	2.73	6.05	12.67		
1986	0.27	0.51	0.65	0.81	1.04	1.33	2.32	1.82	2.91	3.64	7.05	11.51	
1987	0.25	0.42	0.65	0.79	0.93	1.13	1.49	1.80	2.37	2.20	4.45	6.77	15.67
1988	0.30	0.47	0.66	0.85	0.94	1.06	1.27	2.40	2.48	3.61	3.99	13.91	15.32
1989	0.28	0.49	0.70	0.89	1.06	1.11	1.17	1.29	2.03	3.59	5.16	6.94	7.66
1990	0.33	0.54	0.76	0.96	1.14	1.24	1.27	1.35	1.44	2.34	6.47	8.74	5.66
1991	0.27	0.48	0.69	0.93	1.09	1.25	1.40	1.36	1.37	1.68	3.88	7.92	18.63
1992	0.30	0.43	0.72	0.93	1.10	1.25	1.49	1.89	1.98	1.41	1.43	1.62	
1993	0.30	0.45	0.64	0.91	1.06	1.26	1.41	2.21	1.49	2.47	1.53	5.23	8.81
1994	0.31	0.46	0.66	0.83	1.12	1.34	1.49	1.58	2.42	2.83	1.96	1.83	
1995	0.25	0.50	0.67	0.84	1.03	1.25	1.60	2.33	2.54	3.36	3.60	6.62	8.59
1996	0.34	0.45	0.77	0.93	1.10	1.29	1.58	2.36	2.59	4.32	3.54	1.76	4.19
1997	0.26	0.52	0.77	1.10	1.28	1.60	1.64	1.83	2.08	2.30	2.60	2.97	

Table 12: Mean lengths (cm) at age of southern Gulf cod from research vessel surveys, 1960-1997.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971	14.45	22.93	35.16	43.00	49.51	53.14	59.49	67.84	77.80	82.60	85.99	74.35	73.00	75.68	87.61
1972	17.01	24.83	34.42	42.17	49.97	53.87	57.72	64.12	71.81	75.87	82.03	82.34	77.65	101.00	85.00
1973	14.27	26.44	33.26	43.11	49.79	54.40	58.27	61.97	65.25	77.88	79.50	93.98	70.66	66.41	79.00
1974	16.87	28.19	36.20	42.46	49.60	55.42	59.70	61.20	62.02	69.96	73.39	80.96	102.15		76.00
1975	15.80	19.71	30.51	41.58	48.93	56.08	61.48	65.44	67.83	73.45	77.41	82.36	100.30	104.67	112.00
1976	17.23	25.16	30.29	42.25	51.39	57.44	62.87	66.70	66.53	73.49	79.62	74.67	85.04	79.00	70.00
1977	17.08	23.95	32.71	40.99	52.13	58.59	65.21	75.88	73.10	81.07	78.92	82.98	92.11		114.67
1978	15.92	26.60	33.52	42.91	50.20	59.22	62.19	70.12	80.10	84.63	93.32	92.76		87.74	98.84
1979	15.21	24.76	31.85	41.11	47.77	54.09	60.39	65.24	70.82	86.11	87.32	83.39	101.68	73.98	105.13
1980	14.47	22.91	33.53	40.37	46.63	50.96	55.57	67.90	73.02	77.78	81.57	88.01	99.52	102.41	94.00
1981	15.24	19.74	31.68	41.41	45.61	50.50	53.62	57.53	68.77	74.31	77.06	93.59	108.04	100.83	108.78
1982	18.12	26.08	30.97	39.80	46.43	49.25	53.23	55.79	60.68	73.81	84.51	101.64	92.29	112.00	
1983	16.76	25.45	31.91	37.02	44.33	51.30	52.53	55.89	59.42	59.42	73.45	83.87	105.94	76.00	100.00
1984	20.64	25.05	31.77	36.76	41.09	48.16	53.12	53.89	58.93	60.91	69.20	104.47	91.00	104.47	91.00
1985	15.60	24.51	33.20	38.24	42.32	45.12	49.72	56.43	56.80	59.40	63.85	84.31	107.81		
1986	17.16	24.71	30.36	37.85	40.91	44.04	47.54	51.07	60.03	56.23	64.04	69.12	84.70	102.73	
1987	19.12	24.90	31.07	36.81	42.19	44.88	47.27	49.92	53.59	56.98	59.86	59.32	70.67	79.83	115.08
1988	17.87	26.03	32.00	37.09	41.62	45.22	46.73	48.50	51.15	59.88	63.09	65.73	69.58	110.78	114.80
1989	18.03	24.23	31.17	37.59	42.22	45.72	48.31	49.05	49.93	51.56	57.59	65.47	76.07	81.76	82.75
1990	16.86	26.85	32.89	38.49	43.16	46.56	49.10	50.45	51.12	51.92	52.87	59.62	83.32	88.53	79.22
1991	17.34	25.14	30.58	37.36	42.06	46.42	48.64	50.72	52.50	52.03	52.28	55.16	68.82	91.40	124.18
1992	16.52	26.56	31.95	35.83	42.61	46.45	48.97	50.92	53.75	56.11	58.08	53.11	53.64	56.00	
1993	16.80	24.87	31.96	36.87	41.35	46.33	48.63	51.35	52.46	59.54	54.07	61.44	54.97	77.56	94.00
1994	15.81	24.45	32.54	36.60	41.38	44.62	49.14	52.04	53.60	54.36	60.88	66.03	59.51	58.08	
1995	18.57	24.88	29.93	37.99	41.88	44.94	47.89	50.97	54.46	60.72	62.10	68.05	70.55	85.76	95.78
1996	15.41	27.83	33.41	36.51	43.54	46.25	48.68	50.92	54.21	60.10	62.64	72.73	67.82	57.00	75.00
1997	14.48	24.94	30.46	38.58	43.64	48.86	51.19	54.23	54.73	56.03	57.40	61.06	64.03	67.48	

Table 13: Summary statistics from two multiplicative analyses of research survey catches at age of southern Gulf of St. Lawrence cod, 1971-97.

Analysis	N	R^2	Effect	DF	F-ratio	P
Age 2-3, set 127 in 1995 excluded	54	0.91	age	1	41.4	<.0001
			year-class	26	7.4	<.0001
Age 4-6, set 127 in 1995 excluded	81	0.91	age	2	18.1	<.0001
			year-class	28	16.3	<.0001

Table 14: ADAPT parameter estimates for two SPA calibrations of southern Gulf of St. Lawrence cod. The upper part of the table gives results for a calibration where M was assumed to be fixed at 0.2 for the years 1971 - 85, then fixed at 0.4 for 1986 - 97. The lower part of the table is for a calibration where M was fixed at 0.2 for the entire analysis.

M = 0.2, 1971-85, M = 0.4 1986 - 97

Age	k	Base Pop	Mean Boot	Bias	Rel. Bias	Adj. '97	CV
3	0.000230	25393	28617	3224	0.127	22169	0.55
4	0.000354	23415	24525	1110	0.047	22304	0.32
5	0.000477	24873	24950	77	0.003	24796	0.20
6	0.000545	17363	17570	207	0.012	17156	0.16
7	0.000564	12395	12833	438	0.035	11957	0.16
8	0.000580	8862	8869	7	0.001	8855	0.14
9	0.000558	8061	8236	175	0.022	7886	0.13
10	0.000652	3641	3696	55	0.015	3586	0.11
11		2855	2883	28	0.010	2827	0.08
12		1048	1058	10	0.010	1038	0.08
13		289	292	3	0.010	286	0.08
14		108	109	1	0.009	107	0.08
15		72	73	1	0.014	72	0.08
RMSE	0.129						

M = 0.2 1971 - 97

Age	k	Base Pop	Mean Boot	Bias	Rel. Bias	Adj. '97	CV
3	0.000336	14985	17837	2851	0.19	12134	0.76
4	0.000470	16004	17139	1135	0.07	14869	0.38
5	0.000590	19545	19563	18	0	19526	0.25
6	0.000641	15551	16077	526	0.03	15024	0.21
7	0.000640	12577	13160	584	0.05	11993	0.18
8	0.000642	10126	10147	21	0	10104	0.16
9	0.000606	10644	10958	314	0.03	10331	0.15
10	0.000706	5270	5352	82	0.02	5188	0.13
11		4028	4071	43	0.01	3984	0.1
12		1478	1494	16	0.01	1463	0.1
13		408	412	4	0.01	403	0.1
14		153	155	2	0.01	151	0.1
15		102	103	1	0.01	101	0.1
RMSE	0.173						

Table 15: Beginning of year population numbers ('000) for southern Gulf cod using an ADAPT calibration with M = 0.2 from 1971 - 85, and M = 0.4 from 1986 - 97.

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	Total 3+	SSB
1971	89959	39965	31719	31720	19037	6062	3305	1674	506	562	150	300	441	225400	152476
1972	35529	73647	30821	19389	17590	10233	2854	1574	900	296	139	55	137	193165	138862
1973	49054	26212	40167	14360	9843	7560	5165	1476	794	400	134	68	32	155265	113079
1974	57013	38919	15128	19768	6939	4693	3656	2545	704	344	237	47	13	150005	91987
1975	47665	43970	26978	7831	7417	2874	2164	1390	1130	341	102	121	13	141997	79852
1976	124604	37607	27938	15814	4113	3089	1160	760	413	310	143	36	30	216017	78216
1977	172488	101558	27087	13829	6636	1822	1392	517	364	204	123	74	14	326108	91352
1978	169424	140625	78660	16839	8318	3829	1130	882	259	195	122	52	52	420388	151818
1979	123638	138217	106052	54542	9628	4384	2133	704	498	112	94	60	38	440101	205779
1980	129193	101092	108513	72430	34475	4708	2030	963	310	179	32	47	34	454005	227656
1981	108583	105507	81030	75565	46504	19368	2477	931	423	124	119	10	32	440674	243866
1982	231844	88812	82917	59664	44546	26207	10247	1202	343	163	38	17	6	546005	244743
1983	334120	189349	71246	58231	40977	25125	14522	6098	582	152	64	26	12	740506	251131
1984	209099	273517	153988	52621	36706	22749	13652	7023	2578	351	79	37	12	772411	260137
1985	223315	171169	222743	122265	36378	21832	12337	6497	3092	1259	151	17	24	821078	314427
1986	211172	182677	138729	173040	84573	22235	12360	6504	3259	1653	711	100	9	837022	367046
1987	164624	141442	119549	86201	96633	48717	11573	5795	2418	1204	451	346	51	679006	302436
1988	138566	110285	93969	74077	48898	49274	26916	5916	2506	1048	466	194	141	552256	249025
1989	151768	92793	72514	58698	40437	25350	23081	12464	2477	886	321	147	88	481025	203568
1990	111952	101675	60844	43642	29196	18334	11003	9226	4121	850	213	90	58	391204	161013
1991	99777	74602	65721	34638	20565	11214	6573	3717	2383	1071	254	43	30	320586	122141
1992	68022	66648	45768	35563	15370	6895	3640	1808	1056	815	237	96	8	245926	90003
1993	60305	45198	41862	20436	15723	5972	1795	754	467	290	239	67	55	193163	66674
1994	57531	40380	30081	27312	12753	9783	3610	1025	398	254	167	137	39	183470	69884
1995	55388	38541	27024	20083	18133	8315	6432	2363	665	251	165	108	90	177557	74576
1996	33313	37069	25720	17989	13351	11965	5461	4261	1563	435	163	109	72	151471	78771
1997	22169	22304	24796	17156	11957	8855	7886	3586	2827	1038	286	107	72	123039	81137
1998		14852	14933	16589	11435	7917	5842	5183	2286	1830	672	185	69	81793	72872

Table 16: Fishing mortality for southern Gulf cod using an ADAPT calibration with M = 0.2 from 1971 - 85, and M = 0.4 from 1986 - 97.

