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Flatfish Stock Assessments for the west coast of Canada for 1997 and recommended yield options for 1998

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Abstract

Interim assessments were prepared for important stocks of flatfish caught in the B.C. trawl fishery . In the past CPUE from the commercial trawl fishery has been used as a surrogate for stock abundance for the assessments for Area 5A-B rock sole and Area 3C-D and 5C-E Dover sole. However, the behaviour of the fishing fleet has been dramatically altered by changing trip limits and other regulatory measures in recent years and CPUE can no longer be considered a reliable index of relative abundance. Only summaries of the landing statistics are presented for the stocks listed above. Until more comprehensive assessments for these stocks are undertaken the yield options will remain the same as those recommended for the 1997 fishery. The assessments for Area 5C-D rock sole and English sole stocks are based on catch-age analysis and include biological samples collected during the 1996 fishery. Assessments were produced for four species and six stocks.

Petrale sole stocks are at low abundance. Rock sole biomass in Areas 5C-D in 1996 was above the long term average for the last 50 years. The estimate of fishing mortality for the stock in 1996 was below $F_{0.1}$. The yield recommendations for this stock in 1998 are unchanged from those recommended for 1997. English sole biomass in Areas 5C-D in 1996 was slightly above the long term average for the last 50 years. The estimate of fishing mortality for the stock in 1996 was below $F_{0.1}$ as well. The yield recommendations for this stock for 1998 remain the same as those recommended for 1997. Landings of Dover sole from Areas 5C-E in 1996 were near the longterm sustainable harvest for that stock while effort in 1996 was close to the optimum corresponding to MSY.

Résumé

Des évaluations provisoires ont été préparées pour d'importants stocks de poissons plats faisant l'objet de la pêche au chalut en C.-B. Les PUE de la pêche commerciale au chalut étaient antérieurement utilisés comme indices de l'abondance du stock aux fins des évaluations de la fausse limande des zones 5A-B et de la limande-sole des zones 3C-D et 5C-E. Les modifications apportées aux limites par sortie et d'autres mesures réglementaires adoptées ces dernières années ont fortement modifié le comportement de la flottille de pêche de sorte que les PUE ne constituent plus des indices fiables de l'abondance relative. Les statistiques sur les débarquements des stocks mentionnés plus haut ne sont présentées que sous forme résumée. Tant que des évaluations plus détaillées n'auront pas été réalisées, les options de rendement demeureront les mêmes que celles recommandées pour la pêche de 1997. Les évaluations des stocks de fausse limande et de carlottin anglais de 5C-D sont fondées sur l'analyse des prises selon l'âge et des échantillons biologiques prélevés pendant la pêche de 1996. Des évaluations ont été faites pour quatre espèces et six stocks.

L'abondance des stocks de plie de Californie est faible. La biomasse de la fausse limande en 5C-D en 1996 était supérieure à la moyenne à la long terme des 50 dernières années au moins. La mortalité par pêche estimée du stock était inférieure au $F_{0,1}$ en 1996. Les recommandations relatives au rendement de ce stock en 1998 demeurent inchangées par rapport à celles de 1997. La biomasse du carlottin anglais en 5C-D en 1995 était légèrement supérieure à la moyenne à long terme des 50 dernières années au moins. La mortalité par pêche estimée du stock en 1996 était aussi inférieure au $F_{0,1}$. Les recommandations relatives au rendement en 1998 demeurent inchangées par rapport à celles de 1997. Les débarquements de limande-sole en provenance de 5C-E en 1996 approchaient la récolte soutenue à long terme pour ce stock tandis que l'effort en 1996 se rapprochait de la valeur optimale correspondant au RMS.

1.0 General Introduction

This year interim assessments have been prepared for all flatfish stocks. Catch and effort statistics have been updated for all stocks to include information from the 1996 fishery. The 25% qualified median CPUE from the commercial fishery has been used as the index for monitoring stock status for petrale sole (*Eopsetta jordani*), Area 3C-D Dover sole (*Microstomus Pacificus*), Area 5A-B rock sole (*Pleuronectes bilineata*) and Area 5C-E Dover sole (Fargo and Kronlund 1997). Catch-age analysis provides of assessment for Hecate Strait rock sole and Hecate Strait English sole (*Pleuronectes vetulus*).

The groundfish trawl fishery has changed significantly in recent years. All option A vessels were required to carry an observer on every fishing trip beginning in 1996. Transferable vessel quotas were used to regulate the 1997 fishery. Observers recorded information on area, depth, catch and effort for the trip. Port monitors provided estimates of the landings for each trip. Stock assessment analyses of fishery catch-effort data assume that CPUE is proportional to stock abundance. Cases where this assumption is false far outnumber cases where it is true. Changes in management of groundfish fisheries including the use of trip limits and changes in vessel efficiency and fishing patterns over time have nullified the use of the fishery CPUE index for many cases (Richards and Schnute 1986). Hyperstability of the index has been documented in many situations. That is, in cases where vessel trip limits have been invoked by managers or in the case of multispecies fisheries, the CPUE index will 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 basis of assessment for any of the cases presented here. In the presence of skewed observations, both the mean of ratios and the ratio of means of CPUE can perform badly; 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). Accordingly, the median statistic has been presented for each case where time series of catch effort data exist. In the analysis herein year to year changes in the CPUE index, were not considered. The rate of decrease or increase in the index over four or five years is discussed in the context of changing management and results of independent analysis of biological data. To aid in evaluation of the index the 90% bootstrapped confidence intervals for each CPUE estimate were computed. The bootstrapping was implemented in S-plus version 4.0 (Mathsoft 1997). For each case the bootstrap procedure included resampling 1000 new samples, each of the same size as the observed data. Each new sample was drawn with replacement from the observed data. The median statistic was first calculated using the observed data and then re-calculated using each of the new samples to yield a bootstrap distribution. The resulting replicates were used to calculate the bootstrap estimates of bias, mean and standard error for the median statistic.

Whenever possible, analysis of age composition data was used as the basis for assessment. Catch curves of the most current age composition data were used for 'northern' Dover sole and Petrale sole to estimate the total instantaneous mortality rate for these stocks. For Hecate Strait Rock sole and English sole the state space model of

Schnute and Richards was applied to age composition data time series' to reconstruct the stock history. Yield for these cases was determined for the 25th and 50th percentiles of the 95% confidence region for the 1996 biomass estimate using a specific target fishing mortality rate. Yield options for 1997-98 are summarised in Table 4.1.

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 population off the west coast of Vancouver Island is composed of two stocks based on results from tagging experiments conducted in the 1960s (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 intensive fishery occurring from 1950 to 1970 is not available because the fishery was carried out largely by U.S. trawlers and no comprehensive data were collected. Petrale sole recruit to the commercial fishery beginning at age four but recruitment is not knife-edged and fish are not fully recruited until age 8. Length of 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 effort data series and a lack of age composition data after 1970. The backlog of age composition data is now being processed. Due to PSARC's concern over the long term decline in landings for these stocks, only incidental landings of this species have been permitted since 1991. The stock catch histories and biological data available are used as the basis for this assessment.

Previous catch-age analyses by Ketchen and Forrester (1966) and Pedersen (1975b) indicated that '*there appears to be no need for regulation of the summer fishery and the effects of winter fishing on the spawning concentrations appeared to be overshadowed by environmentally induced variations in the production of recruits*' (Ketchen 1979). More recently 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; thus, environment regulates recruitment for this species. However, in view of the low abundance of these stocks, we continue to recommend that no target fishery be permitted at this time.

1.3.1.2 Landing statistics

Landings for the southern stock decreased slightly to 314 t in 1996 from 353 t in 1995 while landings for the northern stock decreased 67% to 145 t in 1996 from 446 t in 1995, (Tables 4.2-4.3). The time series of landings for this species shows cyclic fluctuations with peaks occurring about once a decade (Figure 4.1). Fluctuations in landings coincide with recruitment cycles for the species (Ketchen and Forrester 1966, Castillo et al. 1994). For both stocks, landings show an overall decline since the start of the fishery. Regulatory measures are partly responsible for the decline in landings from these stocks since 1985. 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 in 1997 there was a coastwide cap of 479 t.

Effort for both stocks has decreased dramatically over the last four years with no target fishery permitted on the spawning stock. Effort for southern stock decreased to 139 h in 1996 from 414 h in 1995 while effort for the northern stock has remained lower than 100h for the 1994-96 period. Catch per unit effort for the southern stock increased to 0.233 t/h in 1996 from 0.120 t/h in 1995 while CPUE for the northern stock increased to 0.271 t/h in 1996 from 0.126 in 1995.

1.3.1.3 Biological data

The age composition of petrale sole females (the number of males sampled was too low to produce meaningful results) sampled from the 1994 fishery (the most recent data available), is presented in Figure 4.2. The maximum age of 35 y is older than any previous age determinations made from otolith surfaces (maximum age =25 y). This is likely due to the use of the burnt otolith cross-section technique employed. Prior to this time otolith surfaces were read. Older fish are under aged by this method (Fargo and Kronlund 1997). The instantaneous total mortality rate, z, was estimated as the slope of the linear regression relationship of ln(numbers) on age. Estimates for z ranged between 0.15 and 0.18 depending on the range of ages used (Table 4.4 and Figure 4.3). Ketchen and Forrester suggested that M for females was around 0.20. At that time they believed that maximum age for the species was between 20 and 25 years. Recent age composition data suggests that M, for these stocks is between 0.15 and 0.2 (Fargo 1995). This analysis suggests that the fishing mortality rate for petrale sole in recent years has been negligible. We caution that these estimates of z are preliminary and require corroboration with age composition time series which can be used to estimate the instantaneous total mortality rate for cohorts. In addition, the small sample size (233 fish) hampers the utility of this type of analysis.

1.3.1.4 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 are accurate the stock should have started to rebuild. However it is too early to tell if the low removals over the last three years will produce a measurable change in stock abundance. Further, evidence suggests that environment mitigates stock abundance. The recent El Nino should produce temperature regime that is favourable for stock production. In any case these stocks remain at a low level. Given, their turnover rate (approximately 20-30 years) any significant change in stock abundance will probably not be discernible for at least a decade.

1.3.1.5. 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 and environment on recruitment. This analysis is still several years away.

Precautionary yield option: Managers should continue to permit incidental landings only for these stocks in 1997, as in 1996.

1.3.2 Area 3CD Dover sole

1.3.2.1 Area 3CD Introduction

In the last assessment for Area 3CD Dover sole, Fargo and Kronlund (1997) noted a significant decline in catch per unit effort (CPUE) in this fishery since it began in the late 1980s. Although this decline was due in part to a regulatory effect it persisted in every index of CPUE estimated regardless of the qualification level. Vessel participation in this fishery has increased threefold since 1988 and the area over which the fishery takes place has expanded from shallower to deeper depths. However there was little evidence that adjusting the CPUE series for differences in the fishery over time would be of benefit. Significant changes in the age structure of the stock have also occurred between 1981 and 1995 but it was difficult to attribute this to the fishery.

The Dover sole is a right-eyed flounder that inhabits the Pacific coast of North America from California to the Bering Sea (Hart 1973). It occupies mud-bottom and feeds primarily on benthic invertebrates. Abundance has been shown to decrease with increasing latitude (Westrheim *et al.* 1992). Significant commercial quantities of this species occur between California and British Columbia. Results of U.S. adult tagging studies indicate that a number of individual stocks exist along the Pacific coast and that there is minimal intermingling of adults among stocks (Westrheim *et al.* 1992). This suggests that 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). Length of 50% sexual maturity, L_{50}, is 37.1 cm (4-5 y) for males and 39.5 cm (8 y) for females. Little north-south movement of adults has been observed, although they do undertake bathymetric migrations from shallow (140-200 m) to deep (400-800 m) water for spawning (Westrheim *et al.* 1992). Adults 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 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 growth rate for this species is relatively slow (von Bertalanffy k=0.12 for males and 0.09 for females (Fargo and Workman 1995) and maximum age is 52 years among (Westrheim 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 within the recommended yield. 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 imposed on the trawl fleet. Commercial catch and effort data and results from research surveys of this resource in 1981 and 1995 provide the basis for assessment of this stock.

1.3.2.3 Area 3CD Commercial catch and effort data

Annual catch and effort statistics for Area 3CD Dover sole are presented in Table 4.5 and Figure 4.4. CPUE and effort for 1996 are not directly comparable to the observations for previous years because the estimates are determined from observations made by at-sea observers while estimates for previous years are determined from logbook information recorded by the vessel captains (Kronlund and Fargo 1997). Landings of Area 3CD Dover sole decreased to 1083 t in 1996 from 1630 t in 1995 while effort decreased to 2318 h in 1996 from 5352 h in 1995. CPUE declined to 0.229 t/h in 1996 from 0.259 t/h in 1995. The bootstrapped 95% confidence intervals of median CPUE estimates (Efron 1989) are large for years prior to 1988 due to the limited fishery (few observations) and narrow considerably after 1990. There was a significant decline in CPUE, partly due to vessel trip limits imposed, between 1992 and 1996.

1.3.2.4. Stock status

The significant expansion of the fishery on this stock over area and depth and the change in the stock age structure indicated in last year's assessment (Fargo and Kronlund 1997) indicate that the stock is probably fully exploited. Unfortunately, no biological samples were obtained from this stock from the 1996 fishery. Analysis of age composition data over time will provide estimates of mortality rates for the stock, critical information for this assessment. The effect of lower removals and lower fishing effort in 1996 cannot be assessed for several years. Landings should be restricted to that level until a more detailed assessment can be undertaken.

1.3.2.5 Recommendations and yield options

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 Introduction

The rock sole (*Pleuronectes 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. Yield is dependent upon recruitment which has been highly variable over time (Fargo 1995). Rock sole recruit to the fishery at age 4 but recruitment is not knife-edged. Length of 50% maturity, L_{50}, is 32.4 cm (5 y) for females and 27.6 cm (4 y) for males. Managers have used a coastwide trip limit as a catch limitation measure for this species. This interim assessment of the Area 5A and 5B stocks is based on analysis of catch-effort data.

The trawl fishery for rock sole in areas 5A and 5B was unregulated prior to 1986. During the period from 1986 to 1992 a 30,000 lb trip limit was imposed followed by a 20,000 lb trip limit in 1993. Various trip limits less than 20,000 lb were used by managers in recent years. Quotas for 1996 were set for each quarter year with a total harvest of 880 t allowed for areas 5A and 5B.

