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Flatfish Stock Assessments for the west coast of Canada for 1998 and Recommended Yield options for 1999

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Abstract

Interim assessments were prepared for important stocks of flatfish caught in the B.C. trawl fishery. A summary of landing statistics including the observations from the 1997 fishery is presented for all of these. Additional data was available for only two stocks, Hecate Strait rock sole and Hecate Strait English sole. Assessments for those two stocks have been updated accordingly. There is no change from last year in any of the yield recommendations.

Landings for Area 3C-D and 5C-E Dover sole declined in 1997 and were below the low risk level identified last year. Landings of Petrale sole in Area 3C-D in 1997 were similar to those in 1996. These stocks are at low abundance and a coast-wide bycatch cap limits the current fishery for this species.

Rock sole biomass in Areas 5C-D in 1997 was above the long-term average for the last 50 years and declined slightly from 1996. The estimate of fishing mortality for the stock in 1997, was F =0.14, below $F_{0.1}$ (F=0.22). With fixed exploitation at this level there is a 95% chance that the stock will maintain its spawning biomass and ensure the recruitment necessary to sustain itself in the future. English sole biomass in Areas 5C-D in 1997 was slightly above the long-term average for the last 50 years and increased slightly from 1996. The estimate of fishing mortality for the stock in 1997 was F=0.16, below $F_{0.1}$ (F=0.25). With fixed exploitation at this level there is a 84% chance that the stock will maintain its spawning biomass and ensure the recruitment necessary to sustain itself in the future.

Résumé

Des évaluations provisoires ont été réalisées pour les importants stocks de poissons plats exploités par la pêche au chalut de la C.-B. Un résumé des statistiques des débarquements comportant les observations de la pêche de 1997 est présenté pour tous les stocks. Des données supplémentaires n'ont pu être obtenues que pour deux stocks, la fausse-limande et le carlottin anglais du détroit d'Hécate, et une mise à jour a été faite. Les recommandations relatives au rendement sont les mêmes que pour l'an dernier.

Les débarquements de limande-sole en provenance des zones 3C-D et 5C-E ont diminué en 1997 et étaient inférieures au niveau de risque faible indiqué l'an dernier. Les débarquements de plie de Californie des zones 3C-D de 1997 sont semblables à ceux de 1996. L'abondance de ces stocks est faible et un maximum imposé aux prises accessoires à la grandeur de la côte limite actuellement la capture de ces espèces.

La biomasse de fausse-limande des zones 5C-D de 1997 était supérieure à la moyenne à long terme des 50 dernières années et légèrement inférieure à celle de 1996. La mortalité par pêche estimée de ce stock en 1997 était de F=0,14, en deçà du $F_{0.1}$ (F=0,22). Une exploitation fixe à ce niveau correspond à une probabilité de 95 % que le stock conserve sa biomasse de géniteurs et garantit le recrutement nécessaire à son maintien. La biomasse de carlottin anglais des zones 5C-D en 1997 était légèrement supérieure à la moyenne à long terme des 50 dernières années et a légèrement augmenté par rapport à 1996. La mortalité par pêche estimée de ce stock en 1997 était de F=0,16, inférieure au $F_{0.1}$ (F=0,25). Une exploitation fixe à ce niveau correspond à une probabilité de 84 % que le stock conserve sa biomasse de géniteurs et garantit le recrutement nécessaire à son maintien.

1.0.. General Introduction

This year interim assessments have been prepared for all flatfish stocks. Landing statistics have been updated for all stocks to include information from the 1997 fishery. Landings, effort and 25% qualified median CPUE are presented for Petrale sole (*Eopsetta jordani*), Area 3C-D Dover sole (*Microstomus Pacificus*), Area 5A-B Rock sole (*Lepidopsetta bilineata* and *Lepidopsetta petraborealis*) and Area 5C-E Dover sole (Fargo and Kronlund 1997). The catch-age analysis has been updated for the assessments of Hecate Strait Rock sole and Hecate Strait English sole (*Parophrys vetulus*).

The groundfish trawl fishery has changed significantly in recent years. Changes in the management of groundfish fisheries including observer coverage, vessel quotas and changes in vessel catching coefficients over time have nullified the comparison of fishery CPUE over time. As well, the hyperstability of this index has been documented for many situations. Fishery CPUE often does not provide a signal of stock decline until the stock has been depleted (Hillborn and Walters 1992, Richards and Schnute 1986). Accordingly, CPUE is not used as the sole basis of assessment for any of the cases presented here. The median statistic has been presented for each case as a gross indicator of abundance for select periods of time where there was no regulatory effect and differences in fleet catching coefficients were negligible. In the presence of skewed observations, both the mean of ratios and the ratio of means of CPUE perform badly as they are sensitive to a small number of outliers. The median or 50% trimmed mean provides a robust alternative to the two former statistics (Fargo and Kronlund 1997).

For Hecate Strait Rock sole and English sole the state space model of Schnute and Richards (1995) was applied to a time series of age composition data to reconstruct stock histories. Yield for these cases was determined using the 25^{th} and 50^{th} percentiles of the 95% confidence region for the 1997 biomass estimate using the target fishing mortality $F_{0.1}$. Yield options for 1998 and 1999 are summarised in Table 1.1.

1.1. Coastwide

Yield options are not proposed for flatfish species on a coastwide basis.

1.2. Strait of Georgia

Yield options are not proposed for flatfish for this region.

1.3. West Coast of Vancouver Island (Areas 3C and 3D)

1.3.1. Petrale sole

1.3.1.1. Introduction

The Petrale sole *(Eopsetta jordani)* population off the west coast of Vancouver Island is thought to be composed of two stocks (Ketchen and Forrester 1966), (Pedersen 1975a). The southern stock occupies both the Canadian and U.S. portions of Area 3C, while the northern stock occupies Areas 3D-5D. Detailed data for the fishery is not available prior to 1970.

Petrale sole recruit to the commercial fishery beginning at age four. Recruitment is not knife-edged. Fish are not fully recruited until age 8. Length at 50% maturity, L_{50}, is 38.1 cm (7 y) for males and 44.3 cm (8 y) for females (Ketchen and Forrester 1966). Assessment of these stocks is hampered by the lack of fishery and age composition data. The backlog of age composition data is now being processed. Due to concern over the long term decline in landings/abundance from both of these stocks, no directed fishery has been permitted since 1991.

Castillo et al. (1994) showed that offshore Ekman transport of eggs and larvae accounted for 55% and 65% of the variation in Petrale sole year-class strength in PMFC Areas 2B and 3A, respectively. They concluded, as have previous investigators, that density-independent survival variation at the early life stages is high compared to variation in spawning biomass. However, the low abundance level of these stocks has been flagged as an area of concern by PSARC (Fargo 1995). A coastwide landings cap invoked by managers permits only a non-directed fishery. There will be no change in the yield recommendations until age composition data are available for analysis and a detailed assessment can be conducted. Results from last year's analysis indicate that the current rate of total mortality, Z, for these stocks is between 0.15 and 0.18, within the range of the natural mortality rate (Fargo 1995, Fargo 1998).

1.3.1.2 Landing statistics

Landings for the southern stock decreased slightly to 300 t in 1997 from 314 t in 1996 while landings for the northern stock decreased to 126 t in 1997 from 145 t in 1996, (Tables 1.2-1.3). Landings for this species exhibit cyclic fluctuations with peaks occurring about once a decade. Fluctuations in landings have coincided with recruitment cycles for the species (Ketchen and Forrester 1966, Castillo et al. 1994). Landings for both stocks show a marked decline since the start of the fishery. Since 1985 regulatory measures have exacerbated this. A trip limit of 40,000 lb was in effect for the first quarter from 1985 to 1991. From 1991 to 1995 a trip limit of 10,000 lb was in effect during the first quarter of the year while in 1996 only incidental catches were permitted, and a coastwide landings cap of 479 t was in place for the 1997 and 1998 fisheries.

Due to the landings cap and lack of a directed fishing on the spawning stock fishing mortality for both stocks has been greatly reduced in recent years. Effort for southern stock was 537 h in 1997 while effort for the northern stock was 147 h in 1997. Catch per unit effort for the southern stock decreased to 0.186 t/h in 1997 from 0.233 t/h in 1996. CPUE for the northern stock decreased to 0.156 t/h in 1997 from 0.271 in 1996.

1.3.1.3 Stock status

The significant decrease in fishing effort, on these stocks over the last three years could have a positive effect on stock abundance in the future. If the estimates of total mortality in last year's assessment are accurate the stock should be rebuilding. It is unlikely that a measurable change in stock abundance will be detected using catch and effort data from the current fishery. The age composition data from the fishery hold the most promise for a reliable index of stock abundance and this is still several years away. Further to this, evidence suggests that environment mitigates stock abundance and the recent El Nino event should produce a temperature regime favourable for year-class production (Ketchen and Forrester 1966). In any case these stocks are considered to be at a low level of abundance at present. Given their turnover rate (approximately 30 years), any significant change in stock abundance will probably not be discernible for at least a decade.

1.3.1.4. Recommendations and Yield Options

The catch histories for these stocks indicate that yield decreased substantially after large removals by the U.S. fleet between the mid 1940s and mid 1960s. Age composition data are needed to reconstruct the stock history and examine the effect of spawning biomass on stock productivity. Given the current low abundance of these stocks,managers should continue to permit incidental landings only, with a coastwide cap for these stocks in 1999, as in 1998.

1.3.2 Area 3CD Dover sole

1.3.2.1 Area 3CD Introduction

Significant commercial quantities of Dover sole *(Microstomus pacificus)* occur along the Pacific coast from California to Alaska. Dover sole abundance has been shown to decrease with increasing latitude (Westrheim *et al.* 1992). Results of U.S. tagging studies indicate that a number of individual stocks exist along the Pacific coast and that there is minimal intermingling of the adults among stocks (Westrheim *et al.* 1992). However, the larvae of this species undergo a prolonged pelagic phase offshore that can last as long as two years. Thus, the larvae of different stocks could intermingle extensively. The population off the West Coast of Vancouver Island is probably a discrete stock. Dover sole become vulnerable to the commercial trawl fishery at about 5 years of age but are not fully recruited until age 7-8 (Fargo and Workman 1995). Adults undertake a bathymetric migration from shallow (140-200 m) to deep (400-800 m) water for spawning (Westrheim *et al.* 1992). They spawn over a six month season (December-May) and spawning is age specific with older fish spawning earlier than younger fish (Hunter *et al.* 1992). The maximum age for Area 3CD

Dover sole estimated from biological samples collected to date is 49 years (Fargo and Workman 1995).

1.3.2.2 Area 3CD Management History

The Area 3CD Dover sole fishery was unregulated prior to 1992. In 1992, a 20,000 lb (9 t) trip limit was invoked after 70% of the quota was caught. Since 1992, variable trip limits less than 50,000 lbs (23 tons) have been used to manage the fishery. During the period from 1988 to 1996, trips where less than 50,000 lb (23 t) of Dover sole were landed accounted for 60%-95% of the total landings from this area. Trips greater than 50,000 lb (23 t) were not permitted after 1993 and in 1996 vessel quotas were invoked on the trawl fleet. Landing statistics from the commercial fishery have been updated for this assessment using data from the 1997 fishery.

1.3.2.3 Area 3CD Commercial Catch and Effort Data

Landing statistics for Area 3CD Dover sole are presented in Table 1.4. CPUE and effort statistics for 1996 and 1997 are not directly comparable to those for previous years because the estimates are determined from observations made by at-sea observers while estimates for previous years were determined from logbook information recorded by the vessel captains (Kronlund and Fargo 1998). Landings of Area 3CD Dover sole in 1997 were 788 t, well below the low-risk level, compared to 1083 t in 1996. Effort decreased to 1876 h in 1997 from 2318 h in 1996. CPUE increased to 0.263 t/h in 1997 from 0.229 t/h in 1996.

1.3.2.4. Stock status

There was a significant expansion of the fishery on this stock by area and depth with respect to time (Fargo and Kronlund 1997). This combined with the change in the age structure of the stock (Fargo and Workman 1995) in recent years suggests that the stock is probably fully exploited. The lack of biological samples from the 1996 and 1997 fisheries limits the assessment of this stock. However, the removals in 1997 were below the low risk level and fishing effort was relatively low compared to previous years.

1.3.2.5 Recommendations and yield options

There is no change in the yield recommendations for this stock in 1999.

Low-risk yield option:

A yield of 1000 t appears sustainable based on the trend in commercial CPUE between 1988 and 1990.

High-risk yield option:

Yields above 1500 t observed from 1991 to 1995 are associated with a significant decline in the commercial CPUE index. A yield of 1500 t can be considered as an upper limit of the sustainable range for this stock at the present time.

1.4 QUEEN CHARLOTTE SOUND (AREAS 5A and 5B)

1.4.1 Rock sole

1.4.1.1 General Introduction

The Rock sole (*Lepidopsetta bilineata*) is a minor component of the shelf, on-bottom trawl fishery in Queen Charlotte Sound and Hecate Strait. Four discrete stocks have been identified based on results from numerous tagging experiments (Ketchen 1982, Fargo and Westrheim 1987). Landings of Rock sole are coincidental with landings of lingcod (*Ophiodon elongatus*) and Pacific cod (*Gadus macrocephalus*) in Queen Charlotte Sound. Rock sole recruit to the fishery at age 4 but are not fully recruited until age 5. These interim assessments contain landing statistics updated with observations from the 1997 fishery.

The trawl fishery for Rock sole in Areas 5A-B was unregulated prior to 1986. During the period from 1986 to 1992 a 30,000 lb trip limit was invoked. This was followed by a 20,000 lb trip limit in 1993. Managers used various trip limits less than 20,000 lb from 1980 until 1996 when individual vessel allocations were invoked.

1.4.1.2 Area 5A Landing Statistics

Landing statistics for Rock sole from the trawl fishery in Area 5A are presented in Table 1.5. These landings include contributions by U.S. fishermen in this area prior to 1978. The CPUE index for this fishery deteriorated in the 1980s because of the effect of regulations and increase in vessel efficiency. In addition CPUE and effort statistics for 1996 and 1997 are not directly comparable to those for previous years because those estimates are determined from observations made by at-sea observers while estimates for previous years were determined from logbook information recorded by the vessel captains (Kronlund and Fargo 1998). Landings, effort and CPUE for this stock in 1997 were similar to those in 1996.

1.4.1.3 Stock status

Age composition data are not available for assessment of this stock. However, biomass and recruitment have been declining for stocks elsewhere since the early 1990s (See section 1.5.1.3). The decline in Rock sole landings from Area 5A may mean that this has been occurring for that stock as well. The lack of biological data for this stock hampers assessment. Age composition data for this stock are now being processed. Until those data are available for analysis there will be no change in the yield recommendations for this stock. However, in light of the uncertainty about stock status the high risk option should be avoided.

1.4.1.4. Recommendations and Yield Options

There is no change in the yield recommendations for this stock in 1999.

Low risk yield option

A yield of 200 t, equivalent to the low-risk yield for last year's assessment, appears to be sustainable at this time.

High risk yield option:

Yields greater than 400 t, the maximum annual yield observed can be considered as an upper limit for this stock.