Age	3	4	5	6	7	8	9	10	11	12	13	14	15	Ave 7-12
1971	0.00	0.06	0.29	0.39	0.42	0.55	0.54	0.42	0.33	1.19	0.81	0.58	0.48	0.58
1972	0.10	0.41	0.56	0.48	0.64	0.48	0.46	0.48	0.61	0.59	0.52	0.33	0.47	0.55
1973	0.03	0.35	0.51	0.53	0.54	0.53	0.51	0.54	0.64	0.32	0.84	1.44	0.52	0.51
1974	0.06	0.17	0.46	0.78	0.68	0.57	0.77	0.61	0.52	1.01	0.47	1.13	0.69	0.69
1975	0.04	0.25	0.33	0.44	0.68	0.71	0.85	1.01	1.09	0.67	0.85	1.19	0.93	0.83
1976	0.00	0.13	0.50	0.67	0.61	0.60	0.61	0.54	0.50	0.73	0.45	0.74	0.57	0.60
1977	0.00	0.06	0.28	0.31	0.35	0.28	0.26	0.49	0.42	0.32	0.65	0.16	0.37	0.35
1978	0.00	0.08	0.17	0.36	0.44	0.39	0.27	0.37	0.64	0.52	0.51	0.11	0.32	0.44
1979	0.00	0.04	0.18	0.26	0.52	0.57	0.59	0.62	0.82	1.05	0.49	0.37	0.61	0.70
1980	0.00	0.02	0.16	0.24	0.38	0.44	0.58	0.62	0.71	0.21	0.97	0.21	0.60	0.49
1981	0.00	0.04	0.11	0.33	0.37	0.44	0.52	0.80	0.76	1.00	1.74	0.25	0.66	0.65
1982	0.00	0.02	0.15	0.18	0.37	0.39	0.32	0.52	0.61	0.73	0.16	0.14	0.42	0.49
1983	0.00	0.01	0.10	0.26	0.39	0.41	0.53	0.66	0.31	0.46	0.37	0.55	0.59	0.46
1984	0.00	0.01	0.03	0.17	0.32	0.41	0.54	0.62	0.52	0.65	1.32	0.24	0.58	0.51
1985	0.00	0.01	0.05	0.17	0.29	0.37	0.44	0.49	0.43	0.37	0.21	0.48	0.47	0.40
1986	0.00	0.02	0.08	0.18	0.15	0.25	0.36	0.59	0.60	0.90	0.32	0.26	0.47	0.47
1987	0.00	0.01	0.08	0.17	0.27	0.19	0.27	0.44	0.44	0.55	0.44	0.50	0.35	0.36
1988	0.00	0.02	0.07	0.21	0.26	0.36	0.37	0.47	0.64	0.78	0.75	0.39	0.42	0.48
1989	0.00	0.02	0.11	0.30	0.39	0.43	0.52	0.71	0.67	1.03	0.87	0.52	0.61	0.62
1990	0.01	0.04	0.16	0.35	0.56	0.63	0.69	0.95	0.95	0.81	1.20	0.70	0.82	0.76
1991	0.00	0.09	0.21	0.41	0.69	0.73	0.89	0.86	0.67	1.11	0.57	1.24	0.87	0.82
1992	0.01	0.07	0.41	0.42	0.55	0.95	1.17	0.95	0.89	0.83	0.86	0.17	1.06	0.89
1993	0.00	0.01	0.03	0.07	0.07	0.10	0.16	0.24	0.21	0.15	0.16	0.14	0.20	0.16
1994	0.00	0.00	0.00	0.01	0.03	0.02	0.02	0.03	0.06	0.03	0.03	0.02	0.03	0.03
1995	0.00	0.00	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.02
1996	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01
1997	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.05	0.03	0.03	0.03	0.03	0.03	0.03

Table 17: Ln residuals for an ADAPT calibration of southern Gulf cod with M = 0.2 from 1971 - 85, and M = 0.4 from 1986 - 97.

Year	3	4	5	6	7	8	9	10	Ave
1971	-0.72	-0.28	-0.28	-0.6	-0.52	-0.48	-1.2	-0.67	-0.59
1972	0.19	0.08	-0.19	-0.1	-0.28	-0.39	-0.68	-0.43	-0.23
1973	0.25	-0.06	-0.2	-0.05	-0.04	-0.12	-0.17	-0.37	-0.09
1974	0.29	0.05	0.07	0.09	0.05	-0.06	0.39	-0.61	0.03
1975	-0.38	-0.18	-0.18	-0.07	-0.23	0.3	-0.08	-0.04	-0.11
1976	0.44	-0.05	-0.06	-0.29	-0.32	-0.43	-0.04	0.08	-0.08
1977	-0.25	-0.45	-0.25	-0.33	-0.26	0.21	0.15	0.72	-0.06
1978	0.49	0.01	-0.37	-0.09	0.1	-0.35	-0.03	0.37	0.02
1979	0.26	0.46	0.03	-0.28	0.26	0.18	0.22	0.05	0.15
1980	0.48	0	0.3	-0.07	-0.29	-0.03	0.23	0	0.08
1981	0.02	0.77	0.61	0.69	0.31	0.59	0.78	0.94	0.59
1982	-0.68	0.03	0.05	0.73	0.48	0.27	0.04	0.01	0.11
1983	-0.23	-0.19	-0.04	-0.2	0.07	0.13	0.06	0.43	0
1984	-0.92	-0.81	-0.23	-0.22	-0.35	0.21	0.07	-0.17	-0.3
1985	-0.14	-0.22	-0.26	0.33	0.1	-0.22	0.07	-0.15	-0.06
1986	-0.02	-0.25	-0.23	-0.33	0.01	0.18	-0.67	0.3	-0.13
1987	-0.12	-0.47	-0.23	-0.25	-0.06	-0.49	-0.46	-0.13	-0.28
1988	1.08	0.81	0.49	0.33	0.13	0.25	0.37	0.16	0.45
1989	0.29	0.3	0.22	0.49	0.3	0.31	0.48	0.67	0.38
1990	0.61	0.01	0.01	0.01	0.16	0.07	0.12	0.48	0.18
1991	-0.08	0.59	0.28	-0.02	0.13	0.35	0.17	0.07	0.19
1992	-0.16	-0.21	0.01	-0.48	-0.53	-0.21	0.18	-0.3	-0.21
1993	-0.15	0.17	0.11	0.31	-0.24	-0.4	-0.02	0.19	0
1994	-0.27	-0.19	-0.09	0.07	0.38	-0.41	-0.28	-0.17	-0.12
1995	-0.48	0	0.03	-0.01	0.31	0.3	-0.38	-0.69	-0.12
1996	0.2	0.26	0.2	0.27	0.3	0.45	0.53	-0.61	0.2
1997	0	-0.2	0.22	0.06	0.04	-0.22	0.13	-0.12	-0.01

Table 18: Beginning of year population numbers ('000) for southern Gulf cod using an ADAPT calibration with M = 0.2, from 1971 - 97.

Age	3	4	5	6	7	8	9	10	11	12	13	14	15	N 3+	SSB
1971	89965	39977	31757	31726	19040	6095	3323	1670	508	560	151	305	405	225481	152482
1972	35523	73652	30831	19420	17594	10235	2881	1589	897	298	138	56	141	193255	139094
1973	49020	26207	40171	14368	9868	7564	5167	1497	806	398	135	67	33	155301	113292
1974	57010	38891	15124	19771	6945	4714	3659	2546	722	354	235	48	12	150031	92172
1975	47482	43967	26955	7828	7419	2879	2182	1392	1131	356	111	119	13	141835	80032
1976	123143	37457	27935	15795	4111	3091	1164	774	415	311	155	43	29	214422	78327
1977	170364	100361	26964	13827	6621	1820	1393	521	375	206	123	84	20	322679	91174
1978	165378	138886	77681	16738	8316	3817	1128	884	261	204	123	53	60	413529	150710
1979	116742	134904	104628	53740	9546	4383	2122	703	499	115	102	61	39	427583	203153
1980	116602	95446	105801	71264	33818	4640	2028	955	309	180	34	54	35	431165	222723
1981	86175	95198	76408	73345	45549	18830	2422	930	416	123	120	12	37	399565	234693
1982	153472	70465	74477	55880	42728	25425	9807	1157	342	157	37	18	8	433971	227002
1983	207394	125183	56225	51321	37878	23637	13882	5737	545	152	60	26	13	522053	217977
1984	110055	169762	101454	40323	31048	20212	12434	6499	2283	321	78	33	12	494512	201737
1985	104485	90078	137796	79254	26309	17200	10260	5499	2663	1017	126	17	20	474724	213868
1986	84155	85387	72337	103491	49358	13992	8568	4804	2442	1302	513	80	8	426436	217228
1987	68875	68777	66700	51719	63337	31598	7774	4263	1787	916	339	276	48	366410	188771
1988	57782	56318	55379	47914	32526	34724	19527	4329	1967	829	373	158	125	311949	165290
1989	64004	47207	44548	40598	29041	18421	17435	9823	1899	732	257	122	84	274172	141451
1990	53027	52338	37150	30985	22021	14082	8462	7373	3363	659	179	72	56	229767	113275
1991	42257	42926	40161	23622	15765	8793	5211	2885	1834	884	191	36	26	184592	84636
1992	29080	34338	30460	23497	10666	5292	2915	1395	775	638	193	74	7	139331	60632
1993	27324	23368	25004	13618	10269	3946	1209	524	319	173	183	56	50	106043	41956
1994	27767	22323	18893	19644	10104	7571	2797	793	309	196	111	123	40	110673	49953
1995	29294	22708	18228	15379	15890	8015	6059	2226	625	236	154	87	99	119001	61620
1996	18196	23920	18464	14785	12468	12800	6437	4906	1800	500	188	124	71	114659	74848
1997	12134	14869	19526	15024	11993	10104	10331	5188	3984	1463	403	151	101	105271	87916
1998		9925	12154	15951	12228	9710	8168	8344	4117	3190	1172	323	121	85405	93000

Table 19: Fishing mortality for southern Gulf cod using an ADAPT calibration with M = 0.2 from 1971 - 97.

Age	3	4	5	6	7	8	9	10	11	12	13	14	15	Ave 7-12
1971	0.00	0.06	0.29	0.39	0.42	0.55	0.54	0.42	0.33	1.20	0.80	0.57	0.48	0.58
1972	0.10	0.41	0.56	0.48	0.64	0.48	0.45	0.48	0.61	0.59	0.52	0.33	0.47	0.54
1973	0.03	0.35	0.51	0.53	0.54	0.53	0.51	0.53	0.62	0.33	0.83	1.50	0.52	0.51
1974	0.06	0.17	0.46	0.78	0.68	0.57	0.77	0.61	0.51	0.96	0.48	1.08	0.69	0.68
1975	0.04	0.25	0.33	0.44	0.68	0.71	0.84	1.01	1.09	0.63	0.75	1.22	0.92	0.83
1976	0.00	0.13	0.50	0.67	0.61	0.60	0.60	0.52	0.50	0.73	0.41	0.58	0.56	0.59
1977	0.00	0.06	0.28	0.31	0.35	0.28	0.26	0.49	0.41	0.31	0.65	0.14	0.37	0.35
1978	0.00	0.08	0.17	0.36	0.44	0.39	0.27	0.37	0.63	0.49	0.50	0.11	0.32	0.43
1979	0.00	0.04	0.18	0.26	0.52	0.57	0.60	0.62	0.82	1.01	0.44	0.37	0.61	0.69
1980	0.00	0.02	0.17	0.25	0.39	0.45	0.58	0.63	0.72	0.20	0.88	0.18	0.61	0.49
1981	0.00	0.05	0.11	0.34	0.38	0.45	0.54	0.80	0.77	1.01	1.71	0.21	0.67	0.66
1982	0.00	0.03	0.17	0.19	0.39	0.41	0.34	0.55	0.61	0.77	0.16	0.13	0.44	0.51
1983	0.00	0.01	0.13	0.30	0.43	0.44	0.56	0.72	0.33	0.46	0.40	0.57	0.64	0.49
1984	0.00	0.01	0.05	0.23	0.39	0.48	0.62	0.69	0.61	0.73	1.33	0.27	0.65	0.59
1985	0.00	0.02	0.09	0.27	0.43	0.50	0.56	0.61	0.52	0.48	0.26	0.50	0.59	0.52
1986	0.00	0.05	0.14	0.29	0.25	0.39	0.50	0.79	0.78	1.14	0.42	0.31	0.64	0.64
1987	0.00	0.02	0.13	0.26	0.40	0.28	0.39	0.57	0.57	0.70	0.56	0.59	0.48	0.48
1988	0.00	0.03	0.11	0.30	0.37	0.49	0.49	0.62	0.79	0.97	0.91	0.44	0.56	0.62
1989	0.00	0.04	0.16	0.41	0.52	0.58	0.66	0.87	0.86	1.21	1.07	0.58	0.77	0.78
1990	0.01	0.06	0.25	0.48	0.72	0.79	0.88	1.19	1.14	1.04	1.40	0.83	1.03	0.96
1991	0.01	0.14	0.34	0.60	0.89	0.90	1.12	1.11	0.86	1.32	0.75	1.45	1.12	1.03
1992	0.02	0.12	0.61	0.63	0.79	1.28	1.52	1.28	1.30	1.05	1.03	0.20	1.40	1.20
1993	0.00	0.01	0.04	0.10	0.10	0.14	0.22	0.33	0.29	0.24	0.19	0.15	0.27	0.22
1994	0.00	0.00	0.01	0.01	0.03	0.02	0.03	0.04	0.07	0.04	0.04	0.02	0.03	0.04
1995	0.00	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.02
1996	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.01
1997	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.02

Table 20: Ln residuals for an ADAPT calibration of southern Gulf cod with M = 0.2 from 1971 -97.

