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Update assessment of silvergray rockfish (*Sebastes brevispinis*)

Mise à jour de l'évaluation du sébaste argenté (*Sebastes brevispinis*)

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Abstract

This document summarizes a re-assessment of silvergray rockfish (*Sebastes brevispinis*) in British Columbia waters and provides yield recommendations for the 2003/2004-2006/2007 fishing years. The catch at age analysis of the previous 2000 assessment was updated with two additional years of catch and proportion at age data, and a 2001 survey biomass estimate for a portion of the Area 3CD stock off the west coast of Vancouver Island. The assessment model for the three more northerly stocks was tuned to the last six years of commercial CPUE, unlike the “un-tuned” analyses conducted previously. The principal objective of this review was to examine whether the previous work had underestimated the stocks. The bias was presumed to have arisen because of an “over-reliance” on a sparse and possibly biased array of age samples for the three northern stocks.

This review indicates terminal biomass estimates about 10% higher for the 5AB stock in Queen Charlotte Sound and 50% higher for the 5CD stock in Hecate Strait. No difference was observed for the 5E stock off the west coast of the Queen Charlotte Islands. Analysis of the 3CD stock tends to indicate a lower biomass owing to the 2001 low survey estimate from the U.S. triennial survey. Some modelling scenarios for this stock predicted a terminal biomass for 2001 of less than half of what was reported in the earlier assessment.

The large uncertainty in the analyses effectively precludes the opportunity of detecting a statistically different stock status. The changes in estimates of current biomass result more from a re-scaling of the biomass trends rather than changes over the last two years. Nevertheless, the document recommends updating the management quotas based on the results from this review and provides a summary of harvest options.

Résumé

Le présent document est un résumé d’une nouvelle évaluation du sébaste argenté (*Sebastes brevispinis*) dans les eaux de la Colombie-Britannique et contient des recommandations en matière de rendement pour les années de pêche 2003-2004 à 2006-2007. L’analyse de la capture à l’âge présentée dans l’évaluation de 2000 a été mise à jour à partir de deux années supplémentaires de données sur les prises et de leur proportion par classe d’âge, ainsi qu’à partir d’une estimation de la biomasse établie lors du relevé de 2001 pour une partie du stock de la zone 3CD de la côte ouest de l’île de Vancouver. Contrairement aux analyses précédentes, le modèle d’évaluation utilisé pour les trois stocks les plus au nord a été ajusté sur les six dernières années de captures commerciales par unité d’effort. Le principal but de cet examen était d’établir si les stocks avaient été sous-estimés dans les travaux antérieurs. Ces travaux ont en effet été basés en grande partie sur une série d’échantillons d’âges clairsemés et peut-être biaisés pour les trois stocks du Nord, ce qui pourrait être à la source de la distorsion.

Le présent examen révèle que les estimations de la biomasse pour la dernière année d’analyse dépassent d’environ 10 % celles du stock 5AB du détroit de la Reine-

Charlotte et de 50 % celles du stock 5CD dans le détroit d'Hécate. Aucune différence n'a 5E au large de la côte ouest des îles de la Reine-Charlotte. 3CD tend à indiquer une biomasse moins importante en raison de la faible estimation pour 2001 tirée du relevé triennal des États-Unis. À partir de certains scénarios de modélisation pour ce stock, on a prévu qu'en 2001, la biomasse pour la dernière année d'analyse correspondrait à moins de la moitié de celle rapportée dans

La grande incertitude des résultats d'analyse empêche effectivement de détecter une différence statistique dans l'état des stocks. Les changements dans les estimations de la biomasse actuelle découlent davantage d'une nouvelle pondération des tendances de la biomasse que de changements survenus au cours des deux dernières années. Néanmoins, le document recommande de mettre à jour les quotas de gestion en regard des résultats du présent examen et comporte un résumé des options de pêche.

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1. Introduction

This document summarizes a re-examination of an assessment of silvergray rockfish (*Sebastes brevispinis*) provided to the Pacific Scientific Advice Review Committee (PSARC) in November 2000 (Stanley and Kronlund 2000). While the general PSARC approach is to conduct single species rockfish assessments at a frequency of no more than once every four years, the review was requested owing to the widespread perception by fishers that the previous assessment was too conservative (Appendix 1).

Stanley and Kronlund (2000) stated that there was no credible abundance index for three of the four stocks. Therefore, the catch at age analyses of these stocks were reliant on the sparse collection of ageing samples. The harvest recommendations were derived by comparing the estimates of F (instantaneous fishing mortality rate) for the terminal year (1999) against a target harvest reference point of $F=M=0.06$ (M= instantaneous natural mortality rate).

Many review comments focussed on the assumption of comparability and adequacy of the ageing samples over time. Since most of the samples were collected opportunistically in the commercial fishery, the assumption of comparability over time was dependent on the fishery being prosecuted in a similar manner. Fishers commented that the introduction of Individual Vessel Quotas (IVQ's) in April 1997 had forced them to move their effort away from localities associated with high catch rates of silvergray rockfish so that they would not exceed their silvergray rockfish IVQ's too early in the fishing year. They questioned whether the pre- and post-IVQ samples were comparable.

Reviewers also noted the paucity of samples from the earlier years (1970-1995). They suggested that there were too few to be considered representative which, while not necessarily biased, would render the analyses overly sensitive to those few samples. The Department of Fisheries and Oceans, Canada (DFO) offered to re-examine the data but suggested waiting two years. This would not only provide an additional two years of ageing data, but the delay would provide five years of comparable commercial CPUE data (post-IVQ) with which to tune the model and reduce the reliance on the ageing data. As this review is an update of the assessment conducted in 2000, readers are urged to refer to the earlier document for background details (Stanley and Kronlund 2000).

2. Stock boundaries

We provide recommendations for four putative stocks (Fig. 1). These include the west coast Vancouver Island stock (Pacific Marine Fisheries Commission Areas 3C and 3D), the Queen Charlotte Sound stock (Areas 5A and most of 5B), the Hecate Strait-Moresby Trough stock (Areas 5C and 5D, and a small part of 5B), and the west coast of the Queen Charlotte Islands (Area 5E). The official boundary between the Areas 5AB and the 5CD was modified slightly to correspond to the midpoint of Reed Trough between Goose Island and Middle Banks. Thus, the landings on each side of Reed Trough were allocated separately. We emphasise that there is little biological basis for any of the current stock boundaries.

3. Landings data

Catch data were modified and updated for the 1996 to March 2002 period (Tables 1-3). Two changes were made to the catch summary. Firstly, total catch was summarized by Fishing Year (FY) following the management fishing year of April 1-March 31, unlike the previous treatment by calendar year. Limited catches for the January 1- March 31, 1997, prior to implementation of IVQ's, were added to the 1996 catch total. Catch data prior to 1996 represents calendar year. We refer to fishing years of 1996 and 1997/1998 as FY1996 and FY1997.

Secondly, we used the DFO "Official" trawl catch estimation algorithm to represent total catch by stock (FY1996-FY2001). This estimate is a merge of the visual on-board observer estimates collected for each tow with the landing weights obtained from the dockside monitoring program (DMP). Details of the merging logic are available on-line at the Groundfish Catch data website (contact K. Rutherford). It adds DMP estimates of retained catch to observer estimates of discards, but prorates catch by area using the at-sea observer log data. A small amount of catch remains unassigned to area (Table 2). This results from DMP observations of retained catch when none were reported by observers for entire trips. Since DMP estimates of retained catch tend to be higher than observer estimates (see also Sinclair 1999), catch estimates in this review are higher than previous. As before, hook-and-line landings are added to the trawl catches.

4. Silvergray rockfish management

DFO continued to use an $F=M$ harvest strategy in establishing the silvergray rockfish TAC's for all areas except 5AB (Fisheries and Oceans, Canada 2001). In 5AB, the process was delayed wherein the TAC would be stepped downward by 60 tonnes for each of FY2001, FY2002, and FY2003 to achieve the $F=M$ strategy. FY2002 trawl quotas for Areas 3CD, 5AB, 5CD, and 5E were 272, 443, 248 and 224 t respectively (Table 1). The total coastwide trawl quota was 1,187 t. The overall gear allocation permits 88.43% to be taken by trawl gear and 11.57% by hook-and-line gear, for a coastwide TAC of 155 t for the hook-and-line sector.

5. Relative and absolute abundance estimates of silvergray rockfish

5.1. Commercial CPUE indices pre-FY1996

Estimates of commercial catch per unit effort (CPUE) are available for the trawl fisheries from 1967 for both U.S. and Canadian fisheries. However, as noted in the previous document, we have assumed that changes in the fishery and the data collection procedures compromised the comparability of CPUE between 1984 and 1996. Furthermore, we suggest that the introduction of 100% observer coverage as the source of catch data and the introduction of IVQ's in 1997, with its presumed impact on fishing strategies, further altered the relationship between CPUE and abundance. Fishers now report that much of their IVQ's of silvergray rockfish are subscribed from incidental catch while targeting on other species. For these reasons, and others summarized in the previous document, we continue to assume that commercial CPUE data for the period prior to 100% observer coverage and IVQ's cannot be used to index abundance.

5.2. Commercial CPUE indices for FY1996-FY2001

We derived CPUE indices independently for each stock for FY1996-FY2001. Between January 1-March 31 of 1997, there was a virtual closure of the trawl fishery. These few catch records were not included in the CPUE analysis. The initial data extraction from PacHarvTrawl, the DFO-Groundfish Trawl Catch database, selected all bottom trawl tows that were coded as "usable" and which included estimates of time fished and location. This excluded a small number of tows, which were not deployed properly or were significantly damaged during fishing. These at-sea observer estimates of catch were not adjusted by DMP. We also excluded shallow tows conducted in depths of 0-50m. During the extraction of the data for each tow, we included the name of the most abundant retained species in that tow, which we refer to as the *catch-target* (Table 4).

The intent of using c*atch-target* was to allow the model to account for the variability in catch rates owing to fishing in different habitats within a depth/month stratum. For example, it allows the model to identify the higher catch rates of silvergray rockfish when fishers target on rockfish over "hard" bottom as opposed to targeting on arrowtooth flounder on "soft" bottom, albeit at similar depths. Species assemblages would probably provide a better surrogate for habitat classification. We were not able to refine this approach although we did conduct sensitivity runs related to this issue.

The data set also included an additional field for each tow that indicated the mean silvergray rockfish catch per hour (averaged over FY1996-2001) for all tows conducted in the 2 km^2 block in which the tow was conducted. This value was generated by calculating the mean catch/h of silvergray rockfish for all 2 km^2 blocks off the BC coast. Tow location was determined from the estimated mid-point of the tow.

The baseline CPUE examination for each stock excluded tows from blocks that had yielded a mean catch of less than 5 kg/h over the FY1996-2001 period. Following from the work of Schnute *et al*. (1999) and their use of CPUE "hotspots" for studying thornyhead (*Sebastolobus* spp.) abundance, our intention was to eliminate tows from poor fishing locations, or "coldspots", that had very little likelihood of catching silvergray rockfish. The threshold criteria of 5 kg/h eliminated approximately 43% of all the records, but still provided a significant number of observations within those *catch-target* categories for which silvergray rockfish was a minor bycatch. We did not explore alternative measures of central tendency, such as median kg/h, which may improve the basis for screening the observations.

We used General Linear Modelling (GLM) implemented in S+ software (Version 6.1, Insightful Corporation©) to estimate the annual (FY) signal in the commercial catch rates (Quinn and Deriso 1999, Starr and Haigh 2000). The analysis focused on the main effects in an additive fixed effects model on the log scale:

$$\log CPUE_{i,j,k,l,m} = m + a_i + b_j + f_k + g_l + l_m + e_{i,j,k,l,m} \quad (1)$$

where:

m	is the overall mean catch rate;
a_i	is the fixed effect of the ith level of the *catch-target* factor, i=1,….I;
b_j	is the fixed effect of the jth level of the depth factor, j=1,….J;
f_k	is the fixed effect of the kth level of the month factor, k=1,….K;
g_l	is the fixed effect of the lth level of the boat factor, l=1,….L;
l_m	is the fixed effect of the mth level of the Fishing Year factor, l=1,….M;
$e_{i,j,k,l,m}$	is the normally distributed residual error with mean 0 and variance d^2.

Zero values were converted to 1 kg/h. The yearly index was taken directly from the coefficients corresponding to each FY, as were confidence limits for these coefficients (Quinn and Deriso 1999). Results are shown on the back-transformed scale and standardized to 1.0 for the first year. The *FY* effect was examined in each stock separately.

Prior to fitting the model for each stock, the data were further filtered by removing tows conducted by vessels that did not participate over the six years (FY1996-FY2001). Vessels were excluded if they conducted less than five tows in three or more of the six years. The main effect of this criterion was to remove many vessels that stopped participating after the introduction of IVQ's in 1997. Minor *catch-targets* were also removed if there were fewer than 10 tows over the six years in that category (Table 4). Depths were binned in 50m strata (50-100, 100-150, 150-200, 200-250, 250-300, 300-350, 350+m). Results from main effects model were used to tune the catch-at-age runs. While interaction terms were often significant and met the Akaike Information Criterion (AIC), they explained little of the variance and had negligible effect on the trends.

Prior to analysing the CPUE data, we were concerned with potential biases in the first and last years of the series. FY1996 was the first year of 100% observer coverage but last year prior to implementation of IVQ's. The consensus among fishers was that the fishery for silvergray rockfish changed with IVQ's from being partly a target fishery to a bycatch or avoidance fishery. It might be assumed therefore, that catch rates would decrease for this reason alone after FY1996.

We were also concerned with the comparability of catch rates observed in the most recent year, FY2001. Largely because of lower quotas, trawl landings declined for Areas 3CD, 5AB and 5CD by 22%, 8% and 44%, respectively. Landings increased by

2% for Area 5E. If the fishery was already a nuisance fishery, one might assume that, a reduction in catches would be achieved through increased avoidance. This would be achieved by a combination of less frequent targeting on silvergray rockfish and exercising greater caution when targeting on co-habitants such as canary rockfish and lingcod. Within the data extracted for the GLM, we note that the number of tows in which silvergray rockfish was the dominant retained species ranged from 502-826 tows for FY1996-FY2000 and declined to 378 tows in FY2001.

If fishers could compensate by less targeting, then including *catch-target* in the GLM might accommodate this potential bias. However, it can also be assumed that fishers would become more cautious even when targeting on other co-habitants. To address this bias, we conducted sensitivity tests wherein we fitted the GLM after removing tows with *catch-targets* such as canary rockfish and lingcod. We were attempting to estimate CPUE trends derived from fishing where silvergray rockfish avoidance would not be an issue. In addition, we fitted the GLM after screening localities associated with higher catch rates of silvergray rockfish (hotspots). We also conducted catch at age model runs omitting FY2001.

5.3. Silvergray rockfish biomass surveys

The previous document noted that no Canadian groundfish trawl surveys were useful for indexing silvergray rockfish abundance. Fortunately, U.S. researchers have been more persistent in their attempts to provide swept-area estimates of many commercial groundfish species. Their random stratified coastwide survey has been conducted every three years from 1977-2001 and has often extended into the southern half of Area 3CD (Weinberg *et al*. 2002) (Fig. 1, Table 5).

The initial focus of the survey was to estimate absolute abundance of shelf rockfish but shifted to other species in the 1980's owing to frustration over the low precision and obvious bias since the estimates were usually exceeded by annual catches. Nevertheless, the results have been used to tune many rockfish assessments (see Crone *et al*. 1999 for canary rockfish and Tagart *et al.* 2000 for yellowtail rockfish). We discuss the results of the survey in greater detail in Section 10.1.

In response to requests from hook-and-line fishers, we also provide a comparison of silvergray rockfish catch rates during rockfish longline surveys in four experimental sites. The intent of these surveys was to monitor yelloweye rockfish catch rates and proportion at age (*S. ruberrimus*) (Kronlund and Yamanaka 2001). We have provided silvergray rockfish catch rates (pieces/hook) for two sites from the southern area of 5AB and two from Area 5E (Fig. 2). These data appear too limited for monitoring silvergray rockfish abundance over the short time period nevertheless they provide no evidence that abundance has increased between 1997-1998 and 2001.

6. Proportion at age data

The DFO-GFBIO database at the Pacific Biological Station (PBS), Nanaimo, British Columbia contains data on silvergray rockfish sampled from Canadian waters through FY2001. Samples come from port samples, observer trips and research cruises. For calculating proportion at age, we removed samples that were stratified or collected during special circumstances (GFBIO Sample_ID's 98975, 99003, 99321, 99537). Ages were determined using the otolith burnt section technique (MacLellan 1997). Between-reader agreement is poor for silvergray rockfish. Agreement to ±1 year is 60-80% for ages less than 20 and then slowly deteriorates with increasing age.

Maximum ages observed in Canadian samples are 82 and 81 for males and females respectively. The $A_{99.9\%}$ (age at 99.9% quantile) for males is 77 years and for females is 76. While the number of specimens aged reached the hundreds for many years from 1977-1997, the actual number of aged samples was often limited to less than 4/stock/year (Table 6).