1.4.1.5 Area 5B Landing Statistics

Landing statistics for Rock sole from the Area 5B trawl fishery are presented in Table 1.6. These landings include contributions from U.S. fishermen in this area prior to 1978. As in the case of Area 5A the CPUE index for this fishery deteriorated in the 1980s due to the combined effect of changes in management and vessel efficiency. Interpretation of the catch-effort data for Area 5B Rock sole is further complicated by the fact that this stock is a minor component of the multispecies trawl fishery in Area 5B. In addition, effort and CPUE statistics for 1996 and 1997 are not directly comparable to those in previous years because of the implementation of the at-sea observer program and individual vessel quotas in those years. Landings in 1997 were 169 t, down from 231 t in 1996. The level of effort in 1997 was similar to that in 1996. CPUE in 1997 decreased to 0.126 t/h in 1997 from 0.176 t/h in 1996.

1.4.1.6 Stock status

Age composition data are not available for this stock. However, biomass and recruitment have been declining for other stocks since the early 1990s (See section 1.5.1.3). The decline in landings over the last three years, given a fairly constant level of effort, may indicate a similar scenario for this stock. The lack of age composition data for this stock does not permit investigation of this at this time. However, age composition data for this stock are now being processed. Until those data are available for analysis there will be no change in the yield recommendations for this stock. However, in light of the uncertainty about stock status the high risk option should be avoided.

1.4.1.7. Recommendations and yield options

The risk options for 1999 are the same as those recommended in 1998.

Low risk yield option:

A yield of 200 t, is sustainable with low risk to the area 5B stock.

High risk yield option:

Yields greater than 500 t, equivalent to the maximum for the last 40 years, constitute a greater risk to the area 5B stock.

1.5. HECATE STRAIT (Areas 5C and 5D)

1.5.1. Rock sole - Hecate Strait

1.5.1.1. Introduction

Stock delineation work of Ketchen (1982) and Fargo and Westrheim (1987) indicates that there are probably several stocks of Rock sole in Hecate Strait. However, these stocks are treated as a unit for assessment and management. An age composition data series is available for Rock sole caught in the fishery taking place at Two Peaks and Butterworth fishing grounds at the north end of the Strait. Past work has suggested that both density-dependent and density-independent factors regulate the abundance of this species. Spawning biomass and ocean temperature at the time of spawning are two significant determinants of recruitment. Low recruitment has been associated with low spawning biomass and warm ocean temperatures during larval development (Forrester and Thomson 1969, Fargo and McKinnell 1989). Recruitment for these stocks has fluctuated over time with the last significant increase occurring during the late 1980s and early 1990s. For this assessment a fishery update is provided which includes landing statistics from the 1997 fishery. The age composition data series has been updated with 1997 fishery samples and the results from the analysis of this data is the basis for this assessment.

1.5.1.2. Landing statistics

Landing statistics for Rock sole in Hecate Strait are presented in Table 1.7. Annual statistics for the 1945-97 period are calculated directly from data observations. No data records exist prior to 1954 and the index of Forrester and Thomson (1969) has been used.

Landings and effort in 1997 were similar to values calculated for the 1996 fishery. Median CPUE decreased slightly to 0.191 t/h in 1997 from 0.207 t/h in 1996. Since the early 1980s there has been little contrast in the commercial CPUE series. Area-specific trip limits have influenced the fishing patterns of the fleet in the past. For the 1996 and 1997 fisheries,managers invoked individual vessel quotas and at-sea observer data collection. This has resulted in more comprehensive data but prevents direct comparison of these data with data for previous years.

1.5.1.3 Catch-age Analysis

The Rock sole age composition time series was updated with biological data collected during the 1997 trawl fishery. Only samples collected from Minor Area 4 (Major Area 8) were used for the catch-age analysis. These data also provide the longest time series for analysis, 1945 to 1996. The range of ages used for the catch-age analysis was 4 to 12+ with the last age group representing fish aged 12 years or older. Three-year-olds are not fully recruited and fish 12 and older were grouped together because of differences in the ageing technique. Otolith surface readings (1945-72) under-estimate the ages of older fish (beginning at age 12) compared to readings made from otolith burnt cross-sections (1973-96).

The catch-age model of Schnute and Richards (1995) was used for this assessment. This model is fundamentally similar to most other catch-age models (Fournier and Archibald 1982, Methot 1989) but does differ in the specification of the model error structure. Parameters in the model likelihood include standard deviations $\sigma 1$, $\tau 1$, and $\tau 2$, corresponding to the error in the recruitment, biomass index and proportions at age, respectively. The variance ratio $\rho=\sigma_1^2/(\tau_1^2+\tau_2^2)$ must be specified in the likelihood calculation, analogous to emphasis factors in the stock synthesis model of Methot (1989, 1990).

The model sensitivity to changing values for ρ was examined in the previous assessment (Fargo and Kronlund 1996). Briefly, increasing or decreasing ρ explicitly increases or decreases the standard deviation for the recruitment index. Broader confidence intervals for the model estimates of recruitment occurred with high values for ρ and narrower intervals occurred for low values of ρ. Changing the value of ρ (7 ρ 9) had virtually no effect on the biomass index and there were no changes in the overall trends for the population estimates. Fargo (1995) examined the sensitivity of the model to changing values for M. He found that the best fit occurred with M fixed at 0.20 to 0.25. The lower value for M was chosen because it produces more conservative population estimates. The natural mortality rate could also be treated as a parameter to be estimated by the model although this was not done for this assessment. Work by Richards et al. (1997) indicated broader confidence intervals for population estimates when M was treated as a parameter to be estimated. The best fit of the model, as indicated by the model likelihood statistic, occurred with ρ=0.7 and M fixed at 0.20. This is the same configuration that was used in the last assessment (Fargo and Kronlund 1997, Fargo 1998). Details of the model are provided in Appendix A.1.

Input data included landed catch, proportions at age in the catch (numbers) (Figure 1.1), mean weight at age, maturity at age and CPUE estimates for Rock sole (adults) obtained from the Hecate Strait surveys conducted between 1984 and 1996. Mean weight at age was computed for each year from age-length data using an allometric length-weight relationship derived for this stock. The length-weight data was obtained from samples collected from the commercial fishery. Maturity at age was computed from maturity schedules for the stock obtained from the research surveys. The survey CPUE data was used as an index of population biomass for the years that it was available. The diagonals in Figure 1.1 represent cohorts. Strong recruitment for this stock has occurred about once a decade. Cohorts adjacent to relatively large cohorts also appear large. This is probably due to ageing error of 1 to 2 years. The inconsistency in cohort trends in these data suggests some systematic sampling error or changes in selectivity.

The model residuals were examined to assess goodness of fit. There were trends in the residuals for the first and last age groups (Figure 1.2). In addition, there were negative residuals for the plus group for the early years. This is likely a result of the change in age determination methods. The model expected a greater proportion of older fish than that indicated by the age proportion data. The positive trend in the residuals for the youngest age group may be the result of changing selectivity over time. A minimum codend mesh regulation implemented in 1995 has altered the selectivity of this fishery since that time and the model does not capture this. A length-specific selectivity component accounting for this should be built in to the model for future analysis.

Biomass and recruitment trajectories from the model are presented in Figure 1.3. Between 1980 and 1990, exploitable biomass for this stock increased to the highest level recorded in the last 50 years. Since the early 1990s biomass has declined but remains above the long term average for the time series. The estimate of exploitable biomass in 1997, B_{97}, was 4930t ±2205t (for the 95% confidence interval). The trend for recruitment is synchronous with that for biomass. Recruitment increased to the highest level on record in the late 1980s. Since the early 1990s recruitment has steadily declined. The uncertainty in the population estimates is highest for the later years, a function of the low number of observations used to determine them.

A retrospective analysis was used to examine the uncertainty in the terminal biomass estimate from the catch-age analysis (Figure 1.4). The catch-age model was fit to data covering five ranges of years, 1945-93, 1945-94, 1945-95, 1945-96 and 1945-97. The estimate of biomass in year 1993, B_{93}, ranged from 5567 tonnes to 7983 tonnes among the cases. There was no pattern in the estimates with respect to time and estimates of biomass appear to stabilise with 4-5 observations.

The model estimates of annual fishing mortality over time are presented in Figure 1.5. Fishing mortality for the stock in 1996 was 0.14, about the same level as estimated in last year's assessment (Fargo 1998). Although the current rate of fishing appears to be relatively low, more observations are needed before the terminal population estimates and fishing rate for the stock can be considered reliable.

1.5.1.4 Fishing rate reference points

Fishing rate reference points have received much attention over the last decade. These reference points are determined from yield per recruit and spawning stock biomass per recruit analysis. These analyses have been used to examine the effects of fishing mortality on recruitment and spawning stock biomass. Each reference point identified contains relevant information about yield and the effects of exploitation. They have been criticised by some because they make no explicit assumption about a stock-recruit relationship. However, Sissenwine and Shepherd (1987) argue against the inclusion of stock-recruit information in stock assessment analyses in the absence of an explicit relationship. They argue that this can contribute to results that are misleading. Similarly they do not contain explicit information on environmental effects although Walters and Parma (1995) argue that fixed rate exploitation strategies, harvesting a constant fraction of the stock annually allows the spawning stock to track environmental variation. This in turn allows managers to make adjustments that account for this.

Yield per recruit (Figure 1.6) was determined over a range of fishing rates. Two common fishing mortality reference points can be described by this analysis. F_{max} represents the fishing rate that corresponds to the maximum yield while $F_{0.1}$, is the point on the curve where the slope is 10% of that at the origin. The yield per recruit curve for Hecate Strait Rock sole was extremely flat after the inflection point indicating very marginal gains in yield with substantial increases in the fishing rate above F=0.22.

Another class of F reference points associated with recruitment overfishing can be determined from survival ratios determined using the population estimates from catch-age analysis (Shepherd, 1982). The strategy is to avoid stock collapse by managing fishing effort to maintain a stable spawning biomass expressed as spawning stock biomass per recruit (SSB/R) (Patterson 1992). This index was used to evaluate the spawning potential of Hecate Strait Rock sole over a range of fishing mortality rates (Figure 1.7). The calculations are analogous to those in yield per recruit analysis (Gabriel et al. 1989) and when combined with population estimates from catch-age analysis provide a biological reference for maintenance or rebuilding of spawning stock biomass. Rock sole SSB/R ratios were computed over a range of fishing rates (Gabriel et al. 1989) as per yield per recruit calculations. Then, SSB/R was computed for each year using the population estimates of the catch-age analysis (historical series). The percentiles of the SSB/R historical series were used to define fishing mortality reference points on the SSB/R / fishing mortality curve. The percentile of the historical SSB/R associated with these fishing mortality reference points is an estimate of the probability of the stock maintaining its spawning stock biomass. The fishing mortality associated with the median (50% quantile) of the historical SSB/R is F_{med}. With fishing mortality at this level the Rock sole stock has a 50% chance of maintaining its spawning stock biomass (Patterson 1992). The fishing mortality rate associated with the 90% quantile, F_{high}, represents the level of fishing mortality where the stock has only a 10% chance of maintaining its spawning stock biomass. The current fishing rate for Hecate Strait Rock sole, F=0.14, is substantially lower than that needed for this stock to maintain its spawning biomass. With this fishing rate the stock has a 94% chance of maintaining its spawning stock biomass and it is reasonable to assume that, excluding environmental influence, the spawning stock biomass should increase.

The following fishing mortality reference points have been estimated for Hecate Strait Rock sole: $F_{0.1}$=0.22, F_{med}=0.37, F_{max}=0.57 F_{high} =0.63 and F_{low}=0.16. Fishing at a rate equivalent to F_{max} while permitting the maximum yield to be obtained from a stock, has resulted in stock depletion in the past (FAO 1995) and is clearly not relevant for management purposes other than in the short-term. Similarly F_{high} corresponds to a fishing rate that will significantly lower the spawning stock biomass and eventually lead to recruitment overfishing. The target rate F_{med} was intended to serve as an indicator for recruitment overfishing (Sissenwine and Shepherd 1987). That is with the fishing rate below this level the stock will maintain or increase its spawning stock biomass. With the fishing rate above this level the spawning stock biomass will decrease, increasing the probability of poor recruitment which will lead to recruitment overfishing in the long-term. The target fishing mortality reference point $F_{0.1}$ has been advocated by many as a reference point, below F_{med}, to prevent recruitment overfishing (FAO 1995). F_{low} corresponds to a target fishing mortality rate that is consistent with a precautionary management strategy. That is, with the fishing rate at or below this level the spawning stock biomass should increase so that stock rebuilding can take place.

1.5.1.5 Stock status

The results of the catch-age analysis indicate a significant increase in stock biomass occurred in the late 1980s due to strong year-classes produced in the mid 1980s. By the mid 1990s significant declines in recruitment and biomass had occurred. Rock sole CPUE from research trawl surveys conducted in Hecate Strait has declined since the early 1990s as well (Fargo 1998). The El Nino event along the B.C. coast in 1996 and 1997 should produce unfavourable temperature conditions for Rock sole eggs and larvae (Forrester and Thomson 1969, Fargo and McKinnell 1989). Thus, recruitment and yield for this stock should continue to decline over the next several years.

1.5.1.6 Recommendations and Yield Options

The fishing mortality reference point $F_{0.1}$, 0.22, was used to estimate sustainable yield for the stock. As a precautionary strategy yield has been estimated using the 25th and 50th percentiles of the 95% confidence region for the terminal biomass estimate. The values for biomass corresponding to the 25th and 50th percentiles of the distribution for B_{97} are 4068 t and 4930 t, respectively. The $F_{0.1}$ yield range using these estimates is 803 t and 973 t, respectively. These figures are similar to those estimated in last year's assessment and the yield recommendations remain unchanged.

Low risk yield option -- A yield of 800 t, is the low-risk sustainable option for these stocks.

High risk yield option -- A yield of 1100 t, is the high-risk sustainable option for these stocks.

1.5.2. English sole - Hecate Strait

1.5.2.1.Introduction

Stock delineation studies conducted by Ketchen (1956) and Fargo et al. (1984) indicate that a single stock of English sole is resident in Hecate Strait. The stock was probably near the pristine level in the 1940s, declined after large removals in the early 1950s and has remained fairly stable since the late 1960s (Fargo 1998). Both density dependent and density independent factors exert significant influence on the abundance of this stock (Fargo 1994). Spawning biomass and the influence of Ekman transport on eggs and larvae influence subsequent recruitment for this stock. The stock has produced strong year-classes about once a decade with the latest increase in recruitment occurring in the early 1990s. The age of recruitment is 4 years for females although they are not fully recruited until age 5. Only a small proportion of males attain commercial size. Length at 50% maturity, L_{50}, is 25.5 cm (3 y) for males and 35.1 cm (4 y) for females (Foucher et al. 1989). The contribution of strong year-classes to the fishery usually lasts about 4 or 5 years. The series of annual landing statistics has been updated using data from the 1997 fishery. The age composition data series has been updated with data from samples collected from the 1997 fishery as well. Analysis of the age composition data is the basis for this assessment.

1.5.2.2. Landing statistics

Managers used area-specific quotas as a catch limitation tool in the past. These have undoubtedly had an influence on the fishing patterns of the fleet. In 1996 and 1997 individual vessel quotas and at-sea observer data collection were invoked. This has resulted in more comprehensive data but prevents direct comparison with statistics for previous years. Annual landing statistics are presented in Table 1.8. Statistics for 1954-97 are calculated directly from data obtained from vessel skipper logs and observer logs. No detailed records exist prior to 1954 and the catch index of Ketchen (1980) has been used. English sole landings increased to 554 t in 1997 from 455 t in 1996 while effort increased to 1286 h from 570 h over the same period. CPUE in 1997 decreased to 0.227 t/h from 0.310 t/h in 1996.