Age	3	4	5	6	7	8	9	10	Ave 3-10
1971	-1.09	-0.56	-0.49	-0.76	-0.65	-0.58	-1.28	-0.75	-0.77
1972	-0.19	-0.2	-0.4	-0.26	-0.41	-0.49	-0.77	-0.51	-0.4
1973	-0.12	-0.34	-0.41	-0.21	-0.16	-0.22	-0.25	-0.45	-0.27
1974	-0.08	-0.23	-0.14	-0.07	-0.08	-0.16	0.31	-0.69	-0.14
1975	-0.75	-0.47	-0.39	-0.23	-0.35	0.2	-0.16	-0.12	-0.28
1976	0.08	-0.33	-0.27	-0.45	-0.44	-0.53	-0.12	0.01	-0.26
1977	-0.61	-0.72	-0.45	-0.49	-0.38	0.11	0.07	0.64	-0.23
1978	0.14	-0.26	-0.57	-0.23	-0.02	-0.44	-0.11	0.29	-0.15
1979	-0.06	0.21	-0.17	-0.42	0.16	0.08	0.15	-0.03	-0.01
1980	0.2	-0.22	0.12	-0.21	-0.38	-0.09	0.16	-0.06	-0.06
1981	-0.13	0.59	0.46	0.57	0.22	0.54	0.76	0.88	0.49
1982	-0.64	-0.02	-0.04	0.64	0.41	0.22	0.02	0.04	0.08
1983	-0.13	-0.05	0.01	-0.2	0.05	0.12	0.05	0.48	0.04
1984	-0.65	-0.61	-0.01	-0.07	-0.26	0.28	0.14	-0.11	-0.16
1985	0.25	0.15	0.04	0.68	0.41	0.02	0.27	0.04	0.23
1986	0.37	0.09	0.1	-0.04	0.34	0.5	-0.43	0.53	0.18
1987	0.22	-0.18	0.03	0.02	0.18	-0.24	-0.19	0.05	-0.01
1988	1.43	1.07	0.68	0.53	0.35	0.45	0.55	0.38	0.68
1989	0.62	0.56	0.39	0.63	0.45	0.49	0.65	0.81	0.58
1990	0.84	0.26	0.21	0.13	0.28	0.21	0.29	0.68	0.36
1991	0.25	0.75	0.5	0.19	0.27	0.47	0.34	0.27	0.38
1992	0.17	0.05	0.21	-0.22	-0.25	0.06	0.42	-0.03	0.05
1993	0.1	0.4	0.26	0.42	-0.07	-0.2	0.18	0.39	0.19
1994	-0.09	-0.04	0.02	0.09	0.34	-0.4	-0.25	-0.14	-0.06
1995	-0.37	0.08	0.05	-0.05	0.15	0.08	-0.55	-0.87	-0.18
1996	0.25	0.27	0.14	0.14	0.09	0.12	0.13	-0.98	0.02
1997	0	-0.25	0.1	-0.14	-0.25	-0.6	-0.38	-0.73	-0.28

Table 21: Input data for reference point estimation and catch projections. Beginning of year (BOY, from the RV survey) weights, catch weights, and fishing mortality at age are the average for the period 1995-97. Age 3 abundance in 1998 was taken as the average for the period 1993-97.

	Weight at Age			M = 0.2		M = 0.4	
Age	RV BOY	Catch	Maturity	F 95-97	N 98 ('000)	F95-97	N 98 ('000)
3	0.235	0.280	0.121	0.002	22897	0.001	45422
4	0.383	0.493	0.368	0.004	9927	0.003	14853
5	0.586	0.743	0.721	0.006	12155	0.005	14934
6	0.818	1.003	0.905	0.008	15951	0.007	16590
7	0.991	1.323	0.974	0.013	12231	0.013	11436
8	1.221	1.717	1.000	0.015	9716	0.018	7921
9	1.441	2.120	1.000	0.014	8169	0.017	5842
10	1.838	2.537	1.000	0.017	8348	0.025	5186
11	2.226	3.000	1.000	0.018	4120	0.023	2289
12	2.868	3.093	1.000	0.022	3191	0.028	1831
13	3.328	3.800	1.000	0.018	1172	0.024	672
14	3.124	4.393	1.000	0.015	323	0.019	185
15	3.092	4.133	1.000	0.015	121	0.021	69

Ricker Stock/Recruitment Parameters

Calibration Scenario	α	β
M = 0.2	0.7245	0.003117
Mup	0.9414	0.003348

12. Figures

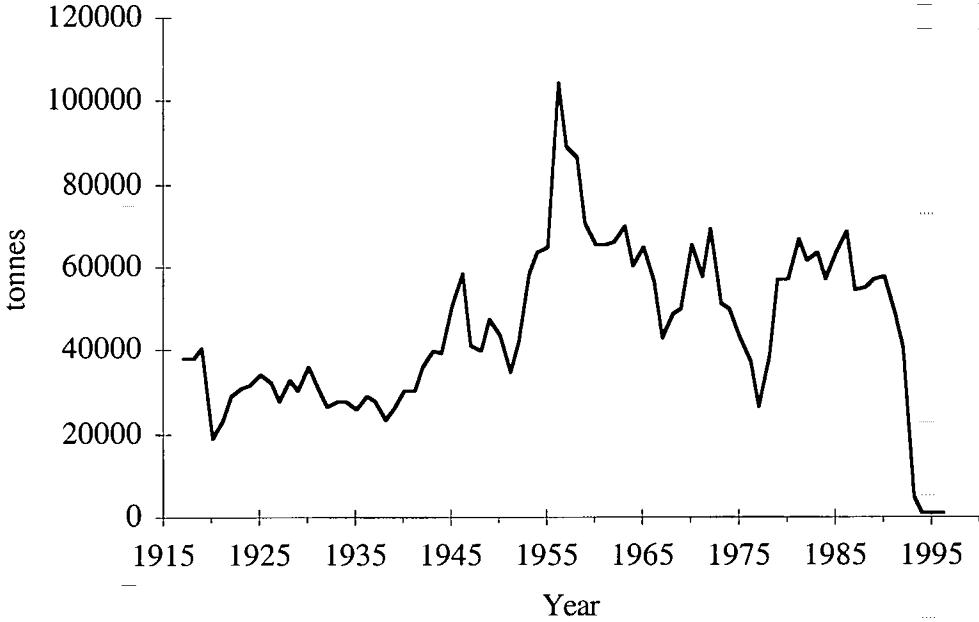

Figure 1: Landings (t) of southern Gulf cod, 1917 - 1997.

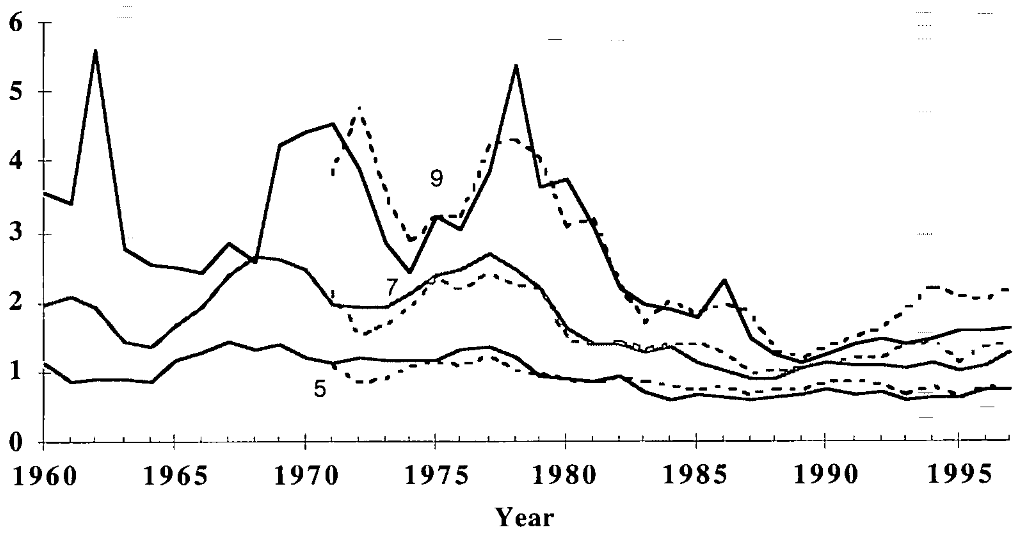

Figure 2: Trends in mean weights (kg) at ages 5, 7, and 9 of southern Gulf cod from the commercial fishery (dashed lines) and the research vessel surveys (solid lines), 1960 to 1997.

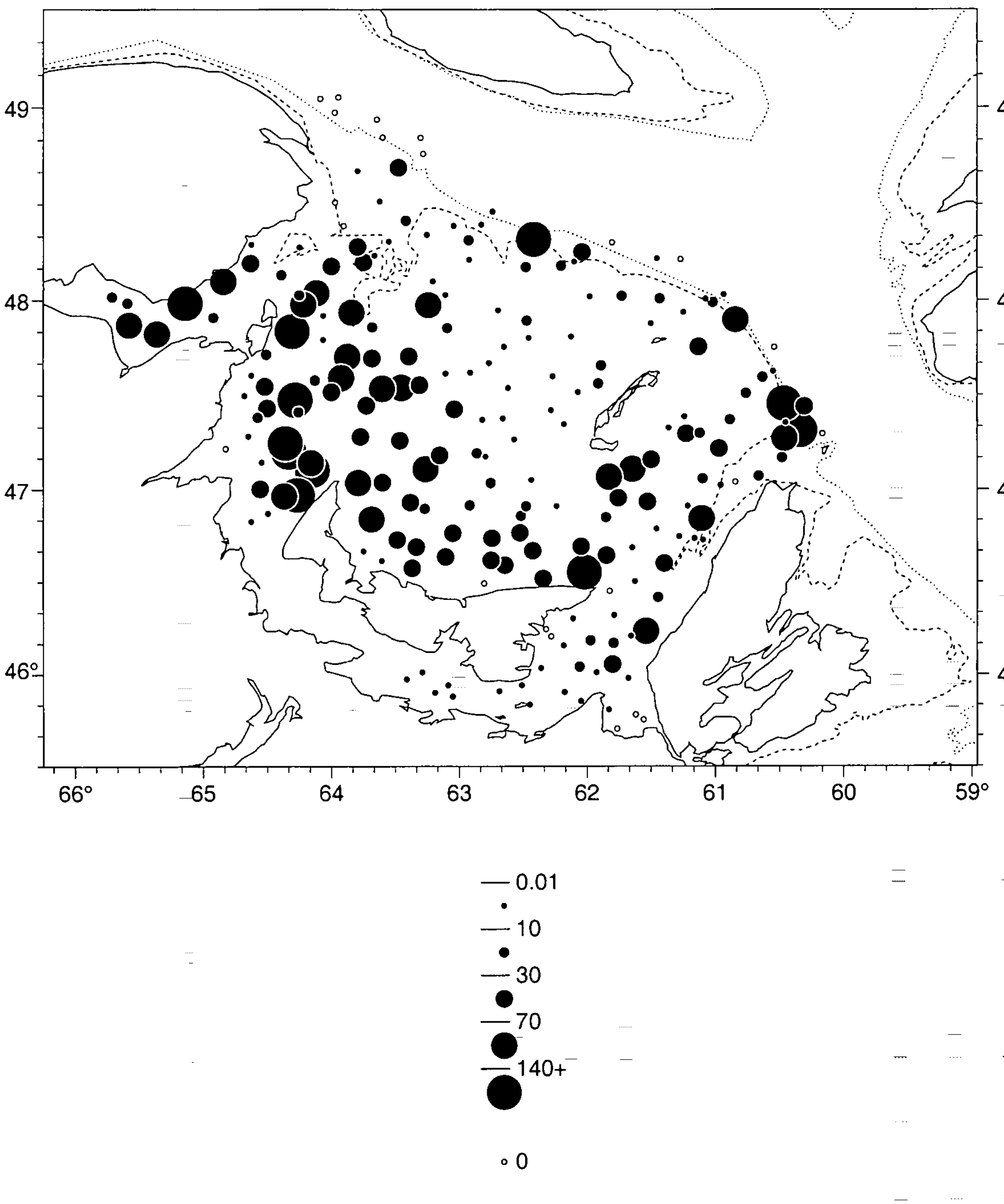

Figure 3: Distribution of cod catches (numbers) in the September 1997 RV survey.

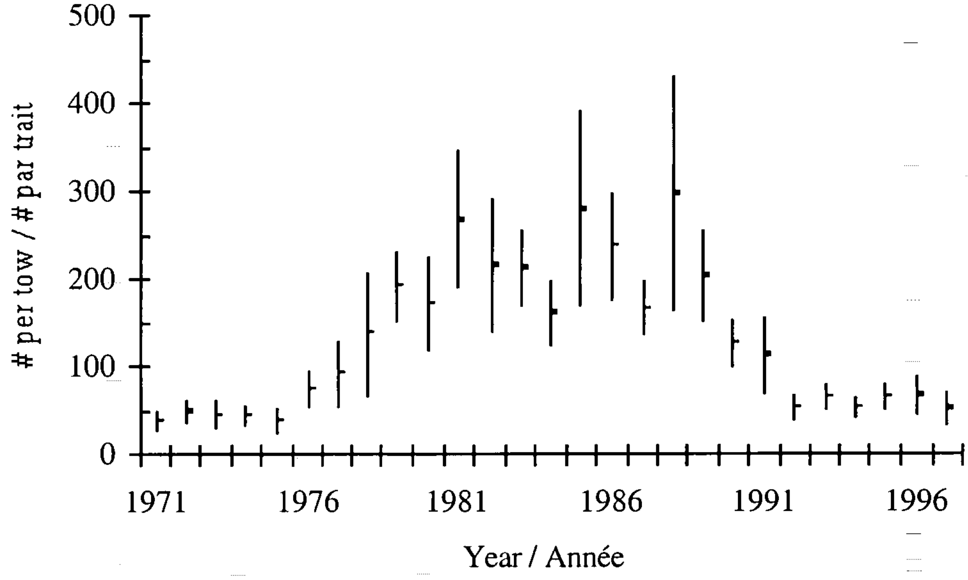

Figure 4: Mean numbers per tow (ages 0+) of southern Gulf cod from the September groundfish survey, 1971 to 1997. Vertical bars give 2 standard errors.