1.4.1.2 Area 5A Landing statistics

Landing statistics for rock sole from the 5A trawl fishery are presented in Fig. 4.5 and Table 4.6. These landings include contributions from the U.S. fishery in this area prior to 1978. The CPUE index for this fishery deteriorated beginning in the 1980s because of the effect of regulations on the fishery since the 1980. For this reason it may not be useful as a measure of stock abundance. Interpretation of the catch-effort data for area 5A rock sole is further complicated by the fact that this stock is a minor component of the Area 5A multispecies trawl fishery. Also, the statistics for 1996 are not directly comparable to those in 1995 due to the mandatory at-sea observer program implemented by managers in 1996. Both landings and fishing effort for this stock decreased significantly in 1996. Landings of rock sole in Area 5A decreased to 87 t in 1996 from 212 t in 1995 while effort decreased to 540 h in 1996 from 939 h in 1995 and CPUE decreased to 0.102 t/h in 1996 from 0.138 t/h in 1995. Although it is difficult to interpret because of changing fishing patterns and regulatory measures a decline in CPUE since 1992 is apparent.

1.4.1.3 Stock status

Age composition data are not available for this stock but analysis of size composition data from port samples in last year's assessment indicate that recruitment has declined in recent years (Fargo and Kronlund 1997). We expect that yield for this stock will decrease over the next several years. However, the level of fishing effort observed in 1996 has probably reduced the risk of overfishing for this stock.

1.4.1.4. Recommendations and Yield Options

There is no change in the yield options recommended for this stock in 1998.

Low risk yield option A yield of 200 t, equivalent to the low-risk yield for lastser 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 a upper limit of the sustainable yield for this stock..

1.4.1.5 Area 5B Landing statistics

Landing statistics for rock sole from the 5B trawl fishery are presented in Fig. 4.6 and Table 4.7. These landings include contributions from the U.S. fishery in this area prior to 1978. The CPUE index for this fishery deteriorated beginning in the 1980s because of the effect of regulations on the fishery since the 1980. For this reason it may not be useful as a measure of stock abundance. 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 Area 5B multispecies trawl fishery. Also, the statistics for 1996 are not directly comparable to those in 1995 because of the mandatory at-sea observer program implemented by managers in 1996. Landings and effort for this stock have decreased steadily since 1991, partly due to lower vessel trip limits applied by managers. Landings in 1996 were 231 t, down from 252 t in 1995. Effort in 1996 was 842 h similar to effort in 1995 while CPUE in 1996 increased to 0.176 t/h in 1996 from 0.150 t/h in 1995. Although it is difficult to interpret because of changing fishing patterns and regulatory measures a decline in CPUE is apparent since the early 1990s.

1.4.1.6 Stock status

Age composition data are not available for this stock but analysis of size composition data from port samples in last year's assessment indicate that recruitment has declined in recent years (Fargo and Kronlund 1997). We therefore expect that yield for this stock will decline in the near future. The impact of the decline in fishing effort on this stock over the last two years should help reduce the risk of overfishing but this effect cannot be properly assessed until more detailed analysis can be performed in light of the loss of the CPUE index. This will not be possible in the near future.

1.4.1.7 Recommendations and yield options

The risk options for 1998 are the same as those recommended in 1997.

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 historic maximum, constitute a greater risk to the area 5B stock.

1.5.1. Rock sole - Hecate Strait

1.5.1.1. Introduction

Stock delineation studies conducted by Ketchen (1982) and Fargo and Westrheim (1987) indicate that there are probably multiple stocks of rock sole in Hecate Strait. However, these stocks are treated as a single unit for this assessment. Past work has suggested that both density-dependent and density-independent factors regulate abundance of this species. Two significant determinants of recruitment for this stock are spawning stock size and ocean temperature at the time of spawning. Low recruitment has been associated with low spawning biomass and warm ocean temperatures (Forrester and Thomson 1969, Fargo and McKinnell 1989). Recruitment for these stocks has fluctuated greatly over time with the last significant increase occurring during the late 1980s and early 1990s. Landing statistics have been updated with data from the 1996 observer program and the age composition data series has been updated with 1996 fishery samples.

Age composition data are available for this stock and analysis of these 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 4.8 and Figure 4.7. Annual catch statistics for the 1945-96 period are calculated directly from data observations. No data records exist prior to 1954 and the index of Forrester and Thomson (1969) was used.

Landings decreased to 670 t in 1996 from 1294 t in 1995 while effort decreased to 2336 h in 1996 from 3538 h. Median CPUE decreased to 0.207 t/h in 1996 from 0.322 t/h in 1995. Since the early 1980s there is little contrast in the commercial CPUE series although stock abundance as determined from catch-age analysis has fluctuated greatly (Fargo and Kronlund 1997). Since 1980 area-specific trip limits have influenced fishing patterns of the fleet and for the most recent years hyperstability is apparent in the CPUE index.

1.5.1.3 Catch-age analysis

The age composition time series for this species was updated with data from the 1996 trawl fishery. Samples collected from Minor Area 4 (Major Area 8) were used for this analysis. This was due to differences among areas in age composition data. Samples from Minor area 4 constitute the longest unbroken time series of rock sole age composition for Hecate Strait. The series covers the period 1945-96 and encompasses a range of fish age between 3 and 21 y (Figure 4.8). 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 due to differences in the ageing technique over time. Otolith surface readings (1945-72) produce underestimates for the ages of older fish compared to otolith burnt cross-sections (1973-96).

The catch-age model of Schnute and Richards (1995) was used for this assessment. The model of Schnute and Richards is essentially similar to 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 $\rho=\sigma_1^2/(\sigma_1^2+\tau_2^2)$ must be specified in the likelihood calculation, analogous to emphasis factors in the stock synthesis model of Methot (1989, 1990). Details of the model are presented in Appendix A.1. The model was run with the instantaneous rate of natural mortality, M, assumed to be constant at 0.20 and ρ fixed at 0.7. These values are the same as those used in last year's assessment (Fargo and Kronlund 1997). Input data included landed catch, proportions at age in the catch, weight at age and CPUE estimates for rock sole (adults) from the Hecate Strait surveys conducted between 1984 and 1996 (Figure 4.9).

The model residuals were examined to assess the fit to the data. There was no trend in the residuals from the model for any year or age group (Figure 4.10). The model fit was poorest (largest residuals) for the 1960 to 1980 period and for the 4-6, age groups. As well, there were negative residuals for the 12+ age group for nearly all 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 in the age proportion data.

Biomass and recruitment trajectories from the model are presented in Figure 4.11. Results indicate that exploitable biomass for this stock increased significantly in the late 1980s, peaked in the early 1990s and is now declining. Recruitment has declined since 1993 (Fargo and Kronlund 1997). The estimate of exploitable biomass in 1996, B_{96}, was 4738t (95% c.i. = 3221t, 6970t) for the 95% confidence interval. This compares to B_{95} of 5963 t (95% c.i. = 3175 t - 8751 t) presented in last year's assessment.

The model estimate of fishing mortality for the stock in 1995 was 0.15, below the level of $F_{0.1}$ and F_{med} (Fargo and Kronlund 1997). $F_{0.1}$ is the fishing mortality rate which generates a marginal increase in yield per recruit of 10% of that from a lightly exploited stock (Gulland and Boerema 1973). This has been determined to be the fishing mortality rate at which marginal yield per recruit was 10% of the slope at F=0.0 (Anthony 1982). For Hecate Strait rock sole this corresponds to F=0.22. Stock-recruit data suggest that this stock has a 50% probability of maintaining its spawning stock biomass (SSB) with a fishing mortality equivalent to 0.21 (F_{med}). This fishing mortality rate was determined from the spawning stock biomass per recruit curve for the stock as the line which bisect the data. The ratio of SSB per recruit determined by this method was then located on an SSB per recruit projection plot for different values of fishing mortality to locate the appropriate value of fishing mortality (Patterson 1992). F_{med} has been suggested by the ICES Comprehensive Fishery Evaluation Working Group as the target fishing mortality rate most consistent with precautionary approach to fisheries suggested by the United Nations (FAO Fisheries Technical Paper 350/1).

1.5.1.4 Stock status

The results of the catch-age analysis indicate a significant increase in stock biomass accompanied by strong recruitment occurred in the late 1980s. By the mid 1990s there declines in recruitment and biomass had occurred. CPUE from research trawl surveys conducted in Hecate Strait has declined since the early 1990s as well. In addition, the El Nino event along the B.C. coast in 1997 will produce unfavourable temperature conditions for rock sole year-class production (Fargo and McKinnell 1989). Thus, yield and recruitment for this stock should continue to decline over the next several years.

1.5.1.5 Recommendations and yield options

The target fishing mortality rate F_{med}, 0.21, was used to estimate sustainable yield for the stock. As a precautionary strategy last year, yield was estimated using the 25th and 50th percentiles of the 95% confidence region for the terminal biomass estimate. Using the estimate B_{96} the corresponding yield range corresponding to the 25th and 50th percentiles of the biomass distribution are 766 t and 897 t, respectively. The yield options for 1998 remain unchanged from last year. The low-risk option may be more appropriate at this time than the high-risk option given the decline in stock biomass.

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 and Kronlund 1997). Both density dependent and density independent factors exert significant influence on recruitment for this stock (Fargo 1994). Spawning stock biomass and Ekman transport during the egg and larval stages influence year-class production 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 both males and females although recruitment is not knife-edged. Length of 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 4-5 years. The series of annual landing statistics has been updated with estimates from the 1996 fishery. The age composition data series has been updated with data from samples collected from the 1996 fishery as well. Age composition data are available for this stock and analysis of these data is the basis for this assessment.

1.5.2.2. Landing statistics

Annual landing statistics are presented in Table 4.9 and Figure 4.12. Statistics for 1954-96 are calculated directly from data observations. No detailed records exist prior to 1954 and the historical catch index of Ketchen has been used (Fargo 1994). English sole landings decreased to 455 t in 1996 from 1190 t in 1995 while effort decreased to 570 h from 2321 h over the same period. CPUE in 1996 decreased slightly to 0.310 t/h from 0.320 t/h in 1995. This stock has been under quota management since the late 1980s and this has influenced the fishing pattern of the fleet. In addition to this a mandatory observer program was initiated by managers for the 1996 trawl fishery and landing statistics for 1996 are not directly comparable to those for 1995.

1.5.2.3. Catch-age analysis

The age composition data series for this stock was updated with age determinations made from samples collected during the 1996 trawl fishery. The data series covers the period 1944-96 and includes fish ranged in age from 3 to 23 years. For the catch-age analysis, the full compliment of years was analysed over an age range of 4 to 12+. Three year olds are not fully recruited while age groups older than 11 were combined because of the bias in age determinations made from otolith surface readings as compared to determinations made from otolith burnt cross-sections (see Section 4.5.1.3).

The catch-age model of Schnute and Richards (1995) was used for this assessment. The model of Schnute and Richards is essentially similar to 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 $\rho=\sigma_1^2/(\sigma_1^2+\tau_2^2)$ must be specified in the likelihood calculation, analogous to emphasis factors in the stock synthesis model of Methot (1989, 1990). The model was run with the instantaneous rate of natural mortality, M, assumed to be constant at 0.20 and ρ fixed at 0.7. These values are the same as those used in last year's assessment (Fargo and Kronlund 1997). Details of the model are presented in Appendix A.1.

Input data for the model included landed catch, proportions at age in the catch (Figure 4.13) weight at age and CPUE estimates for English sole from the Hecate Strait research trawl surveys conducted between 1984 and 1996 (Figure 4.14). For last year's assessment the catch-age model was tuned with the commercial CPUE series rather than the survey CPUE series. 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 (see Section 4.5.2.2).

Model residuals were examined for indications of problems with the model fit (Figure 4.15). There was a negative trend in residuals for the early years (1944 to 1952) with respect to age while no such trend was present for the later years (1958-96). The residuals showed no trend with respect to time for any of the age groups analysed. The model fit was poorest for the younger age groups in the early years and for the older age groups in the later years.

Biomass and recruitment trajectories from the model are presented in Figure 4.16. The estimate of exploitable biomass in 1995, B_{95}, from last year's assessment was 3177 t (95% c.i. = 2766t-3588t). The estimate of B_{96}, was 3071 t (95% c.i. = 2590 t - 3641 t). Exploitable biomass for this stock has declined since 1993 while the level of recruitment has declined since 1991.

The catch-age model estimate of fishing mortality for the stock in 1996 was 0.16, below the level of $F_{0.1}$ (F=0.17) and F_{med} (F=0.19), (see Section 4.5.1.3 for an explanation of these fishing rates). F_{med} has been suggested by the ICES Comprehensive

Fishery Evaluation Working Group as the target fishing mortality rate most consistent with the UN precautionary approach to fisheries (FAO Fisheries Technical Paper 350/1)

1.5.2.4 Stock status

The estimate of fishing mortality, F, for the stock in 1996 from the new catch-age analysis was 0.16, significantly lower than the estimate of 0.37 for 1995 when over 1000t were removed associated with a high level of effort (F=0.37). The estimate, B_{96} , 3071 t (95% c.i. = 2590t-3641t) was used to estimate yield. F_{med} (F=0.19) was the target fishing mortality rate that was used to estimate yield. This fishing rate was applied to the 25th and 50th percentiles of the confidence region for B_{96} to produce a yield range of 496 t-591 t. This range is similar to that in last year's assessment and the yield options for 1998 remain unchanged from those for 1997.

1.5.2.5. 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

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. Length of 50% maturity, L_{50}, is 37.1 cm (5-6 y) for males and 39.5 cm (6-7 y) for females. 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 in 1995 and 1996.

1.5.3.2 Area 5CDE Landing statistics

Landing statistics for Dover sole from the Area 5C-E trawl fishery for 1970-96 are presented in Table 4.10 and Figure 4.17. Landings decreased to 1133 t in 1996 from 1587 t in 1995 while effort decreased to 2245 h in 1996 from 4220 h in 1995 and CPUE decreased to 0.308 t/h in 1996 from 0.320 t/h in 1995. Landings for 1993 to 1995 were the highest recorded for this fishery. The CPUE series exhibits the characteristic high variability 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 and Kronlund 1997). The CPUE estimate for 1996 is the lowest in the time series. Unlike in previous assessments Dover sole are the main target of the trawl fishery in these areas and vessel trip limits have never been applied. The fishery has been subjected to quota management since 1979. The CPUE and effort data from this fishery were analysed for this assessment.

1.5.3.3. Surplus production analysis

A dynamic surplus production model based on the Gompertz growth model (Yoshimoto and Clarke 1992) was employed to estimate maximum sustainable yield, MSY, and optimum effort, E_{opt}, for the stock. The details of the model are presented in Appendix A.2. Input data for the model included median CPUE and fishing effort series for the period 1970-96. Results from this analysis indicated a maximum sustainable harvest of 1048 t for this stock at the present time. The optimum effort level corresponding to MSY was 2288 h very close to the level of effort in 1996.