We assigned equal weighting to each sample within a year for estimation of yearly proportion at age. We did not weight among years proportional to number of samples or specimens. Observations below 10 years of age were excluded; the accumulator age group was 30+. Proportions at age were maintained in a calendar year format leading to a slight mis-alignment between catch by FY and the age data in the catch at age model fitting.

We have presented a graphical summary of the distribution of samples over time and space in response to review comments for a closer inspection of the spatial distribution of the samples (Fig. 3-9). Fishing captains questioned whether the location of the samples had changed with introduction of IVQ's. Also presented are histograms of each sample to examine the heterogeneity in proportion at age among samples (Figs. 10-28). These results are discussed in Sections 10.1-10.4.

7. Life history parameters

7.1. Growth and age at maturity

The same growth, maturity and fecundity relationships were used as before (Tables 7 and 8, Figs. 29 and 30). Females appear to be mature by age 9-12, well before full recruitment nearer to age 20. As this relationship has a significant impact on the target reference point, it must be remembered that age of maturity in the fishery samples may not reflect the actual maturation rate. For example, the proportion mature among age-9 females that have recruited to the fishery may differ from the proportion mature among non-recruited age-9 females. Nevertheless, the available data indicate that the trawl fishery does not capture immature individuals and implies that most females spawn a few times before recruiting to the fishery.

7.2. Natural mortality

Archibald *et al*. (1981) were the first to estimate instantaneous mortality rates for silvergray rockfish from ages derived from the otolith burnt-section technique. Based on samples collected in 1977-1979, they estimated total instantaneous mortality rates (*Z*) for males of 0.03-0.06 and for females of 0.02-0.04. When the sexes were combined, the estimates ranged from 0.04-0.07. It should be noted that these samples were collected from populations that had been fished for 10-20 years. The Hoenig technique indicates estimates of instantaneous natural mortality (*M*) of 0.056 for males and females (Hoenig 1983). Using the $A_{99.9\%}$, to avoid the "creeping" increase in estimates of M from growing sample size (Crone *et al.* 1999), provided estimates of 0.060 and 0.059 and for males and females, respectively. We assumed an estimate of M=0.06 for all model runs.

8. Estimation of spawning potential per recruit

Estimates of *M*, growth, and fecundity, in conjunction with selectivity-at-age as indicated in the catch at age analyses, provide estimates of relative population fecundity of unfished and fished populations (Gabriel *et al*. 1989). The analysis indicates that an $F_{50\%}$ target equates to an F of 0.085 (M=0.06) owing to the early maturity relative to recruitment. The work on target reference points by U.S. researchers (Pacific Marine Fisheries Council 2000) has paralleled the changing perceptions regarding the optimum choice of F ($F_{opt.}$). Earlier work by Clark (1991) recommended target reference points of $F_{35\%}$. The declines in widow rockfish, bocaccio and canary rockfish, have prompted a review of this recommendation. Meta-analysis has indicated that, while $F_{35\%}$ may be appropriate for Dover sole and other groundfishes, whereas reference points of at least $F_{50\%}$ are more appropriate for rockfish. They comment that $F_{50\%}$ tends to correspond to F=0.75*M. The current management plan supports a target harvest rate of $F=M$ (Fisheries and Oceans, Canada 2001). A target F of 0.06, translates to an exploitation rate (u) of 0.0582 (Note: $u = 1 - e^{-F}$).

9. Catch at age model definition and application

We have retained the same model as in the previous assessment (Schnute and Richards 1995, Richards *et al.* 1997, Fargo and Richards 1998) (Appendix 2). Data input to the model include:

- catch (000's tonnes) of silvergray rockfish for each FY;
- stock indices computed from CPUE data or surveys;
- mean weight at age computed by converting individual lengths to weights via a sex-pooled length/weight relationship, and averaging the estimated weights at age;
- proportion of females mature at age.

Estimates of the selectivity parameters (a , b_1) were determined by the model for Areas 3CD, 5AB and 5CD runs. The fitted curves were consistent in indicating an asymptotic function with recruitment starting at age 10, approximately 50% recruitment about age 15 and over 80-90% recruitment by age 20. The model typically fits an implausible straight-line relationship for Area 5E because the model had to rely on samples collected from FY1994-FY2001 during an incoming recruitment event. Therefore, we imposed the Area 5CD selectivity relationship on the 5E runs. The 5CD stock is the closest geographically to 5E and is based on the most complete series of age data.

10. Assessment analyses

Specific stock assessments follow below. In each case, we first review the derivation of the CPUE abundance trend (and survey trend for 3CD) and examine the effects of alternative GLM assumptions on the trends. We then discuss the adequacy of the samples in estimating the proportion at age data used in the model runs.

Following discussion of the input data, we present the results of the model under different assumptions and provide a basis for choosing representative scenarios. The model predictions of final stock biomass are conditioned by the weighting given to the abundance index and the relative error in recruitment (see Appendix 2). The weighting of the abundance index is determined by the value assigned to t_1, the standard deviation of the index. The lower the relative error in the index, the more closely the model is forced to track the index. The lower the relative error in recruitment, (the standard deviation = s_1), the less recruitment is allowed to vary from the overall mean. As in the previous document, we provide a simple sensitivity analysis of these two parameters. We show the results from selected runs assuming relative error in the abundance index and recruitment are set equal to 25, 50 and 100%, for a total of nine runs. We also present some additional runs to examine specific questions, such as the impact of the older age samples. Following the summary of model output, we discuss the uncertainty around the point estimates of the current biomass. This includes a presentation of the likelihood profile of the estimate of exploitable biomass. We then provide a harvest recommendation for the coming four years.

10.1. Area 3CD

Area 3CD Commercial CPUE

The data set used to estimate the 3CD CPUE index contained 3,723 records after exclusion of coldspots, minor *catch-targets* and minor vessels (Tables 9 and 10). Tows from 33 vessels were used in the analysis. The fit to the analysis of variance (ANOVA) indicated that all main effects were significant (Table 11). All factors satisfied Akaike's Information Criterion (AIC) for inclusion using a step-wise removal of the least significant factor (Tables 12). *Catch-target* was the only factor that explained a large component of the variability. The diagnostics indicate the effect of the large number of 0 catch tows in the departure from linearity in the residuals (Fig. 31).

Since landings were 22% lower in FY2001, we attempted to demonstrate increased avoidance by removing tows from areas known to exhibit high catch rates (hotspots >200 kg/h or >700 kg/h), or tows in which silvergray, canary and redstripe rockfish, and lingcod were the *catch-targets*. We observed no impact of this additional filtering (Fig. 32). Reducing the coldspot threshold to <1 kg/h also had no impact. There is no net trend over the six years, although the trend for the last three years is downward. We used the baseline trend, #1, for tuning the model.

U.S. triennial survey index in Area 3CD

The U.S. triennial survey uses a systematic-random design within depth and area strata (Weinberg *et al*. 2002). Depth strata were 55-183 m, 184-366 m, 367-500 m. Tracklines were placed across the survey area from the 55 m isobath due west extending to the 500 m isobath at intervals of 18.5 km along the coast. Stations were randomly placed along tracklines at the rate of one station per 7.4 km in the shallow stratum and one station per 9.3 km in the two deeper strata. The sampling density in the Canadian portion of 3CD in 2001 was 33 successful tows from 66 stations in the 55-183 m stratum, three successful tows of 12 stations in the 184-366 m stratum, and four successful tows from 13 projected stations in the 367-500 m stratum. Note that the survey, even at its furthest northerly extent, only surveys about half the stock area (Fig. 33).

While preparing the previous assessment, we noted the influence of the high biomass estimate of the first survey (1980) and that the estimate for that survey reflected one large tow, so we removed the 1980 estimate from the analysis (Table 5). Our continuing concern over the leverage of such large tows led us to obtain and review the source data for this review. We first note the small number of tows and the fact that few of them were executed in areas known to be hotspots for silvergray rockfish (Fig. 33). Secondly, we note that the median in non-zero tows shows no change, nor does the proportion of zero tows in recent years (Fig. 34). In fact, the estimated biomass simply tracks the log CPUE of the largest tow (Fig. 34). Finally, we note that the 2001 recent survey did not extend as far north as usual although the biomass estimate is expanded to the same area (Fig. 35). The area not fished in 2001 contributed significant catches in some years. In general, we suggest that it is reasonable to tune the catch at age model to the survey but only under the assumption that the survey is highly imprecise.

Proportion at age data for Area 3CD

The proportion at age data for Area 3CD was augmented by samples for 2000 and 2001 (Table 6). The capture location of the samples appears to be widely distributed in the stock area with no obvious trend over time (Figs. 3-4). A review of individual samples indicates significant variation among the samples, especially for early years. There is no obvious variation with depth (Figs. 10-12). The time series of the samples is sparse, particularly for the early years.

Catch at age analysis for Area 3CD

The analysis for Area 3CD was the most problematic of the four stocks. Firstly, we had to fix γ (the recruitment autocorrelation parameter) to be equal to 0.85, the approximate average observed in other stocks. The recruitment function (see Appendix

2) has the property that as $\gamma \rightarrow 0$, then log R (mean recruitment) is normal with mean log R and variance δ_1^2. As $\gamma \rightarrow 1$, the process approaches a random walk with finite moments. If we allowed the model to fit γ, then it moved towards a value of 1.0, ignored the age structure, and selected unreasonably low biomass levels.

Secondly, although the 3CD model was provided the additional structure of the long-term survey index, the outcome was sensitive to the relative error in recruitment. Assuming that the relative error in the survey is 50% or greater (Table 5), then the estimates of B_{2001} range from about 1,000-4,000 t (Runs 1-6: Table 13, Figs. 36-38). The higher biomass estimates result from relative error in recruitment being set at 25%. As this error increases, B_{2001} declines. We suspect that for the model to match the decline in the survey, it requires a sustained period of poor recruitment in recent years much lower than the overall mean recruitment. Thus it requires a larger error in recruitment. Curiously, runs tuned to commercial CPUE provide the same response as survey runs with high survey variance, but are slightly less sensitive to changing the recruitment error (Runs 7-10, Table 13).

The 2001 survey estimate exerts considerable leverage on the model prediction in Area 3CD. If this point is included and the model is allowed to pick the values of key parameters, it is consistent in indicating a declining abundance caused mainly by a sustained period of poor recruitment. More optimistic runs can only be achieved by restricting recruitment variability or by removing the last survey point. Even when tuned to CPUE, the model predicts a declining biomass unless recruitment variability is kept low.

We suggest that Runs #1 and #5 (Tables 13 and 14) provide a reasonable bound for a discussion over appropriate harvest levels in 3CD. Run #1 presents the most optimistic scenario based on the assumptions of high survey error and low recruitment error. It allows the model to pay less attention to the last data point and limits the degree to which the model can indicate recruitment failure in recent years. Whereas, Run #5, assumes moderate survey and recruitment error (50%). The Runs provide point estimates of B_{2001} of 4,187 t and 2,055. The corresponding F_{2001} estimates were 0.061 and 0.129. Perhaps coincidentally, this range is congruent with that indicated in the CPUE-tuned runs.

The more pessimistic outlook, which is driven by the 2001 survey point, is supported by the evidence of a parallel decline in the adjacent population of silvergray rockfish in Washington State (Table 5) and other rockfish stocks to the south. It also parallels the apparent decline in bocaccio (*S. paucispinis*) in the same area (Stanley, Rutherford, and Olsen 2001). Finally, as discussed below, there is growing evidence of a sustained period of poor recruitment in the later 1980's and 1990's for most groundfish species. This would provide a mechanism for this decline.

Qualifying the more pessimistic outlook is the fact that the survey is only indexing 50% of Area of 3CD, the model is highly leveraged by the last survey point, and, to our knowledge, the fishing fleet has not noted the apparent 50% decline in abundance over the last decade as indicated in Run #5.

Summary comment for Area 3CD

The decline in the U.S. survey estimates leaves the model little choice other than to predict a lower terminal biomass (B_{2001}) than reported earlier. However, the uncertainty in the assessment precludes us from stating that the stock abundance is significantly different than reported in the previous work. The degree of uncertainty is reflected in the likelihood profile (Fig. 39).

The level of uncertainty notwithstanding, the point estimates of the two scenarios, in conjunction with a target reference F=0.06, indicate a harvest range of 120-244 (Table 14). This range corresponds to either a catch reduction of 50% or maintaining the status quo. The risk in choosing the higher level, if the lower level is correct, translates to an extra 120 t/y from a biomass of about 2,000 t. If the assessment were not updated for four years, the additional 480 t would represent a significant risk to a biomass of 2000 t, especially if the stock continues to decline from poor recruitment.

We cannot suggest a definitive basis for resolving within this range and therefore propose a mid-point harvest of about 180 t (Table 34). This would limit the potential "overfishing" under the more pessimistic scenario to 60t/y, the equivalent of one extra year's harvest over two years. If the more optimistic scenario is correct, the fishery only loses 60 t/y and with a harvest of 180 t may still be able conduct their multiple-species fishery.

Finally, we emphasize the difficulty in making harvest recommendations given the lack of strategic research plan or assessment timetable. Obviously, the harvest choice in this situation should be conditioned on when the next assessment or survey is going to be conducted. Unfortunately, this information is not available. We note that there is no current plan to continue the U.S. survey into Canadian waters in future years.

10.2. Area 5AB

Area 5AB Commercial CPUE

The final sample size for the GLM examination of Area 5AB was 29,239 records (Tables 15 and 16). Catch results of forty-five vessels were included in the analysis. The ANOVA fit to the 5AB commercial data indicates that all main effects were significant and met the AIC criterion for inclusion (Tables 17 and 18). *Catch-target* was the only factor that explained a large component of the variance. Error diagnostics were similar to those for Area 3CD.

We were not able to demonstrate increased avoidance in FY2001 by removing tows from areas known to exhibit high catch rates (hotspots >200 kg/h or >700 kg/h) (Fig. 40) or *catch-target* species associated with high catch of silvergray rockfish (silvergray, canary, redstripe and yellowmouth rockfish). We selected the baseline run with removal of coldspots <5 kg/h. There is an increase in CPUE from FY1996 to FY1997, no change to FY2000 and a decline in FY2001 (Fig. 40).

Proportion at age data

The proportion at age data were augmented by samples from 2000 and 2001 (Table 6). The capture location of the samples appears to be widely distributed from the stock area with no major changes over time in the location of the samples (Figs. 5-7). A review of individual samples implies considerable heterogeneity among the samples especially in earlier years (Figs. 13-18). There is no obvious variation with depth. The time series of samples is sparse.

Catch at age runs

The 5AB model was tuned to commercial CPUE as described earlier. We conducted runs over the same combinations of relative error in the index and recruitment error as used for Area 3CD (Tables 19 and 20, Figs. 41-42). The nine runs tend to indicate a higher biomass than reported in the previous assessment, 6,654-11,282 t, as compared with 7,246 t. Only Run #9, which assigns low relative error in the CPUE index and high recruitment error, predicts a lower biomass. Although Run #9 indicates a decline from the previous assessment even this run indicates that the current harvest is meeting the target harvest rate. Removing old samples had little impact on the outcome, although it should be noted that the model is now being tuned to CPUE, and presumably less sensitive to the proportion at age data. All the runs indicate a relatively stable biomass over the last decade.

Summary comments on Area 5AB

Given the uncertainty in the estimates (Fig. 43), it cannot be argued that this review of 5AB indicates a significantly higher biomass than reported previously. Nevertheless, unlike Area 3CD, the point estimate of Run #5, which assumes 50% error in the CPUE index and recruitment, indicates a biomass at least 10% higher. At face value, the quota reduction implemented for FY2001 appears to have met the target reference point. If this review is to be used to update the harvest advice, as we recommend for Area 3CD, then we suggest that no further harvest reductions are required and that future quota decisions be based on Run #5. This would permit a harvest about 10% higher that the harvest observed in FY2001. Some of the runs imply that a greater harvest could be appropriate, but given our concerns over the adjacent 3CD stock, we suggest that it would not be a good time to “test” the productivity of Area 5AB. We repeat our comment of earlier, that there is no biological basis for the current stock boundaries.

10.3. Area 5CD

Area 5CD Commercial CPUE

The sample size used to assess CPUE in Area 5CD was 7,524 records (Tables 21 and 22). Thirty-five vessels were included in the analysis. The ANOVA fit to the 5CD data indicates that all main effects were significant and met the AIC criterion for inclusion (Tables 23 and 24). *Catch-target* was the only factor that explained a large component of the variability; diagnostics were similar to other areas. We selected the baseline run with removal of coldspots <5 kg/h. Removing hotspots (>200 kg/h) or, conversely, using all tows had no effect. The CPUE appears to have increased over the first two years with no evidence of a trend since (Fig. 44).

Proportion at age data

The ageing samples appear evenly distributed over the area in the last decade with no obvious trend in location (Figs. 5-9). The age composition shows considerable variability among samples (Figs. 19-24). Like other areas, the time series of proportion at age is sparse.

Catch at age analysis

The 5CD model was also tuned to commercial CPUE. We conducted runs over the same combinations of relative error in the index and recruitment error (Table 25 and 26, Figs. 45-46). The nine runs are consistent in indicating a higher biomass than reported in the previous assessment, 5,296-8,783 t as compared with 4,936 t. Removing old samples indicated about a 10% higher terminal biomass. All the runs indicate a relatively stable biomass over the last decade, thus the increase results form an upward scaling as opposed to a recent increase in biomass.