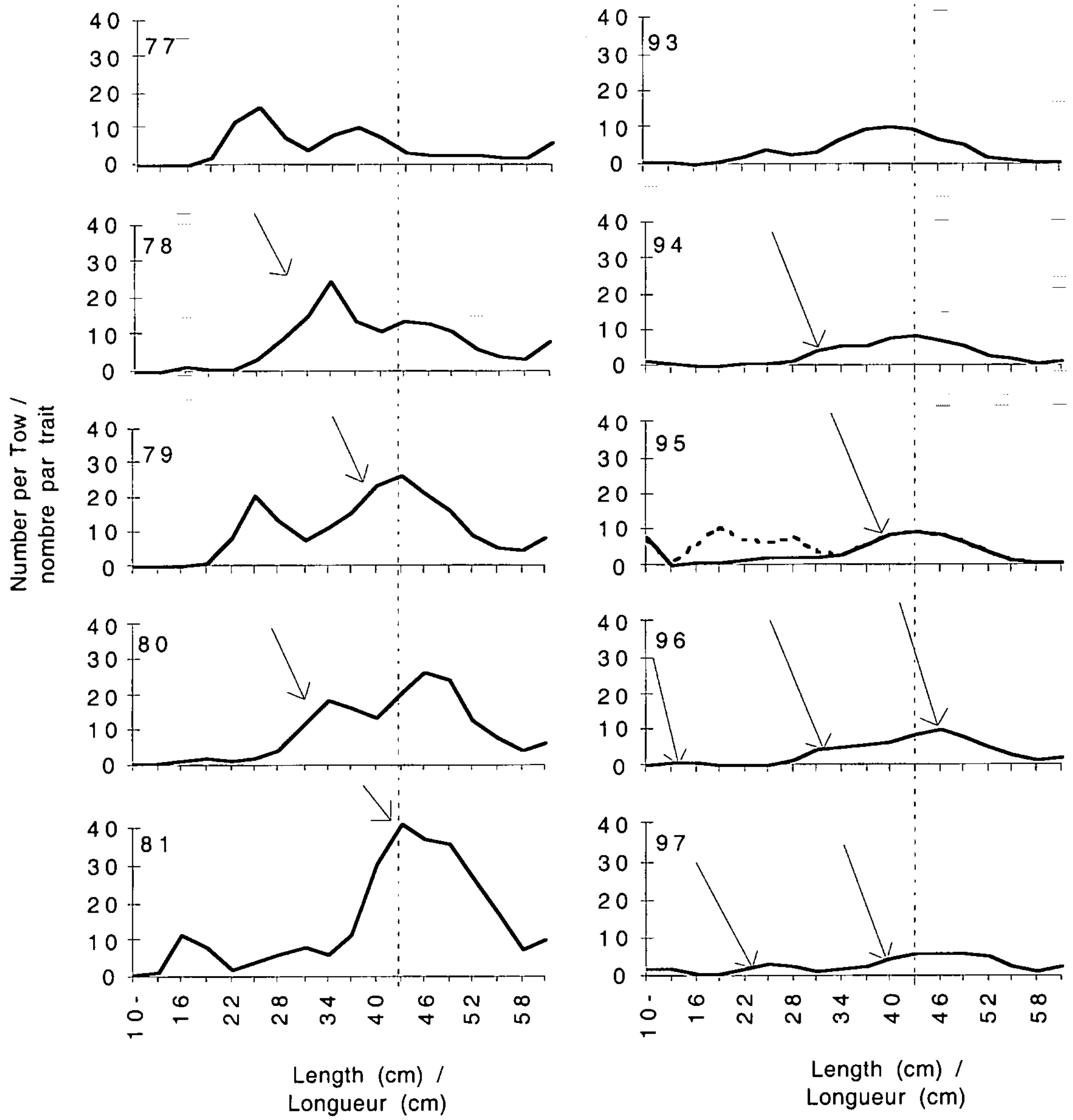

Figure 5: Comparison of survey length composition (numbers per tow) for 4TVn (N-A) cod during the period of the last recovery (1977-1981) and since the moratorium (1993-1997). Fish of 10 cm and less and those of 61 cm and over are combined in the length groups 10 and 61 respectively. Arrows indicate year-classes; the vertical dashed line is the regulated minimum size. The dashed line in 1995 includes set 127, the solid line does not.

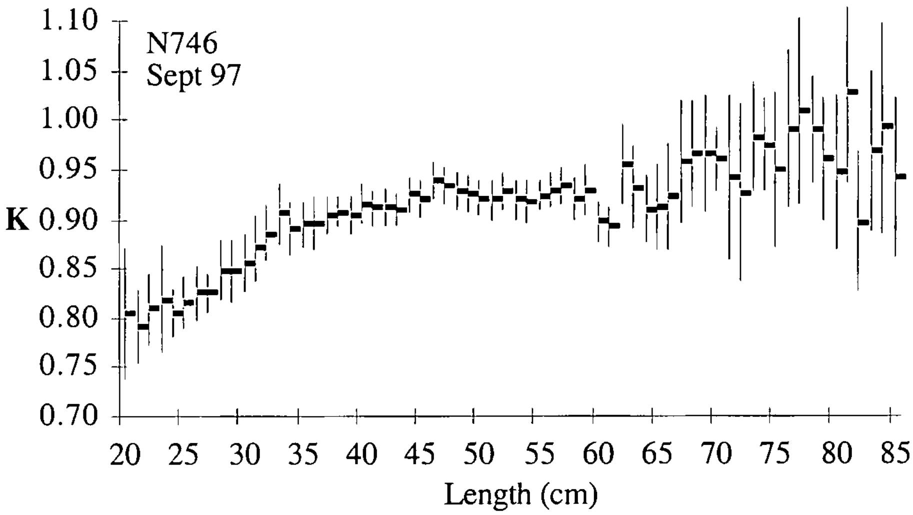

Figure 6: Condition index (round weight/length^3) +/- 2 standard errors from cod sampled during the 1997 groundfish survey in the southern Gulf of St. Lawrence.

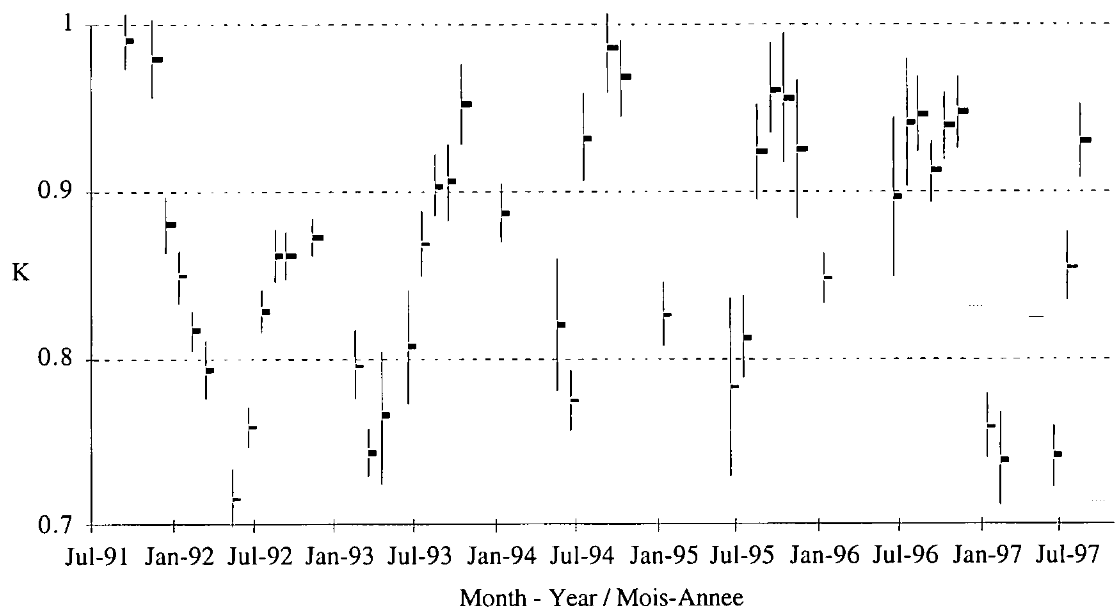

Figure 7: Seasonal change in condition index (carcass weight/length^3) +/ - 2 standard errors for southern Gulf of St. Lawrence cod of 40-50 cm length between September 1991 and August 1997. Error bars give 2 standard errors.

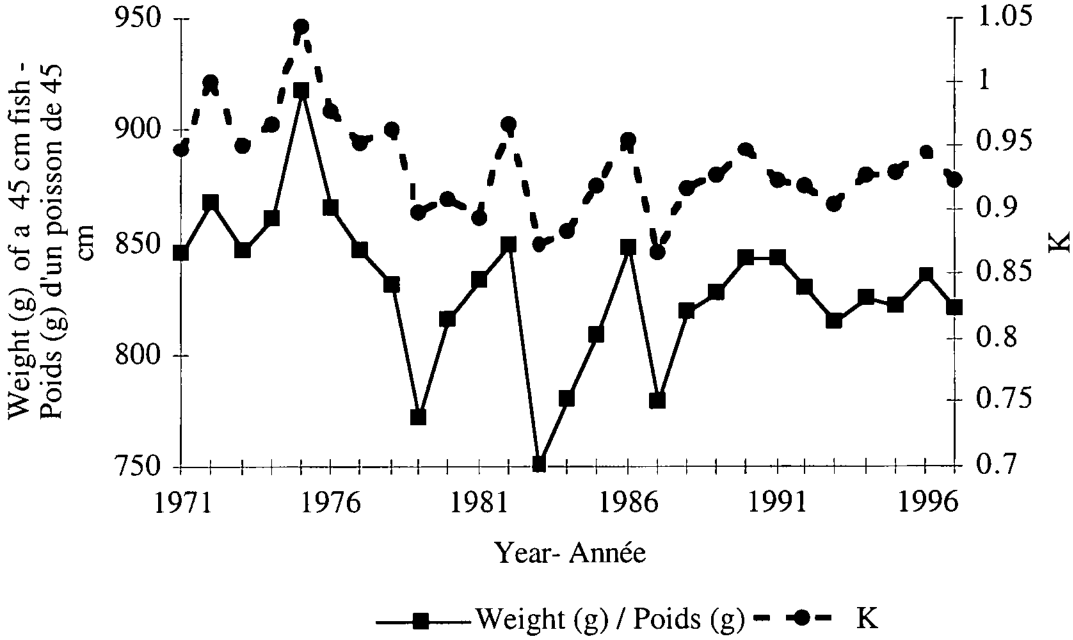

Figure 8: Trends in annual condition indices for southern Gulf cod.

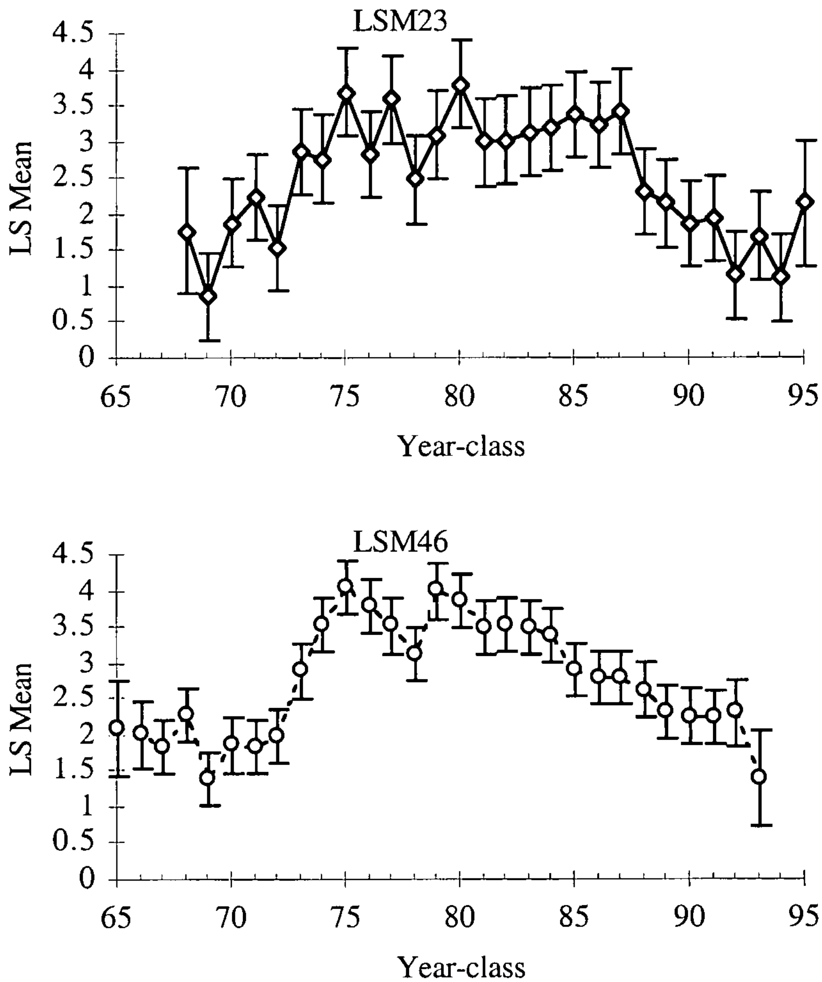

Figure 9: Relative year-class abundance estimated from RV results for southern Gulf cod. The upper panel is for ages 2-3 and the lower is for ages 4-6. Error bars give 2 standard errors. The estimates are in the ln scale.