1.5.2.3 Catch-age analysis

The catch-age model of Schnute and Richards (1995) was used for this assessment. See section 1.5.1.3 for information about the model configuration and Appendix A.1. for details of the model.

The age composition data series for this stock was updated with age determinations for samples collected during the 1997 trawl fishery. The range of ages used for catch-age analysis was 4 to 12+ with the last age group representing fish aged 12 years or older. Three-year-olds are not fully recruited and fish 12 and older were grouped together because of differences in the ageing technique. For the catch-age analysis, the full compliment of years was analysed over a range of ages from 4 to 12+. Three year olds are not fully recruited while age groups 12 and older were combined because of the bias in age determinations made from otolith surface readings as compared to determinations made from otolith burnt cross-sections. Otolith surface readings (1945-72) under-estimate the ages of older fish (beginning at age 12) compared to readings made from otolith burnt cross-sections (1973-96).

Input data for the model included landed catch, proportions at age in the catch (Figure 1.8) weight at age and CPUE estimates for English sole from the Hecate Strait research trawl surveys conducted between 1984 and 1996. We felt it was more appropriate to use the research survey CPUE than the index from the commercial fishery because of problems with the commercial index already described (See Section 1.5.2.2).

Model residuals were examined for indications of problems with the fit (Figure 1.9). There were trends in the residuals for the first and last age groups. In addition, there were negative residuals for the plus group for the early years. This is likely a result of the change in age determination methods. The model expected a greater proportion of older fish than that indicated by the age proportion data. The positive trend in the residuals for the youngest age group may be the result of changing selectivity over time. A minimum codend mesh regulation implemented in 1995 has altered the selectivity of this fishery since that time and the model does not capture this.

Biomass and recruitment trajectories from the model are presented in Figure 1.10. Between 1950 and the mid 1960s the biomass of this stock declined steadily. Biomass increased during the late 1960s and late 1970s and has fluctuated without trend since that time. The estimate of exploitable biomass in 1997, B_{97}, was 4229 t ± 1080 t, (for the 95% confidence interval) well above the longterm average. The trend in recruitment is synchronous with that for biomass. Recruitment increased to the highest level on record between the late 1980s and early 1990s and has declined steadily since that time. Recruitment in 1997 is among the lowest on record. Uncertainty in both sets of population estimates is greatest for the estimates in the later years. This is a function of the low number of observations used to determine them.

A retrospective analysis was used to examine the uncertainty in the terminal biomass estimates from the catch-age analysis (Figure 1.11). The catch-age model was fit to data over five ranges of years, 1945-93, 1945-94, 1945-95, 1945-96, and 1945-97. The estimated of biomass in year 1993, B_{93}, ranged from 4200 tonnes to 5300 tonnes. Estimates of biomass from the five runs stabilised around 1990. This analysis suggests that four to five years of observations are necessary to produce a reliable terminal estimate.

The catch-age model estimate of fishing mortality for the stock in 1997 was 0.16 (Figure 1.12), about the same as that for 1996 in the last assessment. Although the current rate of fishing appears to be low, more observations are necessary before the fishing rate for 1997 can be reliably determined.

1.5.2.4. Fishing rate reference points

As in the case for Hecate Strait rock sole yield per recruit and spawning stock biomass per recruit analyses were applied to data for Hecate Strait English sole. For an explanation of these reference rates refer to Section 1.5.1.4. Results from the yield per recruit analysis is summarised in Figure 1.13. As in the case of Rock sole the yield per recruit curve for Hecate Strait English sole was very flat after the inflection point indicating very marginal gains in yield with substantial increases in the fishing rate above F=0.25.

The spawning stock biomass per recruit ratios for English sole were computed over a range of fishing rates (Gabriel et al. 1989) to produce the yield curve in Figure 1.14. The percent quantiles of the spawning stock biomass per recruit historical series were then used to identify fishing mortality reference points on the fishing mortality curve. These quantiles are equivalent to the probability of the stock maintaining its spawning stock biomass. The fishing mortality associated with median (50^{th} percentile) of the ratios in the historical series is F_{med}. With fishing mortality at this level the stock has a 50% chance of maintaining its spawning stock biomass (Patterson 1992). The fishing mortality rate associated with the 90% percentile, F_{high}, represents the level of fishing mortality where the stock has only a 10% chance of maintaining its spawning stock biomass. The current fishing rate for Hecate Strait English sole, F=0.16, is lower than needed to maintain its spawning stock biomass. In fact, with the fishing rate at this level the stock has an 84% chance of maintaining its spawning stock biomass.

The target fishing mortality references points estimated for this stock from these analyses are: $F_{0.1}$=0.25, F_{med}=0.28, F_{low}= 0.11, F_{high} =0.50 and F_{max}=0.83. For an explanation of these points refer to Section 1.5.1.4. These represent exploitation rates than can be used as fixed harvest strategies for management.

1.5.2.5 Stock status

The estimate of fishing mortality, F, for the stock in 1997 from the catch-age analysis was 0.16, much lower than $F_{0.1}$. The distribution of 1997 biomass estimate, B_{97}, 4229 t (95% c.i. ± 1080 t) was used to estimate yield. $F_{0.1}$ (F=0.25) was the target fishing mortality rate that was used to estimate yield. $F_{0.1}$ was applied to the estimates corresponding to the 25th and 50th percentiles of the confidence region for B_{97}, 3857 t and 4229 t, respectively. The resulting range for yield was 853 t - 935 t. Although this appears to be an increase from the estimates in last year's assessment there is a high degree of uncertainty. The retrospective analysis showed that the terminal estimate of biomass could be displaced up or down (± 15%), as data observations for subsequent years become available. Also, recruitment in 1997 is the lowest on record which seems inconsistent with the 1997 biomass estimate. This is justification for no change in yield recommendations at this time.

1.5.2.6. Recommendations and Yield Options

Low risk yield option -- A yield of 500t t, is the low-risk option.

High risk yield option -- A yield of 600 t, is the high-risk option.

1.5.3 Dover sole (Areas 5C-E)

1.5.3.1 Introduction

The fishery for Dover sole in Areas 5C-E takes place in northern Hecate Strait at 100 to 160 m depths between May and October, and off the west coast of the Queen Charlotte Islands at 400 to 800 m depths from December to April. The seasonal shift in the fishery is related to the bathymetric spawning migration for the species. The fishery off the west coast of the Queen Charlotte Islands takes place on a spawning population. Dover sole begin to recruit to the fishery at 5 years of age but are not fully recruited until age 7-8. The Dover sole fishery in area 5C-E was unregulated prior to 1981. Beginning in 1981, annual quotas were applied: 300t from 1981 to 1984, 500 t from 1985 to 1990, 1000 t from 1991 to 1994, and 1100 t from 1995 to 1998.

1.5.3.2 Area 5CDE Landing Statistics

As in other cases the CPUE index for this fishery deteriorated in the 1980s due to the combined effect of changes in management and vessel efficiency. Also, effort and CPUE statistics for 1996 and 1997 are not directly comparable to those in previous years because of the implementation of the at-sea observer program and individual vessel quotas (IVQs) in those years. Landing statistics for Dover sole from the Area 5C-E trawl fishery for 1970-97 are presented in Table 1.9. Landings decreased to 714 t in 1997 from 1133 t in 1996 while effort decreased to 1563 h in 1997 from 2245 h in 1996 and CPUE increased to 0.326 t/h in 1997 from 0.308 t/h in 1996. CPUE is highly variable in the early years due to low numbers of observations with fishing up (positive trend in CPUE) occurring between the late 1970s and the late 1980s. A marked increase in effort beginning in the late 1980s is associated with an increase in catch and a decrease in CPUE (Fargo 1998).

1.5.3.3 Biomass Dynamics

The biomass dynamic model of Fox based on a Gompertz growth equation (Yoshimoto and Clarke 1993, Breen and Stocker 1993) was used to estimate stock biomass and maximum sustainable yield, MSY. This analysis indicated that the pristine biomass of this stock was around 14400 tonnes while stock biomass in 1997 was around 6500 tonnes corresponding to an equilibrium yield of 735 tonnes (Figure 1.15). MSY for the stock was estimated at 994 tonnes with an optimum effort of 4224 hours. The landings from this fishery in 1997 were 76% of MSY while fishing effort in 1997 was well below the level corresponding to MSY.

1.5.3.4 Stock status

Estimates of the total mortality rate, Z, estimated from stock age composition data from the 1996 fishery ranged between 0.15 to 0.27 (Fargo 1998). No age composition data were available for the 1997 fishery. The rate of fishing mortality for the stock in 1996 was estimated to be between 0.10 to 0.15 while $F_{0.1}$ for the stock is 0.13 (Fargo 1998). Landings in 1997 appear to be sustainable and the current level of fishing mortality is acceptable. The yield recommendations for 1999 remain unchanged from those for 1998.

1.5.3.4 Recommendations and Yield Options

Low risk yield option:

A yield of 800 t, equivalent to the MSY estimated using surplus production analysis (Fargo 1998).

High risk yield option:

A yield of 1200 t is suggested as an upper limit for yield for the area 5CDE Dover sole stock (Fargo 1992).

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Table 1.1. Yield options for British Columbia flatfish species/stocks 1998-99

		1998		1999	
Species	Area	low risk	high risk	low risk	high risk
Petrale sole	Coastwide	incidental catches only		incidental catches only	
Dover sole	Area 3C-D	1000 t	1500 t	1000 t	1500 t
	Area 5C-E	800 t	1200 t	800 t	1200 t
Rock sole	Area 5A	200 t	400 t	200 t	400 t
	Area 5B	200 t	500 t	200 t	500 t
	Area 5C-D	800 t	900 t	800 t	900 t
English sole	Area 5C-D	500 t	600 t	500 t	600 t

Table 1.2. Canada-U.S. landings (t) of Petrale sole from southwest Vancouver Island, Area 3C, 1945-97.

Year	Flattery Spit	Area 3C north	Total Area 3C	Total Canadian	Year	Flattery Spit	Area 3C north	Total Area 3C	Total Canadian	CPUE[a] (t/h)	Effort[b] (h)
1942	-	-	1561	-	1969	255	142	397	52	-	-
1943	-	-	2264	-	1970	80	198	278	142	-	-
1944	-	-	1489	-	1971	74	523	597	366	-	-
1945	-	-	718	-	1972	22	561	583	426	-	-
1946	-	-	906	-	1973	211	452	663	328	-	-
1947	-	-	627	-	1974	230	684	914	466	-	-
1948	-	-	1321	-	1975	474	465	939	295	-	-
1949	-	-	1178	-	1976	304	453	757	172	-	-
1950	-	-	854	362	1977	157	311	468	311	-	-
1951	-	-	794	293	1978	287	126	413	126	-	-
1952	-	-	948	419	1979	256	92	348	92	-	-
1953	-	-	748	367	1980	147	115	262	115	-	-
1954	-	-	664	279	1981	125	180	305	180	-	-
1955	-	-	415	142	1982	45	232	277	232	-	-
1956	40	585	625	173	1983	179	183	362	183	-	-
1957	9	629	638	200	1984	237	218	455	218	-	-
1958	19	609	628	144	1985	122	147	269	147	-	-
1959	33	1072	1105	159	1986	75	197	272	197	-	-
1960	233	974	1207	174	1987	113	123	236	123	0.392	12
1961	375	1109	1484	156	1988	185	183	368	183	0.42	102
1962	215	850	1065	135	1989	191	386	587	386	0.352	450
1963	90	658	748	66	1990	134	478	612	478	0.316	599
1964	71	530	601	141	1991	106	408	514	408	0.217	1026
1965	140	658	798	118	1992	260	128	388	128	0.18	548
1966	118	512	630	90	1993	200	248	448	248	0.139	926
1967	106	259	365	104	1994	189	139	328	139	0.114	453
1968	114	233	347	110	1995	195	158	353	158	0.12	414
					1996	202	112	314	112	0.233	139
					1997	198	102	300	102	0.186	537

[a] Area 3C north 25% qualified CPUE (January - March)
[b] Area 3C north 25% qualified effort (January - March)

Table 1.3. Canada-U.S. landings (t) of Petrale sole from Areas 3D, 5A-D, 1944-97.

Year	Area 3D	Areas 5A-B	Areas 5C-D	Canada & U.S.	Total Canadian	Year	Area 3D	Areas 5A-B	Areas 5C-D	Canada & U.S.	Total Canadian	CPUE (t/h)	Effort (h)
1944	499	303	-	802	-	1969	262	114	22	398	101	-	-
1945	270	1535	193	1998	-	1970	136	56	22	214	65	-	-
1946	623	1258	494	2375	-	1971	127	97	55	280	118	-	-
1947	469	986	769	2224	-	1972	50	154	33	237	102	-	-
1948	943	920	3011	4874	-	1973	197	211	24	432	78	-	-
1949	316	429	1644	2390	-	1974	196	283	14	493	85	-	-
1950	694	569	700	1963	435	1975	234	156	27	417	99	-	-
1951	305	326	642	1273	426	1976	153	132	30	315	118	-	-
1952	265	305	574	1144	249	1977	58	73	24	155	155	-	-
1953	235	450	46	731	92	1978	21	63	13	97	97	-	-
1954	712	234	300	1237	96	1979	10	57	39	106	106	-	-
1955	452	462	94	1008	118	1980	31	40	33	104	104	-	-
1956	291	528	53	872	68	1981	15	41	42	98	98	-	-
1957	1320	333	216	1869	198	1982	30	61	16	107	107	-	-
1958	174	227	171	572	205	1983	29	161	35	225	225	-	-
1959	227	160	216	603	175	1984	77	79	24	180	180	-	-
1960	93	212	120	425	238	1985	50	81	22	153	153	-	-
1961	277	171	102	550	192	1986	24	120	25	169	169	-	-
1962	295	343	165	803	331	1987	37	165	101	303	303	-	-
1963	202	537	82	821	329	1988	276	167	133	576	576	0.552	233
1964	183	421	163	767	359	1989	178	220	151	549	549	0.357	258
1965	300	418	202	920	363	1990	249	148	142	539	539	0.383	425
1966	264	469	260	993	465	1991	137	143	85	365	365	0.313	217
1967	169	485	176	830	350	1992	133	93	72	298	298	0.252	154
1968	293	266	137	696	257	1993	117	105	63	285	285	0.252	146
						1994	53	197	45	295	295	0.118	34
						1995	77	327	42	446	446	0.126	8
						1996	52	68	25	145	145	0.271	57
						1997	42	58	26	126	126	0.156	147

[a] Area 3D 25% qualified CPUE (January - March)
[b] Area 3D 25% qualified effort (January - March)

Table 1.4 Annual landing statistics for the Area 3CD Dover sole trawl fishery, 1980-97.