1.5.3.4. Biological data

Age composition for females from samples collected from the 1996 commercial fishery is presented in Figure 4.18. The instantaneous rate of total mortality, Z, was estimated as the slope in the regression of the ln(numbers) on age ranged from 0.15 to 0.27 (Figure 4.19, Table 4.11). The instantaneous rate of natural mortality for this stock is estimated to be between 0.10 and 0.15 (Fargo and Westrheim 1985). Using the midpoint of the range of total mortality (Z=0.22) and natural mortality (M=0.12) the fishing mortality rate for this stock in 1996 would be F=0.10, slightly lower than the natural mortality rate for the stock. Thus, the stock is close to being fully exploited at the present time. The estimates of Z from this analysis must be considered preliminary at this time. A time series of age composition data is necessary to estimate the total mortality rate of recent cohorts and corroborate preliminary results of the analysis presented here.

1.5.3.5 Area 5CDE Recommendations and yield options

The high-risk yield option was exceeded by 18 to 32 percent during 1993 to 1995. The decline in CPUE since that time suggests that yields above 1200 t increase the risk of overfishing.

Low risk yield option: A yield of 800 t, equivalent to the MSY estimated using surplus production analysis.

High risk yield option: A yield of 1200 t is suggested as an upper limit for yield for the area 5CDE Dover sole stock.

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Table 4.1. Yield options for British Columbia flatfish species/stocks 1997-98

		1997		1998	
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	1100 t	800 t	1100 t
English sole	Area 5C-D	500 t	600 t	500 t	600 t

Table 4.2. Canada-U.S. landings (t) of petrale sole from southwest Vancouver Island, Area 3C, 1945-96.

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

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

Table 4.3. Canada-U.S. landings (t) of petrale sole from Areas 3D, 5A-D, 1944-95.

Year	Area 3D	Areas 5A-B	Areas 5C-D	Total Canadian	Total	Year	Area 3D	Areas 5A-B	Areas 5C-D	Total	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

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

Table 4.4 Estimates of the instantaneous total mortality rate, Z, for west coast Vancouver Island petrale sole.

Age range	Z	r^2
6 - 17	0.15	0.54
6 - 20	0.17	0.65
6 - 26	0.18	0.75
6 - 35	0.17	0.79
7 - 35	0.17	0.78
8 - 35	0.18	0.77

Table 4.5 Annual landing statistics for the Area 3CD Dover sole trawl fishery, 1980-96.

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

Table 4.6. Canada-U.S. landings statistics for rock sole in Area 5A, 1954-96.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	CPUE (t/h)[c]
54	52	175	0.141	0.216
55	119	274	0.208	0.287
56	551	1441	0.230	0.241
57	511	1633	0.176	0.219
58	501	2204	0.160	0.181
59	212	834	0.124	0.162
60	397	1588	0.159	0.148
61	237	757	0.159	0.212
62	196	910	0.099	0.120
63	161	456	0.118	0.170
64	156	346	0.137	0.195
65	157	350	0.152	0.203
66	330	651	0.243	0.283
67	252	822	0.174	0.233
68	435	1224	0.196	0.233
69	293	1230	0.111	0.115
70	167	566	0.140	0.159
71	135	392	0.165	0.162
72	58	117	0.119	0.168
73	57	68	0.245	0.352
74	74	50	0.206	0.351
75	37	191	0.071	0.111
76	182	466	0.107	0.185
77	83	197	0.124	0.209
78	79	230	0.101	0.134
79	202	526	0.166	0.216
80	238	810	0.143	0.206
81	114	404	0.125	0.181
82	189	548	0.176	0.261
83	124	195	0.152	0.266
84	142	348	0.133	0.217
85	56	115	0.121	0.156
86	23	12	0.065	0.112
87	80	74	0.171	0.249
88	128	330	0.118	0.180
89	143	425	0.112	0.164
90	190	554	0.129	0.134
91	200	608	0.127	0.159
92	290	731	0.158	0.231
93	462	1864	0.135	0.199
94	311	1399	0.108	0.150
95	212	939	0.104	0.138
96	87	540	0.102	0.102

[a] Annual effort for 25% qualified landings.
[b] Adjusted for changes in vessel horsepower over time
[c] Median CPUE for 25% qualified landings

Table 4.7. Canada-U.S. landing statistics for rock sole in Area 5B, 1954-96.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	CPUE (t/h)[c]
54	203	133	0.518	0.295
55	267	259	0.280	0.247
56	307	614	0.294	0.270
57	206	531	0.249	0.302
58	379	1338	0.186	0.206
59	344	945	0.253	0.213
60	503	1444	0.227	0.203
61	416	1167	0.180	0.189
62	531	1345	0.222	0.227
63	517	947	0.233	0.225
64	482	559	0.186	0.193
65	568	729	0.216	0.226
66	772	794	0.261	0.253
67	741	423	0.324	0.280
68	392	492	0.244	0.246
69	652	1028	0.192	0.211
70	245	319	0.195	0.192
71	368	790	0.186	0.203
72	382	518	0.244	0.189
73	324	245	0.223	0.238
74	371	165	0.165	0.232
75	408	497	0.209	0.276
76	368	879	0.199	0.218
77	188	351	0.179	0.182
78	217	279	0.327	0.265
79	208	425	0.165	0.209
80	410	846	0.322	0.263
81	220	570	0.193	0.211
82	155	314	0.262	0.287
83	206	447	0.268	0.245
84	87	116	0.171	0.238
85	170	358	0.177	0.269
86	135	178	0.144	0.171
87	205	165	0.325	0.295
88	272	302	0.261	0.329
89	260	520	0.186	0.269
90	419	843	0.195	0.217
91	437	922	0.235	0.284
92	416	1203	0.164	0.227
93	343	1155	0.152	0.224
94	323	1023	0.168	0.215
95	252	848	0.142	0.150
96	231	842	0.176	0.176

[a] Annual effort for 25% qualified landings.
[b] Adjusted for changes in vessel horsepower over time
[c] Median CPUE for 25% qualified landings

Table 4.8. Canada-U.S. landing statistics for Hecate Strait rock sole, 1945-96.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	CPUE (t/h)[c]
45	121	434	0.279	0.279
46	410	2228	0.184	0.184
47	1181	1946	0.607	0.607
48	901	1753	0.514	0.514
49	657	1352	0.486	0.486
50	784	1452	0.540	0.540
51	1024	944	1.085	1.085
52	2292	2014	1.138	1.138
53	779	1227	0.635	0.635
54	926	840	0.889	0.938
55	1560	1558	0.640	0.680
56	1160	1484	0.548	0.644
57	1151	2019	0.392	0.443
58	1256	1331	0.775	0.650
59	416	636	0.499	0.403
60	1127	1100	0.852	0.680
61	744	694	1.104	0.900
62	829	849	0.702	0.735
63	881	735	0.685	0.737
64	743	835	0.507	0.531
65	879	629	0.994	0.545
66	2544	2491	0.691	0.598
67	2162	2324	0.734	0.511
68	2366	4209	0.370	0.386
69	1461	4485	0.417	0.314
70	1403	3660	0.256	0.326
71	1503	3587	0.264	0.255
72	515	650	0.334	0.337
73	507	619	0.334	0.435
74	622	603	0.312	0.475
75	1204	1912	0.301	0.360
76	1438	1830	0.449	0.402
77	846	1896	0.237	0.285
78	874	1662	0.297	0.336
79	1313	1943	0.333	0.330
80	977	2420	0.166	0.254
81	584	806	0.228	0.287
82	291	841	0.174	0.209
83	247	499	0.194	0.286
84	188	573	0.127	0.188
85	112	276	0.201	0.242
86	219	470	0.219	0.345
87	536	577	0.262	0.389
88	1402	2520	0.322	0.41
89	1422	3757	0.228	0.288
90	1519	3948	0.239	0.319
91	2666	6552	0.224	0.295
92	2226	5777	0.241	0.289
93	2080	5851	0.224	0.301
94	1384	4282	0.201	0.275
95	1294	3538	0.234	0.322
96	670	2336	0.207	0.207

[a] Annual effort for 25% qualified landings.
[b] Adjusted for changes in vessel horsepower over time
[c] Median CPUE for 25% qualified landings

Table 4.9. Canada-U.S. landing statistics for Hecate Strait English sole, 1944-96.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	CPUE (t/h)[c]
44	152	215	0.707	0.707
45	304	365	0.832	0.832
46	470	809	0.581	0.581
47	350	538	0.651	0.651
48	937	2740	0.342	0.342
49	795	1893	0.420	0.420
50	2622	4910	0.534	0.534
51	1024	2142	0.478	0.478
52	1347	3293	0.409	0.409
53	871	2084	0.418	0.418
54	455	563	0.245	0.362
55	875	744	0.332	0.401
56	956	1344	0.308	0.349
57	552	640	0.180	0.244
58	693	617	0.251	0.337
59	940	772	0.279	0.315
60	1147	1058	0.307	0.333
61	871	1615	0.230	0.298
62	459	903	0.212	0.247
63	408	568	0.154	0.207
64	436	441	0.243	0.272
65	414	326	0.198	0.317
66	362	354	0.190	0.302
67	534	535	0.373	0.411
68	671	844	0.285	0.302
69	819	1314	0.276	0.390
70	1002	2042	0.262	0.312
71	488	1585	0.168	0.192
72	371	550	0.197	0.230
73	667	514	0.294	0.411
74	500	519	0.372	0.519
75	938	1015	0.383	0.466
76	1133	1627	0.234	0.275
77	1179	2201	0.200	0.310
78	559	944	0.161	0.246
79	864	980	0.237	0.337
80	995	1105	0.220	0.327
81	1327	2149	0.204	0.249
82	428	1062	0.155	0.219
83	430	834	0.163	0.240
84	658	1129	0.221	0.290
85	585	1520	0.166	0.226
86	335	469	0.244	0.365
87	630	396	0.336	0.347
88	688	540	0.324	0.493
89	826	925	0.294	0.385
90	992	1335	0.224	0.383
91	913	940	0.208	0.308
92	987	1602	0.239	0.307
93	1421	2636	0.191	0.295
94	1000	1860	0.200	0.343
95	1190	2321	0.219	0.320
96	455	570	0.310	0.310

[a] Annual effort for 25% qualified landings.
[b] Adjusted for changes in vessel horsepower over time
[c] Median CPUE for 25% qualified landings

Table 4.10. Canada-U.S. landing statistics for Dover sole, Areas 5C-E, 1970-96.

Year	Landings (t)	Effort (h)[a]	CPUE (t/h)[b]	CPUE (t/h)[c]
70	965		0.432	0.590
71	903	1367	0.380	0.556
72	922	1495	0.331	0.543
73	768	910	0.481	0.679
74	767	878	0.531	0.687
75	882	1135	0.339	0.573
76	1022	1465	0.297	0.440
77	577	900	0.217	0.319
78	483	650	0.252	0.497
79	697	1057	0.193	0.333
80	807	724	0.237	0.416
81	840	1079	0.275	0.428
82	512	894	0.242	0.433
83	693	544	0.284	0.568
84	953	1526	0.265	0.448
85	830	1039	0.258	0.485
86	1040	931	0.313	0.562
87	503	432	0.426	0.549
88	649	652	0.360	0.594
89	696	775	0.407	0.567
90	787	1181	0.279	0.542
91	649	1041	0.250	0.428
92	883	1444	0.206	0.381
93	1508	2767	0.225	0.414
94	1418	3117	0.243	0.371
95	1587	4220	0.199	0.320
96	1133	2245	0.308	0.308

[a] Annual effort for 25% qualified landings.
[b] Adjusted for changes in vessel horsepower over time
[c] Median CPUE for 25% qualified landings

Table 4.11 Estimates of the instantaneous total mortality rate, Z, for Area 5C-E Dover sole.

Age range	Z	r^2
8 - 17	0.27	0.89
8 - 22	0.22	0.87
8 - 27	0.22	0.89
8 - 46	0.15	0.81
9 - 17	0.16	0.69
10 - 17	0.25	0.82

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 in 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_l 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 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 recruitment variance and 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. The asymmetric confidence intervals illustrated in the figures were obtained by back transformation.

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 4.1. 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 biomass at the start of year t
u_{at}	exploitable proportion of age-class a fish in year t catch