Summary comments on Area 5CD

While it cannot strictly be argued that this review indicates a significantly higher stock abundance (Fig. 47), the model is consistent is indicating a more optimistic status than reported previously. The B_{2001} estimate for Run #5, which assumes 50% error in the CPUE index and recruitment indicates a biomass 50% higher and, by implication, a quota about 50% more than the 300 t of 2001 (Table 26). Furthermore, unlike Area 5AB, 5CD is not adjacent to Area 3CD. We recommend using Run #5 as the basis for updating quota recommendations (Table 34).

10.4. Area 5E

Area 5E Commercial CPUE

The final CPUE sample size for Area 5E was 700 records and included five *catch-target* categories (Tables 27 and 28). Results from seven vessels were included in the analysis. The baseline ANOVA fit to the 5E data indicates that all main effects were significant and met the AIC criterion for inclusion, except for year (Tables 29 and 30).

Reducing the “coldspot” threshold to <1 kg/h from <5 kg/h had no impact. We again attempted to demonstrate the effect of increased avoidance in FY2001, by removing tows from areas known to exhibit high catch rates (>500 kg/h). In this case, the FY2001 estimate turned upwards, possibly reflecting that catch rates did not decline in fishing locations where silvergray rockfish was not being actively avoided (Fig. 48). Surprisingly, 5E was the only area where catches were not significantly reduced. More stringent removal of hotspots (>200 kg/h) started to lead to instability in the index owing to the reduction in the number of records. Using all tows did not influence the index.

We used the points derived from the baseline run with removal of all coldspots (<5 kg/h) but we remain suspicious about the increase in CPUE in FY1996 and the decline in CPUE in FY2001. We note also, that the GLM analysis indicated that “year” did not meet the AIC criterion for acceptance in the model.

Proportion at age data

Sample data was updated with samples from 2000 and 2001. Most samples have traditionally come from either the Frederick Spit (north-western tip of the Queen Charlotte Islands) or the Hogback (central west coast of the Queen Charlotte Islands) localities (Fig. 49). As noted by fishing skippers (Reg Richards, pers. comm.), the source of age samples has shifted towards the Hogback locality in the last two years (Fig. 8 and 9) and there was concern that this shift might reduce comparability in age samples over time. We note however, that the general age composition seems comparable between these two areas (Fig. 49).

Two “special” samples collected in 2001 emphasise the heterogeneity among age samples that is possible in silvergray rockfish (Fig. 28, first two samples of 2001 from 189 and 203 m). The two samples were obtained when a fishing captain was attempting to obtain “rare” 5E canary rockfish samples for the senior author. They were captured in the Frederick Spit locality in a spot that the fishing captain said has rarely been fished (Reg Richards, pers. comm.). It is noteworthy how much these two samples differ from other samples taken in the same years and in close proximity.

Of more importance in the age data, is a change in the proportion at age in the recently aged 2000 and 2001 samples. While previous years have been relatively consistent in identifying a large recruitment event centred on the 1981 year class, recent age data indicates that the mode has stalled at 18 years of age (Table 31). A similar change can be seen in other stocks. We noted earlier that ageing precision is low. Given the difficulty in ageing, we suspect the change in the age composition may have resulted from changing the individuals who conducted the ageing. We were not able to examine this issue in time for this report.

Catch at age analysis

The 5E model was also tuned to commercial CPUE over the same combinations of relative error in the CPUE index and recruitment (Tables 32 and 33, Figs. 50-51). The nine runs tend to bracket the prediction for B_{1999} of 4,629 t (3,327-6,227 t). Removing older age samples tended to reduce the estimate of current biomass. All the runs indicate a relatively stable biomass over the last decade. We note that the fishery is currently dependent on the recruitment centred on the 1981 (and/or 1982) year class.

As there was some evidence of avoidance in the analysis of CPUE in Area 5E, we ran the model without the FY2001 CPUE estimate. This resulted in a higher terminal biomass. Including the “special” 2001 age samples had no effect. Removing older samples led to a prediction of lower terminal biomass.

Summary comments on Area 5E

The outcome of Run #5 is not distinguishable from the previously reported stock status (Fig. 52). We see no basis for changing the advice of the previous assessment (Table 33 and 34).

11. Summary of environmental considerations and expectation of future recruitment

An examination of groundfish recruitment trends for the northeast Pacific Ocean suggested a period of overall good recruitment from 1977-1989 followed by poor recruitment in the 1990’s (Beamish *et al*. 1999). This implies that for the last decade the silvergray rockfish fishery off B.C. has benefited from a period of good recruitment but is now entering a period that will suffer from relatively poor recruitment from the cohorts of the 1990’s. These conclusions roughly correspond to recruitment trends observed for U.S. stocks of canary rockfish (Crone *et al.* 1999) and widow rockfish (Ralston and Pearson 1997), which indicate strong recruitment in late 1970’s and early 1980’s and declining recruitment since. The U.S. yellowtail rockfish assessment (Tagart et al. 2000) suggested good recruitment in 1990 followed by poor recruitment from 1991 to 1994. Conversely, a recent POP assessment for waters of Oregon and Washington indicates relatively strong year classes being produced in the early 1990’s in comparison with the two previous decades (Ianelli *et al.* 2000).

There is growing evidence of a regime shift in 1998 but it is too early to evaluate its impact on late recruiting silvergray rockfish (McFarlane *et al*. 2000). Furthermore, its impact on the fishery is still a decade away. In summary, current large-scale reviews of environmental change appear to predict poor recruitment from the 1990’s cohorts of groundfish.

12. Summary of harvest advice

The principal intent of this assessment update was to re-examine these stocks for evidence that the stocks were significantly underestimated. While the large uncertainty in the model estimates in both years preclude the opportunity to observe a “statistically significant” result, we have reported substantial changes in three of the four stocks. For the 3CD stock, the decrease in biomass results largely from the addition of a low 2001 survey estimate. It acts both to scale the overall biomass down, as well as indicate a decline in biomass over the last two years. The increased biomass estimates for 5AB and 5CD result from an upward scaling of the overall biomass trend.

Removal of older samples had a major influence on the model’s attempts to reconstruct the early biomass estimates. However, as emphasised in the previous document, for these reasons and others, we advised managers not to choose harvest strategies based on the reconstructed declines in spawning biomass. Rather, we continue to urge managers to use the most recent estimates of biomass (and *F*). Deleting the older samples typically had a mixed and smaller impact on current biomass estimates.

If managers wish to modify harvest rates based on this assessment, we present an updated set of recommendations (Table 34). We recommend that this species be assessed in four years but note that there is no current plan to continue the U.S. survey in 3CD. While it is apparent from the examination of the U.S. survey data that silvergray rockfish are a problematic species for bottom trawl swept-area surveys, we see no alternative indexing tool over the longer term and recommend that more research effort be directed towards developing monitoring surveys. We expect that even with complex GLM treatments of commercial catch data, the underlying relationship between commercial CPUE and abundance will always be evolving in an unknown manner over time. We provide no forecasting of biomass, we believe the advice presented in this document will be sufficient to determine the next four years' harvest. As noted in the reviews, however, we comment that there is a significant likelihood of poor recruitment over the next 5-10 years; therefore these stocks should continue to be assessed on a regular basis.

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Table 1. Summary of quota recommendations (Rec. Quota), quotas and total landings of silvergray rockfish (nr=no recommendation, na=not available). Trawl quotas are included for combined areas only. FY1966 includes January-March landings for 1997. FY1997-FY2001 represents April-March. FY1996-2001 totals represent a merged value from DMP estimates of retained catch and at-sea observer estimates of discards. A small amount of landings which could not be assigned to major area were omitted (see Table 2).

Year	3CD			5AB			5CD			5E			Coastwide		
	Rec. Quota	Trawl quota	Total Ldgs.	Rec. Quota	Trawl quota	Total Ldgs.	Rec. Quota	Trawl quota	Total Ldgs.	Rec. Quota	Trawl quota	Total Ldgs.	H&L Quota	Trawl quota	Total Ldgs.
1965												2,053			2,053
1966												1,344			1,344
1967			335			525			13			669			1,542
1968			267			1,030			6			755			2,059
1969			363			1,369			0			359			2,091
1970			384			203			0			157			744
1971			186			543			36			258			1,023
1972			464			343			74			378			1,259
1973			259			311			37			349			956
1974			248			627			81			239			1,195
1975			135			431			42			245			853
1976			341			664			134			294			1,433
1977			1,063			652			236			166			2,117
1978			994			780			235			36			2,045
1979	250		1,270	600		927	300		429	350		132			2,758
1980	300		787	600		776	300		346	750		59			1,968
1981	300		299	600		415	500		456	750		106			1,276
1982	200		189	600		618	600		259	450		95			1,161
1983	na		646	na		524	Na	300	451	na		43			1,664
1984	na		570	na		982	300-1000	600	647	450		378			2,577
1985	150-900		921	400-1200		997	300-1000	600	1,043	450		323			3,284
1986	150-900		1,093	400-1100		700	300-900		1,082	450		384			3,259
1987	150-900		604	400-1100		1,224	300-900	600	763	nr		380			2,971
1988	275-550		1,197	700-1000		1,051	400-1000	600	893	200-400		386			3,527
1989	400-600	500	857	700-1000	850	809	500-800	650	743	nr		453		2,125	2,862
1990	400-600		654	700-850		730	400-600		587	nr		232		1,900	2,203
1991	400-600		421	200-700		595	400-600		320	nr		123		1,575	1,459
1992	400-600		514	200-700		641	400-600		347	nr		141		1,575	1,643
1993	150-425		474	375-725		520	150-425		478	nr		285		1,275	1,757
1994	150-425		557	375-725		976	150-425		1,049	nr		375			2,957
1995	150-425		462	375-725		870	150-425		588	nr		337		1,446	2,257

Table 1 cont'd

1996	150-425		288	350-700		611	125-400		393	nr		365		1,075	1,689
FY1997	150-425	331	264	350-700	604	427	125-400	302	298	175-300	273	301			1,319
FY1998	150-425	331	246	350-700	604	475	125-400	302	418	175-300	273	281	138		1,440
FY1999	150-425	328	391	350-700	599	582	125-400	300	420	175-300	271	312	137		1,712
FY2000	150-425	301	309	350-700	549	425	125-400	275	419	175-300	248	267	129		1,429
FY2001	302	272	248	422	503	415	287	248	300	270	224	271	155	1,247	1,240
FY2002		272			443			248			224			1,187	
5-y mean			292			465			371			286			1,428
10-y mean			375			594			471			294			1,744
20-y mean			545			709			575			287			2,121

Table 2. Summary of silvergray rockfish catches by gear, FY1996-FY2001 and stock

Year						
3CD						
	Trawl	ZN	Sched II	Halibut	Line total	Total
1996	282.76	5.36	0.00	0.31	5.67	288.43
1997	259.03	4.41	0.01	0.21	4.63	263.66
1998	244.82	1.51	0.02	0.10	1.63	246.45
1999	376.73	14.31	0.02	0.54	14.87	391.60
2000	299.99	6.73	0.00	1.81	8.54	308.53
2001	244.98	2.27		0.69	2.96	247.94
5AB						
	Trawl	ZN	Sched II	Halibut	Line total	Total
1996	594.52	16.30	0.03	0.58	16.91	611.43
1997	418.70	7.69	0.01	0.24	7.94	426.64
1998	460.56	13.77	0.01	0.59	14.37	474.93
1999	561.36	19.26	0.01	0.89	20.16	581.52
2000	389.43	33.68	0.00	1.74	35.42	424.85
2001	361.56	52.79		1.02	53.81	415.37
5CD						
	Trawl	ZN	Sched II	Halibut	Line total	Total
1996	387.13	4.21	0.00	1.57	5.78	392.91
1997	296.06	1.17	0.00	1.04	2.21	298.27
1998	413.72	2.49	0.01	1.87	4.37	418.09
1999	412.02	5.53	0.01	2.41	7.95	419.97
2000	406.85	2.29	0.00	9.45	11.74	418.59
2001	282.17	4.17		13.19	17.36	299.53
5E						
	Trawl	ZN	Sched II	Halibut	Line total	Total
1996	306.06	57.05	0.26	1.28	58.59	364.65
1997	281.83	18.22	0.00	0.91	19.13	300.96
1998	252.17	27.07	0.40	1.36	28.83	281.00
1999	265.52	44.54	0.01	2.41	46.96	312.48
2000	215.85	38.55	0.00	12.57	51.12	266.97
2001	219.63	41.16		10.33	51.49	271.12
UNK						
	Trawl	ZN	Sched II	Halibut	Line total	Total
1996	16.49	14.99			14.99	31.48
1997	13.15	16.70			16.70	29.85
1998	1.51	17.75			17.75	19.26
1999	1.59	5.45			5.45	7.04
2000	2.97	7.33			7.33	10.30
2001	2.81	3.32			3.32	6.13

1996 = all of 1996 until March 31, 1997
All other years are fishing year, April 1 – March 31
Trawl catches from PacHarvTrawl, D_Official_Catch (merge of logs & DMP)
ZN 1996-2000 from PacHarvHL, D_Official_Catch
ZN and Schedule II 2001 from PacHarvHL, D_Official_Catch
Schedule II 1996-2000 from PacHarvHL, Fisherlogs
Halibut fishery 1996-1997, 2000-2001 from Pacharv3 (landings from salmon fishery as well)
Halibut fishery 1998, 1999 from PacHarvHL DMP data

Table 3. Data sources for the silvergray rockfish assessment

Catch and landings data used in catch at age analysis

1) U.S. trawl landings 1967-1982 from Tagart and Kimura (1982)

2) Canadian trawl landings from 1954 to 1995 from GFCATCH (Rutherford, 1999).

3) Canadian trawl and hook-and-line landings from FY1996-FY2001 stored in SQL-Server database, Groundfish Section, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station.

4) Non-North American vessel landings pre-1976, see Stanley and Kronlund (2000).

Biological data used in catch at age analysis

1) Data stored in GFBio ORACLE database. Groundfish Section, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station. User guide available on Fisheries and Oceans, Canada-Intranet.

Table 4. *Catch-target* species used in the GLM

Common name	**Latin name**
Dogfish	*Squalis acanthius*
Big skate	*Raja binoculata*
Pacific cod	*Gadus macrocephalus*
Rougheye rockfish	*Sebastes aleutianus*
Pacific ocean perch	*Sebastes alutus*
Redbanded rockfish	*Sebastes babcocki*
Silvergray rockfish	*Sebastes brevispinis*
Yellowtail rockfish	*Sebastes flavidus*
Bocaccio	*Sebastes paucispinis*
Canary rockfish	*Sebastes pinniger*
Redstripe rockfish	*Sebastes proriger*
Yellowmouth rockfish	*Sebastes reedi*
Shortspine thornyhead	*Sebastolobus alascanus*
Longspine thornyhead	*Sebastolobus altivelis*
Sablefish	*Anoplopoma fimbria*
Lingcod	*Ophiodon elongatus*
Arrowtooth flounder	*Atheresthes stomias*
Petrale sole	*Eopsetta jordani*
Rock sole	*Pleuronectes bilineata*
Dover sole	*Microstomus pacificus*
English sole	*Pleuronectes vetulus*

Table 5. Silvergray rockfish biomass estimates (t) from the U.S. triennial survey.

Year	N. Cal.	Ore.-S. Wash.	N. Wash.	**Can. 3CD**	CV %	Total US Area	CV %	Total Survey	CV %	Northern extent of survey
1977	0	540	14,082			14,622	90			US only
1980	0	473	864	**7,121**	87	1,337	47	8,458	74	49°15'
1983	0	527	3,779	**858**	56	4,307	75	5,165	63	49°15'
1986	0	111	175			565	50			US only
1989	0	46	1,012	**2,445**	45	1,058	42	3,503	39	49°40'
1992	0	70	524	**1,699**	76	595	63	2,294	72	49°40'
1995	0	9	92	**647**	42	102	54	749	42	49°40'
1998	0	16	280	**1,146**	51	297	38	1,443	46	49°40'
2001	0	27	81	**321**	50	108	41	429	41	49°06'

Table 6. Number of specimens (N) and samples (n) of aged silvergray rockfish by stock and calendar year.

	3CD		5AB		5CD		5E		Total	
Year	N	n	N	n	N	n	N	n	N	n
1977			166	2	259	3			425	5
1978	99	1	295	3	286	3			680	7
1979			734	8	196	2			930	10
1980			193	2	200	2			393	4
1981			195	5	25	1			220	6
1982	199	1	25	1					224	2
1983					50	2	25	1	75	3
1984										
1985	873	15			339	2			1212	17
1986	623	8	102	4	288	2			1013	14
1987			48	1					48	1
1988			722	8	675	5			1397	13
1989					75	3	25	1	100	4
1990			192	6	287	8	130	5	609	19
1991	102	2	220	4					322	6
1992			175	3	247	4	50	1	472	8
1993					307	5	101	2	408	7
1994	48	1	443	8	539	9	280	5	1310	23
1995			211	4	353	6	269	4	833	14
1996							155	3	155	3
1997	44	1	261	5	126	2	503	13	934	21
1998	301	6	283	5	184	4	506	9	1274	24
1999	333	5	387	7	466	9	314	6	1500	27
2000	198	4	280	4	232	4	853	14	1563	26
2001	255	5	125	2	242	4	402	9	1024	20

Table 7. Estimate of growth parameters (see Stanley and Kronlund 2000 for details of the growth model).