Year	Landings (t)	Effort[a] (h)	CPUE[b] (t/h)
1980	184	306	0.556
1981	171	461	0.339
1982	129	281	0.361
1983	22	84	0.389
1984	24	79	0.256
1985	3	9	0.280
1986	2	8	0.321
1987	1	4	0.143
1988	371	620	0.426
1989	1115	1754	0.415
1990	1122	1882	0.402
1991	1222	2572	0.316
1992	1382	3034	0.357
1993	1785	4459	0.318
1994	1492	4626	0.267
1995	1630	5352	0.259
1996	1083	2318	0.229
1997	788	1876	0.263

[a] Annual effort for 25% qualified landings
[b] Median CPUE for 25% qualified landings

Table 1.5. Canada-U.S. landings statistics for Rock sole in Area 5A, 1954-97.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[c]
54	52	175	0.216
55	119	274	0.287
56	551	1441	0.241
57	511	1633	0.219
58	501	2204	0.181
59	212	834	0.162
60	397	1588	0.148
61	237	757	0.212
62	196	910	0.120
63	161	456	0.170
64	156	346	0.195
65	157	350	0.203
66	330	651	0.283
67	252	822	0.233
68	435	1224	0.233
69	293	1230	0.115
70	167	566	0.159
71	135	392	0.162
72	58	117	0.168
73	57	68	0.352
74	74	50	0.351
75	37	191	0.111
76	182	466	0.185
77	83	197	0.209
78	79	230	0.134
79	202	526	0.216
80	238	810	0.206
81	114	404	0.181
82	189	548	0.261
83	124	195	0.266
84	142	348	0.217
85	56	115	0.156
86	23	12	0.112
87	80	74	0.249
88	128	330	0.180
89	143	425	0.164
90	190	554	0.134
91	200	608	0.159
92	290	731	0.231
93	462	1864	0.199
94	311	1399	0.150
95	212	939	0.138
96	87	540	0.102
97	74	495	0.095

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Table 1.6. Canada-U.S. landing statistics for Rock sole in Area 5B, 1954-97.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
54	203	133	0.295
55	267	259	0.247
56	307	614	0.270
57	206	531	0.302
58	379	1338	0.206
59	344	945	0.213
60	503	1444	0.203
61	416	1167	0.189
62	531	1345	0.227
63	517	947	0.225
64	482	559	0.193
65	568	729	0.226
66	772	794	0.253
67	741	423	0.280
68	392	492	0.246
69	652	1028	0.211
70	245	319	0.192
71	368	790	0.203
72	382	518	0.189
73	324	245	0.238
74	371	165	0.232
75	408	497	0.276
76	368	879	0.218
77	188	351	0.182
78	217	279	0.265
79	208	425	0.209
80	410	846	0.263
81	220	570	0.211
82	155	314	0.287
83	206	447	0.245
84	87	116	0.238
85	170	358	0.269
86	135	178	0.171
87	205	165	0.295
88	272	302	0.329
89	260	520	0.269
90	419	843	0.217
91	437	922	0.284
92	416	1203	0.227
93	343	1155	0.224
94	323	1023	0.215
95	252	848	0.150
96	231	842	0.176
97	169	806	0.126

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Table 1.7. Canada-U.S. landing statistics for Hecate Strait Rock sole, 1945-97.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
45	121	434	0.279
46	410	2228	0.184
47	1181	1946	0.607
48	901	1753	0.514
49	657	1352	0.486
50	784	1452	0.540
51	1024	944	1.085
52	2292	2014	1.138
53	779	1227	0.635
54	926	840	0.938
55	1560	1558	0.680
56	1160	1484	0.644
57	1151	2019	0.443
58	1256	1331	0.650
59	416	636	0.403
60	1127	1100	0.680
61	744	694	0.900
62	829	849	0.735
63	881	735	0.737
64	743	835	0.531
65	879	629	0.545
66	2544	2491	0.598
67	2162	2324	0.511
68	2366	4209	0.386
69	1461	4485	0.314
70	1403	3660	0.326
71	1503	3587	0.255
72	515	650	0.337
73	507	619	0.435
74	622	603	0.475
75	1204	1912	0.360
76	1438	1830	0.402
77	846	1896	0.285
78	874	1662	0.336
79	1313	1943	0.330
80	977	2420	0.254
81	584	806	0.287
82	291	841	0.209
83	247	499	0.286
84	188	573	0.188
85	112	276	0.242
86	219	470	0.345
87	536	577	0.389
88	1402	2520	0.410
89	1422	3757	0.288
90	1519	3948	0.319
91	2666	6552	0.295
92	2226	5777	0.289
93	2080	5851	0.301
94	1384	4282	0.275
95	1294	3538	0.322
96	670	2336	0.207
97	677	2667	0.191

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Table 1.8. Canada-U.S. landing statistics for Hecate Strait English sole, 1944-97.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
44	152	215	0.707
45	304	365	0.832
46	470	809	0.581
47	350	538	0.651
48	937	2740	0.342
49	795	1893	0.420
50	2622	4910	0.534
51	1024	2142	0.478
52	1347	3293	0.409
53	871	2084	0.418
54	455	563	0.362
55	875	744	0.401
56	956	1344	0.349
57	552	640	0.244
58	693	617	0.337
59	940	772	0.315
60	1147	1058	0.333
61	871	1615	0.298
62	459	903	0.247
63	408	568	0.207
64	436	441	0.272
65	414	326	0.317
66	362	354	0.302
67	534	535	0.411
68	671	844	0.302
69	819	1314	0.390
70	1002	2042	0.312
71	488	1585	0.192
72	371	550	0.230
73	667	514	0.411
74	500	519	0.519
75	938	1015	0.466
76	1133	1627	0.275
77	1179	2201	0.310
78	559	944	0.246
79	864	980	0.337
80	995	1105	0.327
81	1327	2149	0.249
82	428	1062	0.219
83	430	834	0.240
84	658	1129	0.290
85	585	1520	0.226
86	335	469	0.365
87	630	396	0.347
88	688	540	0.493
89	826	925	0.385
90	992	1335	0.383
91	913	940	0.308
92	987	1602	0.307
93	1421	2636	0.295
94	1000	1860	0.343
95	1190	2321	0.320
96	455	570	0.310
97	554	1286	0.227

[a] Annual effort for 25% qualified landings.
[c] Median CPUE for 25% qualified landings

Table 1.9. Canada-U.S. landing statistics for Dover sole, Areas 5C-E, 1970-97.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]
70	965	1324	0.590
71	903	1367	0.556
72	922	1495	0.543
73	768	910	0.679
74	767	878	0.687
75	882	1135	0.573
76	1022	1465	0.440
77	577	900	0.319
78	483	650	0.497
79	697	1057	0.333
80	807	724	0.416
81	840	1079	0.428
82	512	894	0.433
83	693	544	0.568
84	953	1526	0.448
85	830	1039	0.485
86	1040	931	0.562
87	503	432	0.549
88	649	652	0.594
89	696	775	0.567
90	787	1181	0.542
91	649	1041	0.428
92	883	1444	0.381
93	1508	2767	0.414
94	1418	3117	0.371
95	1587	4220	0.320
96	1133	2245	0.308
97	714	1563	0.326

[a] Annual effort for 25% qualified landings.
[b] Median CPUE for 25% qualified landings

Appendix. A.1 Schnute and Richards (1995) Catch-age model

The catch-age model used for the assessments of Hecate Strait rock and English soles is an application of the state space model developed by Schnute and Richards (1995). The model attempts to reconstruct the population history from known controls and observations. In this context, the catch biomass acts as a known control on the population dynamics. Observations, including proportions at age in the catch and a biomass index from survey CPUE values, describe the current state of the system. The model relates the observations, measured with error, to unknown numbers of fish in the population.

Table A.1 contains a deterministic version of the model, with notation described in Table A.2. Equations in Table A.1 are tailored for each application. In particular, the Schnute-Richards model is based on numbers of fish; we use known weights, w_{at} of fish of age a at time t and the maturity ogive m_a to determine the spawning biomass S_t and exploitable population biomass B_t.

Similar to other stochastic catch-age models, our analysis contains a separability assumption. The two parameters α and β_t describe a selectivity function which is time-independent and asymptotic with age. The quantity β_a in equation (A.2) denotes the proportion of age a fish that are vulnerable to the fishery.

Other quantities in the parameter vector Θ are the natural mortality rate M, the survey catchability q, and the time series of recruitments R_t. We treat the recruitments as parameters to be estimated from the data; our analysis does not contain an explicit stock-recruitment function.

The prediction equations (A.14) and (A.15) relate quantities $\bar{I}_t$ and $\bar{p}_{at}$ obtained from the model dynamics to observations I_t and p_{at} of survey CPUE and age proportions, respectively. (We use the convention of a bar over a quantity to denote a prediction for that quantity.) We assume in (A.14) that the survey CPUE indexes the population biomass after half of the annual catch has been removed. The catchability q converts units of population biomass into units of CPUE. Although the relationship (A.14) could be made age-specific, age composition data are not available for the early surveys. The predicted age proportions in the catch are obtained from the underlying population age structure in equation (A.4).

Schnute and Richards (1995) specify stochastic counterparts of the deterministic equations (Table A.1), model residuals, and the model likelihood function. They impose three sources of error: (1) autoregressive lognormal process error among the recruitments R_t;(2) lognormal error in CPUE; and (3) multivariate logistic error in the observed proportions p_{at}. These error structures lead to residual functions

$$\xi_t = \log I_t - \log \bar{I}_t$$

$$\eta_{at} = \log p_{at} - \log \bar{p}_{at} - \frac{1}{A}\sum_{a=1}^{A}[\log p_{at} - \log \bar{p}_{at}]$$

that describe model relationships between predictions and observations of survey CPUE and age proportions, respectively.

The likelihood for this catch-age model conforms to the errors-in-variables paradigm (Schnute 1994); apparent variations in abundance can be explained through high process error σ in recruitment or high measurement error τ in CPUE. Schnute and Richards (1995) resolve this ambiguity by fixing the model variance ratio, $\rho = \frac{\sigma^2}{\sigma^2 + \tau^2}$, between the recruitment variance and the total variance $(\sigma^2 + \tau^2)$.

For the catch-age analysis, we fix the variance ratio ρ=0.7, a value that represents moderate levels of error in both recruitment and survey CPUE. Similar stock reconstructions were obtained for a range of reasonable choices of ρ in preliminary model runs. We also employ a fixed natural mortality rate of M=0.2. Age classes in the model range from recruits to the fishery at age 4 to an accumulator age class for age 12 and older. To reduce the influence on the model likelihood of very small age proportion observations (obtained from a small number of fish), we group consecutive age classes such that $p_{at} \geq 0.02$ for each age a and time t (Richards et al. 1997).

The model was implemented using AD Model Builder software (Otter Research Ltd. 1994). Standard errors for the model parameters and other quantities were obtained from the model hessian matrix. These allow calculation of symmetric confidence intervals, assuming that the parameter estimates have a multivariate normal distribution. In particular, we used AD Model Builder to compute standard errors for log recruitment, log spawner biomass and log exploitable biomass.

Table A.1. Deterministic catch-age model. Calculations begin with the parameter vector Θ and proceed recursively to define all states and observations.

Parameters

(A.1) $\Theta = (\alpha, \beta_1, M, q, \{R_t\}_{t=2-A}^{T})$

Selectivity

(A.2) $\beta_a = 1-(1-\beta_1)\left(\frac{A-a}{A-1}\right)^{\alpha}$

State moments

(A.3) $P_t = \sum_{a=1}^{A} \beta_a N_{at}$

(A.4) $u_{at} = \beta_a N_{at} / P_t$

(A.5) $B_t = \sum_{a=1}^{A} \beta_a w_{at} N_{at}$

(A.6) $S_t = \sum_{a=1}^{A} m_a w_{at} N_{at}$

(A.7) $C_t = D_t / \sum_{a=1}^{A} u_{at} w_{at}$

(A.8) $F_t = \log\left(\frac{P_t}{P_t - C_t}\right)$

Initial states

(A.9) $N_{a1} = R_{2-a} e^{-M(a-1)}$; $1 \le a < A$

(A.10) $N_{A1} = R_{2-A}\left(\frac{e^{-M(A-1)}}{1-e^{-M}}\right)$

State Dynamics

(A.11) $N_{1t} = R_t$

(A.12) $N_{at} = e^{-M}[N_{a-1,t-1} - u_{a-1,t-1} C_{t-1}]$; $2 \le a < A$

(A.13) $N_{At} = e^{-M}[N_{A-1,t-1} + N_{A,t-1} - (u_{A-1,t-1} + u_{A,t-1}) C_{t-1}]$

Predicted Observations

(A.14) $\bar{I}_t = q(B_t - 0.5 D_t)$

(A.15) $\bar{p}_{at} = u_{at}$; $2 \le a \le A$

Appendix table 1.1. Description of the notation for the input data, parameters, and other calculated model quantities in Table A.1.

Symbol	Description
	Index quantities
a	age-class from 1 to A
t	year from 1 to T
	Input data
D_t	observed catch biomass in year t
I_t	observed survey CPUE in year t
m_a	proportion of age-class a fish which are mature
p_{at}	observed proportion of age-class a fish in the year t catch
w_{at}	weight of age-class a fish in year t
	Parameters
Θ	parameter vector
α	selectivity slope parameter
β_1	selectivity of age-class 1
M	natural mortality rate
q	catchability for survey CPUE
R_t	age-class 1 recruitment in year t
	Calculated quantities
β_a	selectivity for age-class a
B_t	exploitable population biomass at the start of year t
C_t	catch number in year t
F_t	fishing mortality rate in year t
N_{at}	number of age-class a fish at the start of year t
P_t	exploitable population numbers at the start of year t
S_t	spawning stock biomass at the start of year t
u_{at}	exploitable proportion of age-class a fish in year t catch

Appendix table 1.2 Values for biological statistics used in the yield per recruit and spawning stock biomass per recruit analysis.