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

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 were:

$$r = 2(1-c2)/(1+c2)$$
$$q = -c3(2+r)$$
$$K = (1/q)\exp(c1(2+r)/2r)$$

Optimum effort, E_{opt}, was estimated as the slope in the regression:

$$U = a - E_{opt}E$$

Maximum sustainable yield, MSY, was estimated as:

$$MSY = qkE_{opt}(\exp((-qE_{opt})/r))$$

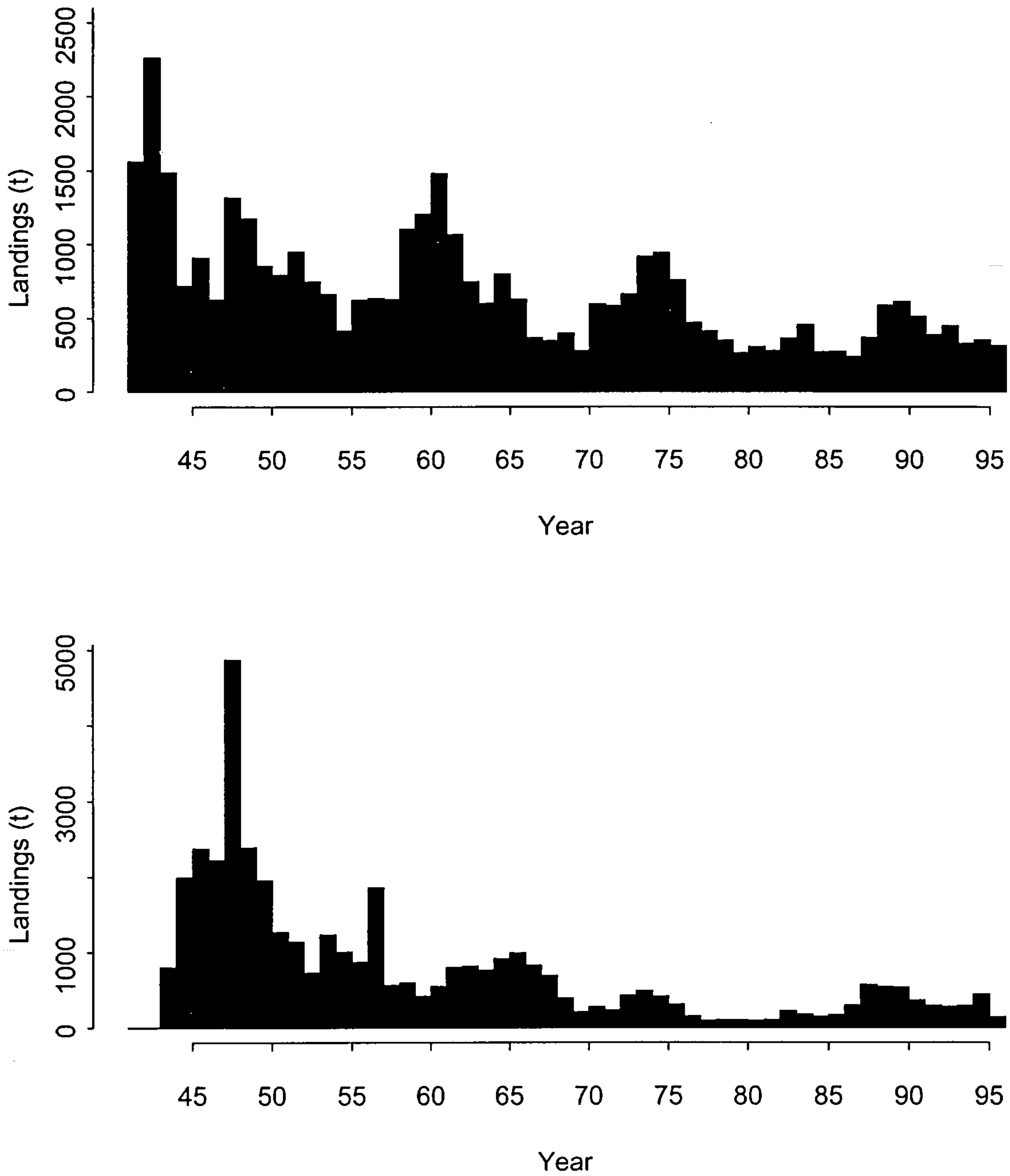

Figure 4.1. Landings (t) from the 'southern' stock of petrale sole (top panel) in British Columbia, 1942-96 and from the 'northern' stock of petrale sole (bottom panel) in British Columbia, 1944-96.

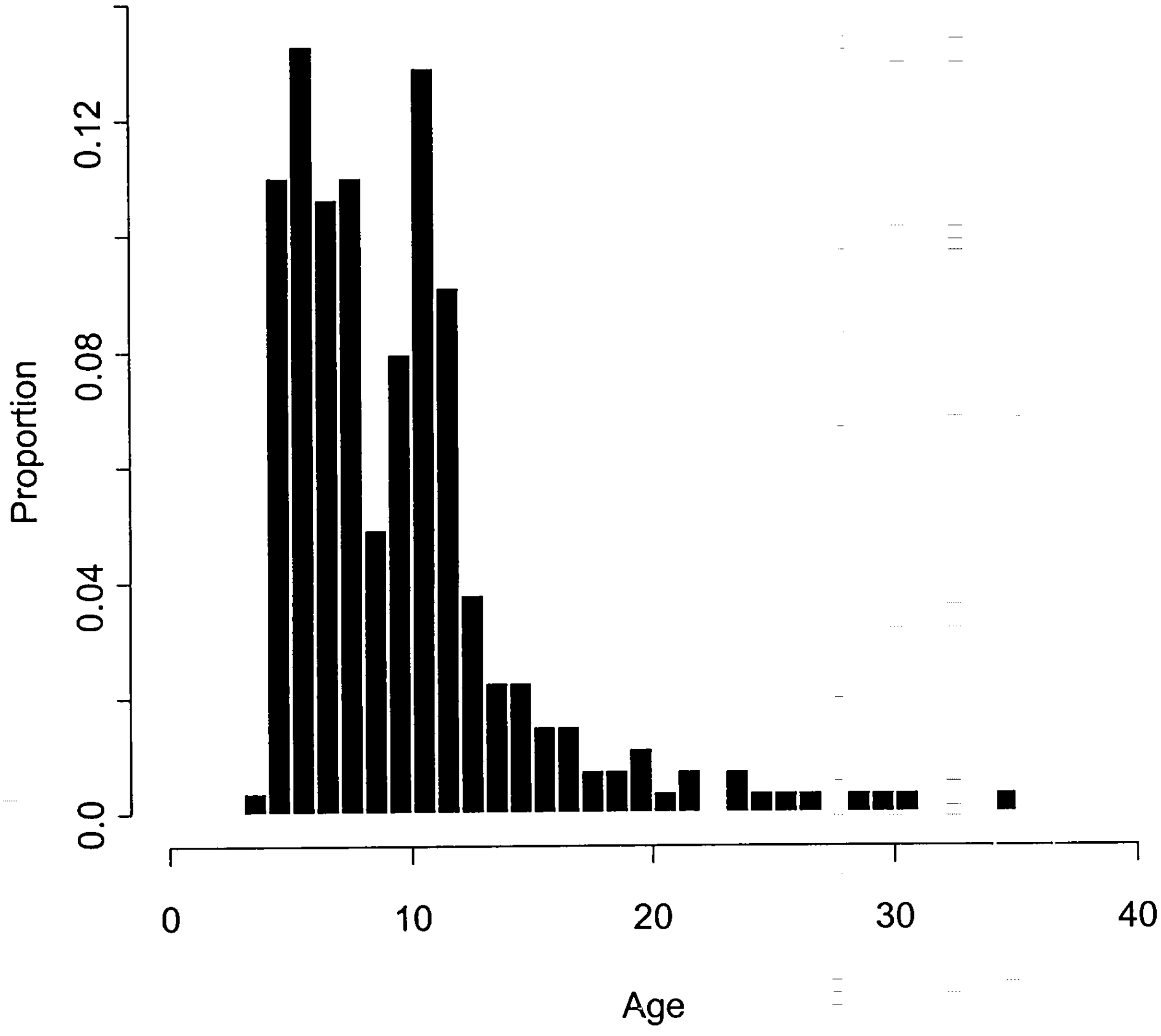

Figure 4.2. Age composition of petrale sole caught in the 1993-94 trawl fishery in British Columbia.

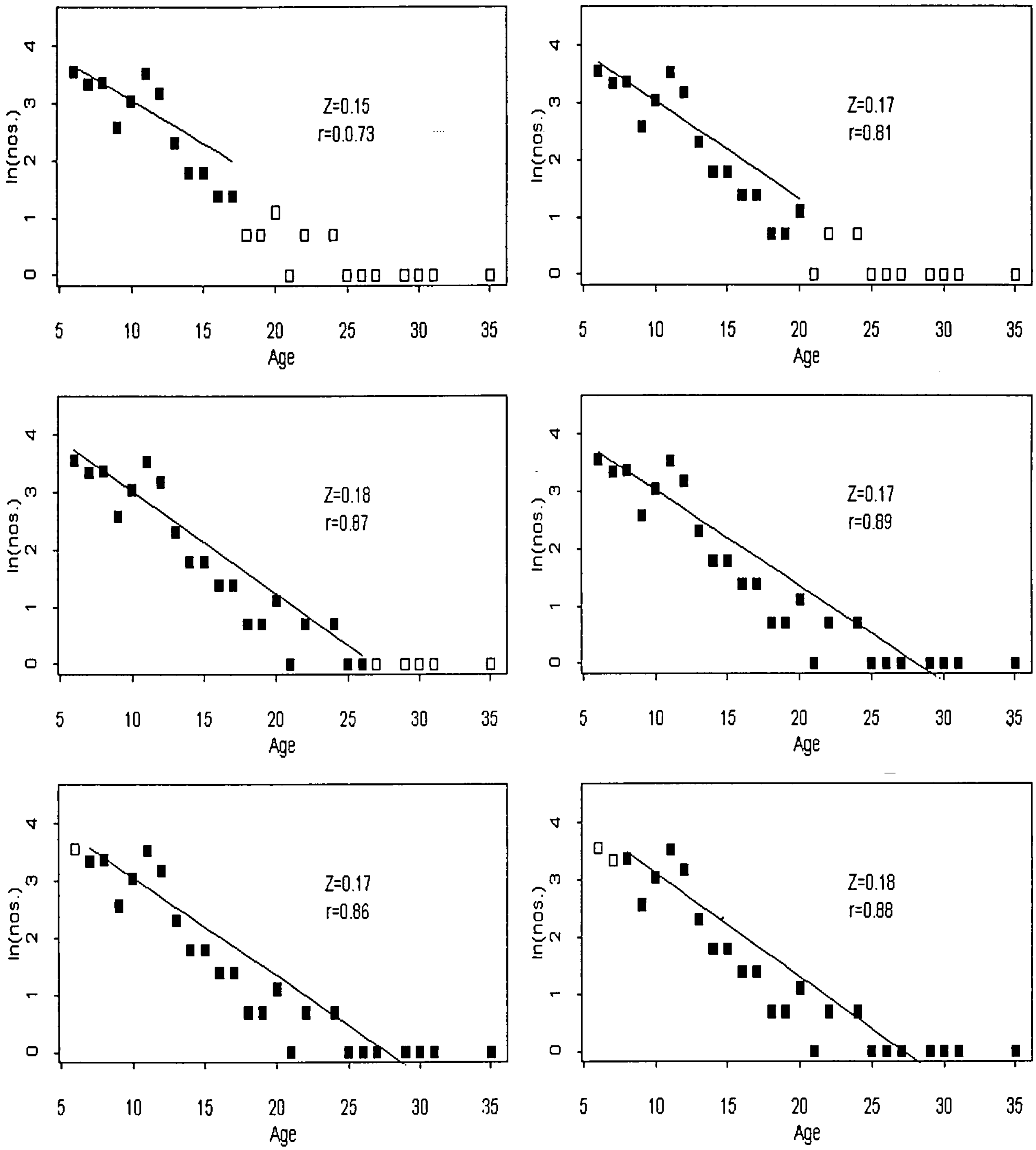

Figure 4.3 Estimates of the instantaneous total mortality rate for west coast Vancouver Island Petrale sole. The filled squares indicate data used to fit the regression.

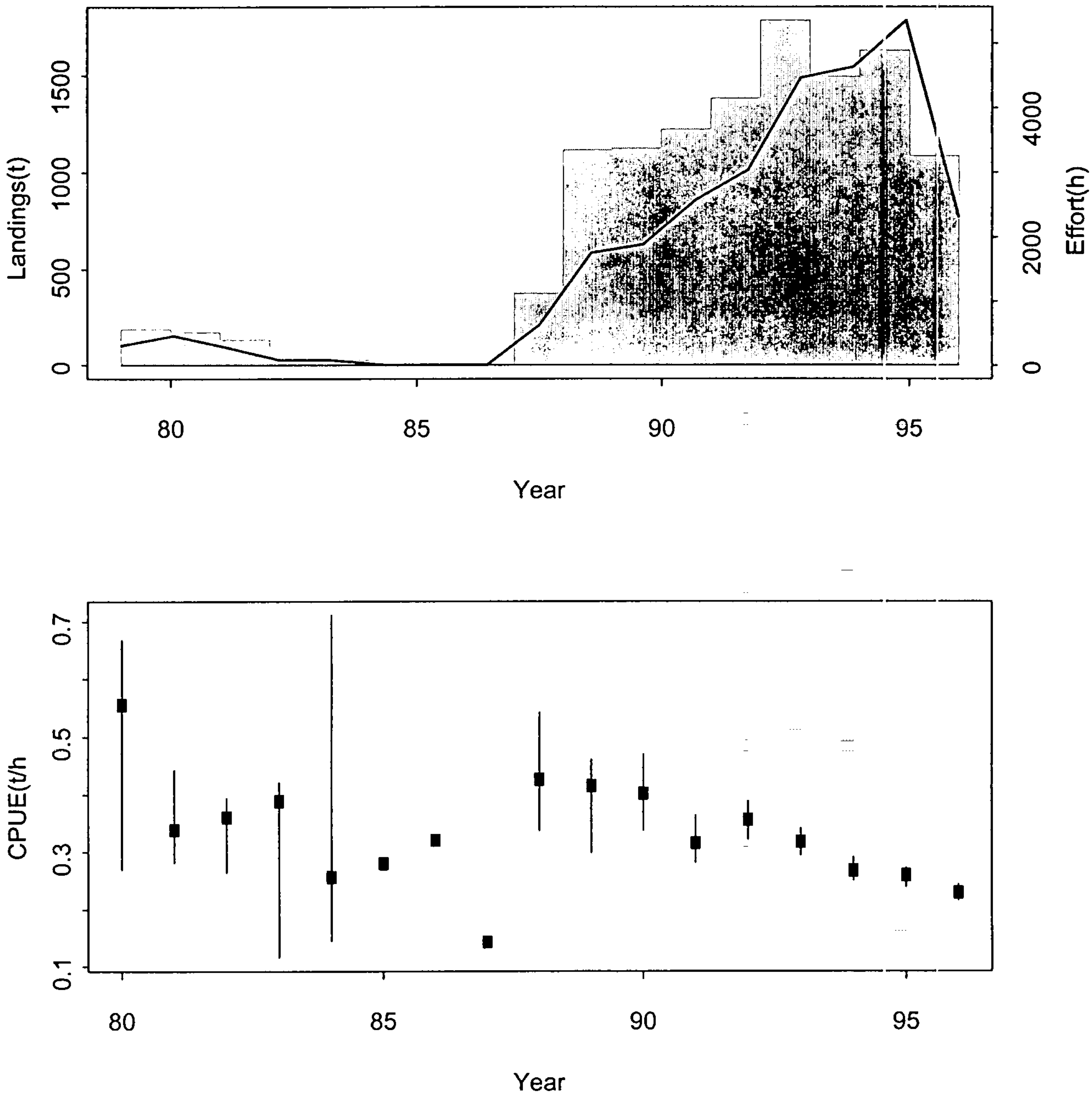

Figure 4.4. Landing statistics for Dover sole in Areas 3C-D, 1980,96. Top panel – bars = landings, line = effort (h). Bottom panel – Median CPUE and 95 % confidence interval.