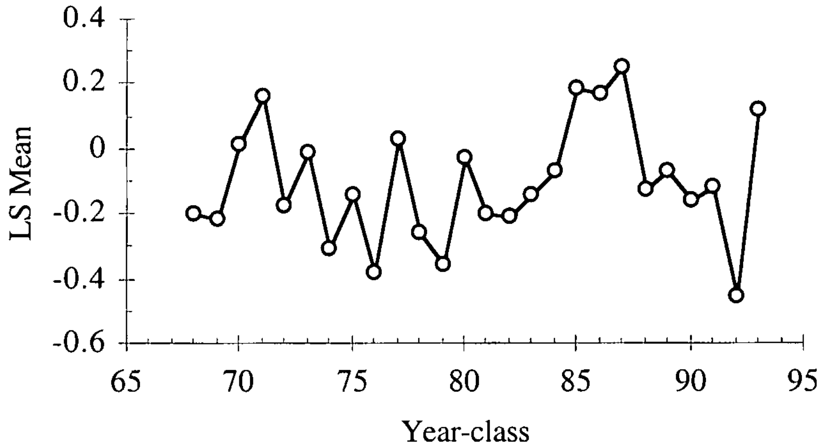

Figure 10: Trend in relative total mortality between ages 2-3 and 4-6 for southern Gulf cod, estimated from multiplicative analyses of RV results.

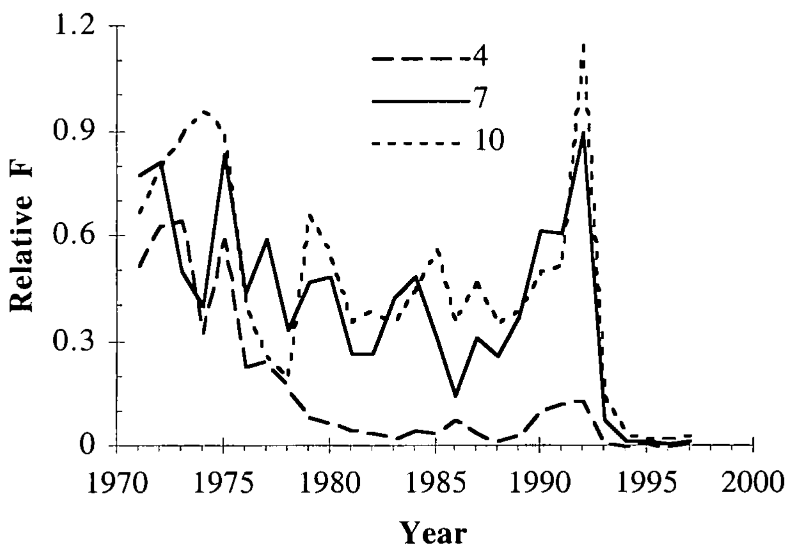

Figure 11: Trend in relative fishing mortality estimated as the ratio of catch at age divided by RV population estimates at age, southern Gulf cod.

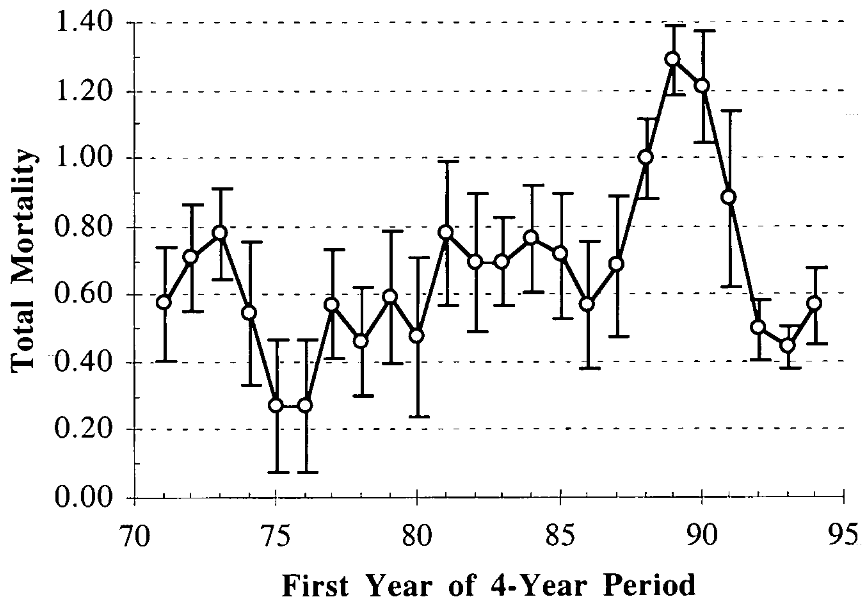

Figure 12: Total mortality of southern Gulf of St. Lawrence cod estimated by a modified catch curve analysis of RV results in 4-year moving windows. Error bars are 95% confidence intervals of the slope.

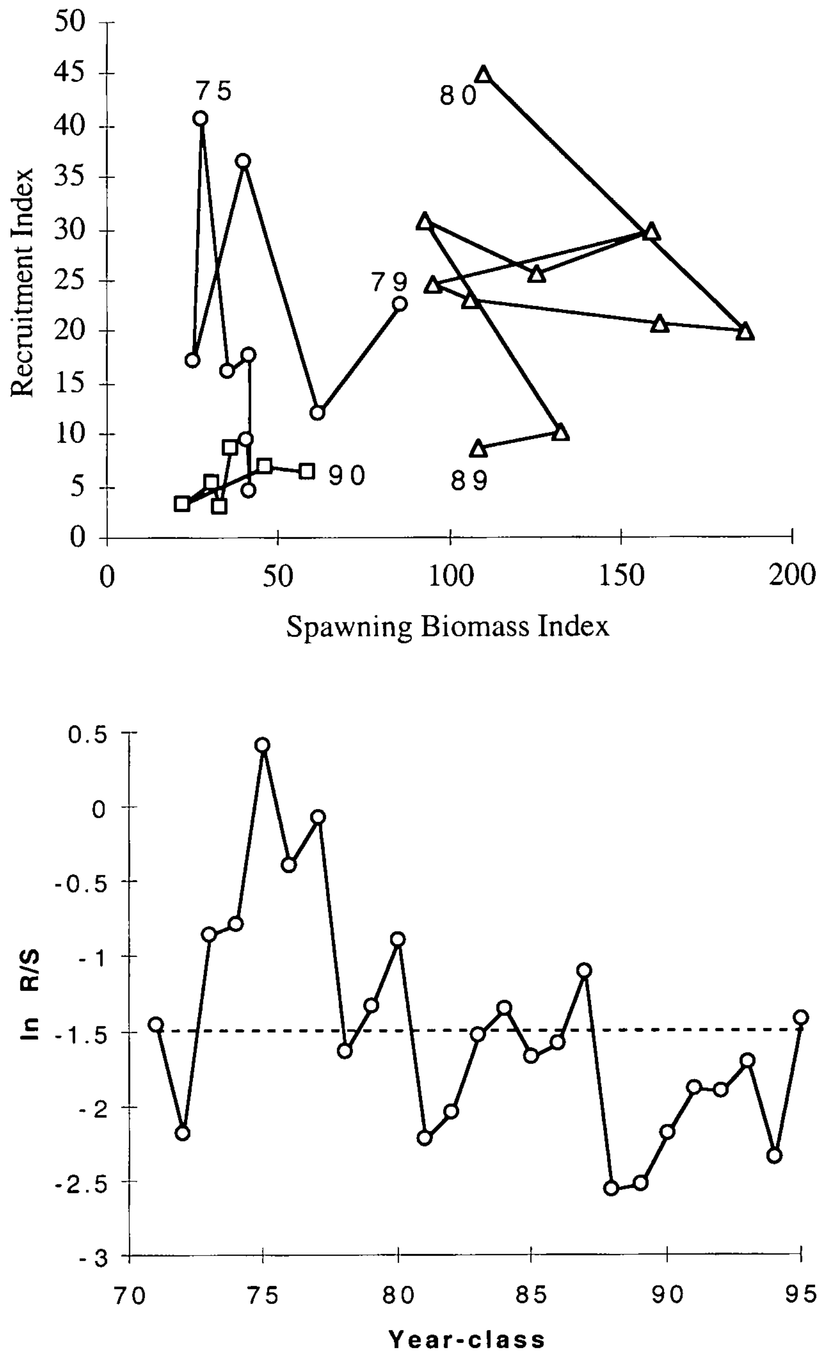

Figure 13: Stock and recruitment estimates for southern Gulf cod obtained from RV survey results. The upper panel plots stock biomass and recruitment, the lower is the ln ratio of R/S. The horizontal line in the lower panel is the mean of the series.

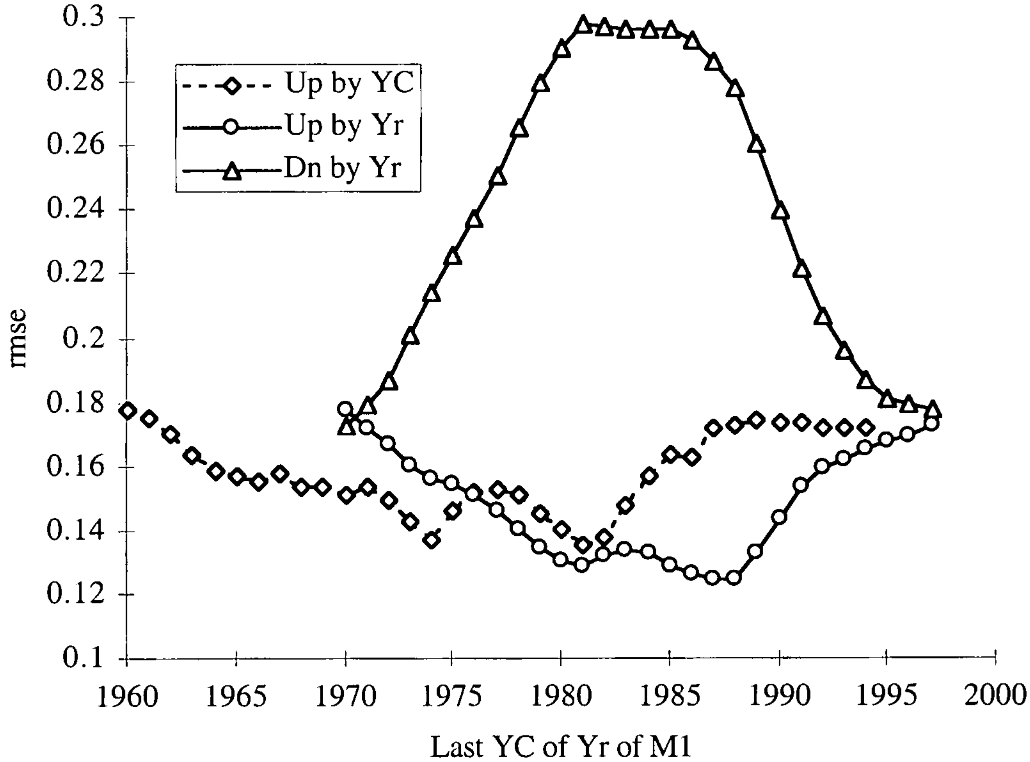

Figure 14: Residual mean square error (rmse) from ADAPT calibrations of southern Gulf cod using different assumptions of a change in M during the assessment period. The x-axis is the last year or year-class for the first M value. Up by YC presents results when M increases from 0.2 to 0.4 by year-class, Up by Yr is when M increases by year, Dn by Yr is when M decreases by year.

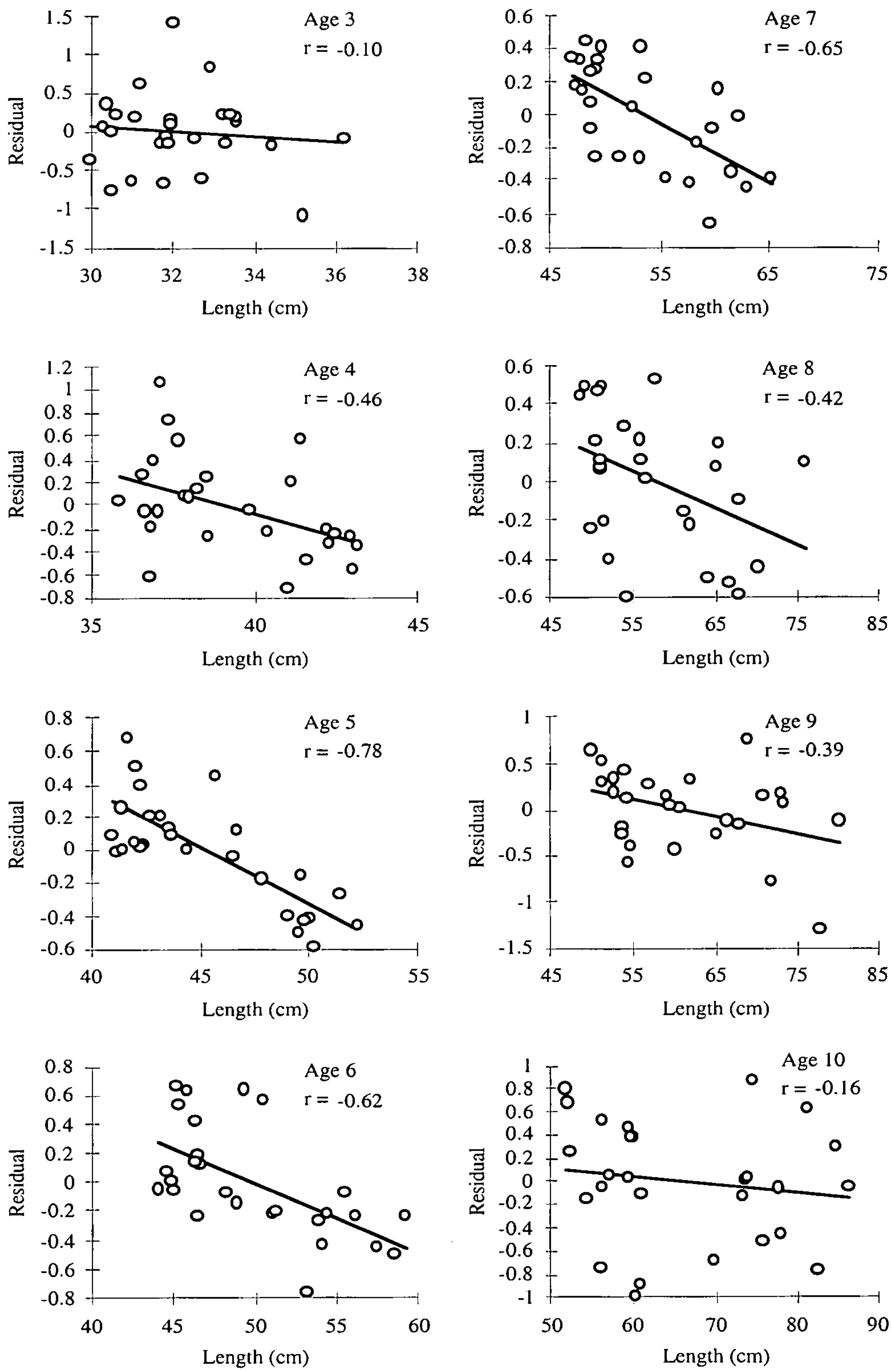

Figure 15: Scatterplots of SPA calibration residuals (q) vs mean length at age from a calibration with M = 0.2 for all years. The negative slopes are contrary to the idea that catchability and size at age were positively correlated.