Parameter or calculated value	Rock sole	English sole
K	0.211	0.275
L	50.5 cm	49.4 cm
W	1847 g	1091 g
t_0	-0.120	-0.039
M	0.20	0.20
t_r	4	4
w_j	503 629 745 869 985	369 424 478 535 595
	1111 1180 1268 1315	662 723 772 848
l_j	33.6 36.0 37.9 39.7 41.3	34.6 36.2 37.6 39.0 40.3
	42.9 43.7 44.7 45.2	41.6 42.8 43.7 45.1
p_j	0.034 0.474 0.910 0.991 0.998	0.470 0.894 0.978 0.993 1.000
	1.000 1.000 1.000 1.000	1.000 1.000 1.000 1.000

Where:

K, L, W and t_0 are von Bertalanffy growth curve coefficients

M is the instantaneous rate of natural mortality

w is the mean weight at age in grams

l is the mean length at age in centimetres

p is the proportion mature at age

and : $_j$ indexes age groups 4-12+

Appendix A.2. The dynamic Fox surplus production model used in the Area 5C-E Dover sole assessment

$\ln(U_{t+1}) = (2r/(2+r))\ln(Kq) + ((2-r)/(2+r))\ln(U_t) - (q/(2+r))(E_t + E_{t+1})$
where:

U = median CPUE(t / h)
E = effort(h)
r = natural growth rate
q = catchability coefficient
K = environmental carrying capacity
and t indexes year

The model fit to the data was expressed as:
$\ln(U_{t+1}) = c1 + c2\ln(U_t) + c3(E_t + E_{t+1})$

where r,q, and K are:
$r = 2(1-c2)/(1+c2)$
$q = -c3(2+r)$
$K = (1/q)\exp(c1(2+r)/2r)$

The stock production curve was determined from:
$C_t = qKE_t \exp(-qE_t / r)$

Biomass in 1997, B_{97}, was estimated from
CPUE in 1997, U_{97} , and q as:
$B_{97} = U_{97} / q$

Optimum effort, E_{opt}, was estimated from the regression:
$U = a - bE$
where:
$U = CPUE$
and
$E = Effort$
and
$E_{opt} = a / 2b$

Maximum sustainable yield, MSY, was
estimated as:
$MSY = qKE_{opt}(\exp((-qE_{opt})/r))$

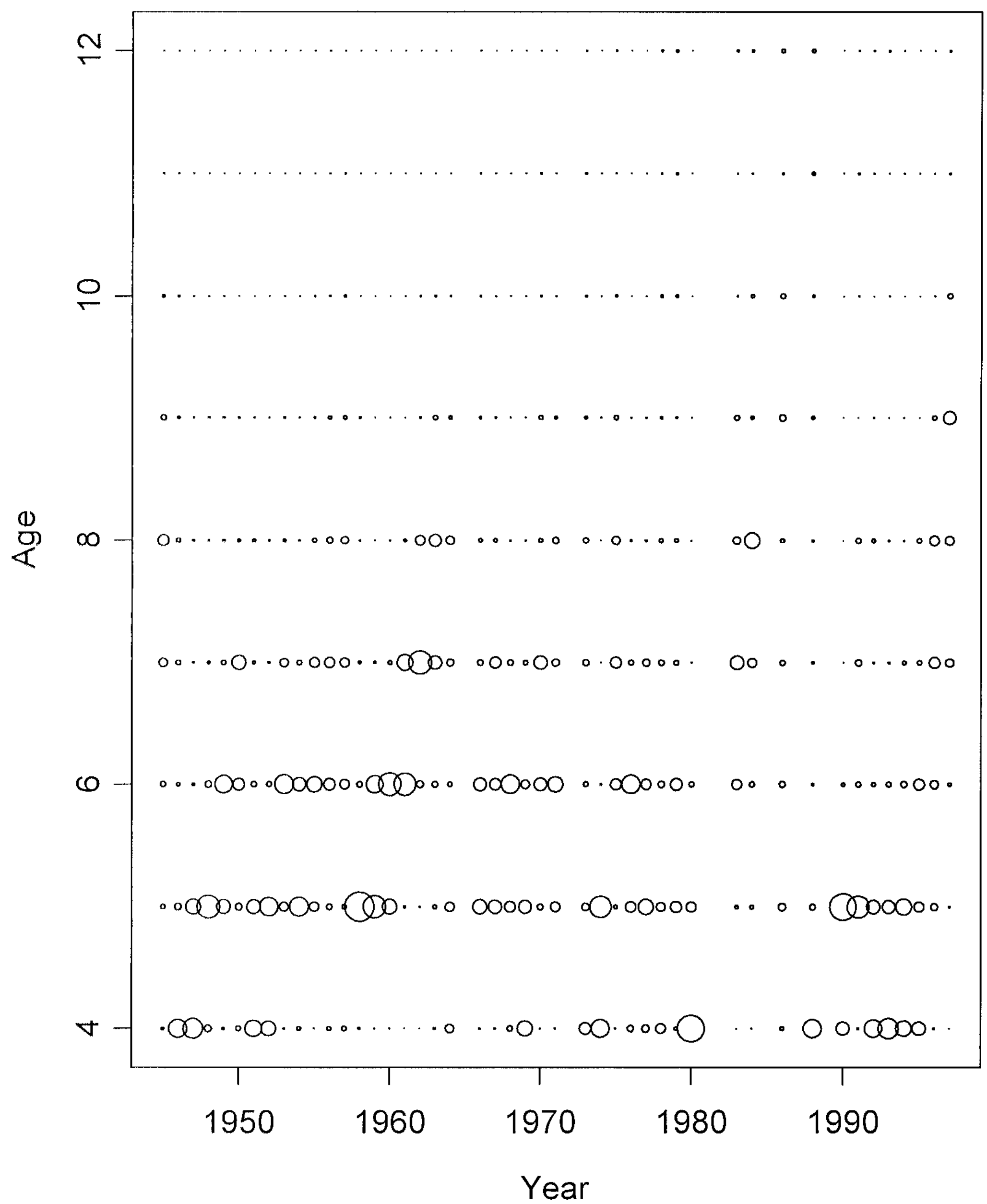


Figure 1.1. Proportion at age data (1945-97) used for the catch-age analysis of Hecate Strait Rock sole. The circle radii are proportional to values for individual age proportions.

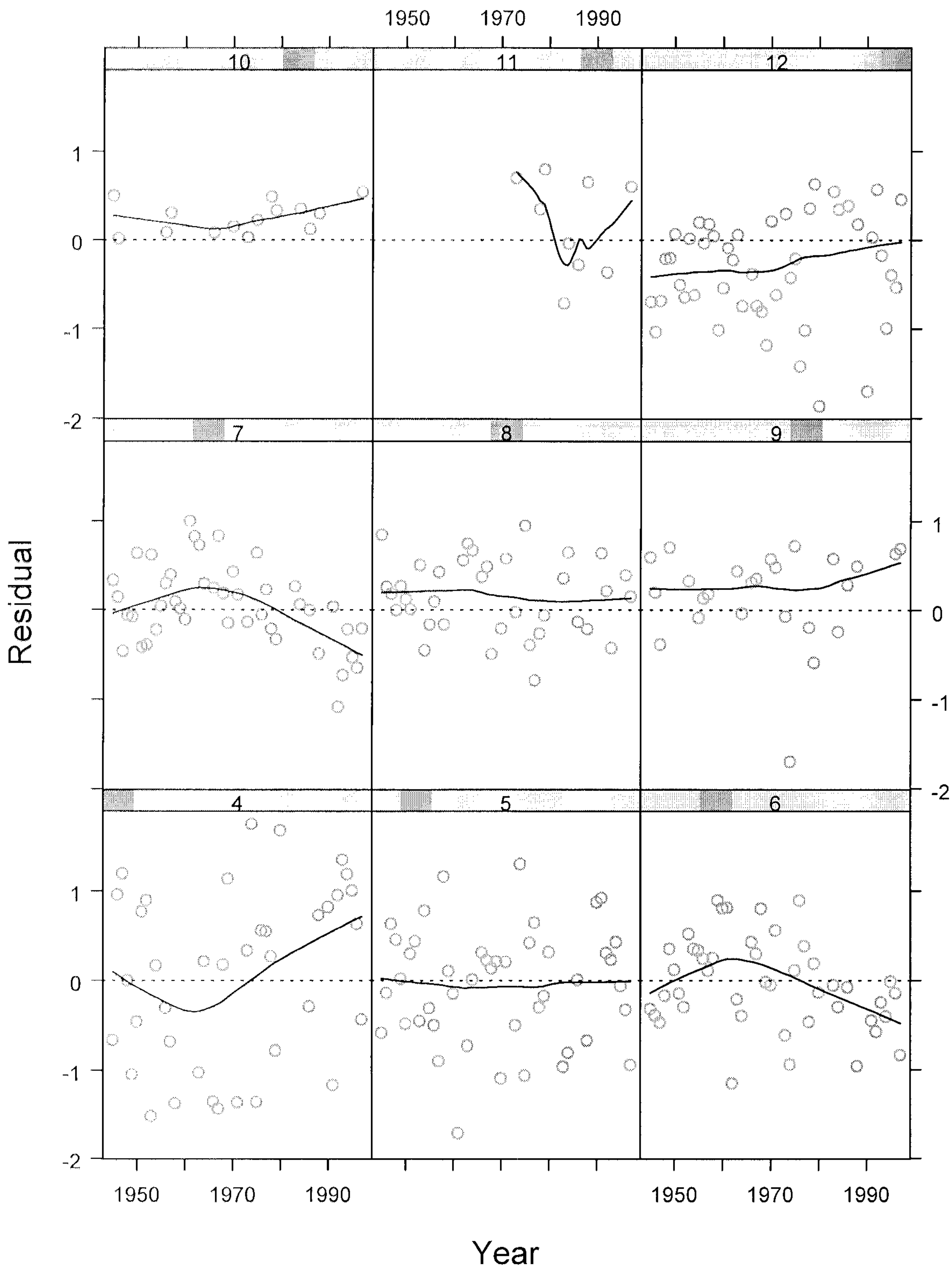
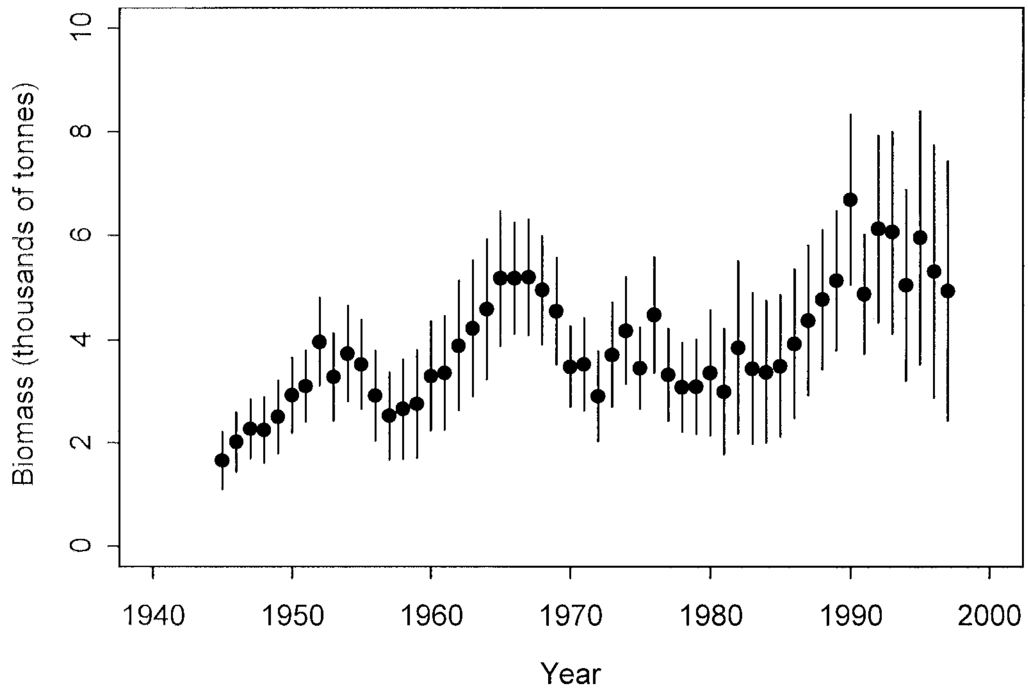


Figure 1.2. Time series (1945-97) plots of model residuals for each age group with loess trend lines. Results from the catch-age analysis of Hecate Strait Rock sole.



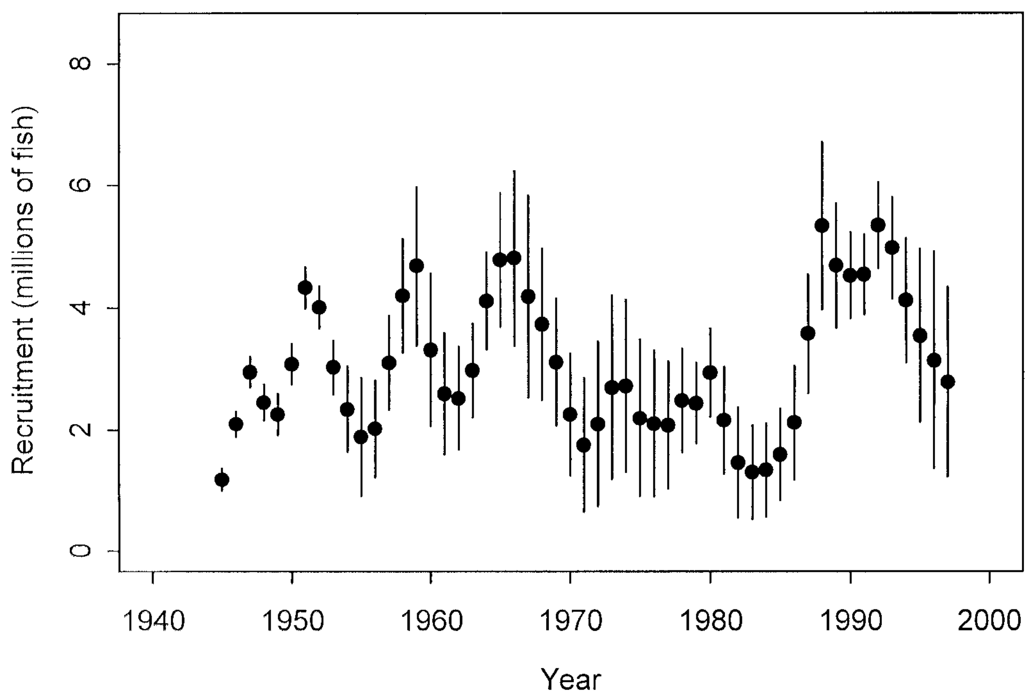


Figure 1.3. Biomass and recruitment trajectories (1945 -97) from the catch-age analysis for Hecate Strait Rock sole. The vertical bars represent the 95% confidence limits for individual estimates.

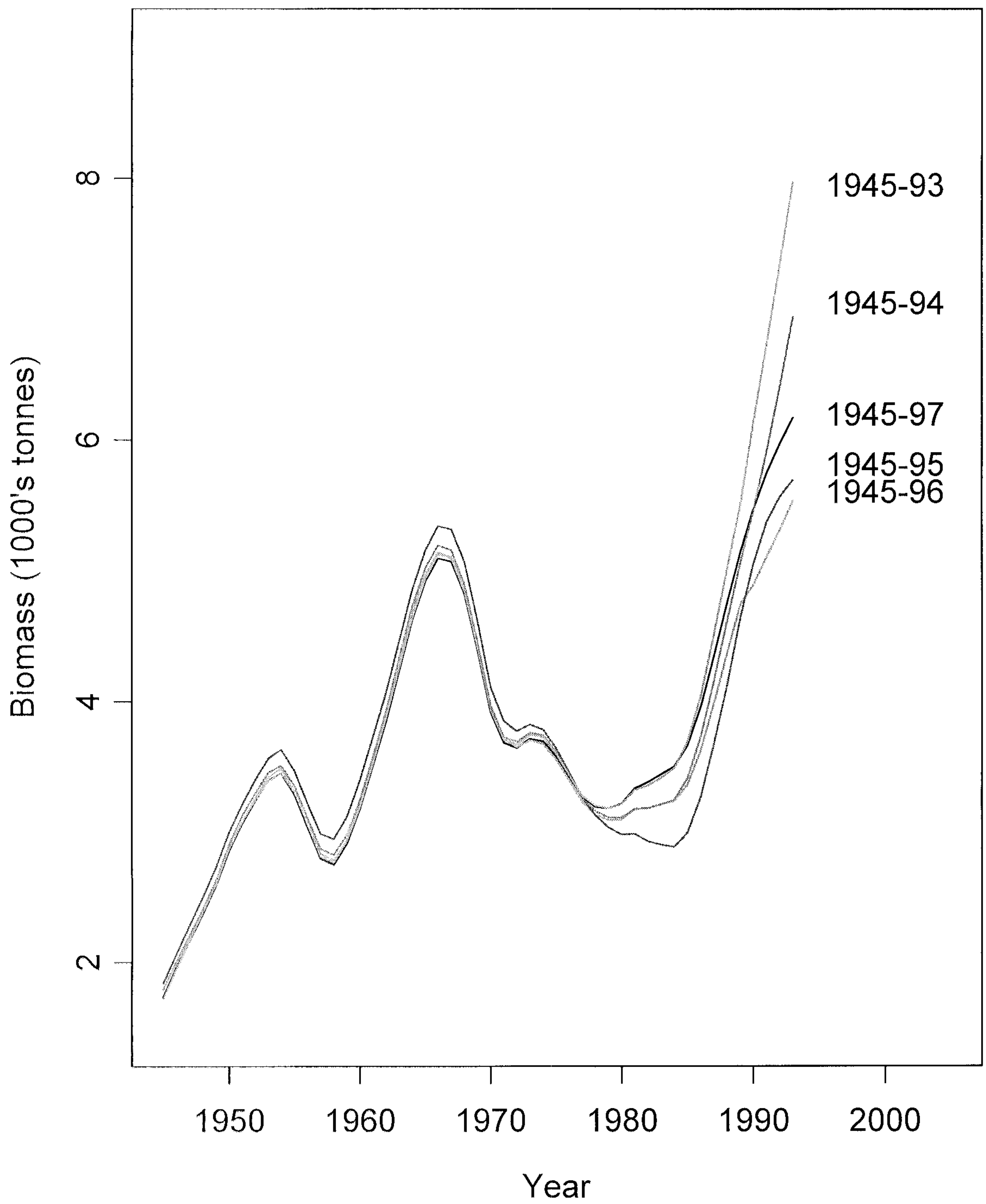


Figure 1.4 Biomass trajectories (loess smoothed) from the retrospective analysis of Hecate Strait Rock sole age proportion data.