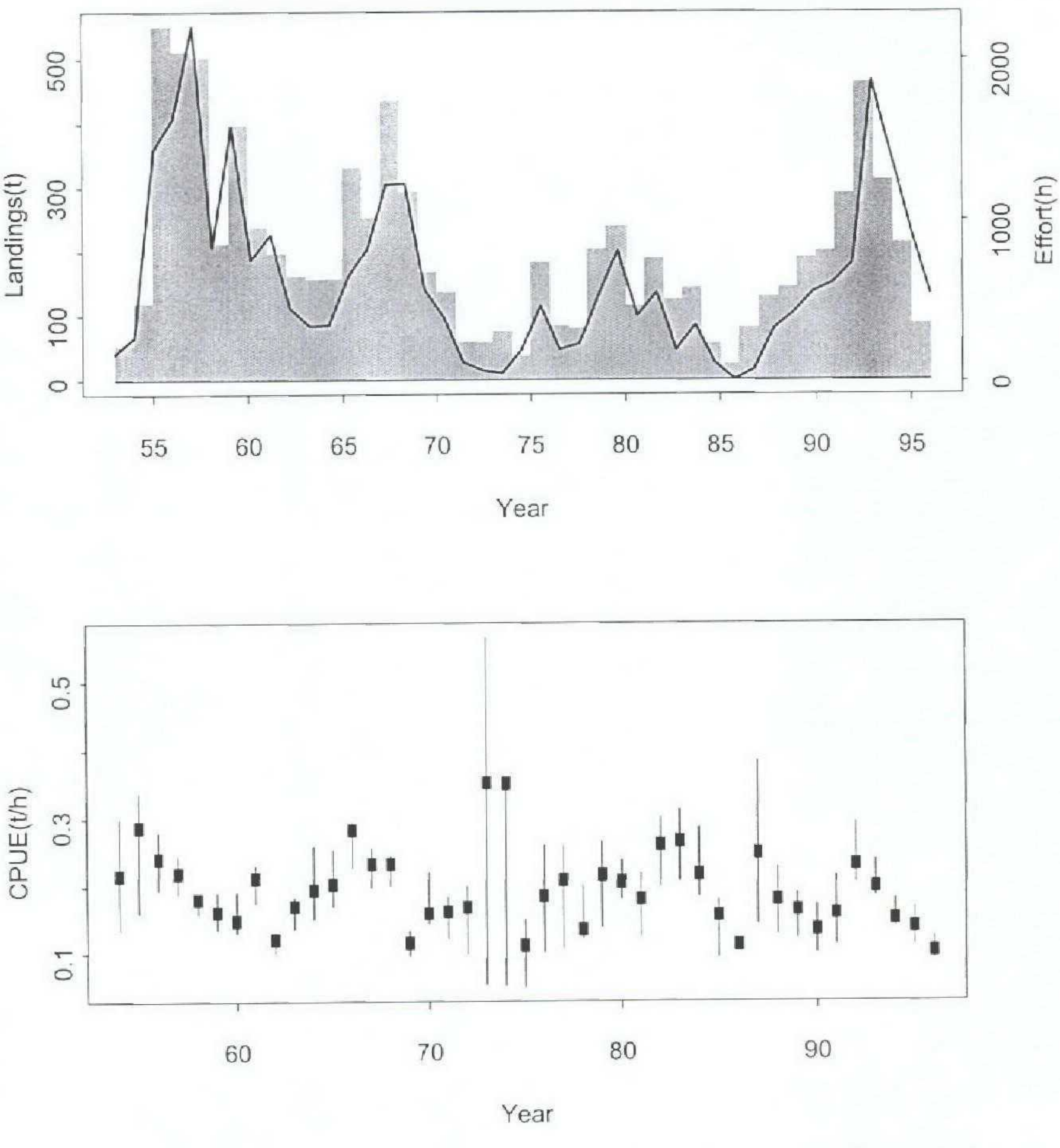

Figure 4.5. Canada-U.S. landing statistics for rock sole in Area 5A. top panel - bars = landings, line = effort. Bottom panel – Median CPUE and 95 % confidence interval.

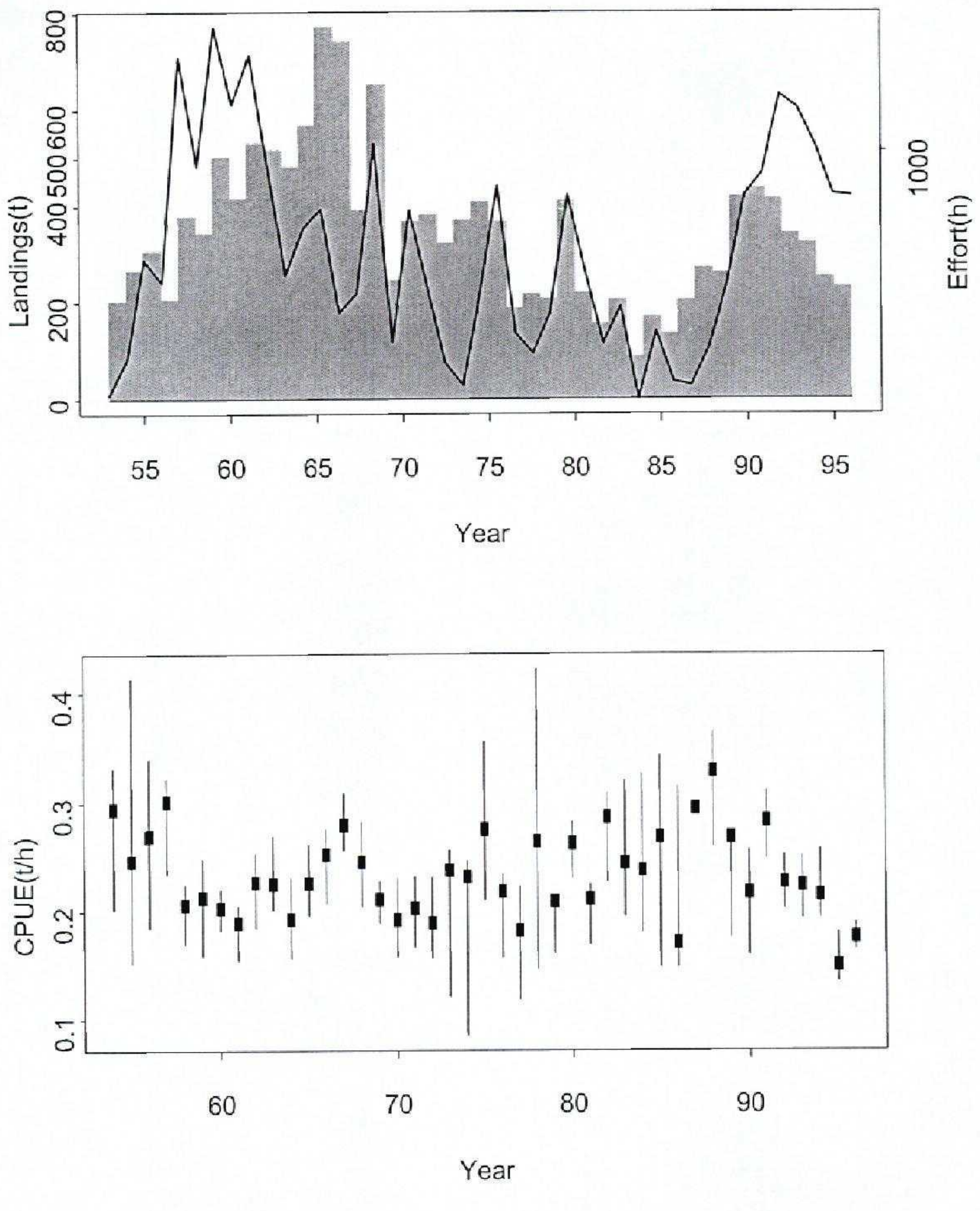

Figure 4.6. Canada-U.S. landing statistics for rock sole in Area 5B. top panel - bars = landings, line = effort. Bottom panel - Median CPUE and 95 % confidence interval.

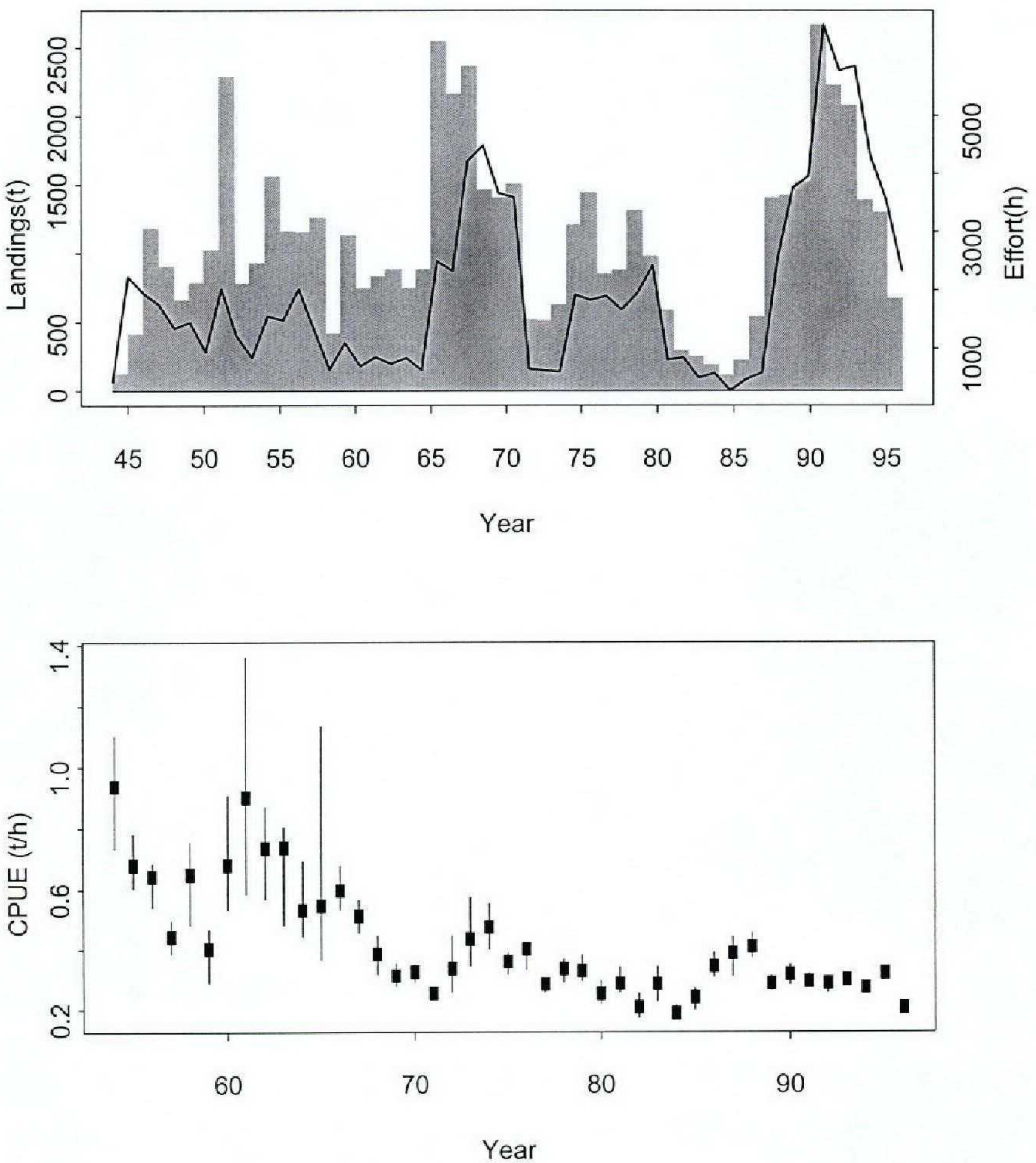

Figure 4.7. Canada-U.S. landing statistics for rock sole in Hecate Strait. Top panel - bars = landings, line = effort. Bottom panel – Median CPUE and 95 % confidence interval.

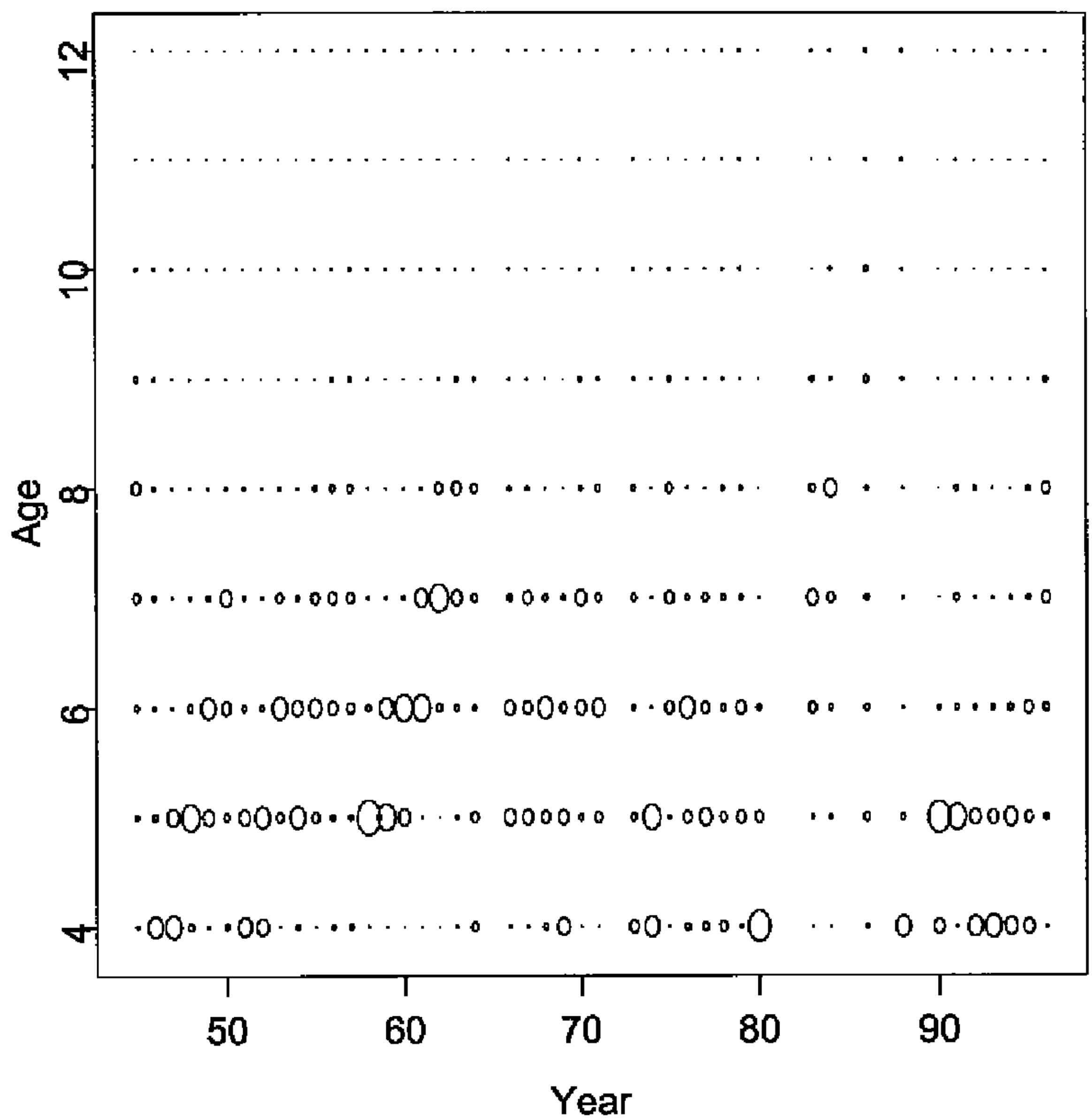

Figure 4.8. Input data for the catch-age analysis of Hecate Strait rock sole, 1945-96. The circle radii are proportional to values for individual age proportions.