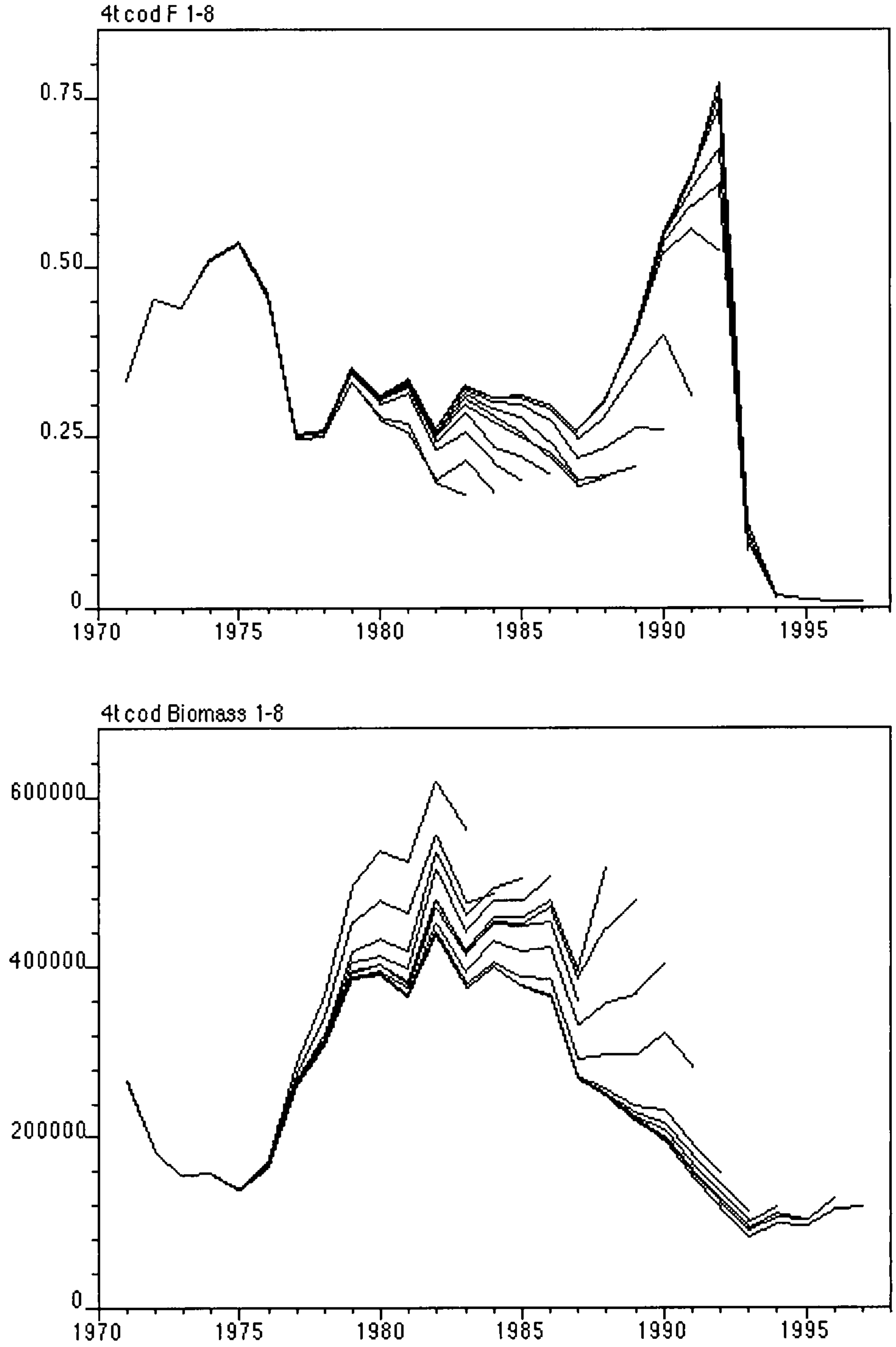

Figure 16: Retrospective plots for M=0.2 all years.

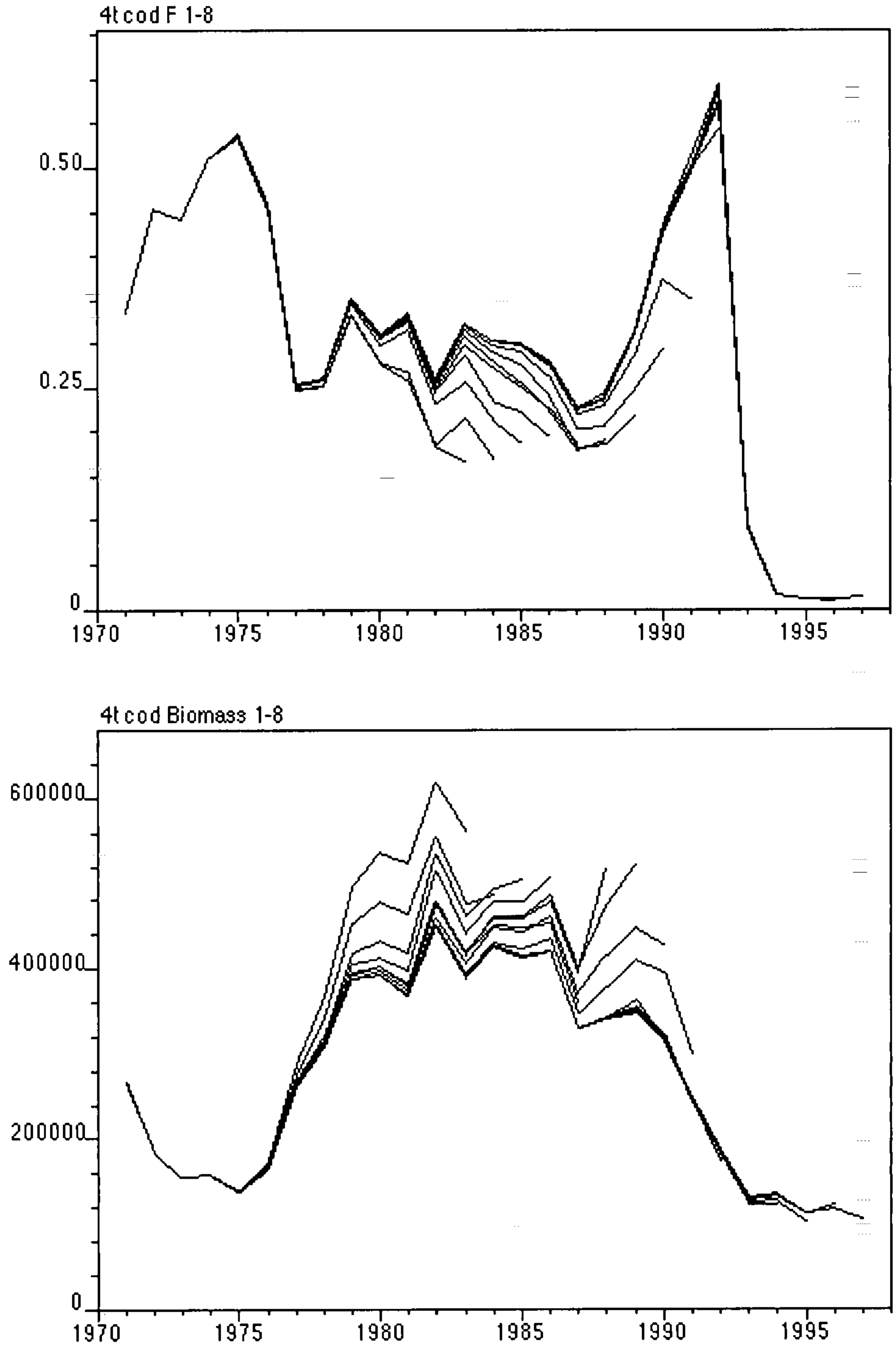

Figure 17: Retrospective plots for M=0.2 1971-88, and M=0.4 1989-97.

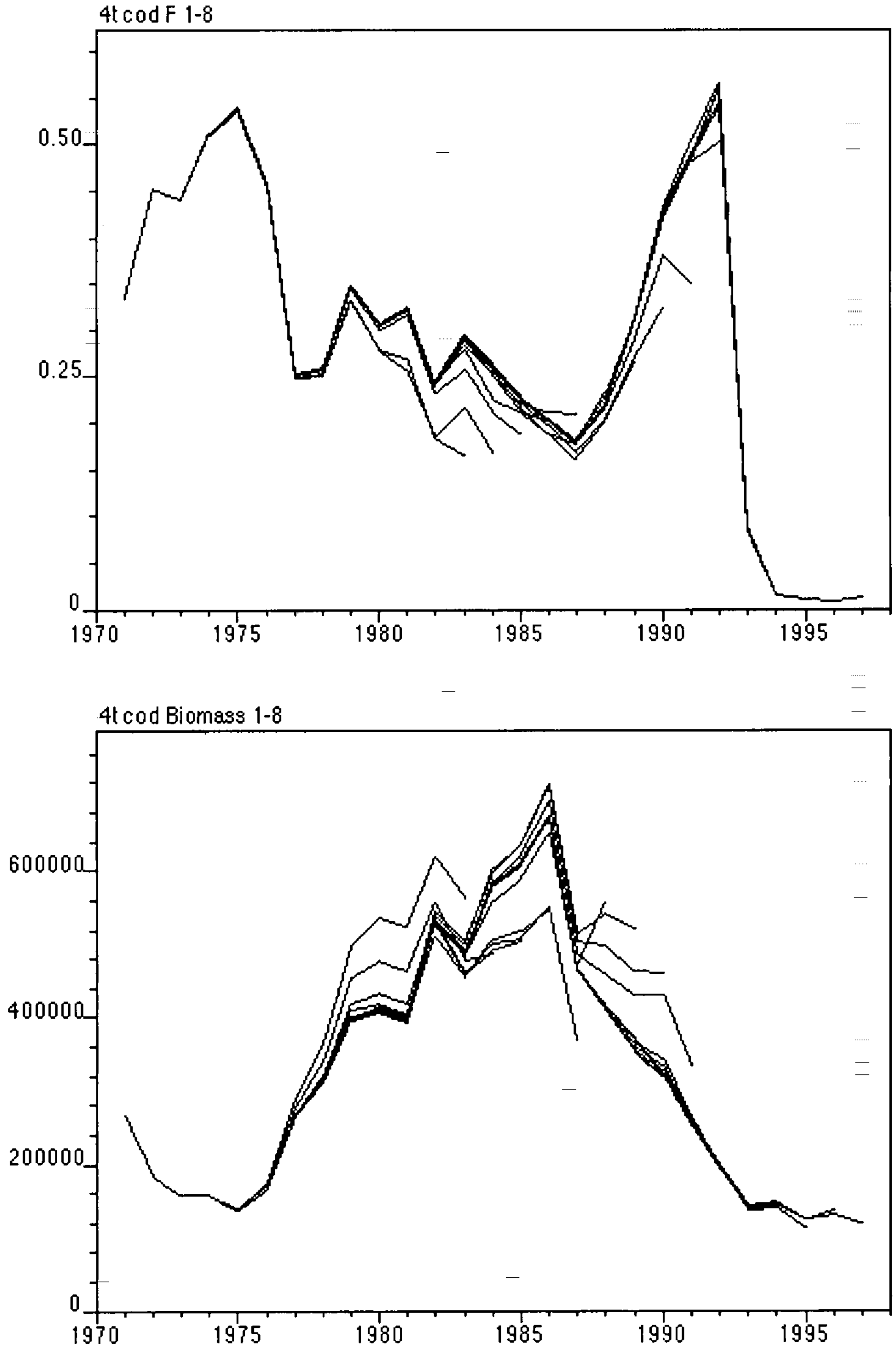

Figure 18: Retrospective plots for M=0.2 1971-85, and M=0.4 1986-97.