Equation	Parameter	Males	Females	Sexes Combined
Length/Weight (ln scale)	a	-2.506	-4.000	-3.634
	b	2.547	2.924	2.833
Length-at-age	y_1	47.887	48.985	48.468
	y_2	56.108	60.628	57.719
	a	0.0708	0.0581	0.0709
	b	1.000	1.0000	1.000
	t_0	-11.610	-12.362	-10.309
	y_∞	56.462	61.549	58.115
	s^2	6.0475	8.7500	8.637
	t_1	15.000	15.000	15.000
	t_2	60.000	60.000	60.000

Table 8. Proportion mature and fecundity (eggs) at age for silvergray rockfish to age 40 (nd=no data).

Age	% Mature		Fecundity
	Males	Females	
4	0.229	0.079	nd
5	0.266	0.163	nd
6	0.322	0.296	nd
7	0.398	0.460	nd
8	0.487	0.620	nd
9	0.587	0.744	nd
10	0.682	0.831	nd
11	0.773	0.888	nd
12	0.852	0.924	493,282
13	0.908	0.946	533,733
14	0.941	0.960	574,152
15	0.960	0.970	614,475
16	0.973	0.977	654,762
17	0.982	0.982	695,081
18	0.988	0.985	735,398
19	0.992	0.987	775,704
20	0.995	0.988	816,100
21	0.996	0.989	857,098
22	0.997	0.990	898,549
23	0.998	0.990	939,559
24	0.999	0.991	979,801
25	0.999	0.992	1,019,451
26	0.999	0.993	1,058,380
27	0.999	0.993	1,091,572
28	0.999	0.994	1,118,438
29	0.999	0.995	1,145,479
30	0.998	0.995	1,170,885
31	0.998	0.995	1,189,743
32	0.997	0.994	1,203,896
33	0.996	0.994	1,219,309
34	0.994	0.995	1,235,096
35	0.992	0.996	1,242,823
36	0.991	0.997	1,245,364
37	0.990	0.998	1,249,554
38	0.991	0.998	1,252,895
39	0.992	0.997	1,254,546
40	0.994	0.997	1,255,775

Table 9. The effect of data filtering on the number of observations used to conduct GLM of trawl catch data for Area 3CD.

Records remaining after general screening	98,022
Records remaining after removing Jan-Mar/1997 and depth=0-50m	95,153
Records remaining after removing other areas	13,523
Records remaining after removal of "Coldspots"<5 kg/h	5,164
Records remaining after removing minor *catch-targets*	4,917
After removing minor vessels	3,723

Table 10. Number of observations by *catch-target* for Area 3CD.

Common name	FY1996	FY1997	FY1998	FY1999	FY2000	FY2001
Dogfish	3	6	5	5	10	6
Pacific cod	7	23	11	15	18	19
Rougheye rockfish	1	1	1	8	10	3
Pacific ocean perch	12	66	50	96	56	44
Redbanded rockfish	3	2	6	5	12	4
Silvergray rockfish	40	45	89	94	78	62
Yellowtail rockfish	9	38	47	51	48	43
Bocaccio	2	1	3	3	5	4
Canary rockfish	17	45	43	59	68	57
Redstripe rockfish	18	18	9	27	30	53
Yellowmouth rockfish	13	11	13	27	14	18
Shortspine thornyhead	2	0	2	13	2	3
Longspine thornyhead	7	0	30	51	11	11
Sablefish	5	6	10	12	10	5
Lingcod	90	72	71	83	208	73
Arrowtooth flounder	44	40	71	51	38	38
Petrale sole	3	6	13	17	12	8
Rock sole	3	7	8	12	24	24
Dover sole	86	89	119	210	162	135
English sole	3	1	0	8	2	2

Table 11. ANOVA results for Area 3CD (terms added sequentially, first to last).

	Df	Deviance	Resid. Df	Resid. Dev	$Pr(\chi)$
NULL			3722	25612.9	
catch-target	19	13941.98	3703	11670.92	0
depth	6	2107.68	3697	9563.23	0
boat	32	476.73	3665	9086.5	0
month	11	132.45	3654	8954.05	0
year	5	114.63	3649	8839.42	0

Table 12. AIC table for baseline GLM of Area 3CD

	Df	Sum of Sq	RSS	AIC
<none>			8839.42	9197.94
catch-target	19	3567.816	12407.24	12673.71
depth	6	1451.421	10290.84	10620.29
boat	32	373.943	9213.37	9416.85
month	11	104.58	8944	9249.23
year	5	114.632	8954.05	9288.35

Table 13. Results from 3CD catch at age model runs under varying assumptions of recruitment variation (relative error) and the relative error in the abundance indices.

Run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Tuning Index	Survey	Survey	Survey	Survey	Survey	Survey	CPUE	CPUE	CPUE	CPUE
Index relative error	100%	100%	100%	50%	50%	50%	100%	50%	25%	50%
Recruitment relative error	25%	50%	100%	25%	50%	100%	25%	50%	100%	50%
										Omit 2001 survey
Total -ln L	-134.221	-105.9	-76.0322	-133.411	-106.215	-76.485	-135.589	-110.943	-83.1656	-107.361
Recruitment -ln L	-108.961	-69.2542	-33.2786	-107.855	-68.9199	-33.3508	-109.01	-69.4654	-33.6725	-69.7036
Stock Index -ln L	1.48783	1.33361	1.24664	1.56733	0.910396	0.747278	0.129781	-3.65037	-6.19332	-0.183345
Age -ln L	-26.7483	-37.9795	-44.0002	-27.1242	-38.2056	-43.8814	-26.7085	-37.8273	-43.2998	-37.4744
alpha	2.87639	2.87964	3.04748	2.94216	2.96524	3.07931	2.85233	2.84025	2.91763	2.85993
Beta	0.0104670	0.0036439	0.0062979	0.0099044	0.0042957	0.0053067	0.0106204	0.0034470	0.0024628	0.0015480
M	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
q1	1.001	1.00051	1.00061	1.00141	1.00179	1.00054	1.00114	1.001	1.00132	1.00147
q2	0.229292	0.303611	0.433854	0.241887	0.334272	0.417003	0.303487	0.441939	0.608629	0.295392
R	0.46839	0.411021	0.327692	0.45423	0.388782	0.332297	0.473016	0.423933	0.371876	0.460714
gamma	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
rho	0.015	0.059	0.2	0.059	0.2	0.5	0.015	0.2	0.8	0.2
kapSq	1.016	1.063	1.25	0.266	0.313	0.5	1.016	0.313	0.313	0.313
sigma1	0.12345	0.250434	0.5	0.125276	0.2502	0.5	0.12345	0.2502	0.5004	0.2502
tau1	1.00038	1.00014	1	0.500306	0.5004	0.5	1.00038	0.5004	0.2502	0.5004
tau2	0.5126	0.4777	0.4599	0.5114	0.4770	0.4603	0.5127	0.4781	0.4619	0.4792
F_{2001}	**0.0611**	**0.1025**	**0.2557**	**0.0679**	**0.1286**	**0.2298**	**0.0591**	**0.0905**	**0.1364**	**0.0648**
B_{2001}	4.18734	2.54547	1.09913	3.77785	2.05529	1.20794	4.32381	2.86741	1.94496	3.95278
SpB_{2001}	3.46601	2.23693	0.961838	3.1192	1.79941	1.04399	3.58415	2.51737	1.69386	3.40291
Catch	0.248	0.248	0.248	0.248	0.248	0.248	0.248	0.248	0.248	0.248
Log B_{2001}	1.432	0.934	0.0945	1.329	0.72	0.189	1.464	1.053	0.665	1.37
Log St. dev B_{2001}	0.344	0.634	0.665	0.3424	0.511	0.52	0.345	0.6414	0.54076	0.567
St. dev B_{2001}	1.4106	1.8851	1.9445	1.4083	1.6670	1.6820	1.4120	1.8991	1.7173	1.7630
Rel Error of B_{2001}	34%	74%	177%	37%	81%	139%	33%	66%	88%	45%

Table 14. Summary of biomass estimates and quota recommendations for Area 3CD. The quotas shown assume a 88.43%/11.57%, trawl/hook-and-line allocation (Fisheries and Oceans, 2002). Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery. The harvest value for 1999 comes from the previous assessment. Column numbers correspond to runs from Table 13.

Statistic		Previous Assessment (1999)	**1** Survey	**5** Survey	**6** Survey	**7** CPUE	**10** Omit 2001 survey point
Index Rel. Error			≈100%	≈50%	≈50%	≈100%	≈50%
Recruitment Rel. error			≈25%	≈50%	≈100%	≈25%	≈50%
20-y mean catch (t)	545 t						
10-y mean catch (t)	375 t						
Rec. quota (t)		296					
FY2001 Trawl Quota (t)		272					
FY2001 HL Quota (t) coastwide		(155)					
Biomass in last year (t)		$5,190_{1999}$	4,187	2,055	1,208	4,324	3,953
Rel. Error. Biomass		$26\%_{1999}$	34%	81%	139%	33%	45%
F in last year		0.070	0.061	0.129	0.230	0.059	0.065
All gear Harvest (t)		330	248	248	248	248	248
2003 @ *F*=0.06 (u=0.0582)			244	120	70	251	230

Table 15. Table 15. The effect of data filtering on the number of observations used for conducting GLM on trawl catch data for Area 5AB.

Records remaining after general screening	98,022
Records remaining after removing Jan-Mar/1997 and depth=0-50m	95,153
Records remaining after removing other areas	67,121
Records remaining after removal of “Coldspots”<5 kg/h	39,408
Records remaining after removing minor and unknown *catch-targets*	37,781
Final number after removing minor vessels	29,239

Table 16. Number of observations by *catch-target* for Area 5AB.

Common Name	FY1996	FY1997	FY1998	FY1999	FY2000	FY2001
Big skate	36	78	87	182	122	119
Pacific cod	121	258	209	197	148	88
Rougheye rockfish	136	49	57	63	78	59
Pacific ocean perch	334	665	747	873	1007	911
Redbanded rockfish	63	74	31	73	57	40
Silvergray rockfish	243	264	288	393	273	188
Yellowtail rockfish	450	775	856	685	644	672
Canary rockfish	67	161	187	215	200	239
Redstripe rockfish	104	170	159	200	296	211
Yellowmouth rockfish	205	469	382	416	406	373
Shortspine thornyhead	26	21	10	9	46	37
Longspine rockfish	16	13	24	14	36	42
Sablefish	5	9	21	26	23	19
Lingcod	450	575	516	745	1154	798
Arrowtooth flounder	360	331	540	497	647	873
Petrale sole	45	101	176	150	159	125
Rock sole	131	189	183	210	255	279
Dover sole	271	214	311	322	345	323
English sole	108	156	140	146	135	126

Table 17. ANOVA results for Area 5AB (terms added sequentially, first to last).

	Df	Deviance	Resid. Df	Resid.	$Pr(\chi)$
NULL			29635	166268.8	
catch-target	18	65476.45	29617	100792.3	0
depth	6	5316.22	29611	95476.1	0
month	11	783.29	29600	94692.8	0
boat	44	1730.27	29556	92962.5	0
year	5	343.55	29551	92619.0	0

Table 18. AIC table for baseline GLM of Area 5AB

	Df	Sum of Sq	RSS	AIC
<none>			92619.0	93151.8
catch-target	18	36909.47	129528.5	129948.4
depth	6	5905.40	98524.4	99019.6
month	11	833.08	93452.1	93915.9
boat	44	1651.50	94270.5	94527.5
year	5	343.55	92962.5	93664.0

Table 19. Results from 5AB catch at age model runs under varying assumptions of recruitment variation (relative error) and the relative error in the abundance indices.

Run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Tuning Index	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE
Index relative error	100%	100%	100%	50%	50%	50%	25%	25%	25%	50%
Recruitment relative error	25%	50%	100%	25%	50%	100%	25%	50%	100%	50%
										New ages only
Total -ln L	-155.37	-126.604	1.2643	-41.3934	-130.563	-97.428	-44.9997	-134.202	-101.002	-114.591
Recruitment -ln L	-88.2493	-52.8765	-17.8462	-92.5019	-52.8079	-17.1008	-92.5321	-52.843	-17.0509	-52.6716
Stock Index -ln L	0.0486277	0.0492853	0.0501535	-3.95864	-3.96599	-3.97487	-7.54553	-7.56357	-7.58927	-3.95065
Age -ln L	-67.1696	-73.7771	49.0604	55.0672	-73.7887	-76.3451	55.0779	-73.7953	-76.3615	-57.9685
alpha	3.44618	3.47834	4.54541	4.70271	3.48129	3.5356	4.73636	3.49157	3.54155	2.44112
Beta	0.0838808	0.0824797	1.00E-11	1.00E-11	0.0826221	0.0840797	1.00E-11	0.0831497	0.0844681	0.0872829
M	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
q1	10.0023	10.0058	10.0021	10.0032	10.0011	10.0021	10.0067	10.0016	10.0013	10.006
q2	0.142838	0.146512	0.108992	0.117467	0.147571	0.174883	0.120157	0.151353	0.177328	0.149508
R	0.681879	0.662965	0.749215	0.757217	0.660959	0.608606	0.748372	0.654041	0.605061	0.670794
gamma	0.830318	0.714534	0.665914	0.882741	0.715131	0.58203	0.882548	0.719106	0.588285	0.602526
rho	0.03	0.109	0.329	0.109	0.329	0.662	0.329	0.662	0.887	0.329
kapSq	1.031	1.123	1.49	0.281	0.373	0.74	0.093	0.185	0.553	0.373
sigma1	0.175869	0.349867	0.70015	0.175011	0.35031	0.699914	0.17492	0.349957	0.700365	0.35031
tau1	1.00003	1.0003	0.999895	0.500371	0.500283	0.50012	0.249806	0.25006	0.249978	0.500283
tau2	0.472508	0.461043	0.72788	0.744316	0.461023	0.456662	0.744346	0.461012	0.456635	0.288464
F_{2001}	0.0500508	0.0516227	0.0374788	0.0408624	0.0520534	0.0633344	0.041966	0.0536006	0.0643997	0.0510284
B_{2001}	8.50081	8.24839	11.2817	10.3649	8.18188	6.76221	10.0979	7.9518	6.65386	8.34199
SpB_{2001}	5.71448	5.46727	7.26446	6.71563	5.421	4.41804	6.52505	5.2611	4.34059	6.09266
Catch	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415
Log B_{2001}	2.1402				2.102				1.895	2.121
Log St dev B_{2001}	0.44089				0.56687				0.7575	0.478
B_{2001}	8.501				8.183				6.653	8.339
St dev. B_{2001}	1.554				1.763				2.133	1.613
Rel Error	18%				22%				32%	19%

Table 20. Summary of model biomass estimates and quota recommendations for Area 5AB. The quotas shown assume a 88.43%/11.57%, trawl/hook-and-line allocation (Fisheries and Oceans, 2002). Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery. The harvest value for 1999 comes from the previous assessment.

Statistic		Previous Assessment (1999)	**1** CPUE	**5** CPUE	**9** CPUE	**10** New ages only
Index Rel. Error			≈100%	≈50%	≈25%	≈50%
Recruitment Rel. error			≈25%	≈50%	≈100%	≈50%
20-y mean catch (t)	709					
10-y mean catch (t)	594					
Rec. quota (t)		422				
FY2001 Trawl Quota (t)		443 (to be reduced in 2002 and 2003)				
FY2001 HL Quota (t) coastwide		(155)				
Biomass in last year (t)		$7,246_{1999}$	8,501	8,182	6,654	8,342
Rel. Error. Biomass		36%	18%	22%	32%	19%
F in last year		0.083	0.050	0.052	0.064	0.051
All gear Harvest (t)		579	415	415	415	415
2003 @ *F*=0.06 (u=0.0582)			495	476	387	486

Table 21. The effect of data filtering on the number of observations used for conducting GLM on trawl catch data for Area 5CD.

Records remaining after general screening	98,022
Records remaining after removing Jan-Mar/1997 and depth=0-50m	95,153
Records remaining after removing other areas	13,049
Records remaining after removal of "Coldspots"<5 kg/h	9,922
Records remaining after removing minor and unknown *catch-targets*	9,609
Final number after removing minor vessels	7,524

Table 22. Number of observations by *catch-target* for Area 5CD.

Common name	1996	1997	1998	1999	2000	2001
Pacific cod	1	2	8	4	5	0
Rougheye rockfish	18	5	2	2	4	3
Pacific ocean perch	541	638	824	974	747	646
Redbanded rockfish	18	10	12	16	22	35
Silvergray rockfish	42	64	77	86	82	66
Yellowtail rockfish	43	42	92	90	63	34
Canary rockfish	7	18	22	32	39	19
Redstripe rockfish	29	10	43	57	63	75
Yellowmouth rockfish	48	54	120	186	170	180
Shortspine thornyhead	2	2	7	1	6	5
Sablefish	1	1	1	4	1	2
Lingcod	77	54	21	1	8	3
Arrowtooth flounder	24	8	45	82	104	143
Petrale sole	5	8	3	24	28	42
Rex sole	2	2	1	5	0	1
Rock sole	2	10	18	25	31	8
Dover sole	18	29	27	53	32	57

Table 23. ANOVA results for Area 5CD (terms added sequentially, first to last).