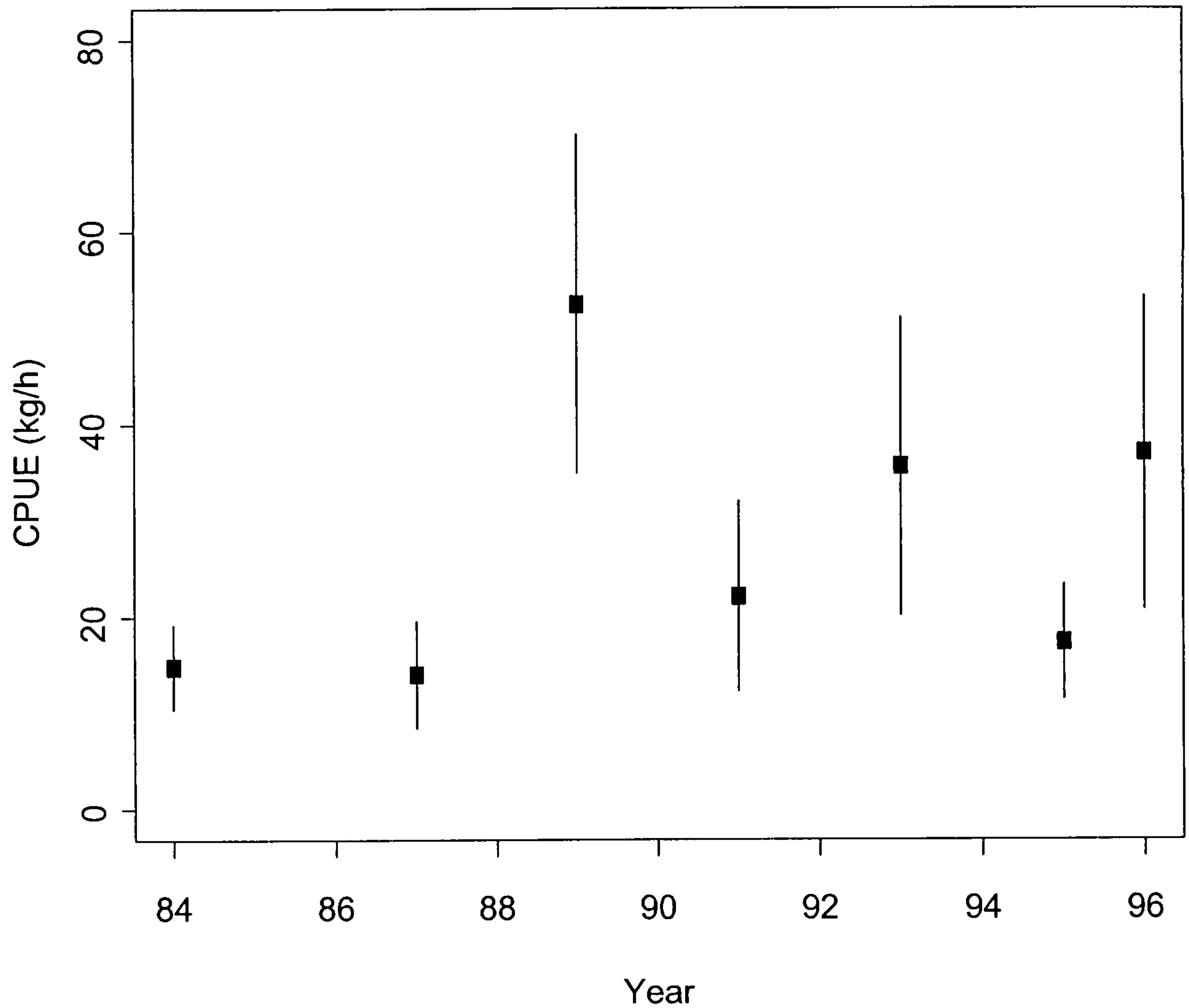

Figure 4.9. Rock sole CPUE from research surveys conducted in Hecate Strait between 1984 and 1996.

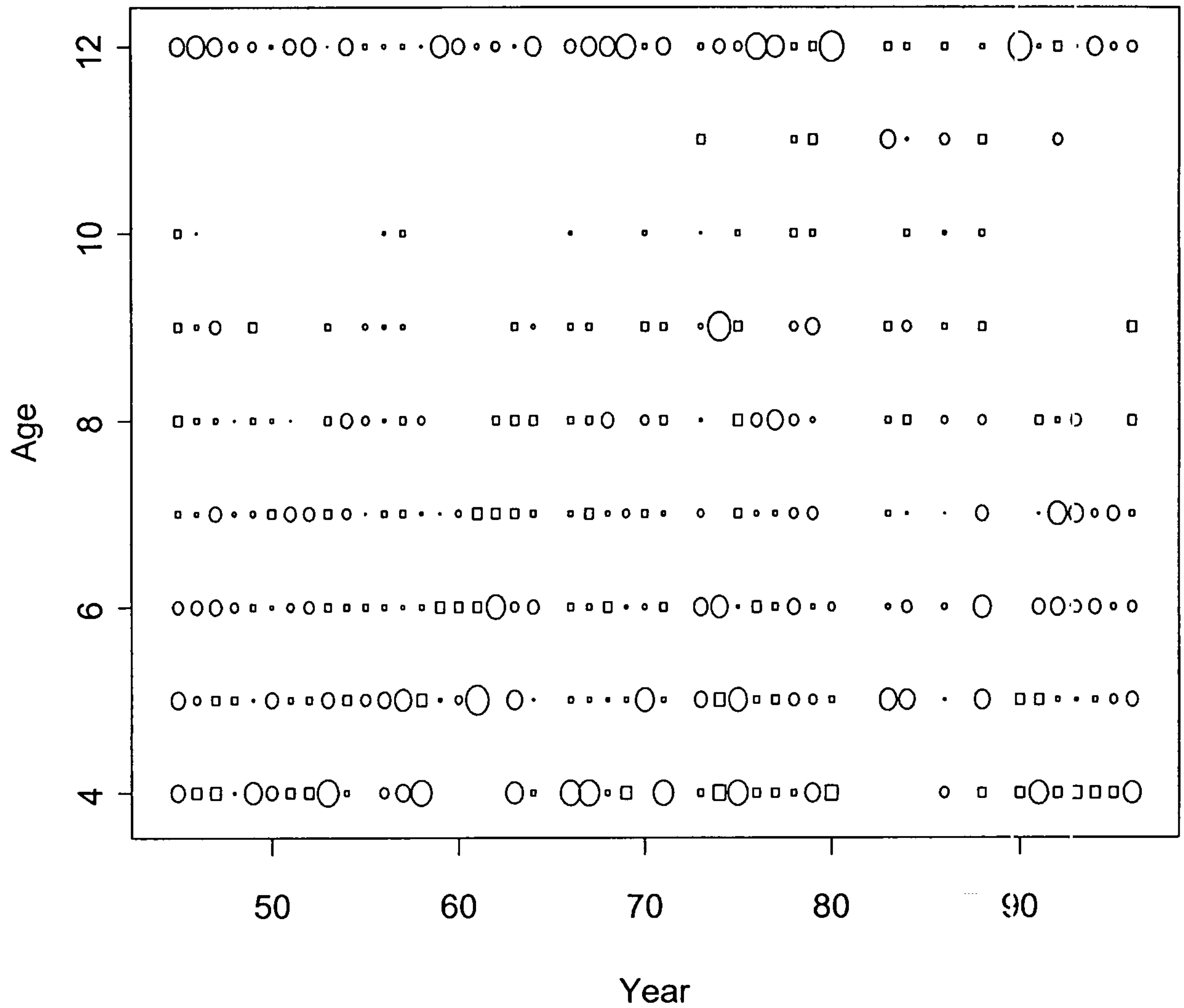

Figure 4.10. Symbol plot of residuals for the age proportion data for the catch-age analysis of Hecate Strait rock sole by year. Circles represent negative residuals while squares represent positive residuals. Circle radii are scaled to the maximum negative residual while the area of each square is scaled to the maximum positive residual. A blank space represents a small age proportion that is grouped with the next older age. Residuals are defined in Appendix Table A.1.

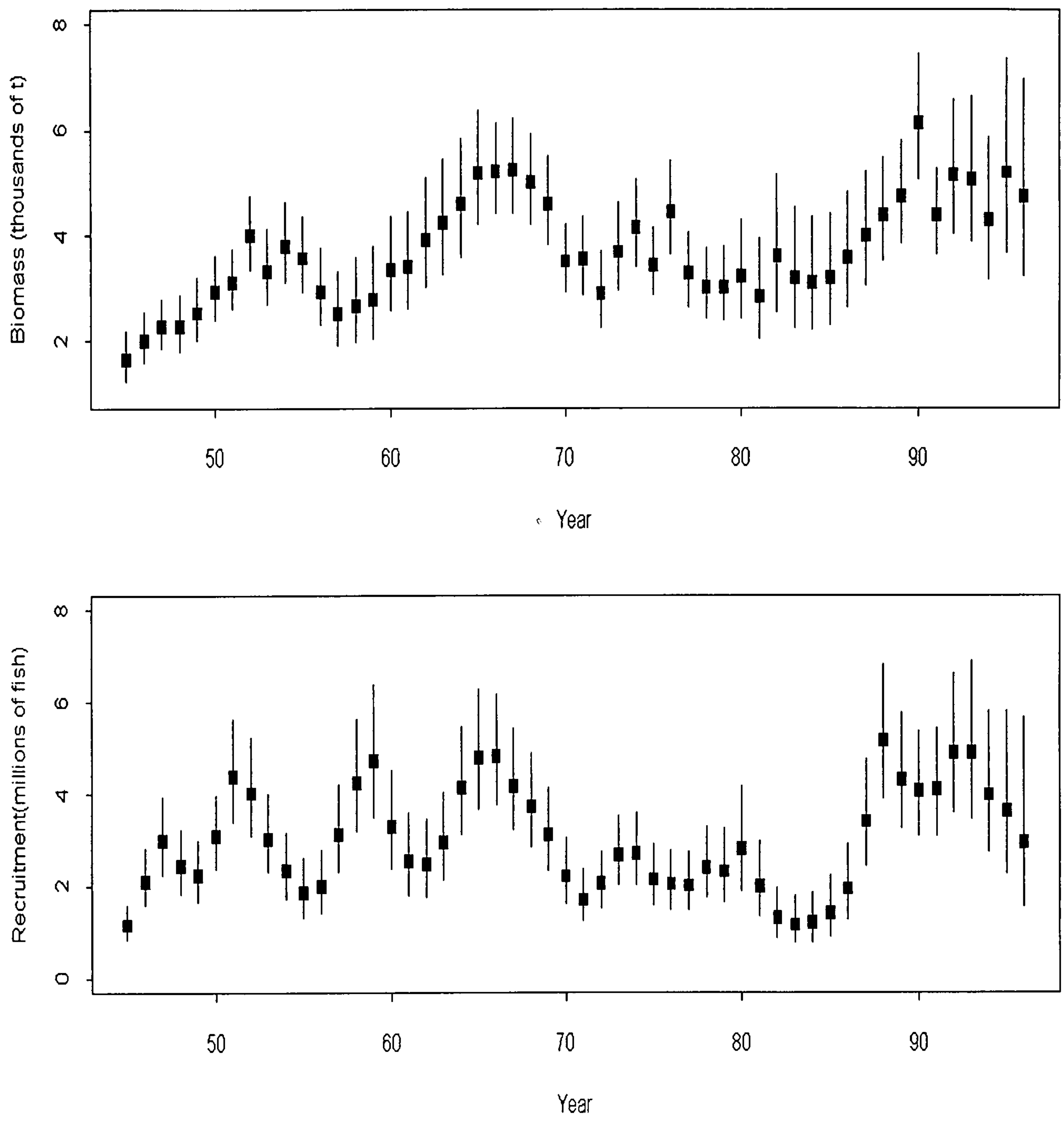

Figure 4.11. Biomass and Recruitment trajectories and 95 % confidence interval from the catch-age model results for Hecate Strait rock sole, 1945-96.