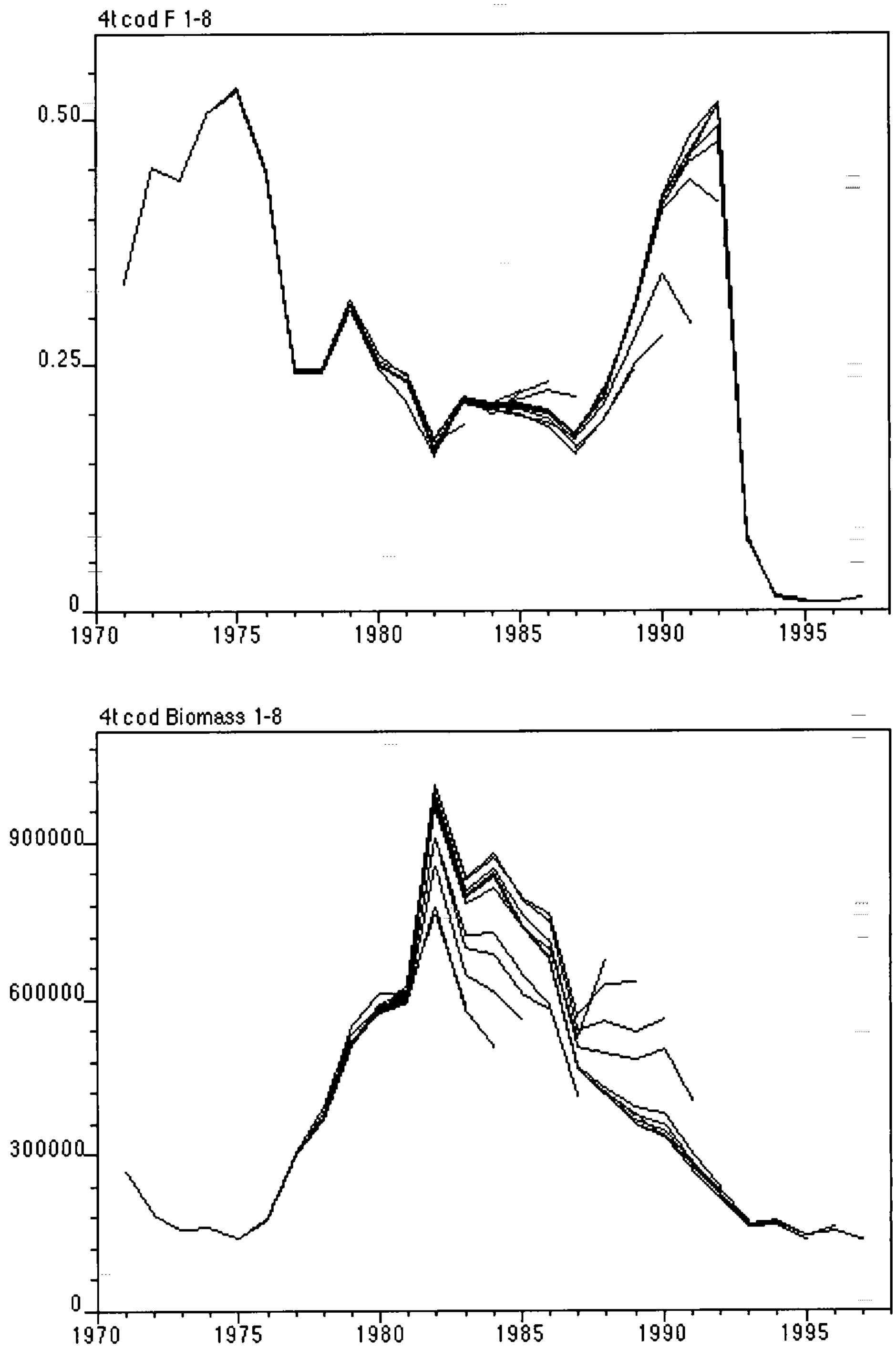

Figure 19: Retrospective plots for M=0.2 1971-81, and M=0.4 1982-97.

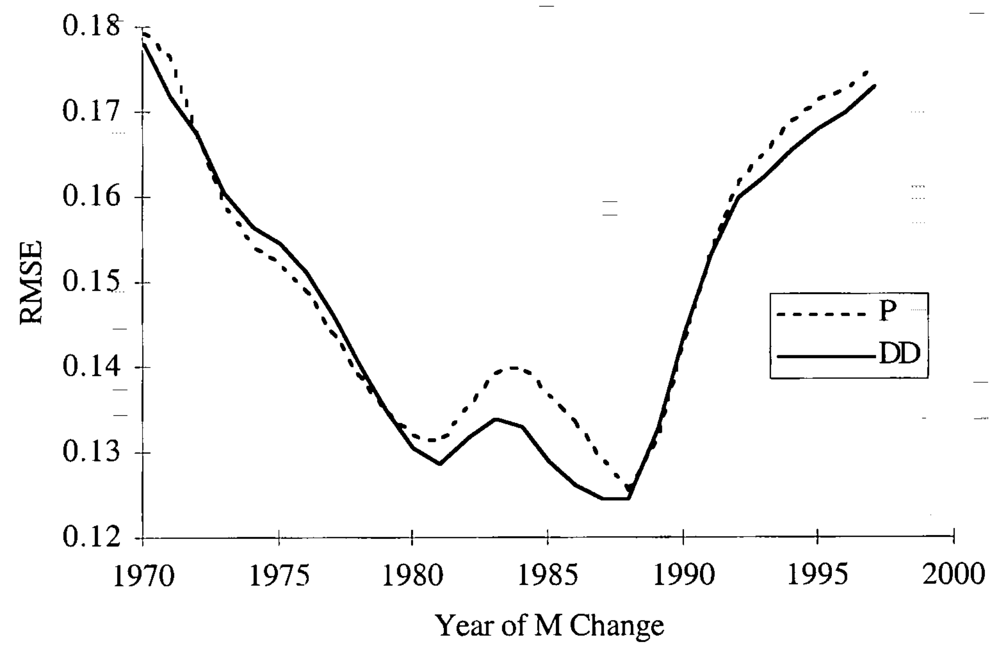

Figure 20: Residual mean square error from ADAPT calibrations where M is changed by year, comparing changes when a proportional calibration relationship is used (P) with a density dependent relationship (DD).

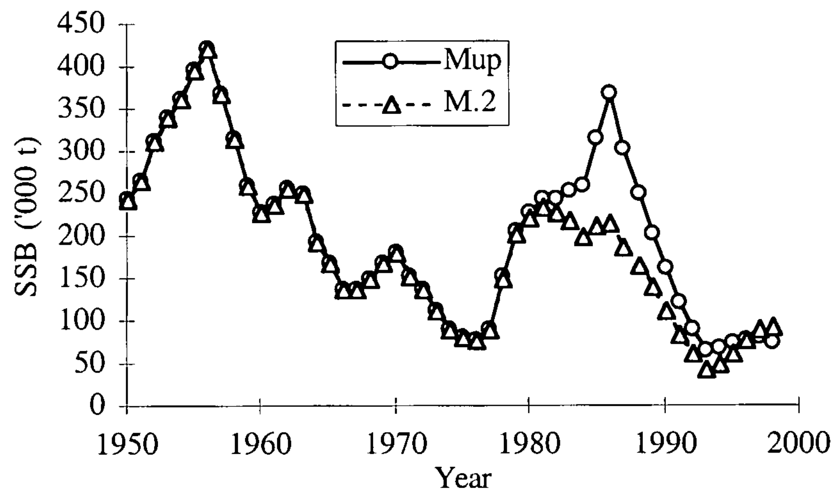

Figure 21: Spawning stock biomass estimates for southern Gulf cod from SPAs using two M scenarios, where M increased from 0.2 to 0.4 in 1986 (Mup) and when M was constant at 0.2 (M.2).

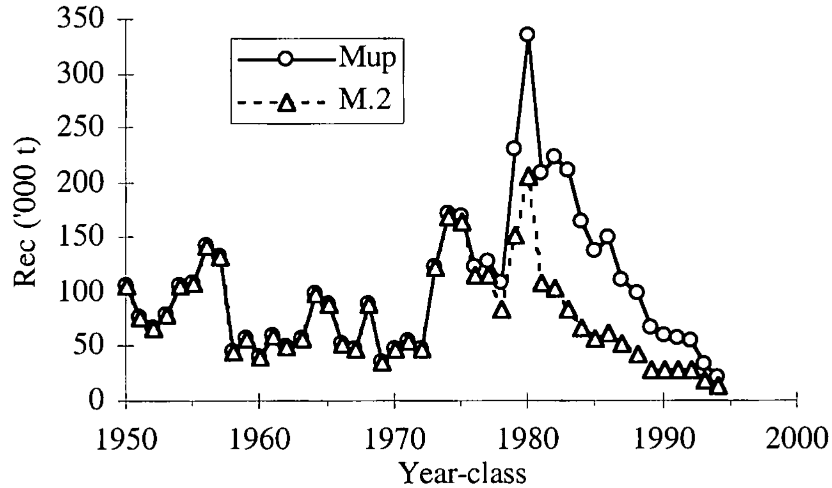

Figure 22: Trends in age 3 recruitment for southern Gulf cod from SPAs using two M scenarios, where M increased from 0.2 to 0.4 in 1986 (mup) and when M was constant at 0.2 (M.2).

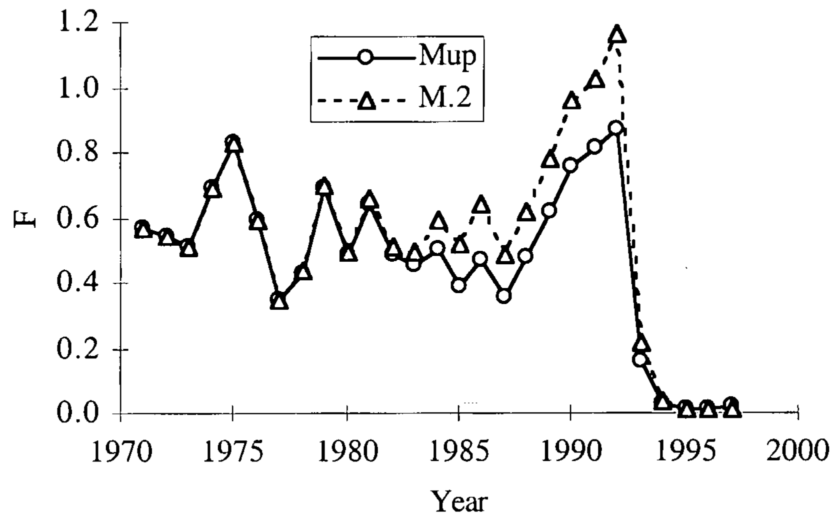

Figure 23: Trends in fishing mortality (F) for southern Gulf cod from SPAs using two M scenarios, where M increased from 0.2 to 0.4 in 1986 (mup) and when M was constant at 0.2 (M.2).

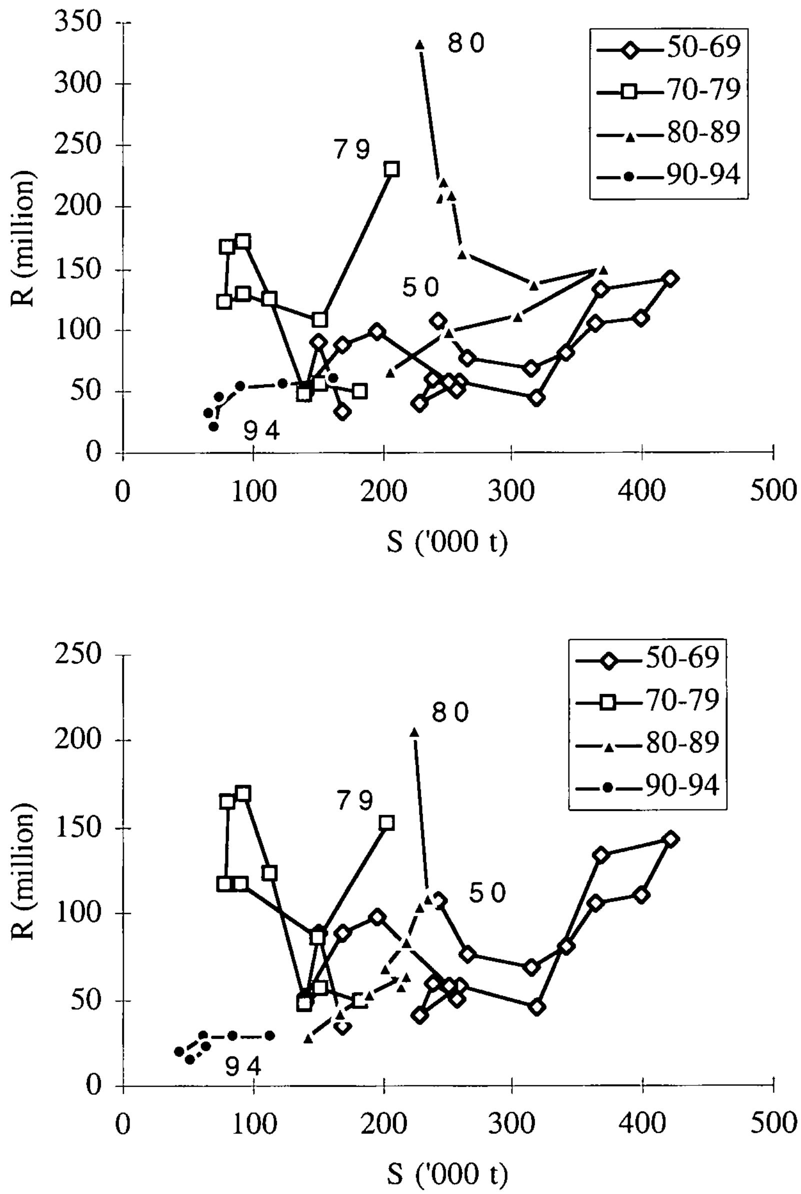

Figure 24: Stock recruitment plots for southern Gulf cod from SPAs using two M scenarios, where M increased from 0.2 to 0.4 in 1986 (upper panel) and when M was constant at 0.2 (Lower panel).