	DF	Deviance	Resid.	Df Resid.	Pr(χ)
NULL			7523	37861.12	
catch-target	16	12895.44	7507	24965.68	0
depth	6	1833.62	7501	23132.07	0
month	11	611.24	7490	22520.82	0
boat	34	875.12	7456	21645.70	0
year	5	217.00	7451	21428.70	0

Table 24. AIC table for baseline GLM of Area 5CD

	Df	Sum of Sq	RSS	AIC
<none>			21428.70	21848.59
catch-target	16	6402.170	27830.87	28158.73
depth	6	1744.479	23173.18	23558.56
month	11	515.347	21944.05	22300.66
boat	34	789.458	22218.16	22442.48
year	5	216.998	21645.70	22036.83

Table 25. Results from 5CD catch at age model runs under varying assumptions of recruitment variation (relative error) and the relative error in the abundance indices.

Run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Tuning Index	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE
Index relative error	100%	100%	100%	50%	50%	50%	25%	25%	25%	50%
Recruitment relative error	25%	50%	100%	25%	50%	100%	25%	50%	100%	50%
Statistic										New ages only
Total -ln L	-195.307	-179.105	-153.713	-199.368	-182.712	-157.457	-202.033	-185.402	-160.002	-116.348
Recruitment -ln L	-110.292	-76.5514	-44.1042	-110.934	-76.3091	-44.2251	-110.413	-76.3334	-44.2878	-80.9343
Stock Index -ln L	0.109302	0.125063	0.151896	-3.72348	-3.6737	-3.59459	-6.62596	-6.49256	-6.37281	-4.02546
Age -ln L	-85.1243	-102.678	-109.761	-84.7101	-102.73	-109.637	-84.9945	-102.576	-109.341	-31.3885
Alpha	2.94893	3.04282	3.14801	2.9407	3.03078	3.1086	2.91485	2.98561	3.02037	2.64423
Beta	1.21E-08	8.72E-09	7.68E-09	1.21E-08	8.60E-09	7.40E-09	1.18E-08	8.30E-09	6.86E-09	0.0017102
M	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
q1	10.0023	10.0109	10.0045	10.0039	10.0067	10.0019	10.0185	10.0039	10.0026	10.0178
q2	0.181448	0.201817	0.264466	0.178994	0.195636	0.23835	0.169449	0.175388	0.190153	0.141201
Recruitment -ln L	0.558723	0.517736	0.45043	0.562943	0.525493	0.471765	0.578751	0.554543	0.524229	0.57095
Gamma	0.896418	0.832381	0.762344	0.897991	0.830801	0.747089	0.900789	0.831005	0.729185	0.781697
Rho	0.01	0.038	0.138	0.038	0.138	0.39	0.138	0.39	0.719	0.138
KapSq	1.01	1.04	1.16	0.26	0.29	0.41	0.073	0.103	0.223	0.29
sigma1	0.100	0.199	0.400	0.099	0.200	0.400	0.100	0.200	0.400	0.200
tau1	1.000	1.000	1.000	0.500	0.500	0.500	0.251	0.251	0.250	0.500
tau2	0.448	0.420	0.410	0.448	0.420	0.410	0.448	0.420	0.410	0.390
F_{2001}	0.038	0.043	0.058	0.037	0.041	0.052	0.035	0.036	0.040	0.037
B_{2001}	8.14976	7.17958	5.29617	8.27448	7.42942	5.95507	8.78347	8.37444	7.6521	8.15866
SpB_{2001}	5.53821	4.77984	3.49058	5.62863	4.94864	3.93278	5.98265	5.59094	5.0761	5.66987
Catch	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Log B_{2001}	2.098				2.0054				2.035	2.0991
Log Std. Dev. B_{2001}	0.3773				0.45929				0.52307	0.6126
B_{2001}	8.149854				7.429065				7.652252	8.158824
St. dev. B_{2001}	1.458342				1.582950				1.687199	1.845223
Rel Error of B_{2001}	18%				21%				22%	23%

Table 26. Summary of model biomass estimates and quota recommendations for Area 5CD. The quotas shown assume a 88.43%/11.57%, trawl/hook-and-line allocation (Fisheries and Oceans, 2002). Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery). The harvest value for 1999 comes from the previous assessment.

Statistic		Previous Assessment (1999)	(1) CPUE	(5) CPUE	(9) CPUE	(10) New ages only
Index Rel. Error			≈100%	≈50%	≈25%	≈50%
Recruitment Rel. error			≈25%	≈50%	≈100%	≈50%
20-y mean catch (t)	575					
10-y mean catch (t)	417					
Rec. quota (t)		287				
FY2001 Trawl Quota (t)		248				
FY2001 HL Quota (t) coastwide		(155)				
Biomass in last year (t)		$4,936_{1999}$	8,150	7,429	7,652	8,159
Rel. Error. Biomass		$42\%_{1999}$	18%	21%	22%	23%
F in last year		0.066	0.038	.041	0.037	.037
All gear Harvest (t)		316	300	300	300	300
2003 @ *F*=0.06 (u=0.0582)			474	432	445	475

Table 27. The effect of data filtering on the number of observations used for conducting GLM on trawl catch data for Area 5E

Records remaining after general screening	98,022
Records remaining after removing Jan-Mar/1997 and depth=0-50m	95,153
Records remaining after removing other areas	1,460
Records remaining after removal of “Coldspots”<5 kg/h	1,071
Records remaining after removing minor and unknown *catch-targets*	1,006
Final number after removing minor vessels	700

Table 28. Number of observations by *catch target* for Area 5E.

Common name	FY1996	FY1997	FY1998	FY1999	FY2000	FY2001
Rougheye rockfish	11	20	13	2	3	7
Pacific ocean perch	30	24	24	25	52	47
Silvergray rockfish	7	2	9	23	19	12
Redstripe rockfish	18	1	26	34	50	29
Yellowmouth rockfish	5	4	29	52	54	68

Table 29. ANOVA results for Area 5E (terms added sequentially, first to last).

	DF	Deviance	Resid. Df	Resid. Dev.	Pr(χ)
NULL			699	4491.793	0
Catch-target	4	1934.284	695	2557.509	0
depth	4	244.640	691	2312.869	0
month	6	83.080	685	2229.789	0
boat	11	91.181	674	2138.608	0
year	5	20.533	669	2118.075	0.0009

Table 30. AIC table for baseline GLM of Area 5E

	Df	Sum of Sq	RSS	AIC
<none>			2118.075	2314.369
catch-target	4	374.9335	2493.009	2663.974
depth	4	189.4162	2307.491	2478.457
month	6	64.8753	2182.950	2341.252
boat	11	74.2003	2192.275	2318.917
year	5	20.5327	2138.608	2303.241

Table 31. Table 31. Proportion at age for recent Area 5E age samples..

Age	1998	1999	2000	2001
16	0.157	.103	.060	.024
17	**<u>0.206</u>**	.175	.140	.072
18	0.109	**<u>.246</u>**	**<u>.184</u>**	**<u>.222</u>**
19	0.053	.145	.147	.178
20	0.034	.068	.082	.148

Table 32. Results from 5E catch at age model runs under varying assumptions of recruitment variation (relative error) and the relative error in the abundance indices.

Run	1	2	3	4	5	6	7	8	9	10
Tuning Index	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE	CPUE
										New ages only
CPUE index rel. error	100%	100%	100%	50%	50%	50%	25%	25%	25%	50%
Recruitment rel. error	25%	50%	100%	25%	50%	100%	25%	50%	100%	50%
Total -ln L	-83.8767	-55.2548	-29.3847	-80.1034	-53.0972	-26.5201	-82.2504	-55.7402	-29.0888	-104.141
Recruitment -ln L	-132.746	-88.7496	-51.6188	-121.998	-79.343	-43.7693	-121.149	-79.2077	-43.8415	-71.208
Stock Index -ln L	0.144787	0.130694	0.151223	-3.60898	-3.65363	-3.57984	-6.26085	-6.46951	-6.44278	-3.64013
Age -ln L	48.7243	33.3641	22.0829	45.5037	29.8994	20.8291	45.1593	29.9369	21.1963	-29.2932
alpha	3.031	3.031	3.031	3.031	3.031	3.031	3.031	3.031	3.031	3.031
Beta	8.60^{E}-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09	8.60E-09
M	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
q1	10.0107	10.0105	10.0019	10.0063	10.0233	10.0015	10.0242	10.0235	10.0021	10.0073
q2	0.499735	0.374142	0.439114	0.450638	0.342958	0.403799	0.401727	0.281212	0.265113	0.3881
R	0.303174	0.325824	0.289978	0.313775	0.333041	0.296279	0.328878	0.363169	0.353978	0.286832
gamma	0.906771	0.889855	0.861441	0.90774	0.882543	0.845952	0.915776	0.887485	0.840417	0.834005
rho	0.007	0.028	0.104	0.038	0.138	0.39	0.138	0.39	0.719	0.138
kapSq	1.007	1.029	1.116	0.26	0.29	0.41	0.073	0.103	0.223	0.29
sigma1	0.0839583	0.169741	0.340682	0.0993982	0.20005	0.399875	0.100369	0.200425	0.400421	0.20005
tau1	0.999975	1.00009	0.999968	0.50012	0.49998	0.5001	0.250851	0.250659	0.250326	0.49998
tau2	0.852766	0.765915	0.707814	0.833775	0.747581	0.701635	0.831769	0.747777	0.703439	0.391719
F_{2001}	0.0849568	0.0631726	0.0774304	0.0759662	0.0577205	0.070482	0.0667352	0.0463835	0.0441318	0.066067
B_{2001}	3.32727	4.42676	3.63717	3.70459	4.83184	3.98204	4.19784	5.97915	6.27719	4.23888
SpB_{2001}	2.47828	3.07726	2.46111	2.71155	3.31004	2.68076	3.05093	4.06816	4.17667	2.8687
Catch	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271
Log B_{2001}	1.2022				1.575				1.8369	1.444
Log Std Dev. B_{2001}	0.3629				0.6197				0.80287	0.43577
B_{2001}	3.3274292				4.8307416				6.2770492	4.237612
Std Dev. B_{2001}	1.4374921				1.8583704				2.2319374	1.546153
Rel Error of B_{2001}	0.4320128				0.3846967				0.3555711	0.364864

Table 33. Summary of model biomass estimates and quota recommendations for Area 5E. The quotas shown assume a 88.43%/11.57%, trawl/hook-and-line allocation (Fisheries and Oceans, 2002). Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery. The harvest value for 1999 comes from the previous assessment.

Statistic		Previous Assessment (1999)	(1) CPUE	(5) CPUE	(9) CPUE	(10) New ages only
Index Rel. Error			≈100%	≈50%	≈25%	≈50%
Recruitment Rel. error			≈25%	≈50%	≈100%	≈50%
20-y mean catch (t)	287 t					
10-y mean catch (t)	294 t					
Rec. quota (t)		270				
FY2001 Trawl Quota (t)		224				
FY2001 HL Quota (t) coastwide		(155)				
Biomass in last year (t)		$4,629_{1999}$	3,327	4,832	6,277	4,239
Rel. Error. Biomass		$50\%_{1999}$	43%	38%	35%	36%
F in last year		0.055	.085	.058	.044	.066
All gear Harvest (t)		248	271	271	271	271
2003 @ *F*=0.06 (u=0.0582)			193	281	365	247

Table 34. Quota recommendations based on point estimates of "selected" model runs from the current assessment.

	Area 3CD	Area 5AB	Area 5CD	Area 5E
Previous recommendation (t)	296	422	287	270
FY_{2001} Harvest (t)	248	415	300	271
B_{2001} (t)	2,055-4,187	8,182	7,429	4,832
F_{2001}	0.129-0.061	0.052	0.041	0.058
F=M harvest (@0.0582) (t)	148-244	476	432	281

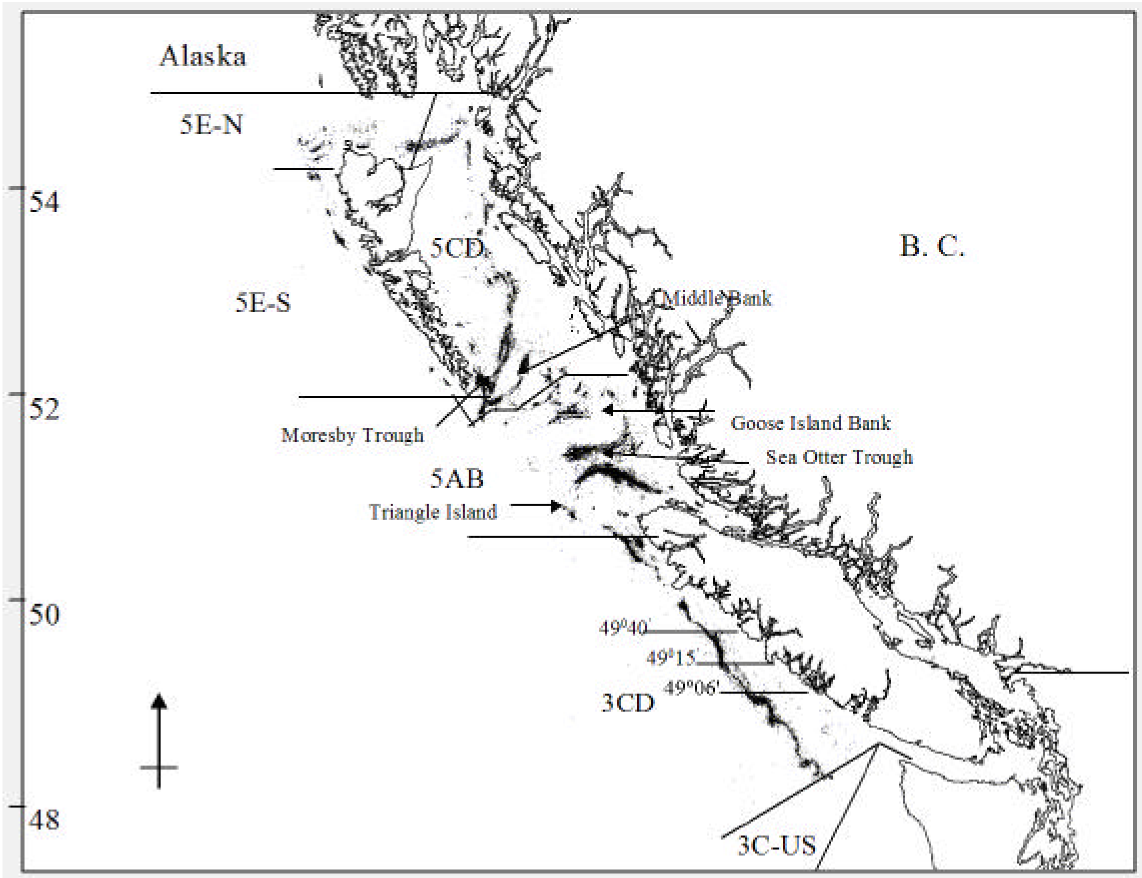


Figure 1. Silvergray rockfish stock boundaries, latitudes of the northern extent of U. S. triennial surveys, and bottom trawl locations with >25 kg of silvergray rockfish, 1996-1999.