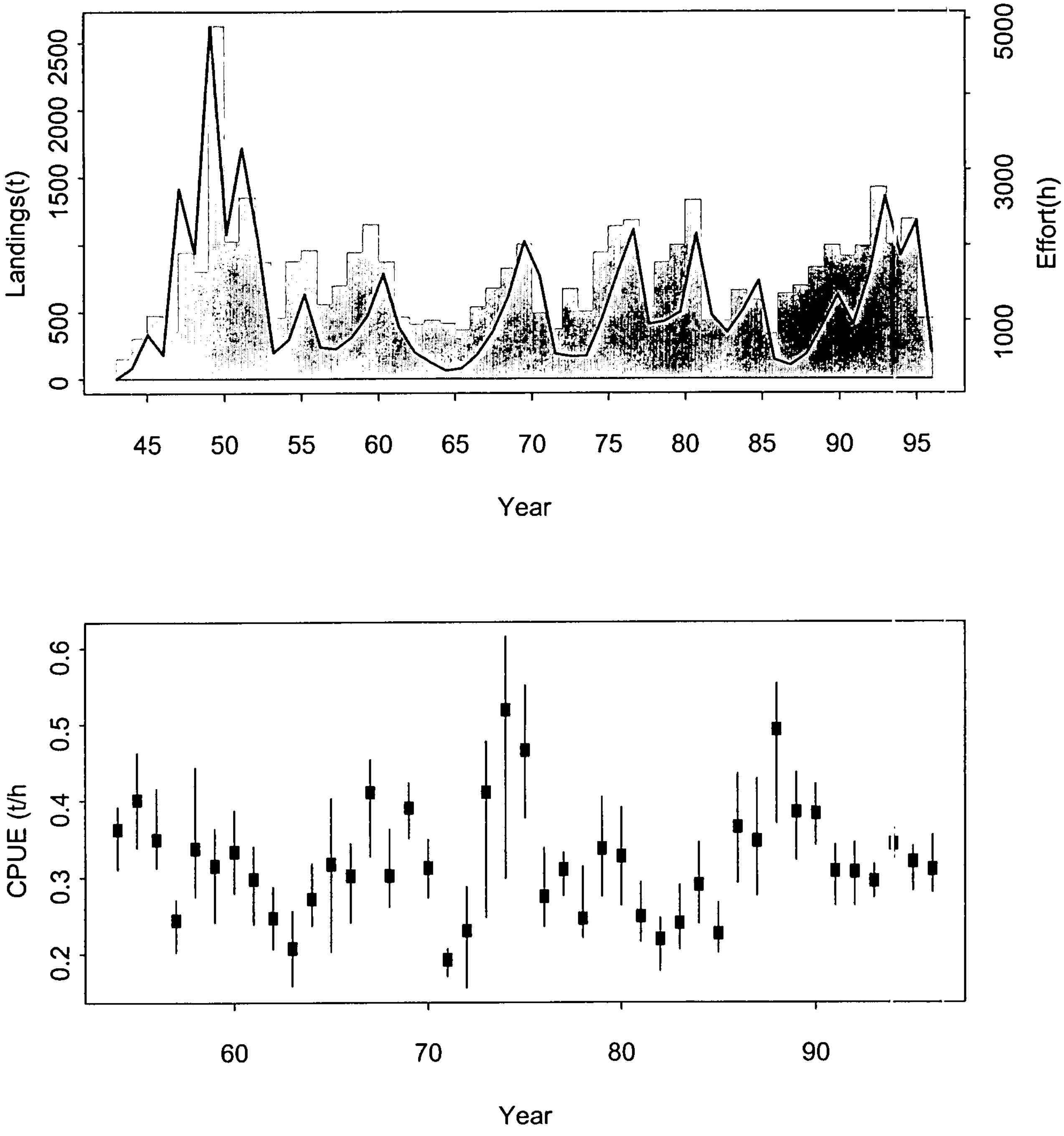

Figure 4.12. Canada-U.S. landing statistics for English sole in Hecate Strait. Top panel – bars = landings, line = effort. Bottom panel – Median CPUE and 95 % confidence interval.

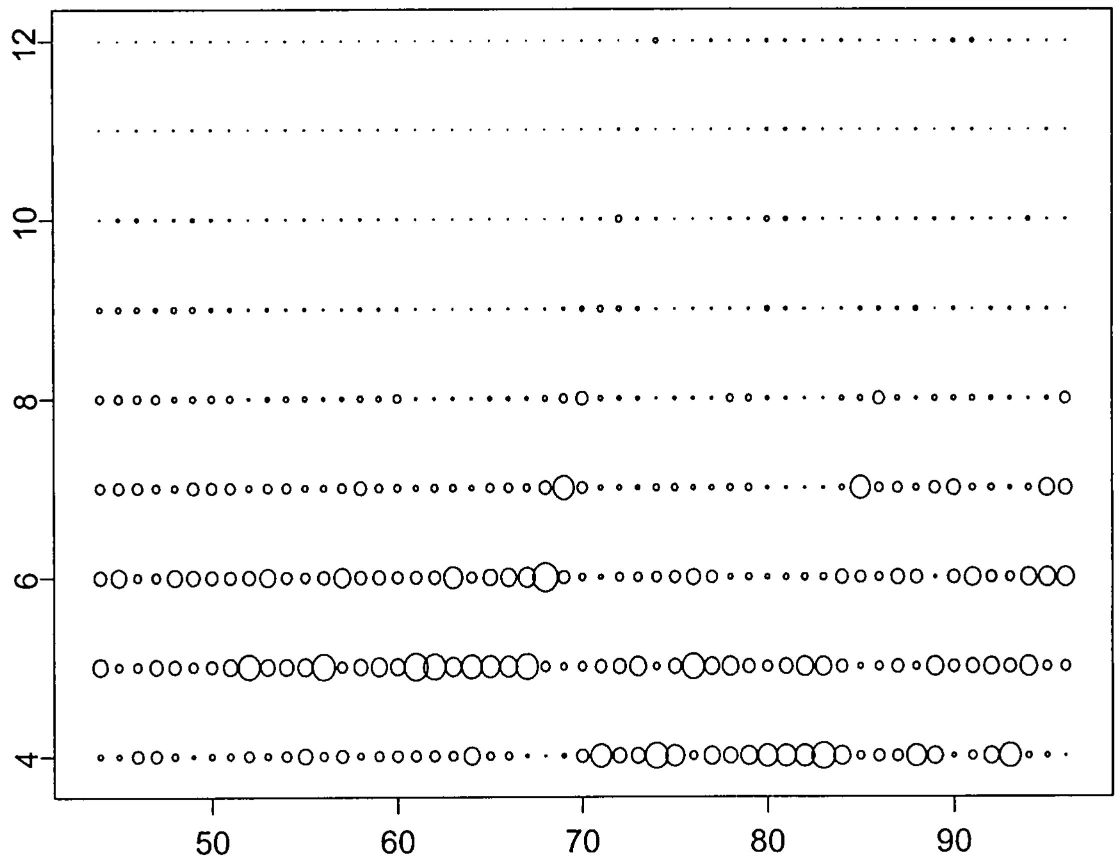

Figure 4.13. Input data for the catch-age analysis of Hecate Strait English sole (ages 4-12+), 1945-96. The circle radii are proportional to values for individual age proportions.

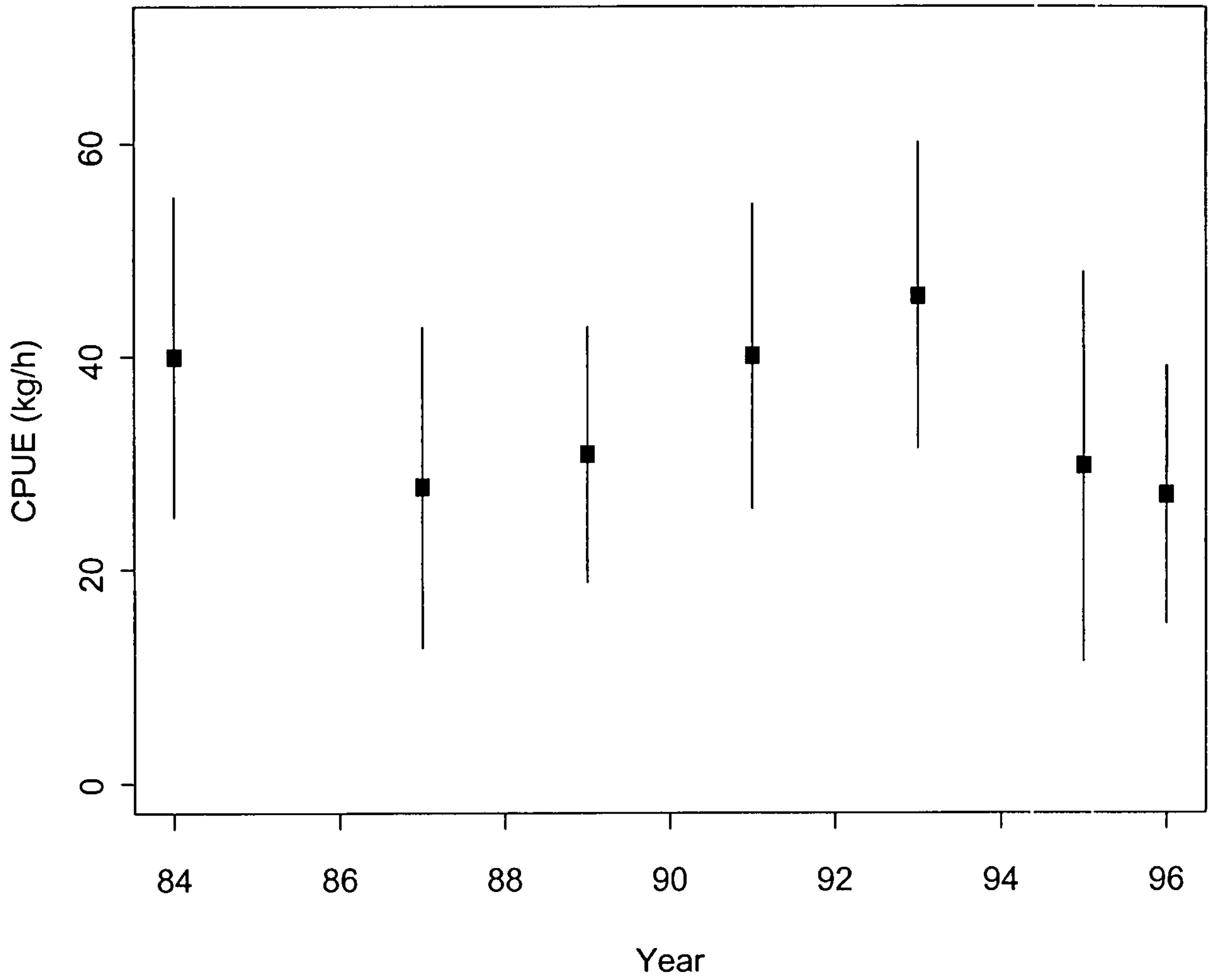

Figure 4.14. English sole CPUE from research surveys conducted in Hecate Strait between 1984 and 1996.

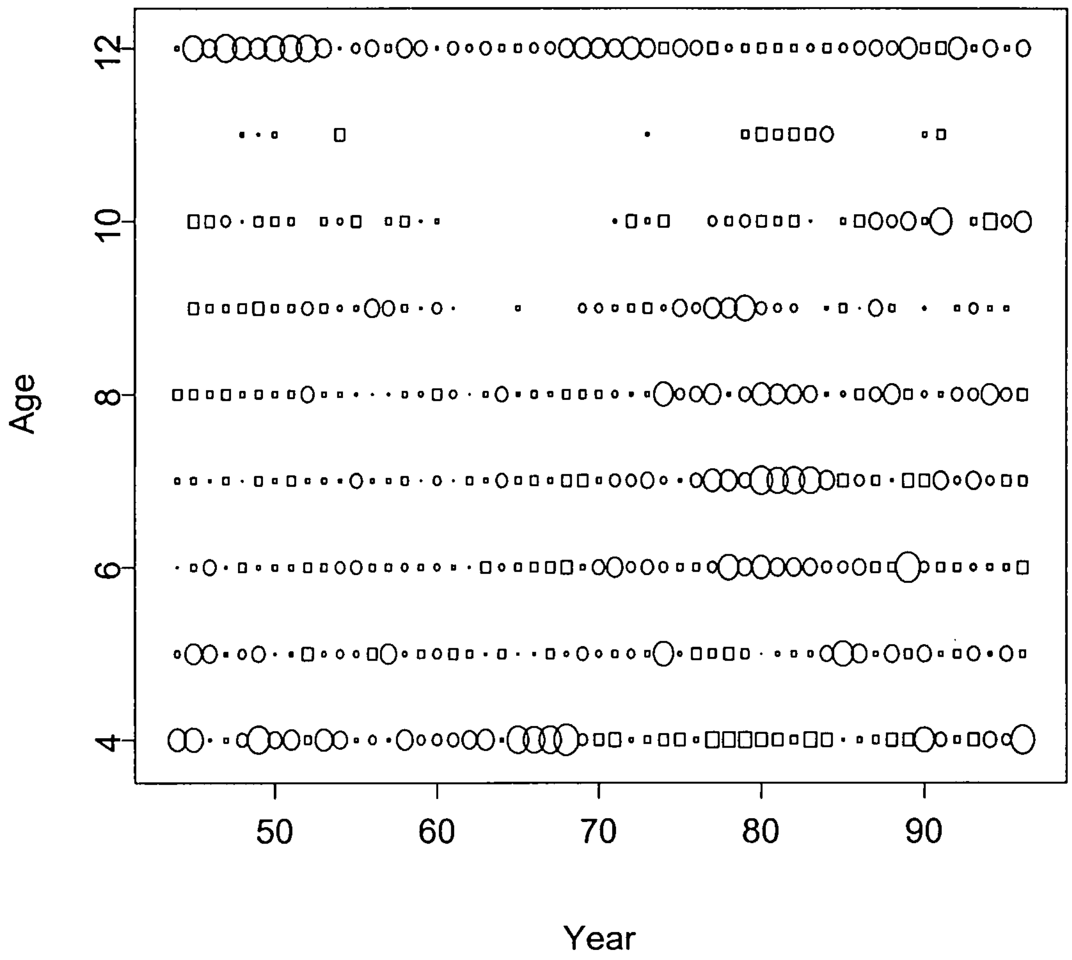

Figure 4.15. Symbol plot of residuals for the age proportion data for the catch-age analysis of Hecate Strait English sole by year. Circles represent negative residuals while squares represent positive residuals. Circle radii are scaled to the maximum negative residual while the area of each square is scaled to the maximum positive residual. A blank space represents a small age proportion that is grouped with the next older age. Residuals are defined in Appendix Table A.1.