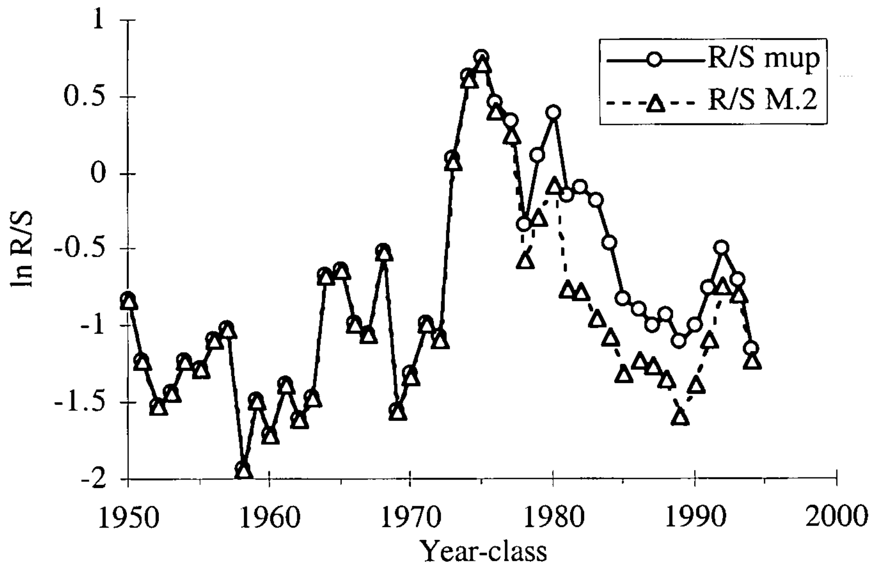

Figure 25: Trends in the ln ratio of S/R for southern Gulf cod from SPAs using two M scenarios, where M increased from 0.2 to 0.4 in 1986 (mup) and when M was constant at 0.2 (M .2).

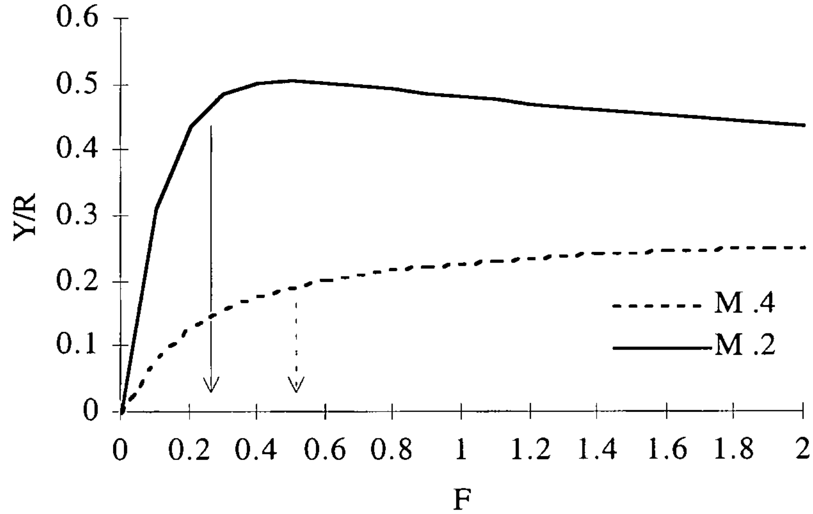

Figure 26: Yield per recruit curves for southern Gulf of St. Lawrence cod estimated with M = 0.2 and M = 0.4. Arrows indicate $F_{0.1}$ estimates for the two scenarios.

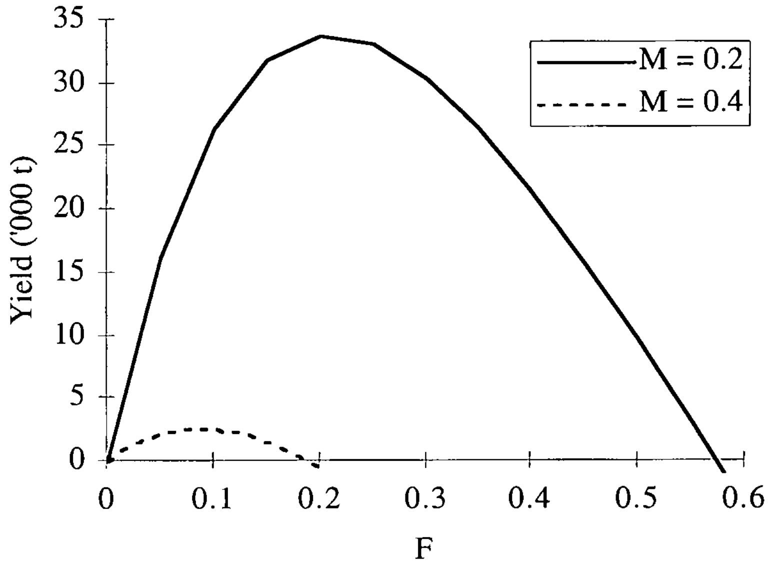

Figure 27: Yield curves from stock production analysis of southern Gulf of St. Lawrence cod at two levels of M, 0.2 and 0.4.

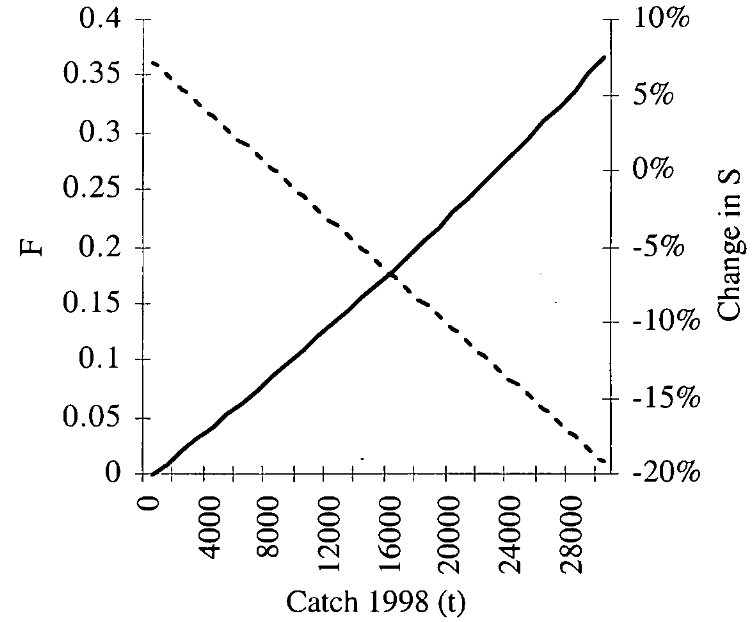

Figure 28: Summary of deterministic catch projections for southern Gulf cod in 1998 assuming M = 0.2. The $F_{0.1} = 0.25$ catch in 1998 is 21,000 t. The 1998 catch that will produce no change in spawning biomass (S) is 8,000 t.

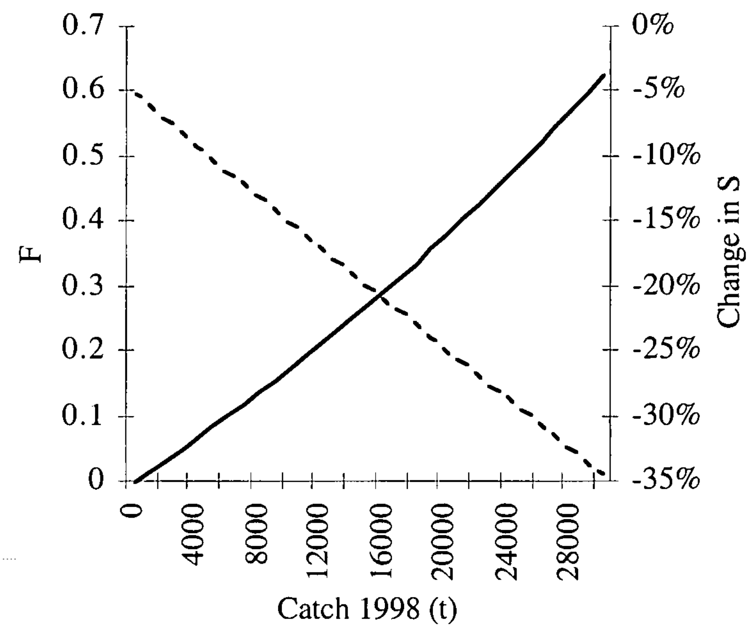

Figure 29: Summary of deterministic catch projections for southern Gulf cod in 1998 assuming M = 0.2 from 1971 - 1985 and M = 0.4 from 1986 - 1997. The projected $F_{0.1} = 0.5$ catch is 25,000 t. The spawning biomass is projected to decline by 5% if there is no catch in 1998.

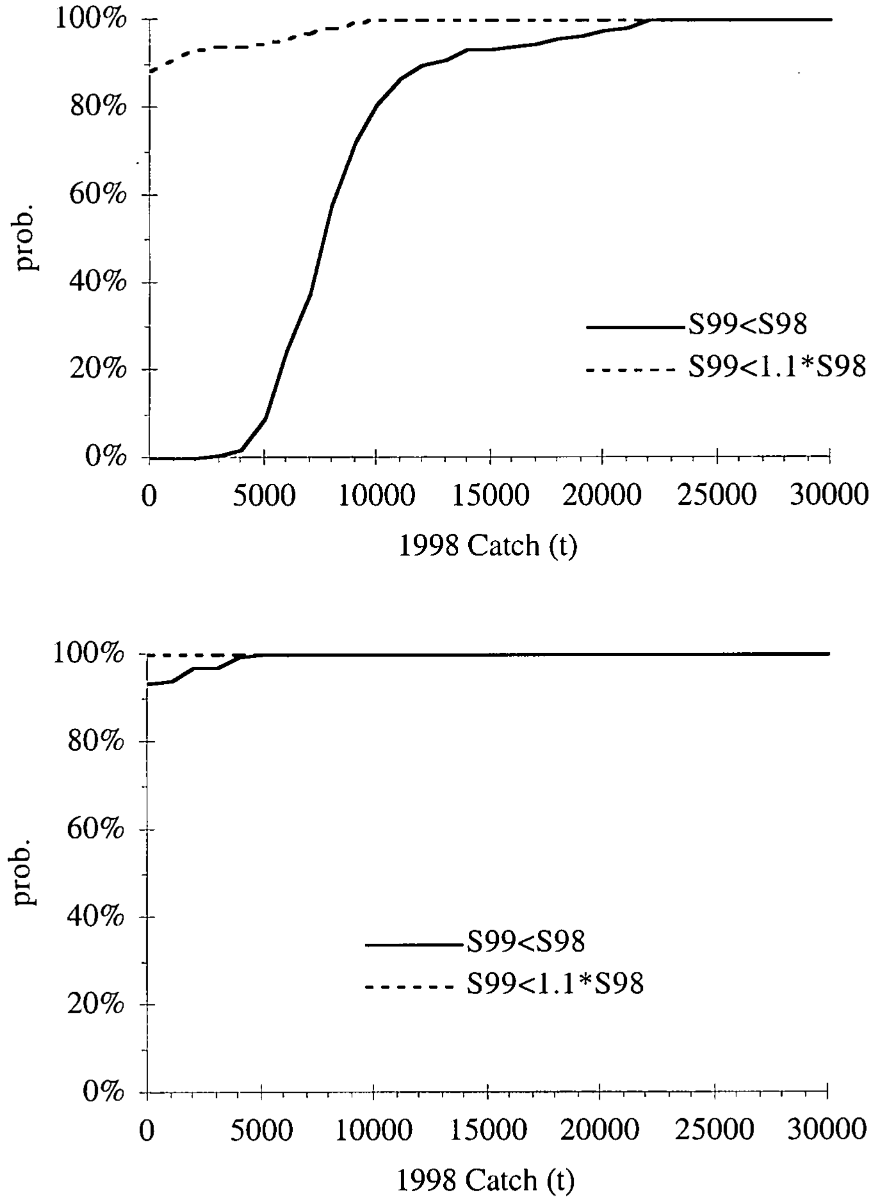

Figure 30: Risk analysis of a reduction in spawning biomass (solid line) and F exceeding F0.1 for southern Gulf cod, estimated from an SPA which assumes M was 0.2 from 1971 - 85 (upper panel) and 0.4 from 1986 - 97 (lower panel).