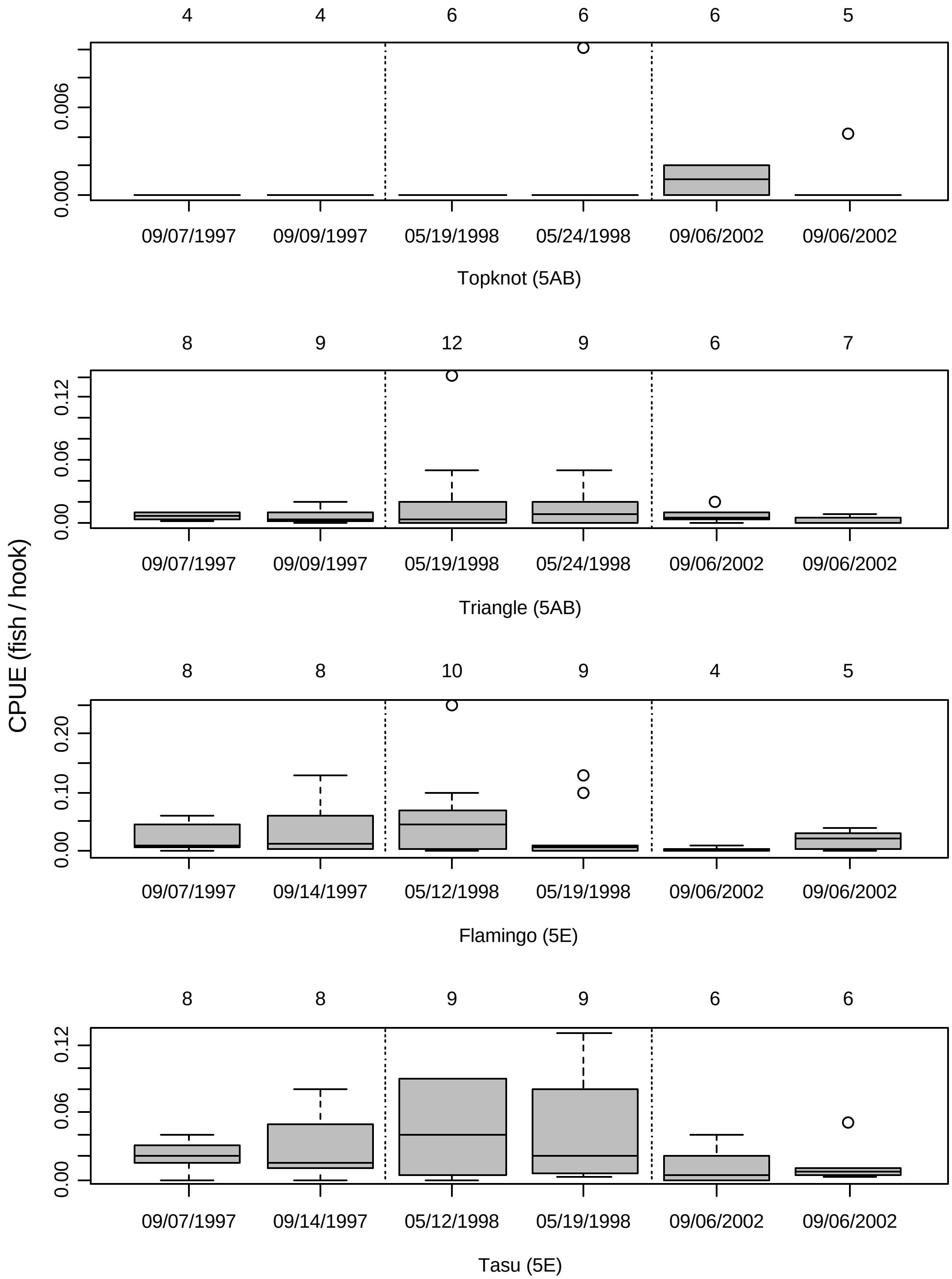


Figure 2. Boxplots of the catch rates (pieces/hook) of silvergray rockfish during hook-and-line yelloweye rockfish surveys 1997, 1998, 2002. The centre line through each box represents the median CPUE while the 2nd and 3rd quartiles are indicated by the lower and upper limits of each box. The “whiskers” on the top and bottom of each box extend to 1.5 times the interquartile range. Any values beyond these are considered outliers and are shown as dots.

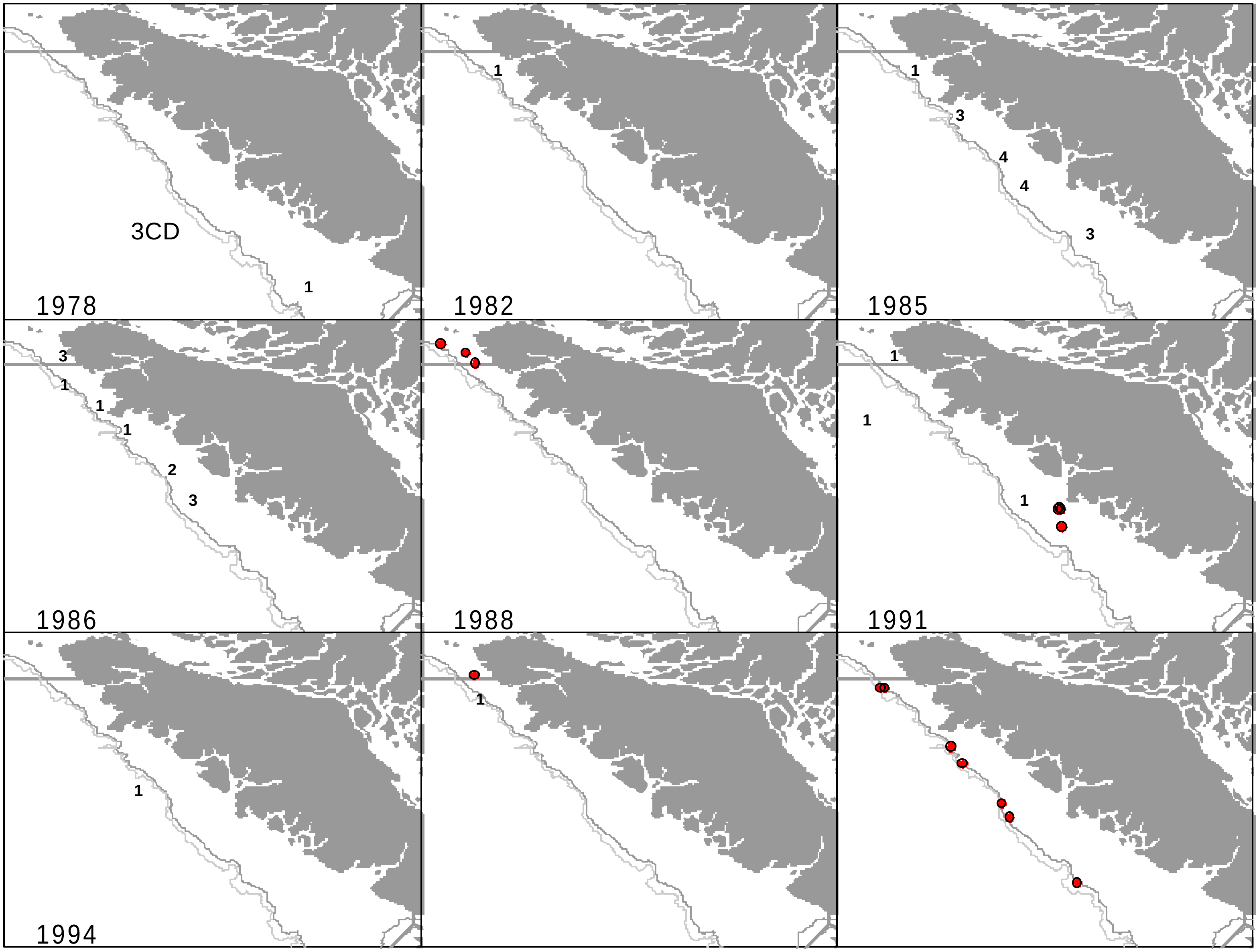


Figure 3. Location of aged samples of silvergray rockfish from Area 3CD (1978-1998). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

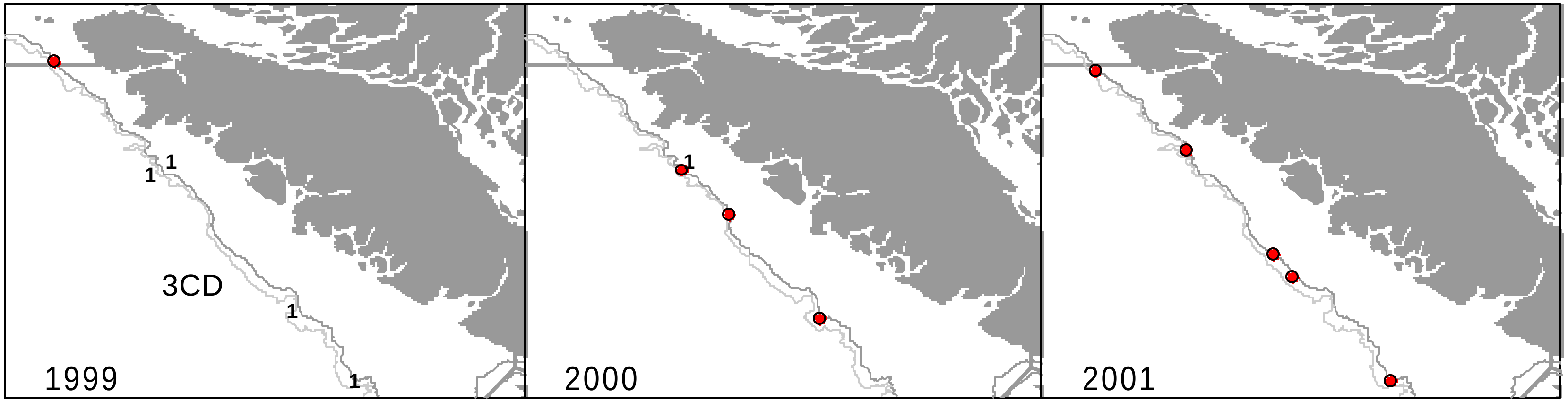


Figure 4. Location of aged samples of silvergray rockfish from Area 3CD (1999-2001). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

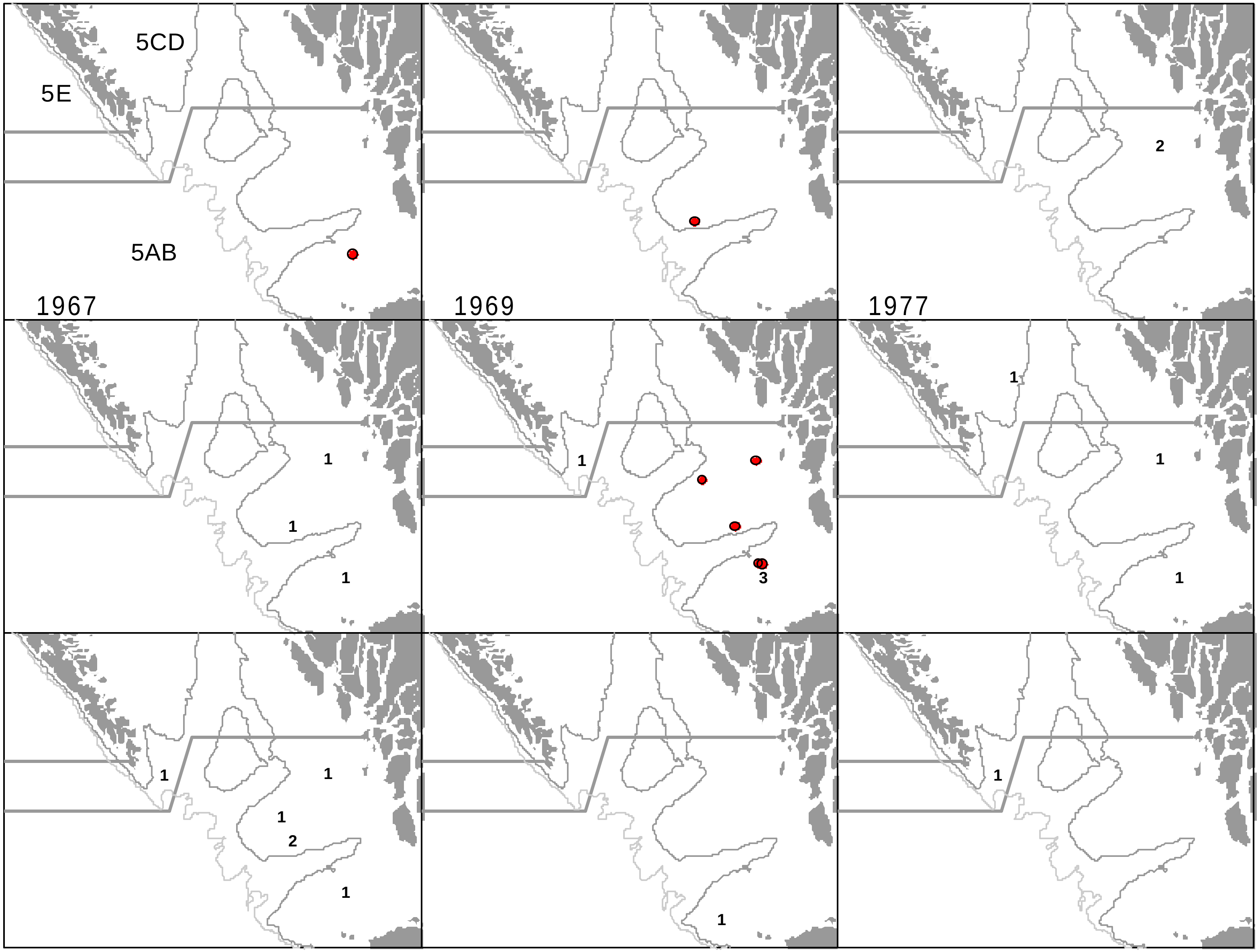


Figure 5. Location of aged samples of silvergray rockfish from Areas 5AB and 5CD (1967-1983). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

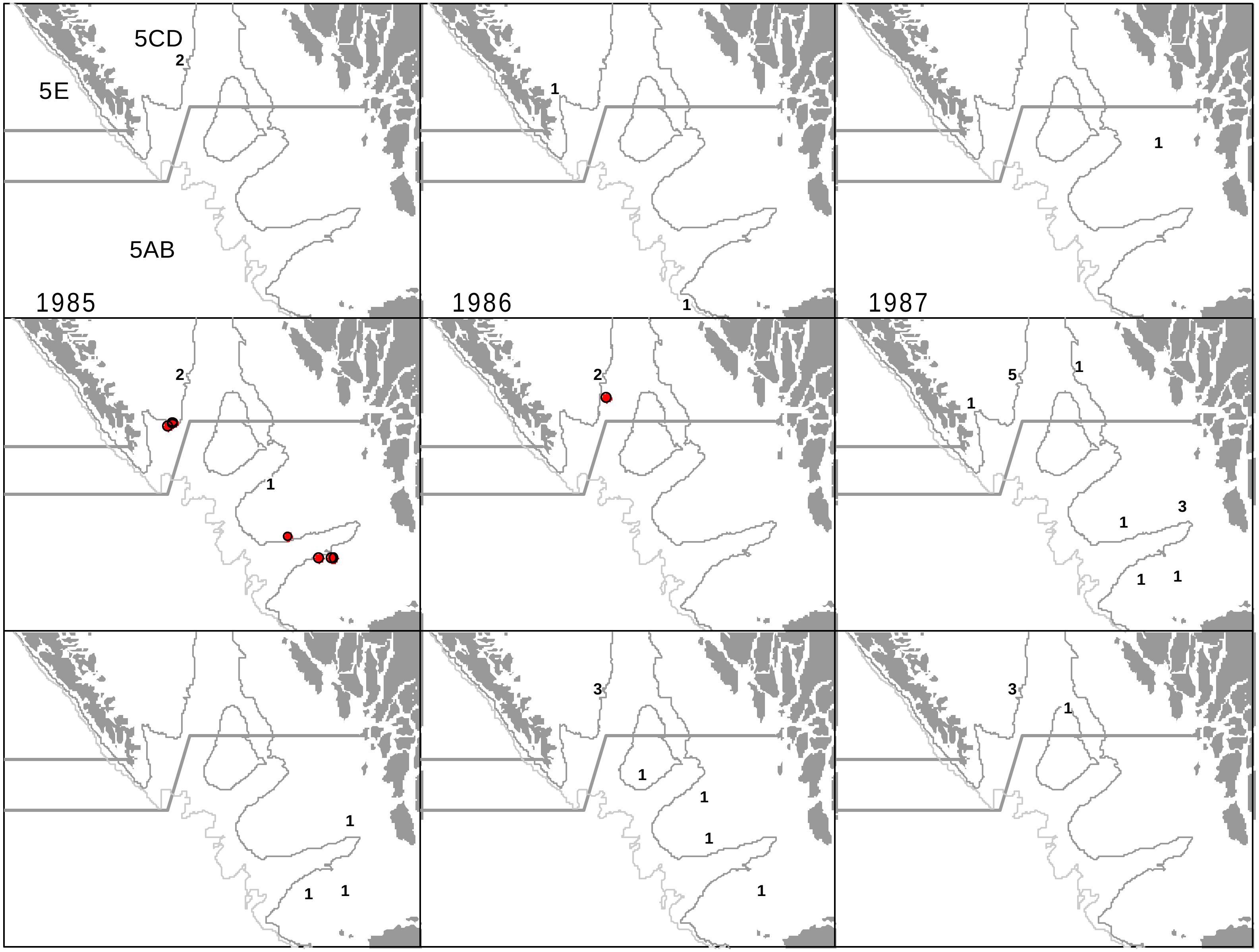


Figure 6. Location of aged samples of silvergray rockfish from Areas 5AB and 5CD (1985-1993). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