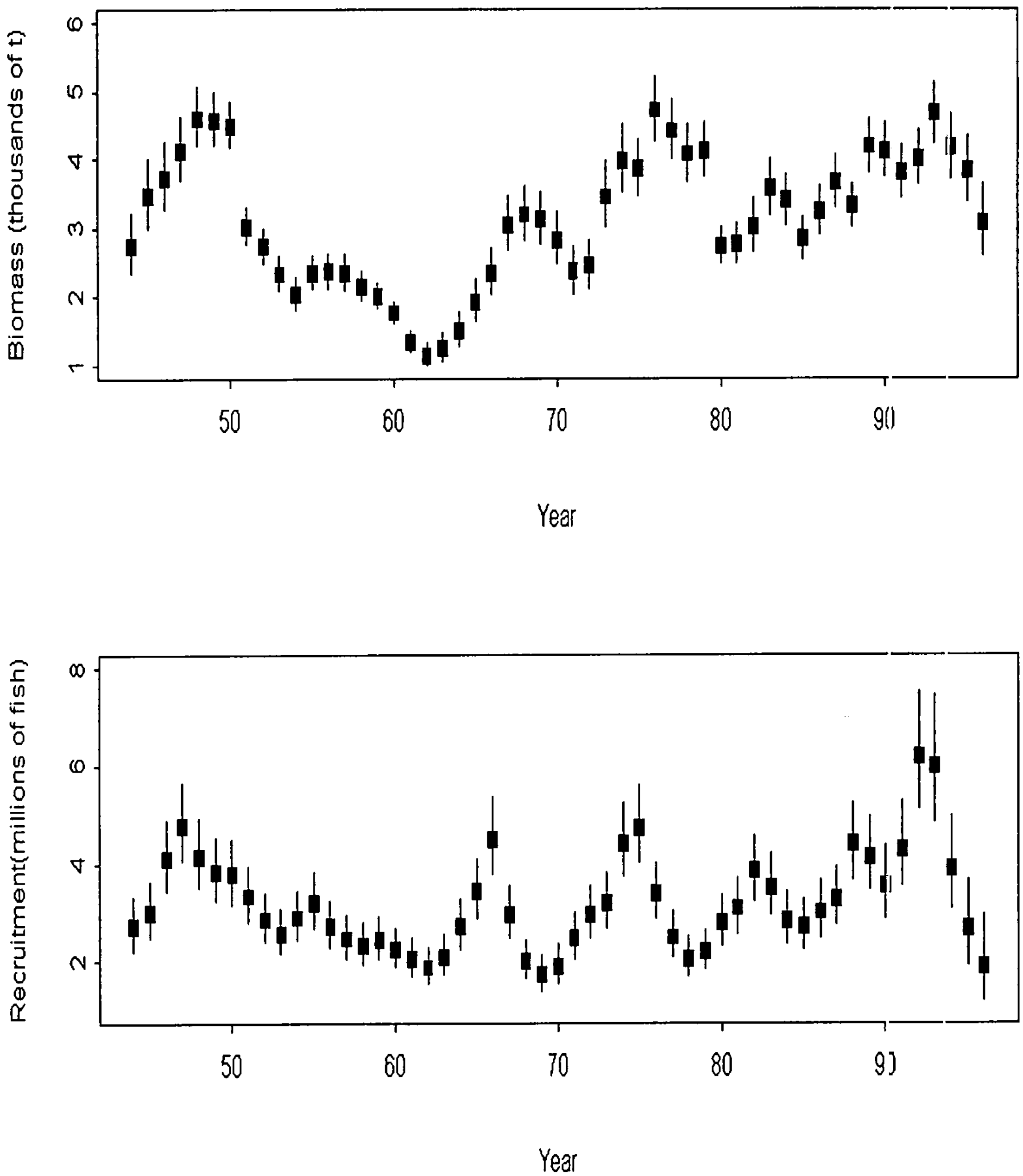

Figure 4.16. Biomass and Recruitment trajectories from the catch-age model results for Hecate Strait English sole, 1944-96.

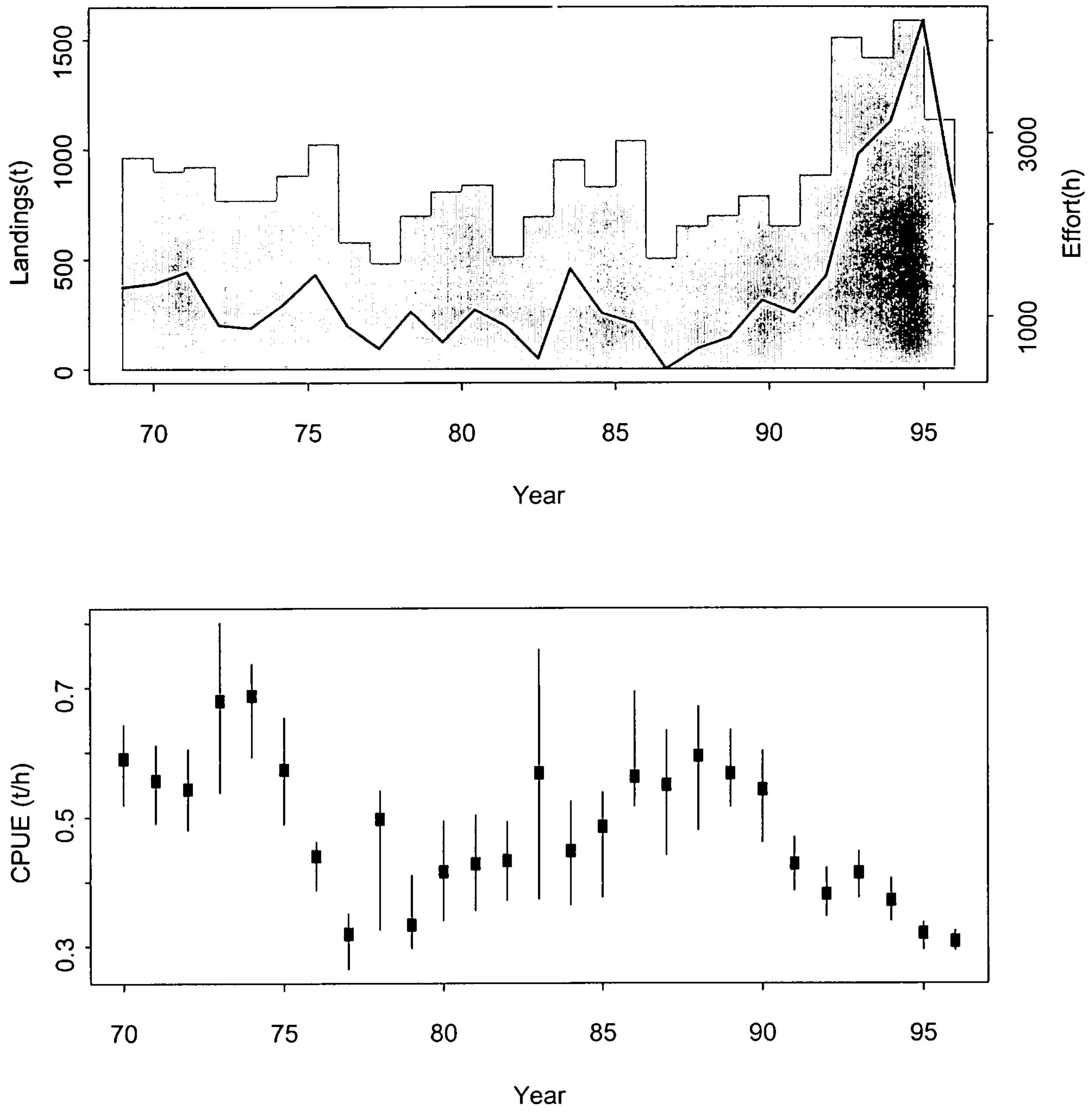

Figure 4.17. Canada-U.S. landing statistics for Dover sole in Areas 5C-E. Top panel - bars = landings, line = Effort (h). Bottom panel – Median CPUE and 95% confidence interval.

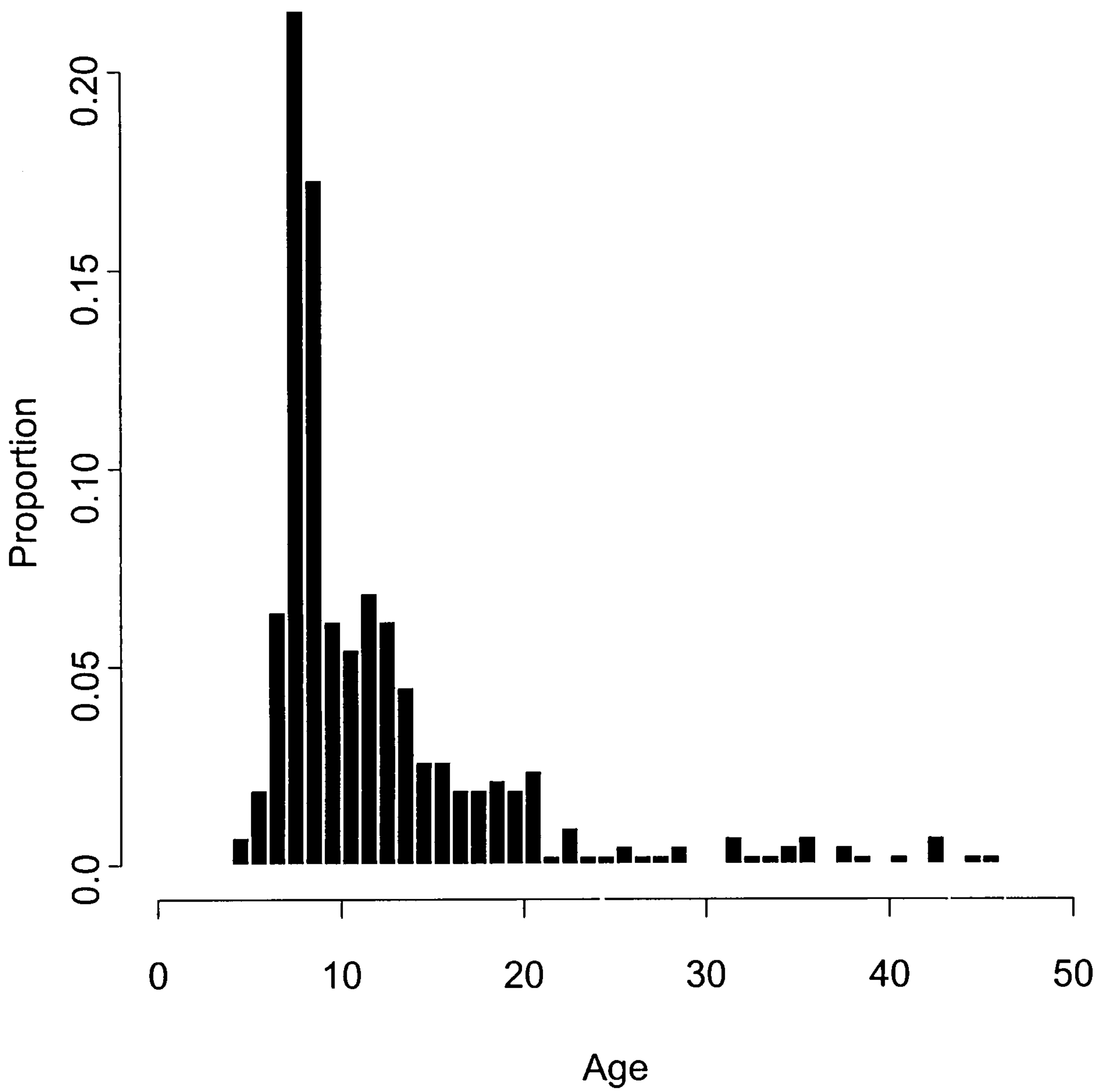

Figure 4.18. Age composition for Dover sole caught in the 1996 commercial trawl fishery in Area 5D.

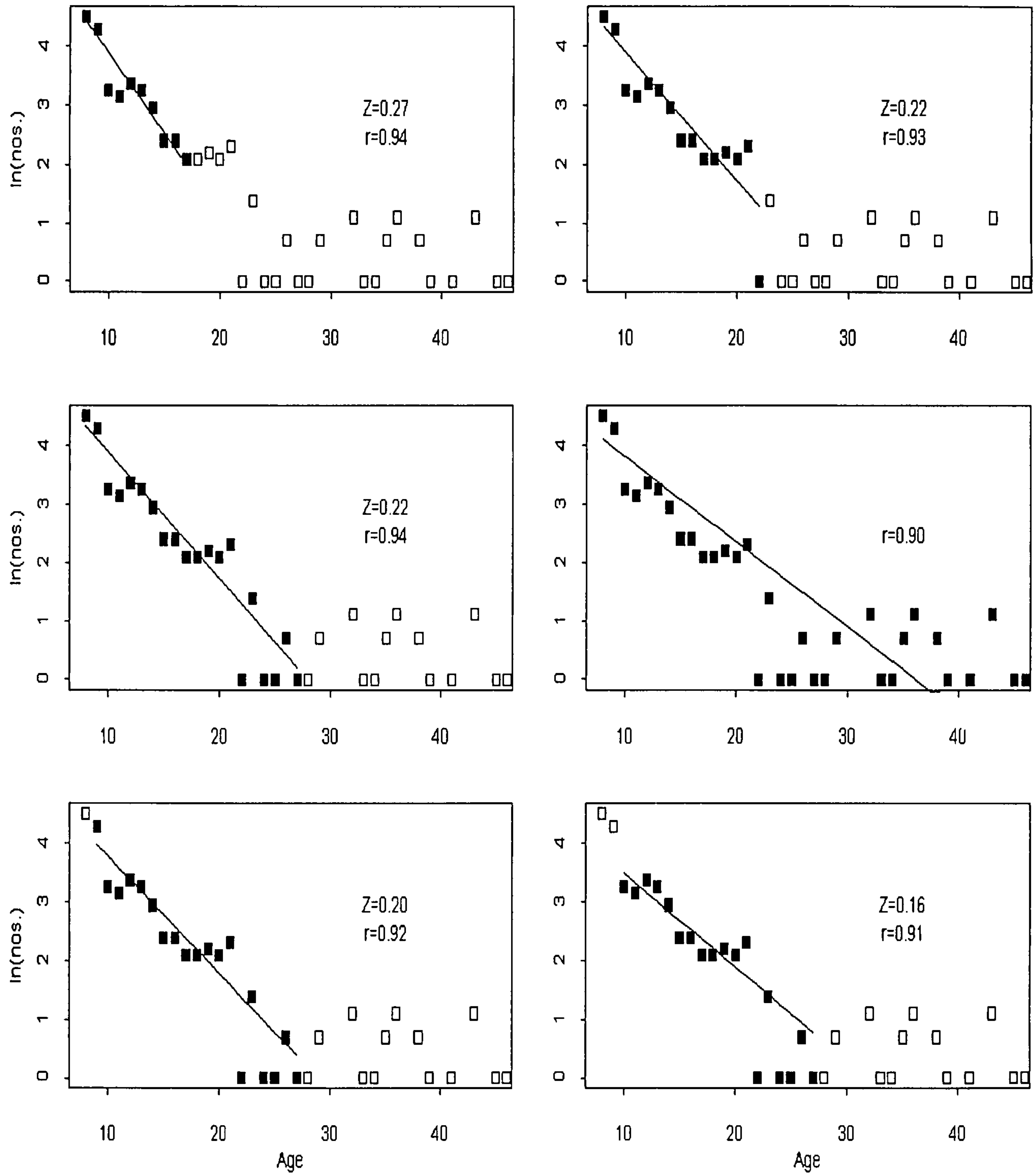

Figure 4.19 Estimates of the instantaneous total mortality rate for Area 5C-E Dover sole. The filled squares indicate data used to fit the linear regression.