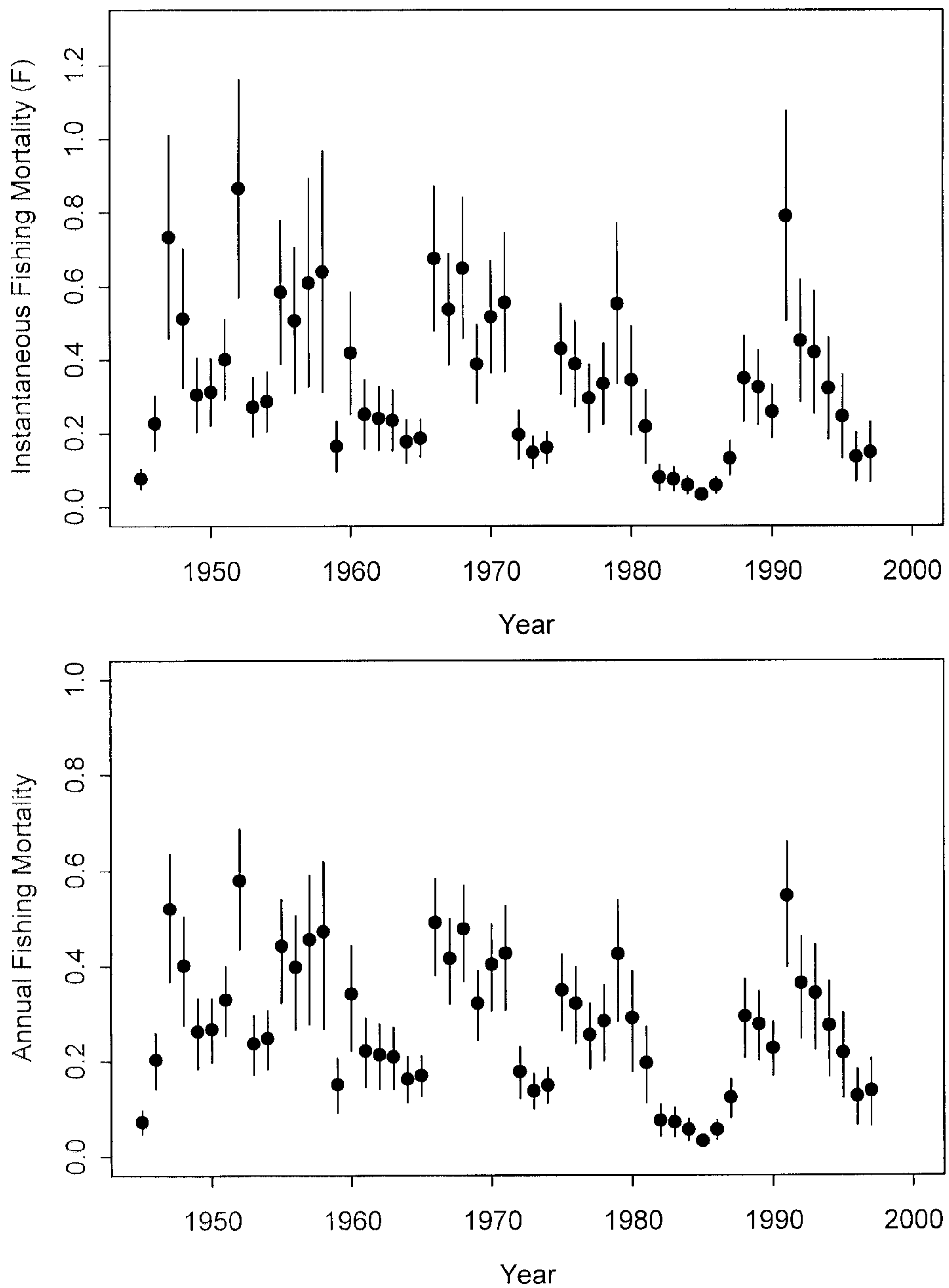


Figure 1.5. Estimates of fishing mortality from the catch-age analysis for Hecate Strait Rock sole. The vertical bars represent the 95% confidence limits for individual estimates.

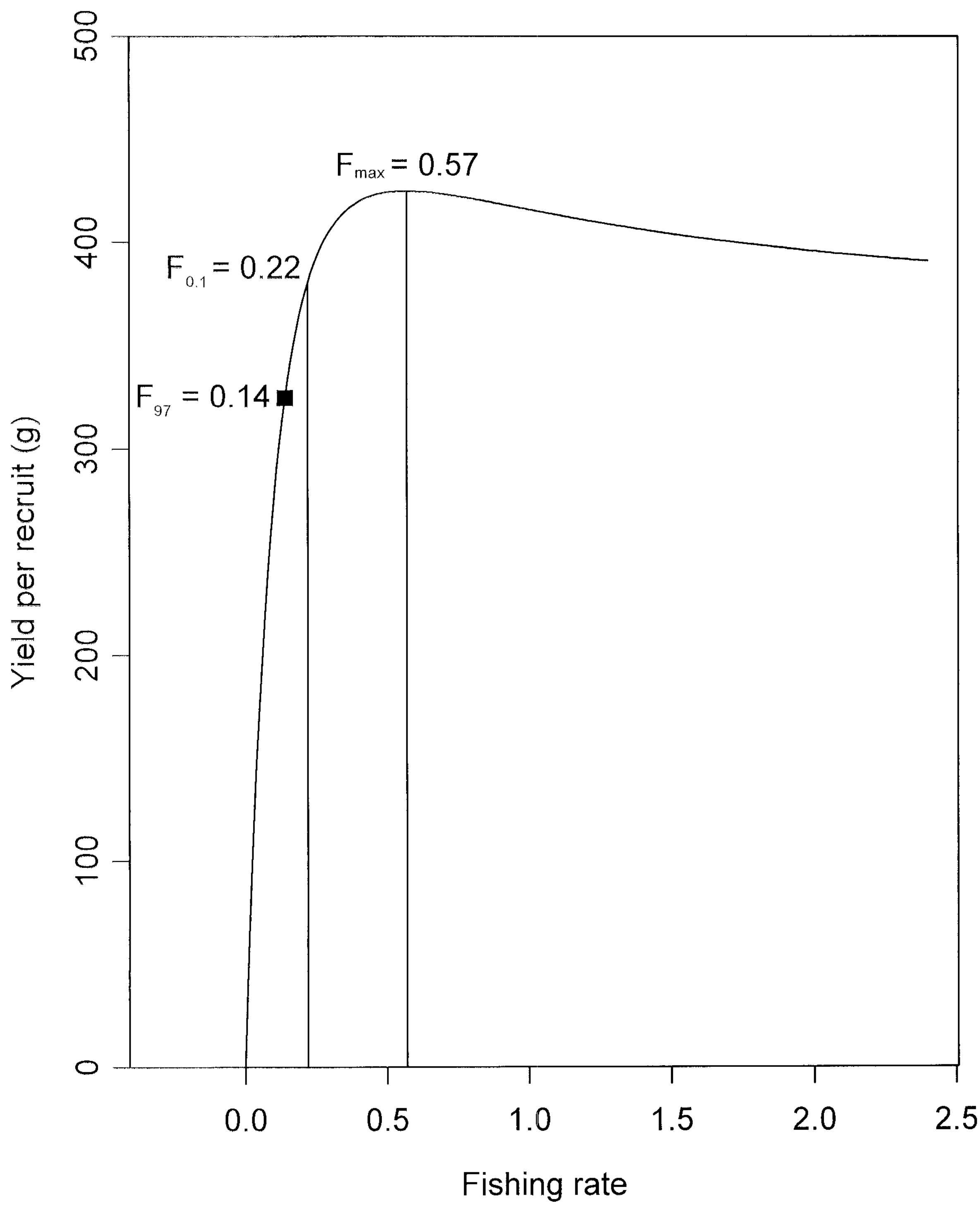


Figure 1.6. Results from the yield per recruit analysis for Hecate Strait Rock sole. $F_{0.1}$ is the fishing rate where the slope of the yield per recruit curve is 10% of that at the origin. F_{max} is the fishing rate where yield is maximised (slope=0).

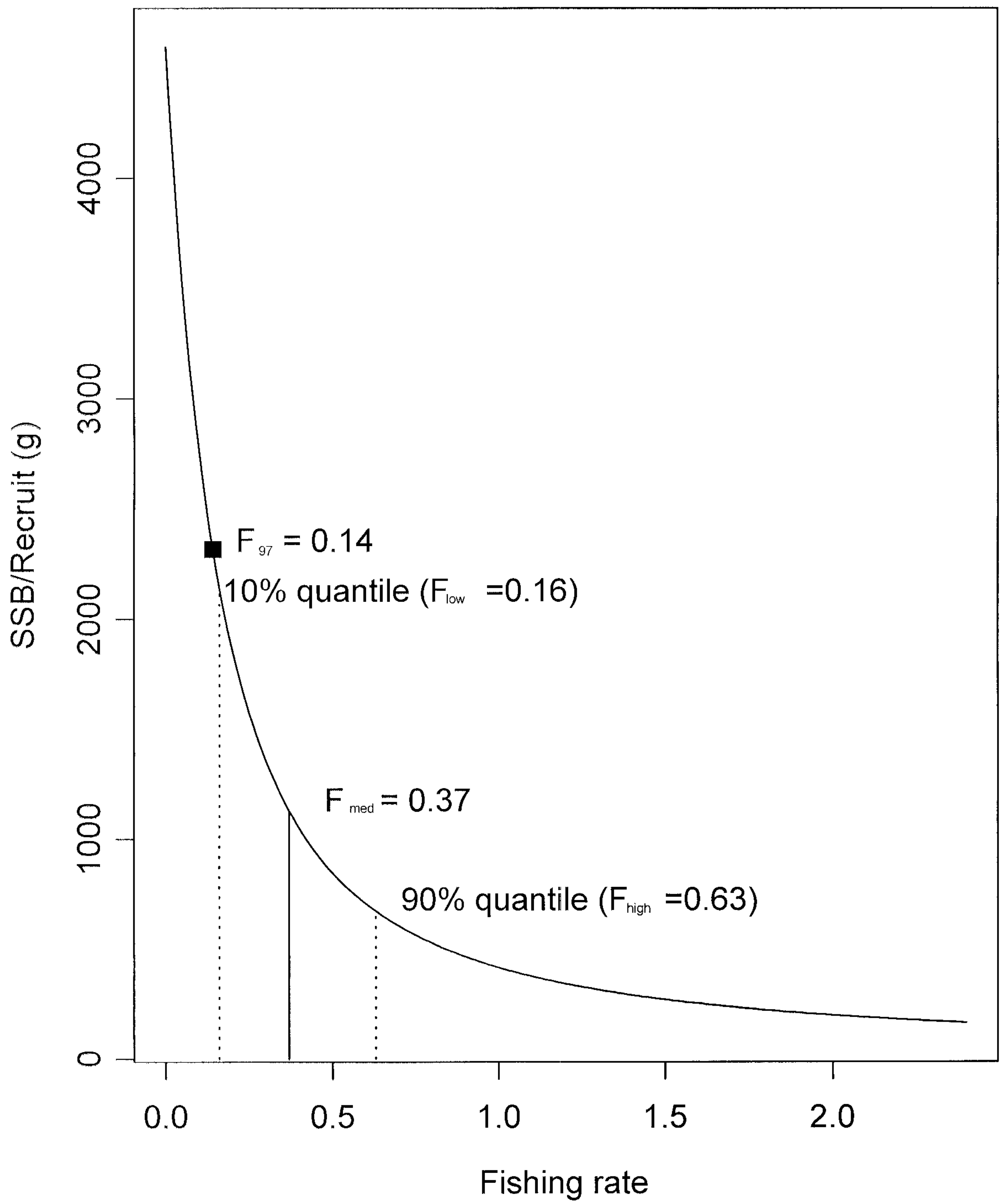


Figure 1.7. Results from the spawning stock biomass per recruit analysis for Hecate Strait Rock sole. The solid line indicates the fishing mortality rate where the stock has a 50% chance of maintaining its spawning biomass (F_{med}). The dotted lines indicate the fishing rates associated with the 10% and 90% quantiles (F_{low} and F_{high}, respectively) of the SSB/R index computed from the population estimates from catch-age analysis.