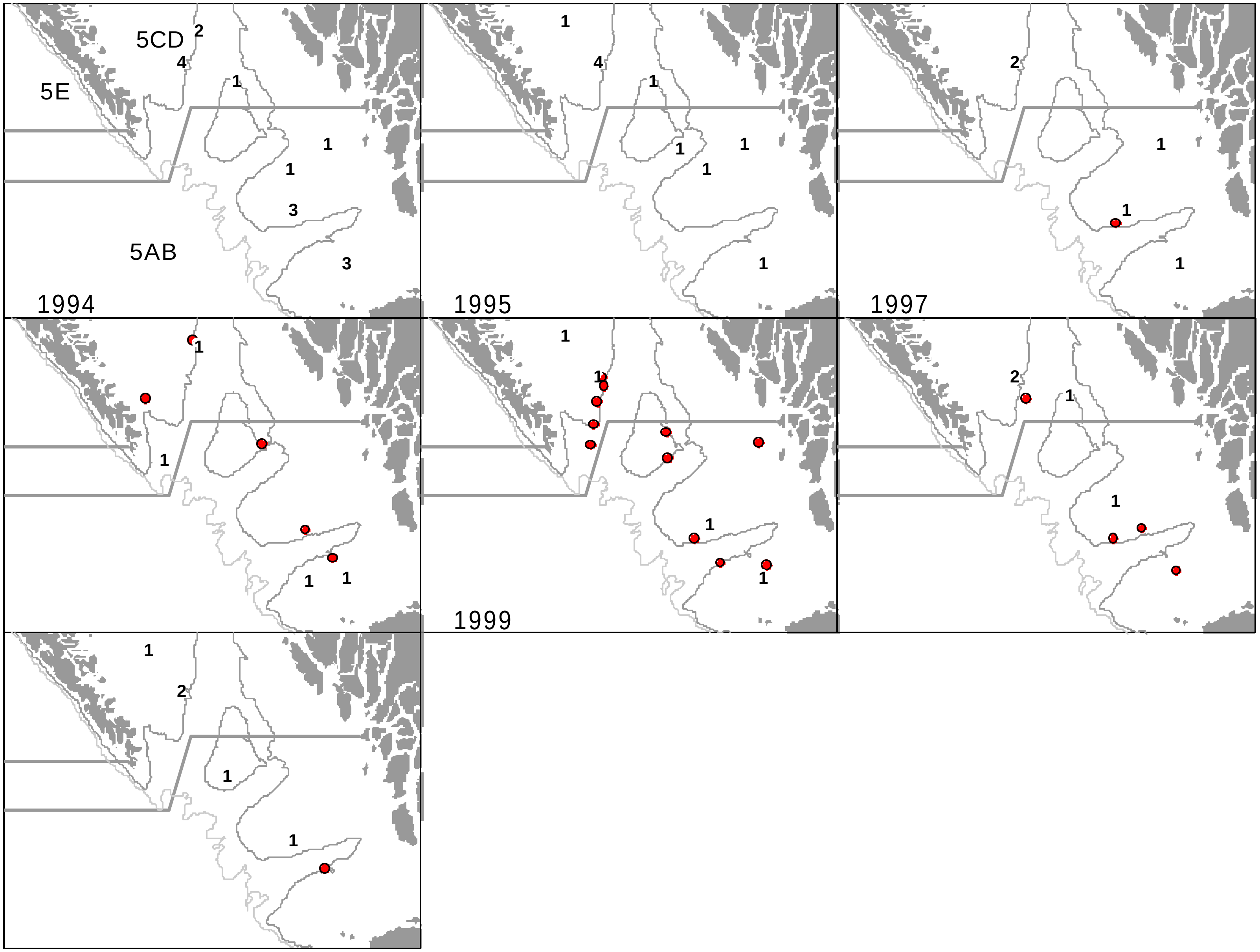


Figure 7. Location of aged samples of silvergray rockfish from Areas 5AB and 5CD (1994-2001). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

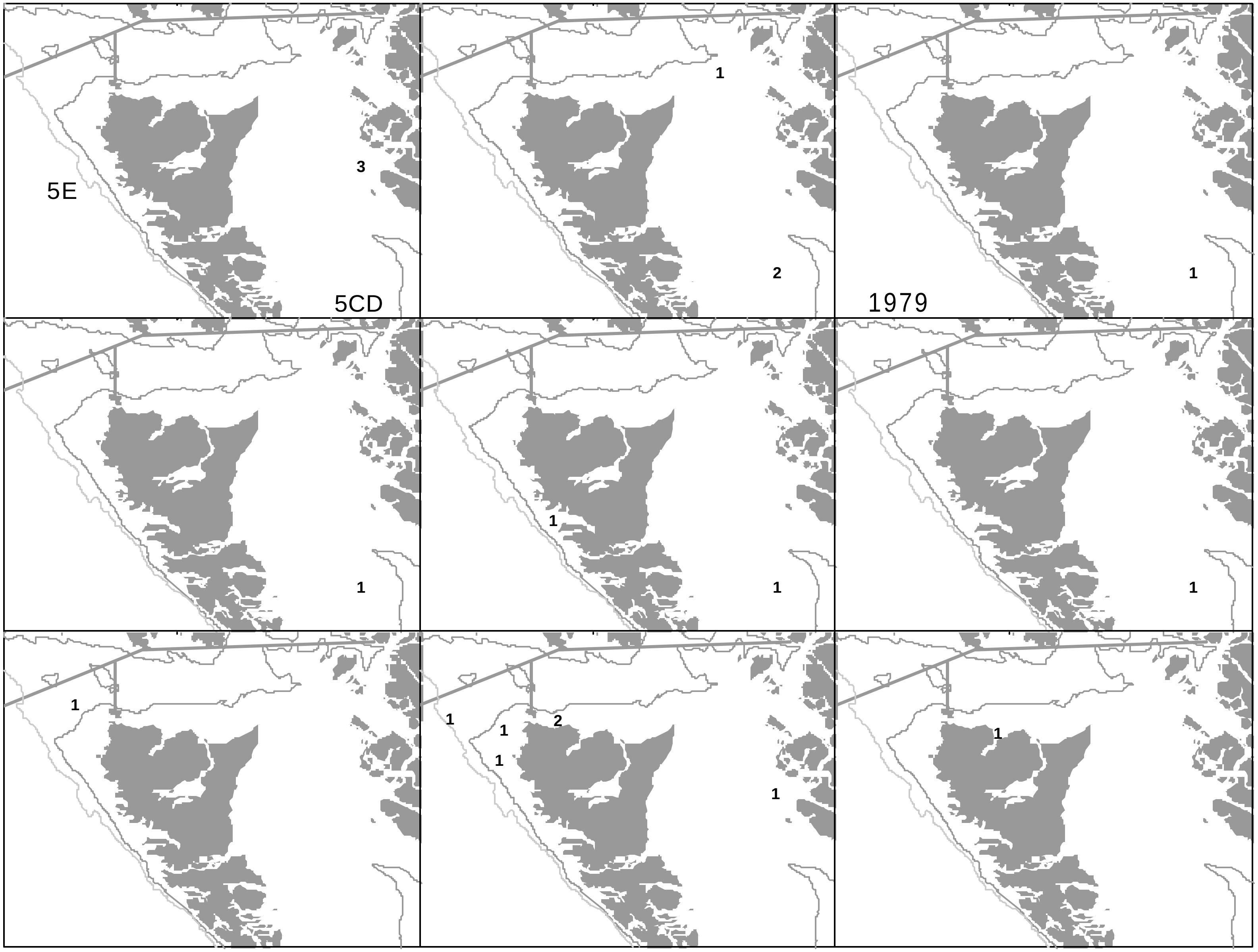


Figure 8. Location of aged samples of silvergray rockfish from Areas 5CD and 5E (1977-1992). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

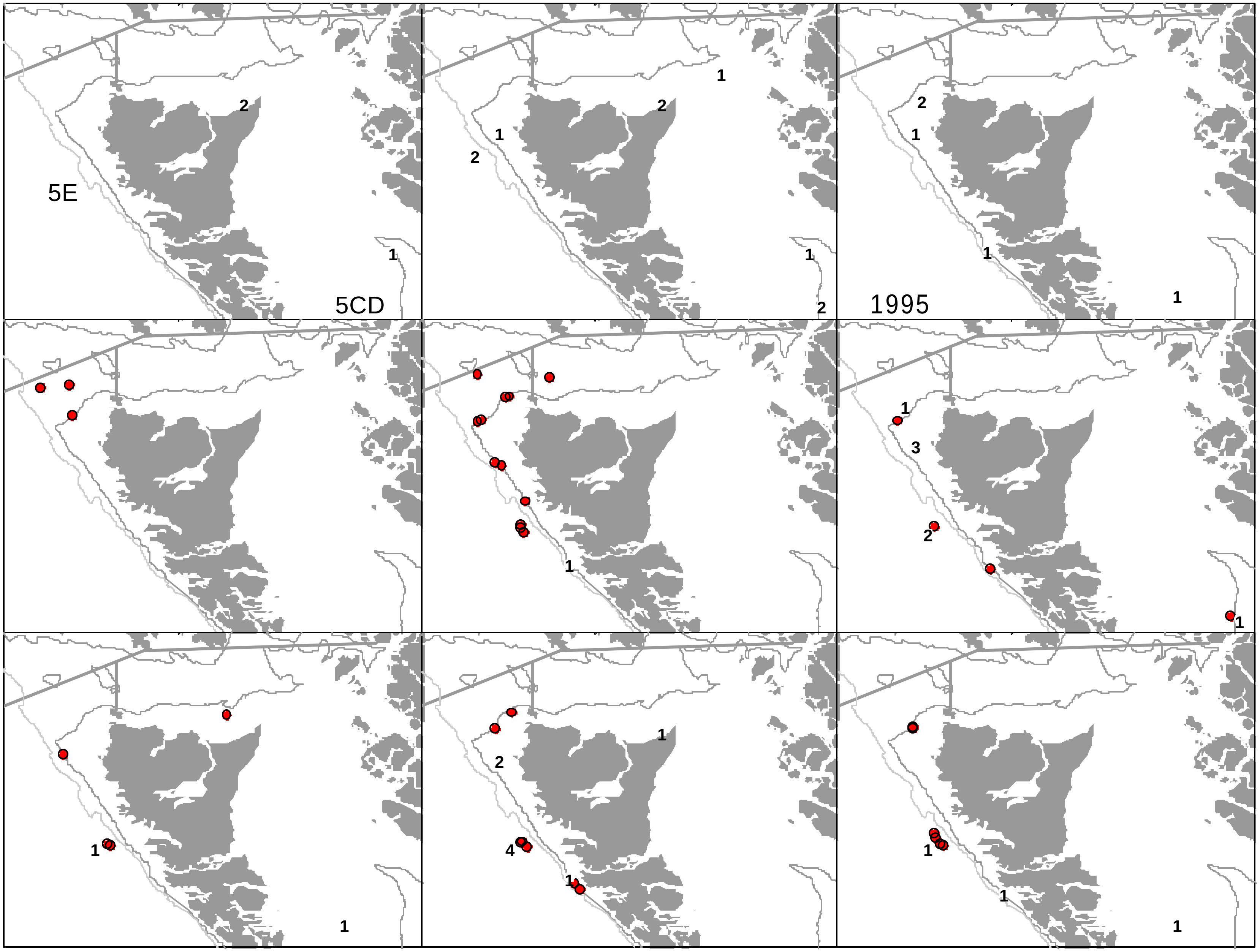


Figure 9. Location of aged samples of silvergray rockfish from Areas 5CD and 5E (1993-2001). Numerals represent number of samples collected at unloading (location known to locality). Dots represent samples collected by at-sea observers (location known with lat/long).

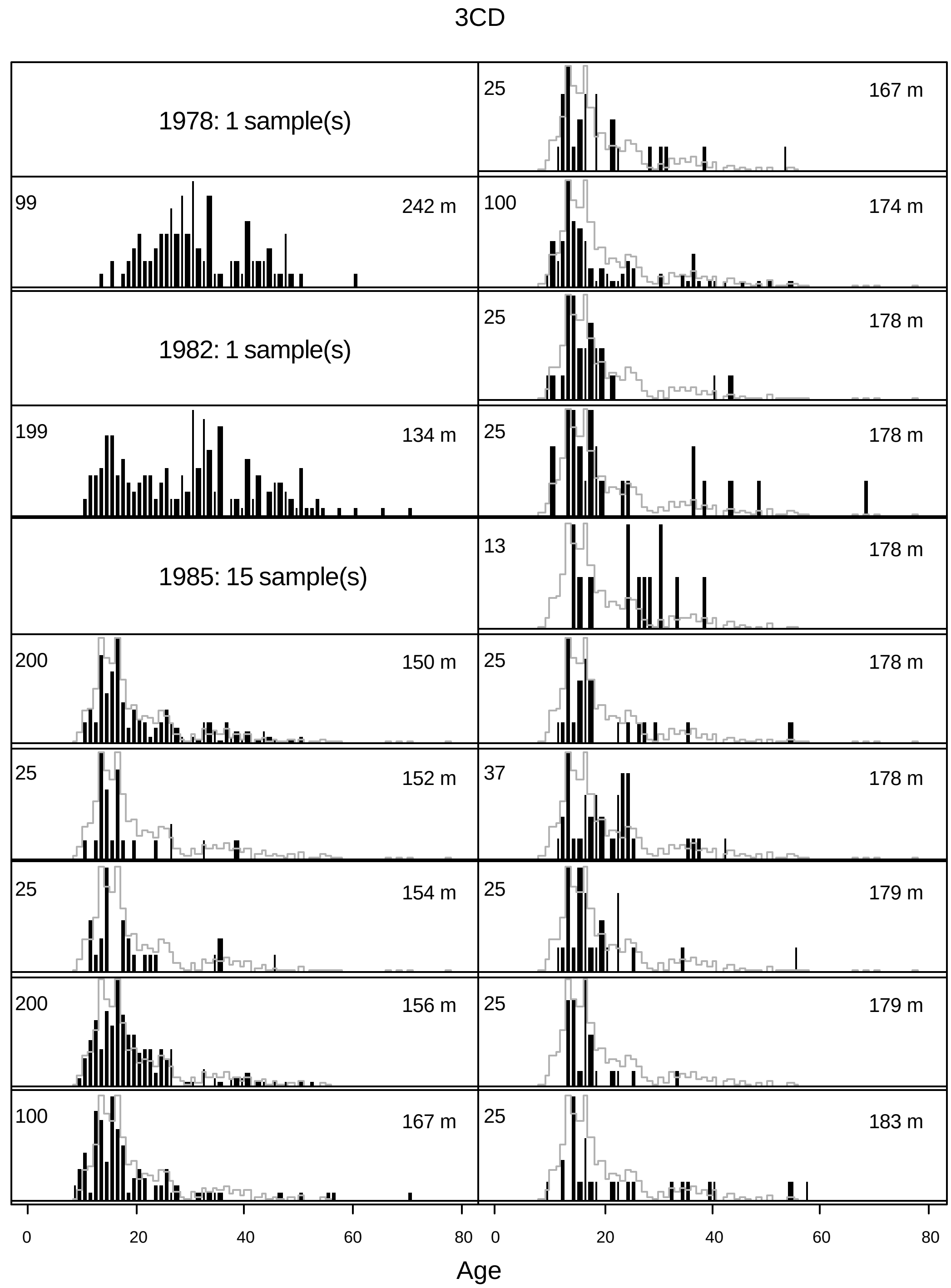


Figure 10. Sample age frequency histograms for Area 3C (1978-1985). Gray-line indicates histogram of all data pooled for that year

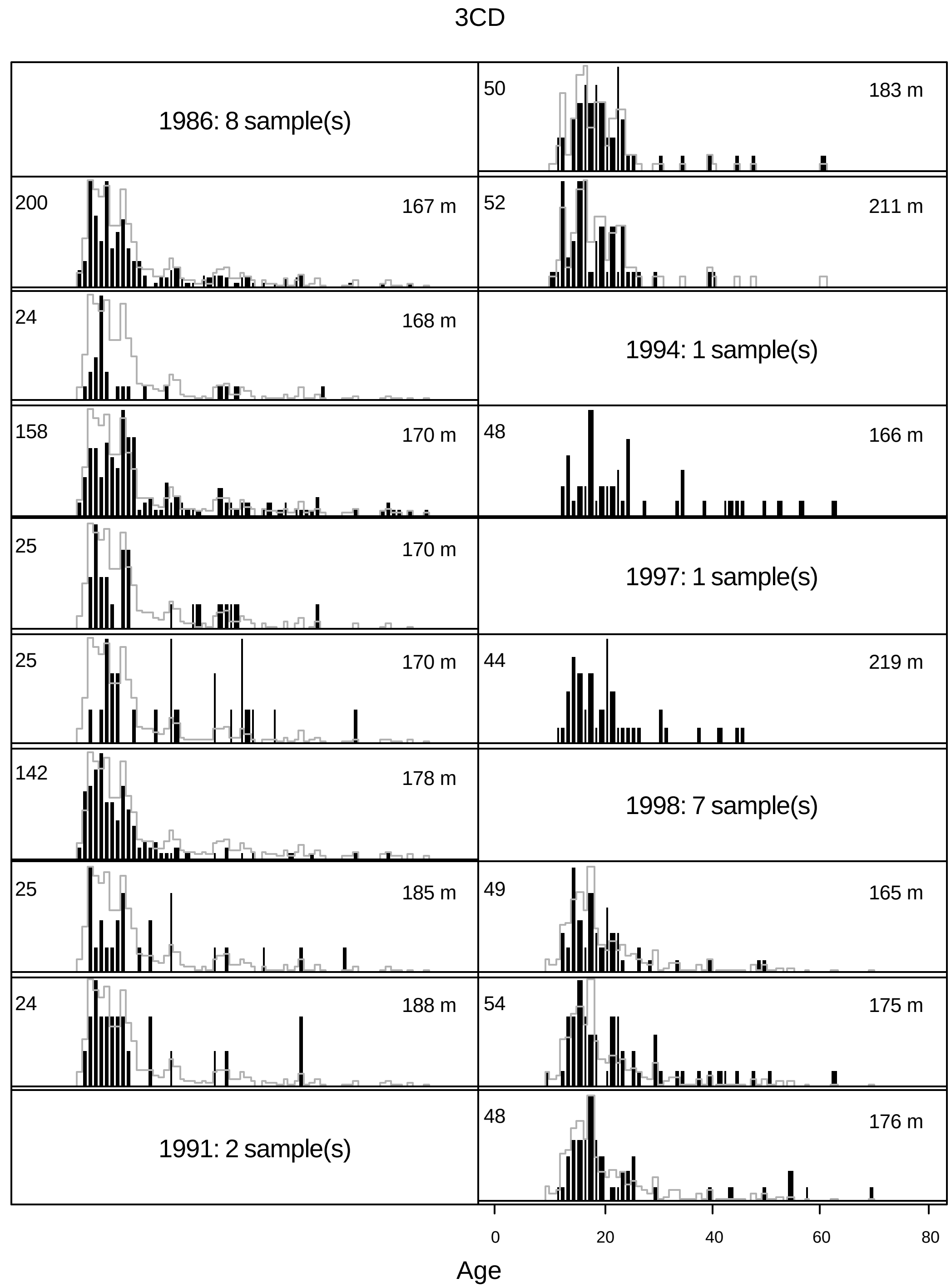


Figure 11. Sample age frequency histograms for Area 3C (1986-1998). Gray-line indicates histogram of all data pooled for that year