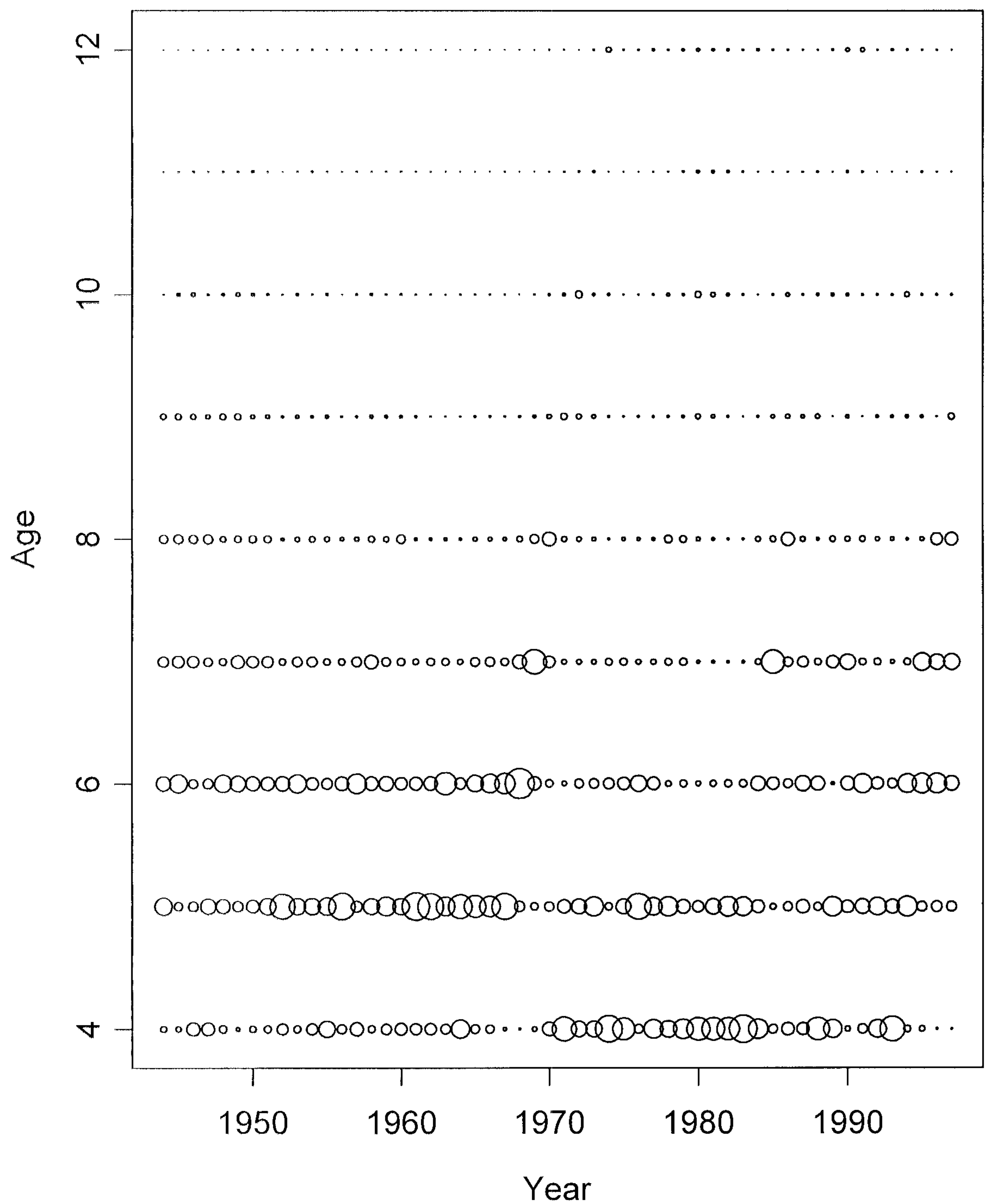


Figure 1.8. Proportion at age data (1944-97) used for the catch-age analysis of Hecate Strait English sole. The circle radii are proportional to values for individual age proportions.

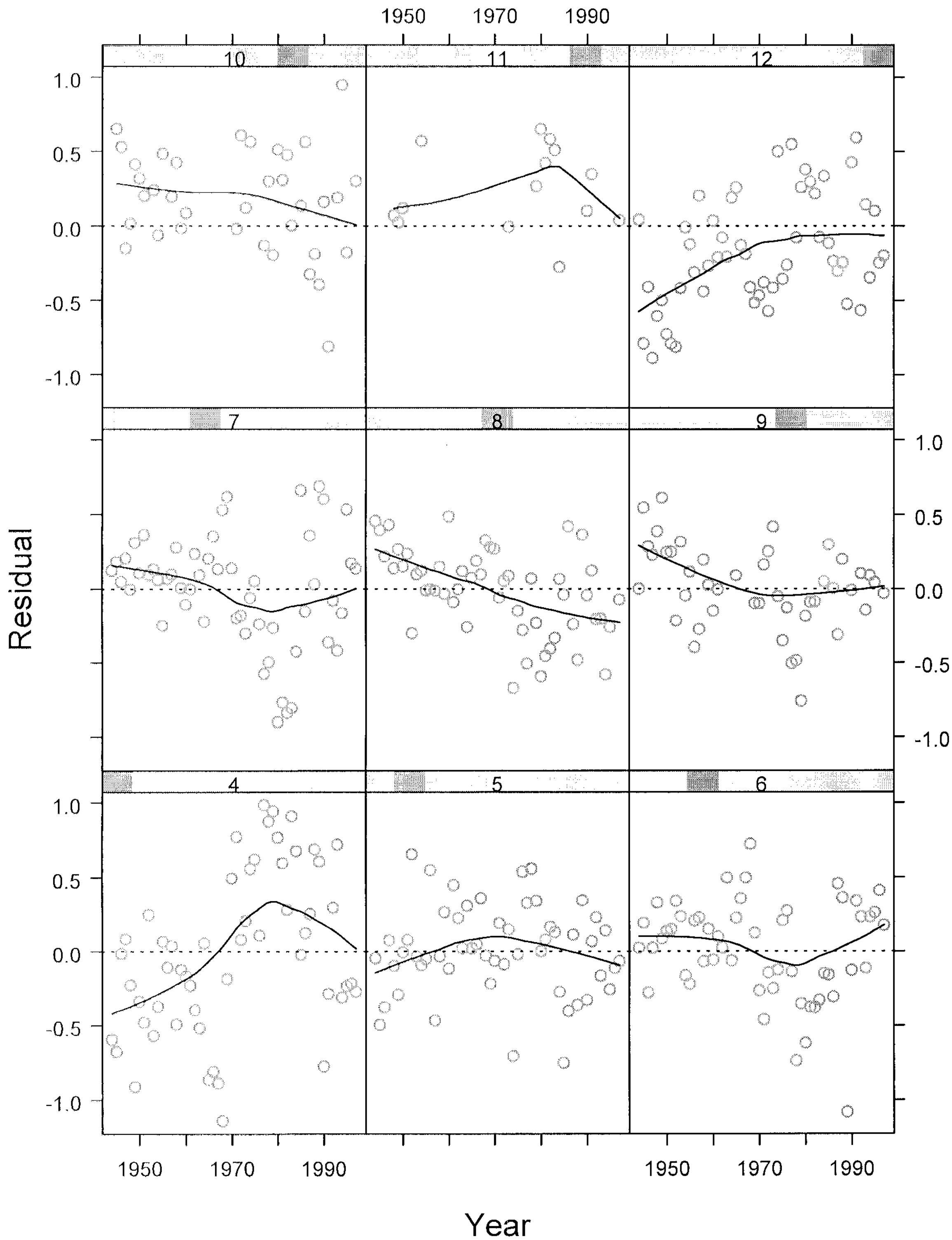


Figure 1.9. Time series (1945-97) plots of model residuals for each age group with loess trend lines. Results from the catch-age analysis of Hecate Strait English sole.

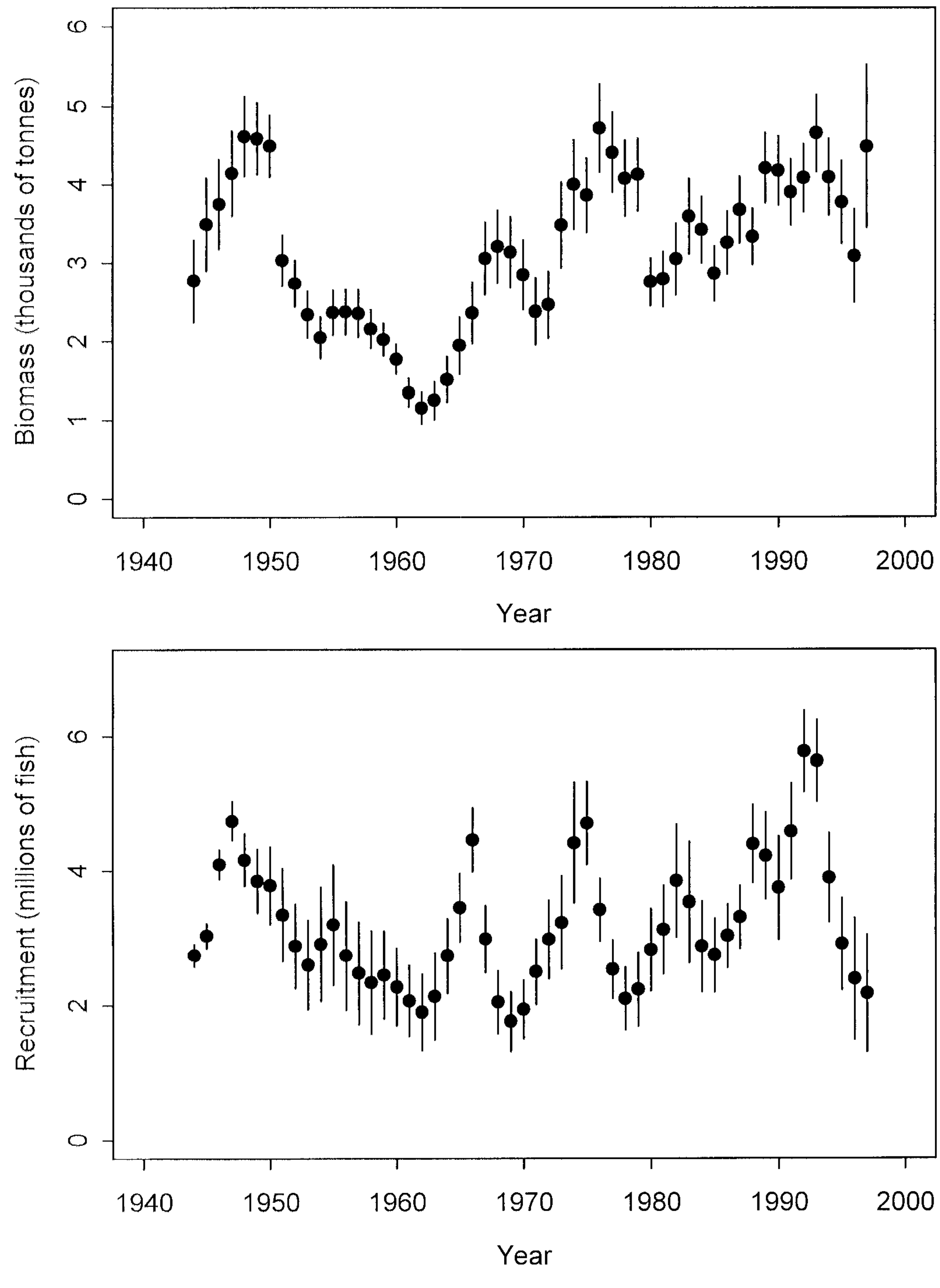


Figure 1.10. Biomass and recruitment trajectories (1945 -97) from the catch-age analysis for Hecate Strait English sole. The vertical bars represent the 95% confidence limits for individual estimates.

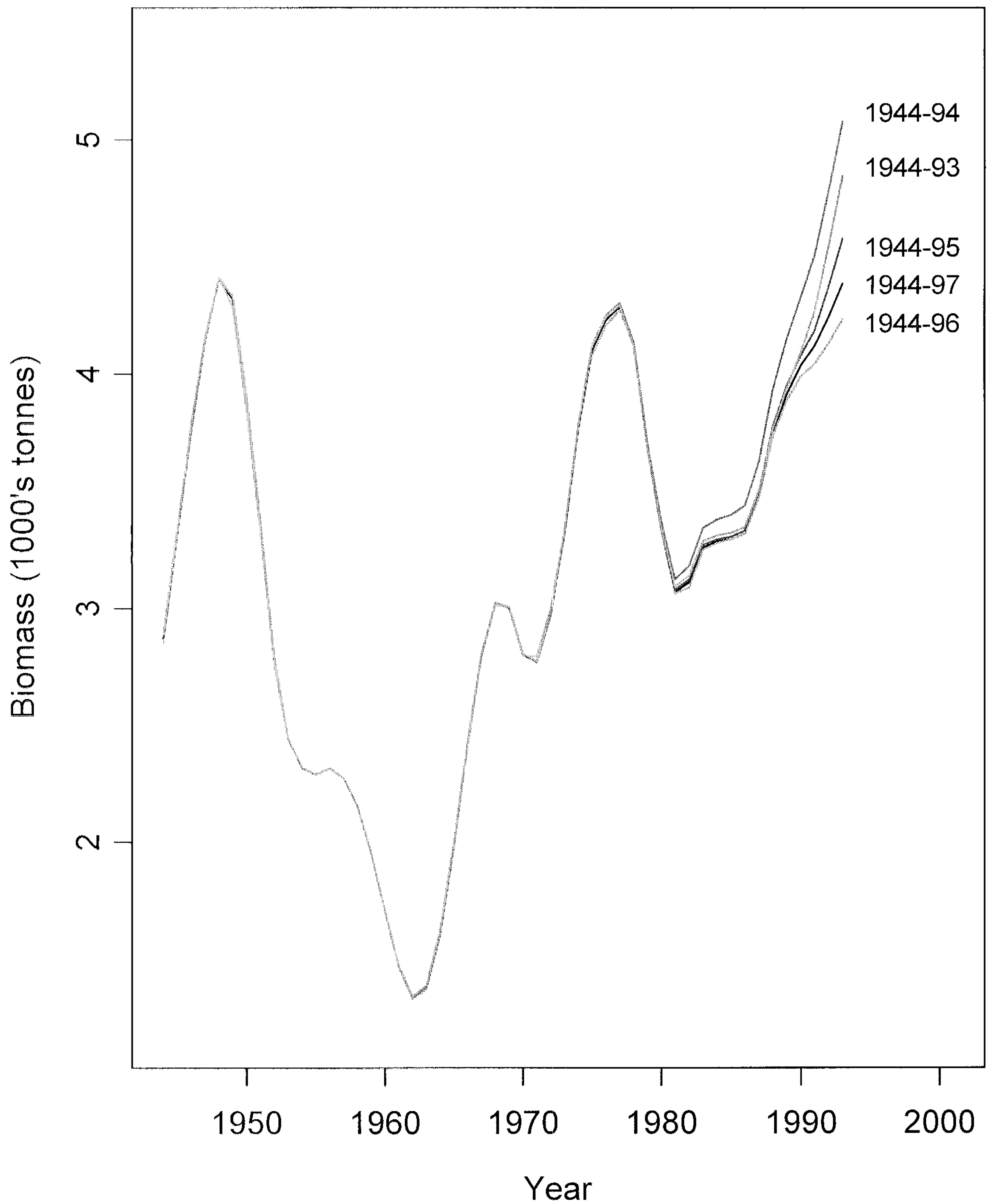


Figure 1.11. Biomass trajectories (loess smoothed) from the retrospective analysis of Hecate Strait English sole age proportion data.

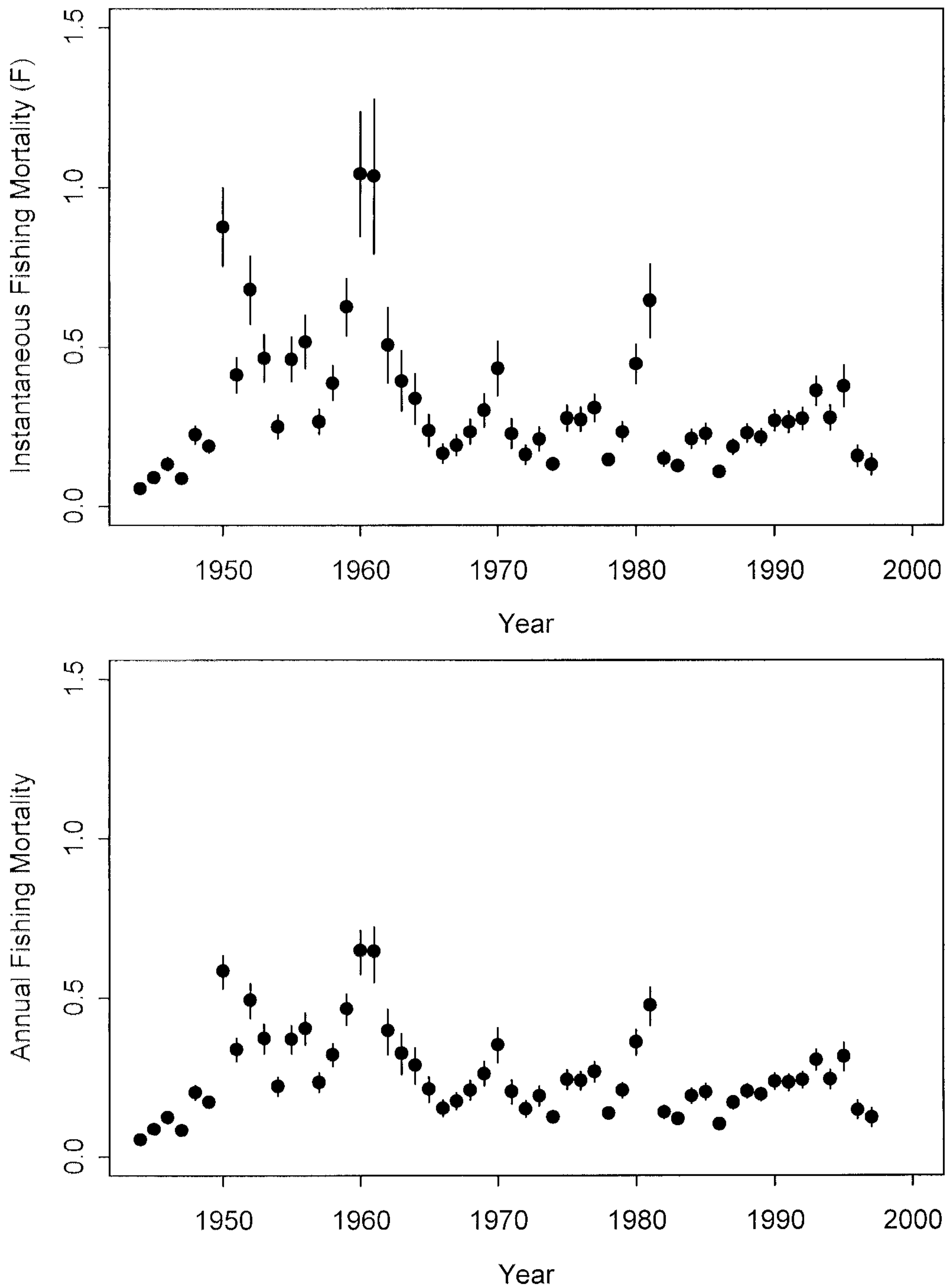


Figure 1.12. Estimates of fishing mortality from the catch-age analysis for Hecate Strait English sole. The vertical bars represent the 95% confidence limits for individual estimates.

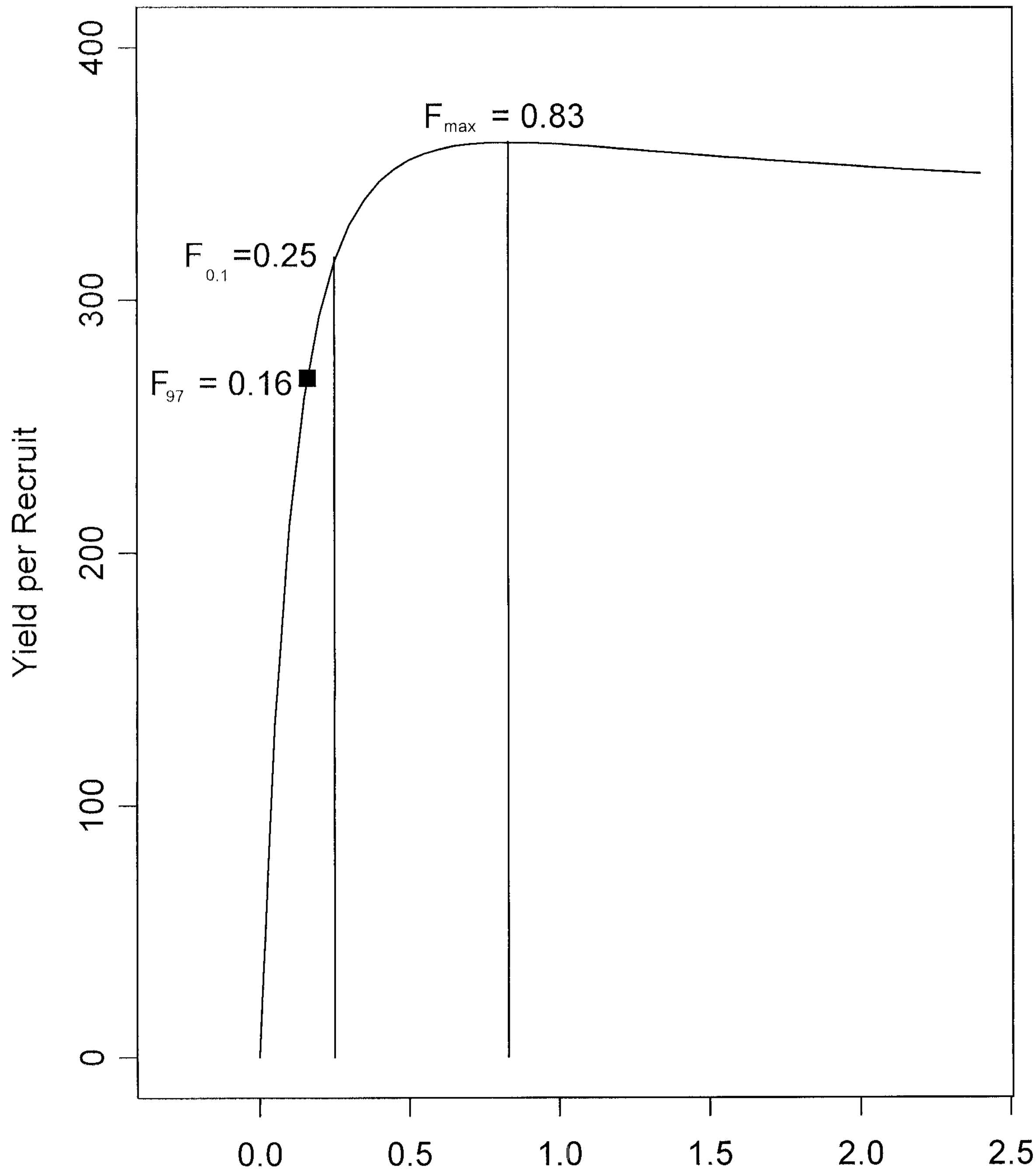


Figure 1.13. Results from the yield per recruit analysis for Hecate Strait English sole. $F_{0.1}$ is the fishing rate where the slope of the yield per recruit curve is 10% of that at the origin. F_{max} is the fishing rate where yield is maximised (slope=0).

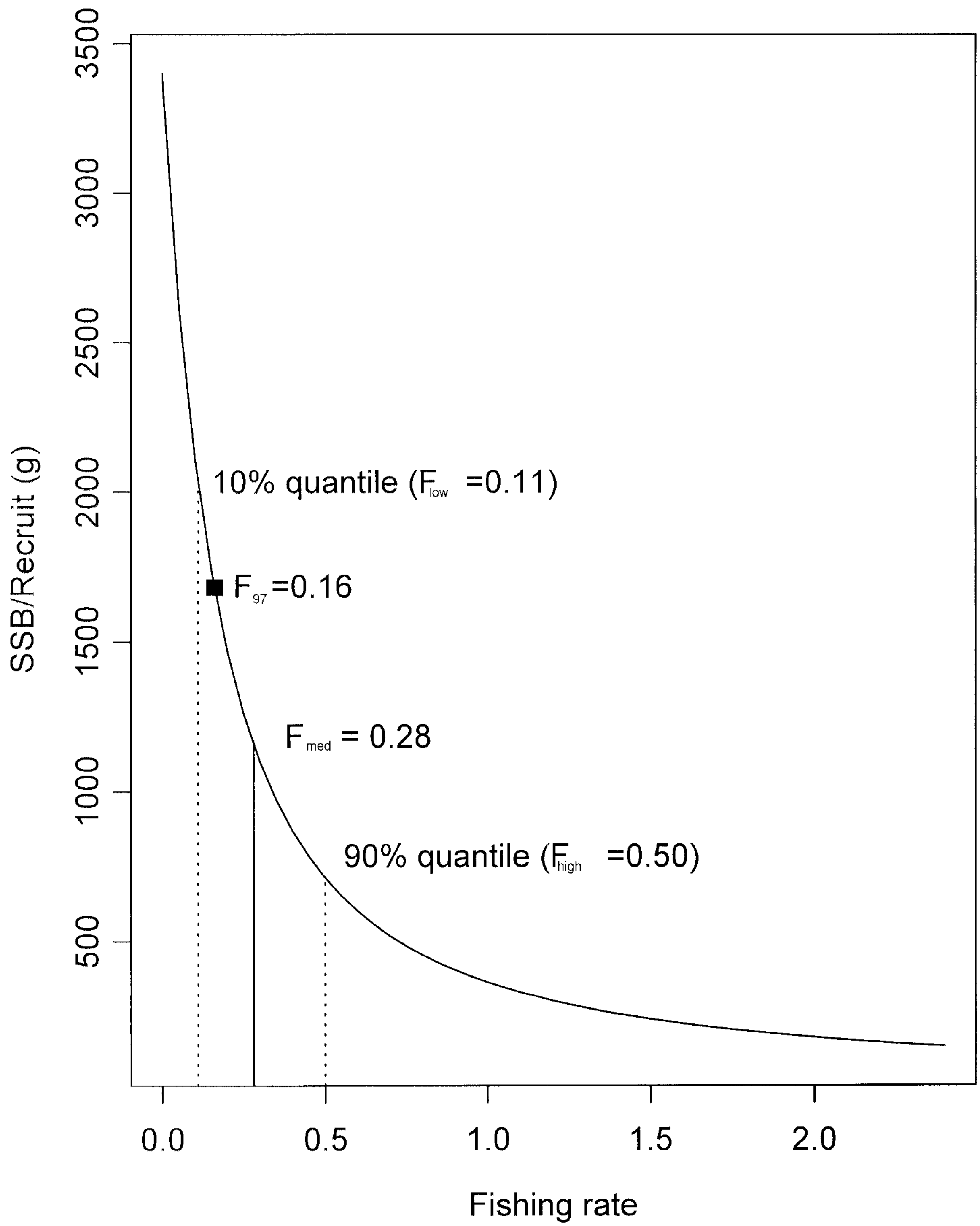


Figure 1.14 Results from the spawning stock biomass per recruit analysis for Hecate Strait English sole. The solid line indicates the fishing mortality rate where the stock has a 50% chance of maintaining its spawning biomass (F_{med}). The dotted lines indicate the fishing rates associated with the 10% and 90% quantiles (F_{low} and F_{high}, respectively) of the SSB/R index computed from the population estimates from catch-age analysis.

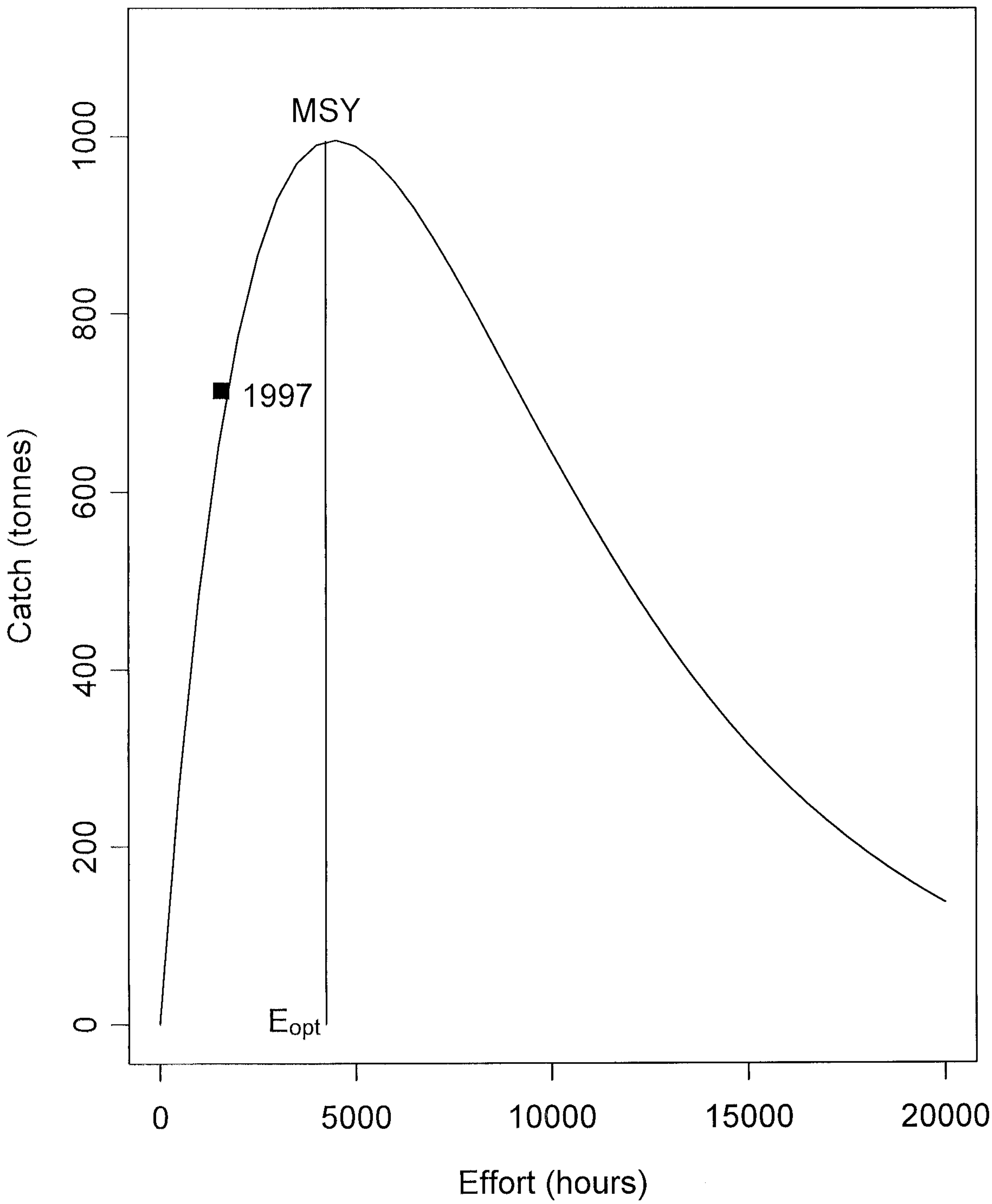


Figure 1.15 The equilibrium stock production curve for Area 5C-E Dover sole. Maximum sustainable yield is 994 tonnes at an optimum effort of 4224 hours. The point labelled 1997 is the catch-effort observation for the 1997 fishery.