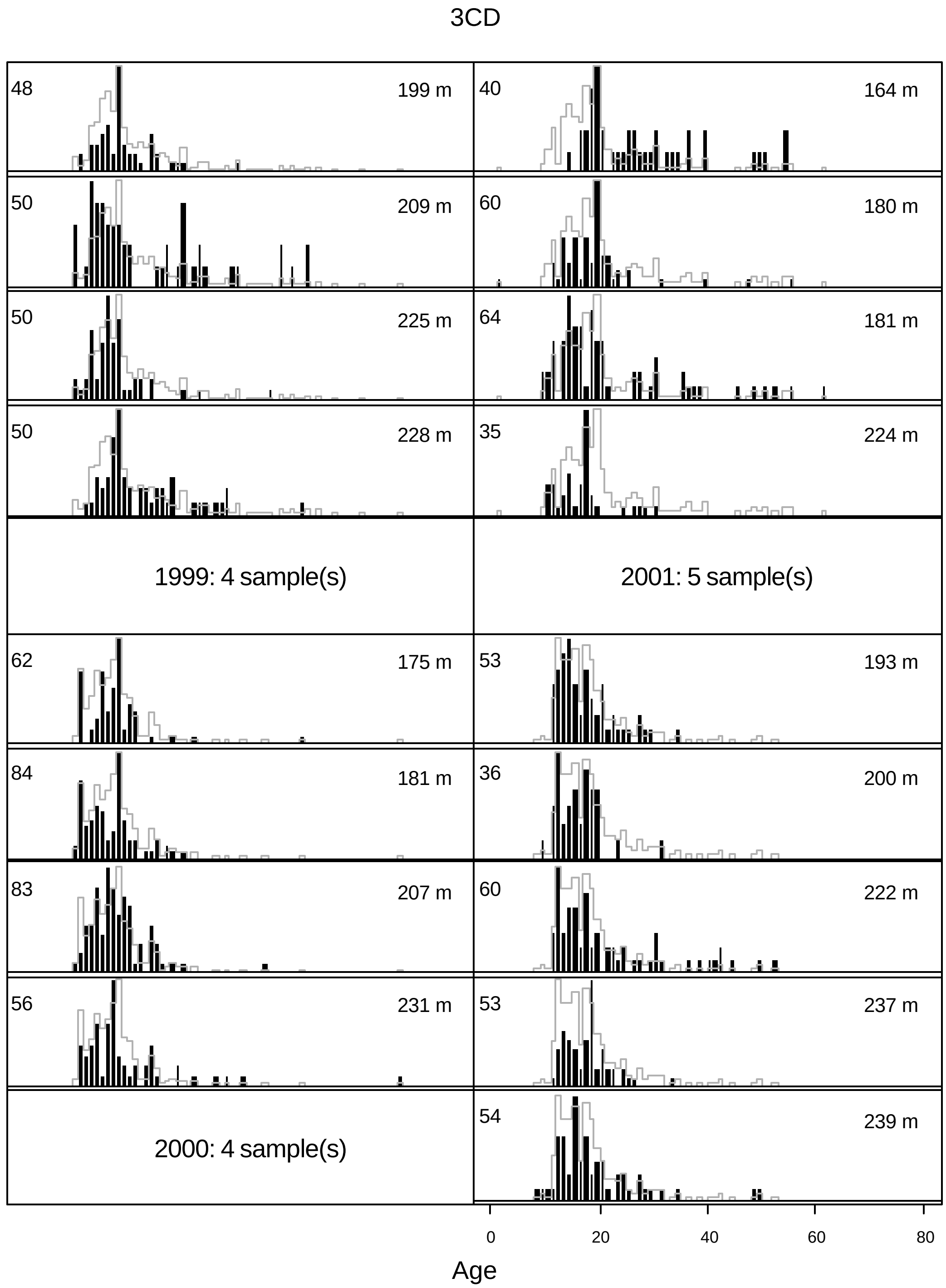


Figure 12. Sample age frequency histograms for Area 3C (1998 continued-2001). Gray-line indicates histogram of all data pooled for that year

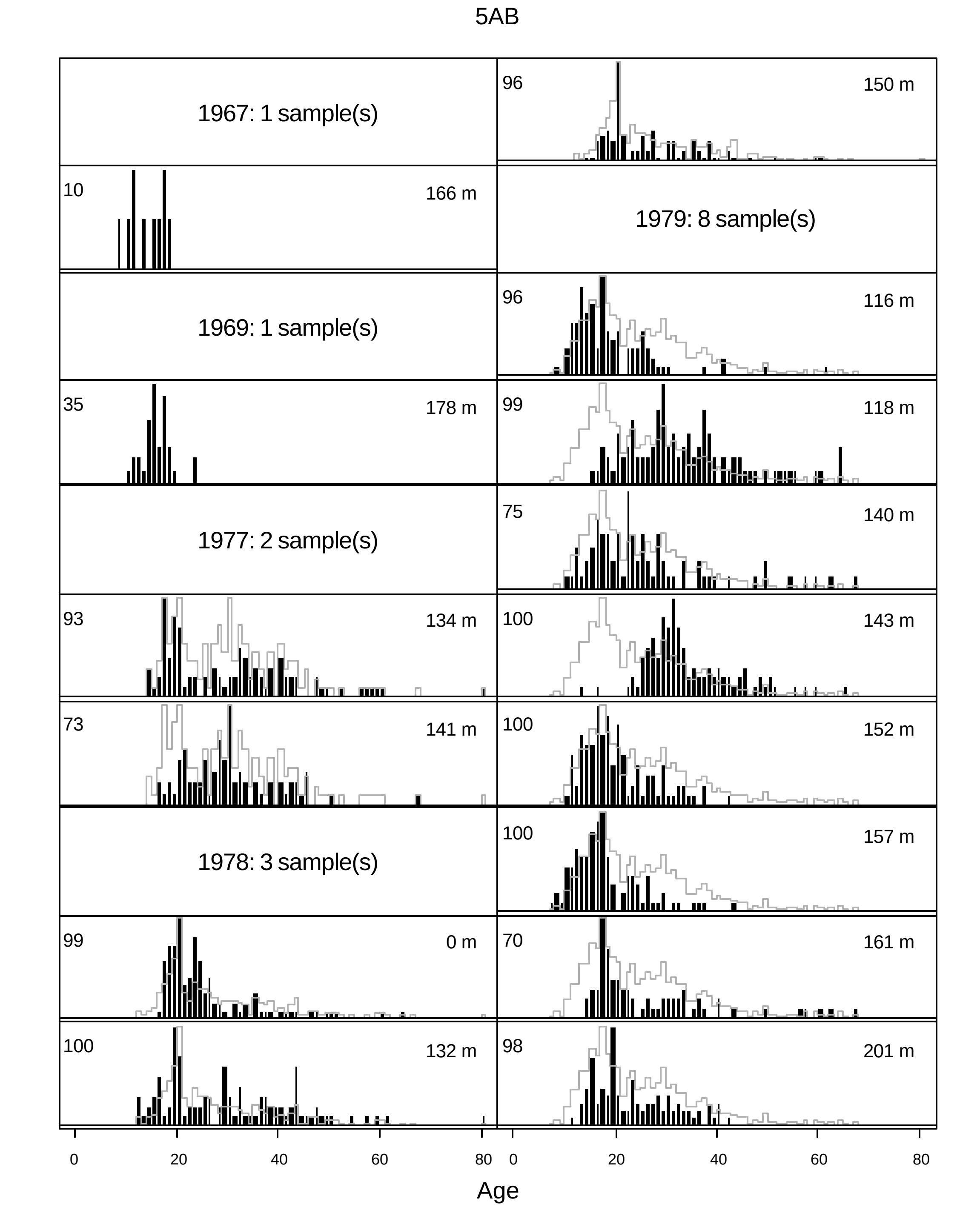


Figure 13. Sample age frequency histograms for Area 5AB (1967-1979). Gray-line indicates histogram of all data pooled for that year

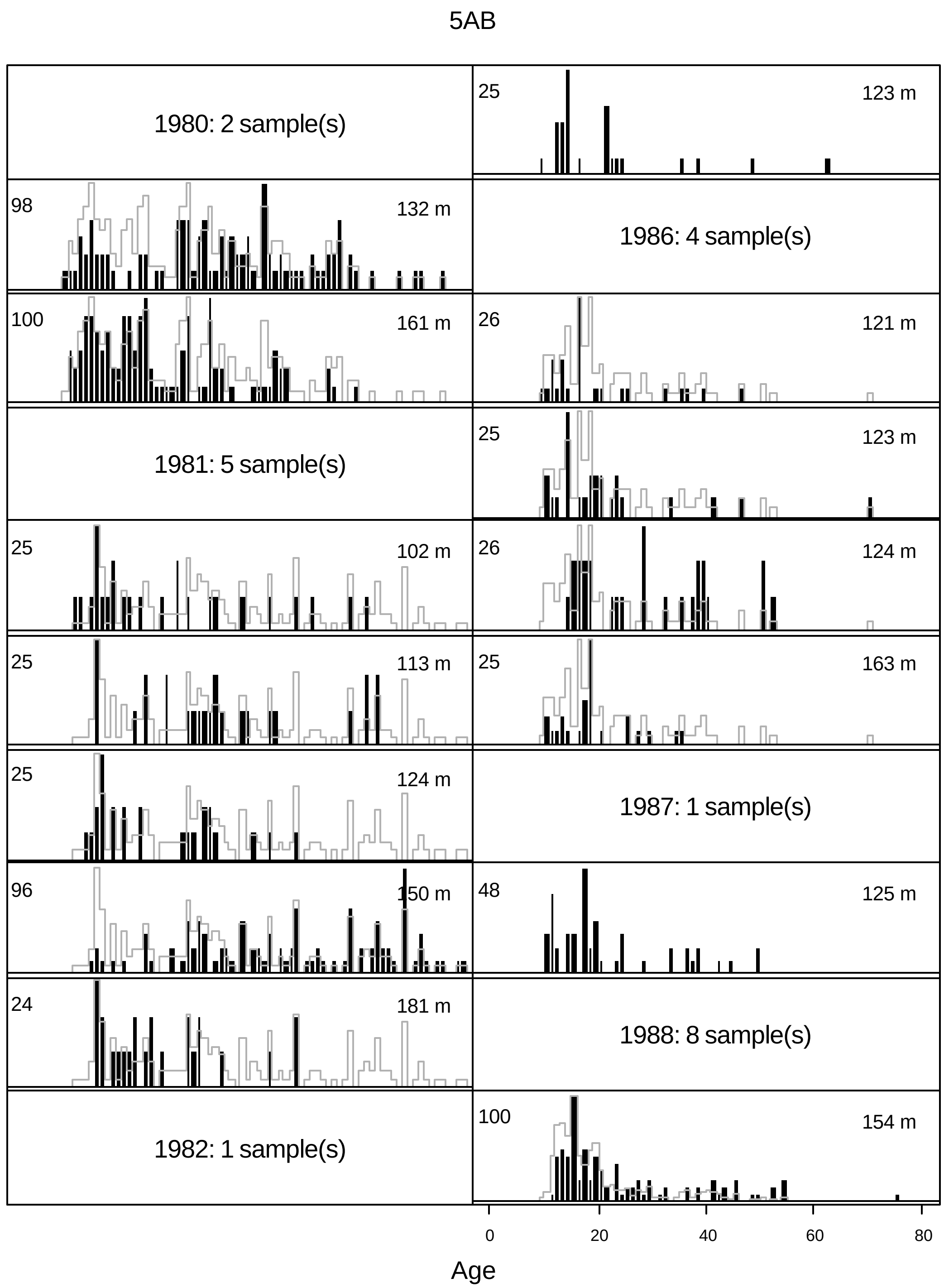


Figure 14. Sample age frequency histograms for Area 5AB (1980-1988). Gray-line indicates histogram of all data pooled for that year

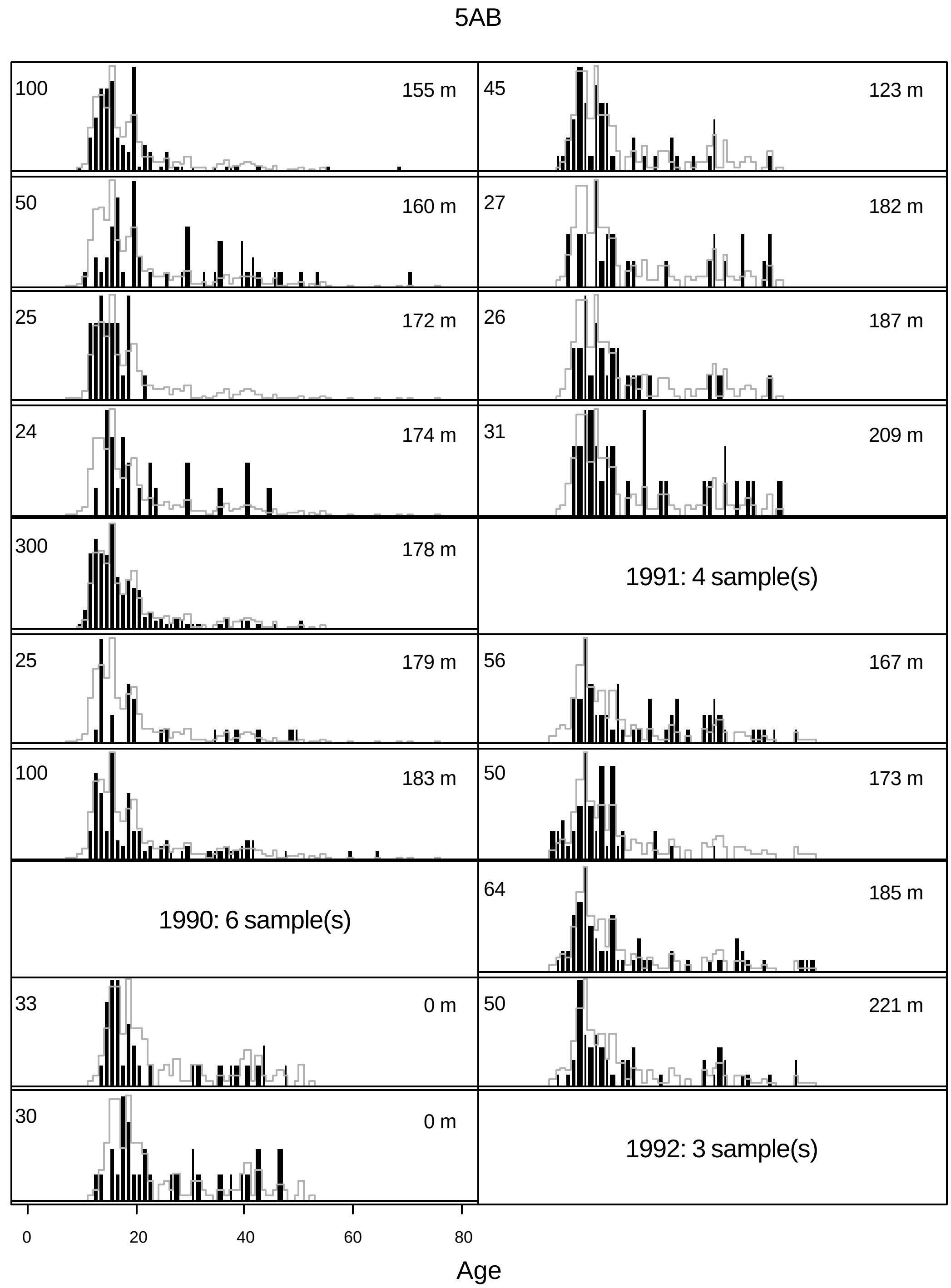


Figure 15. Sample age frequency histograms for Area 5AB (1988 continued-1991). Gray-line indicates histogram of all data pooled for that year

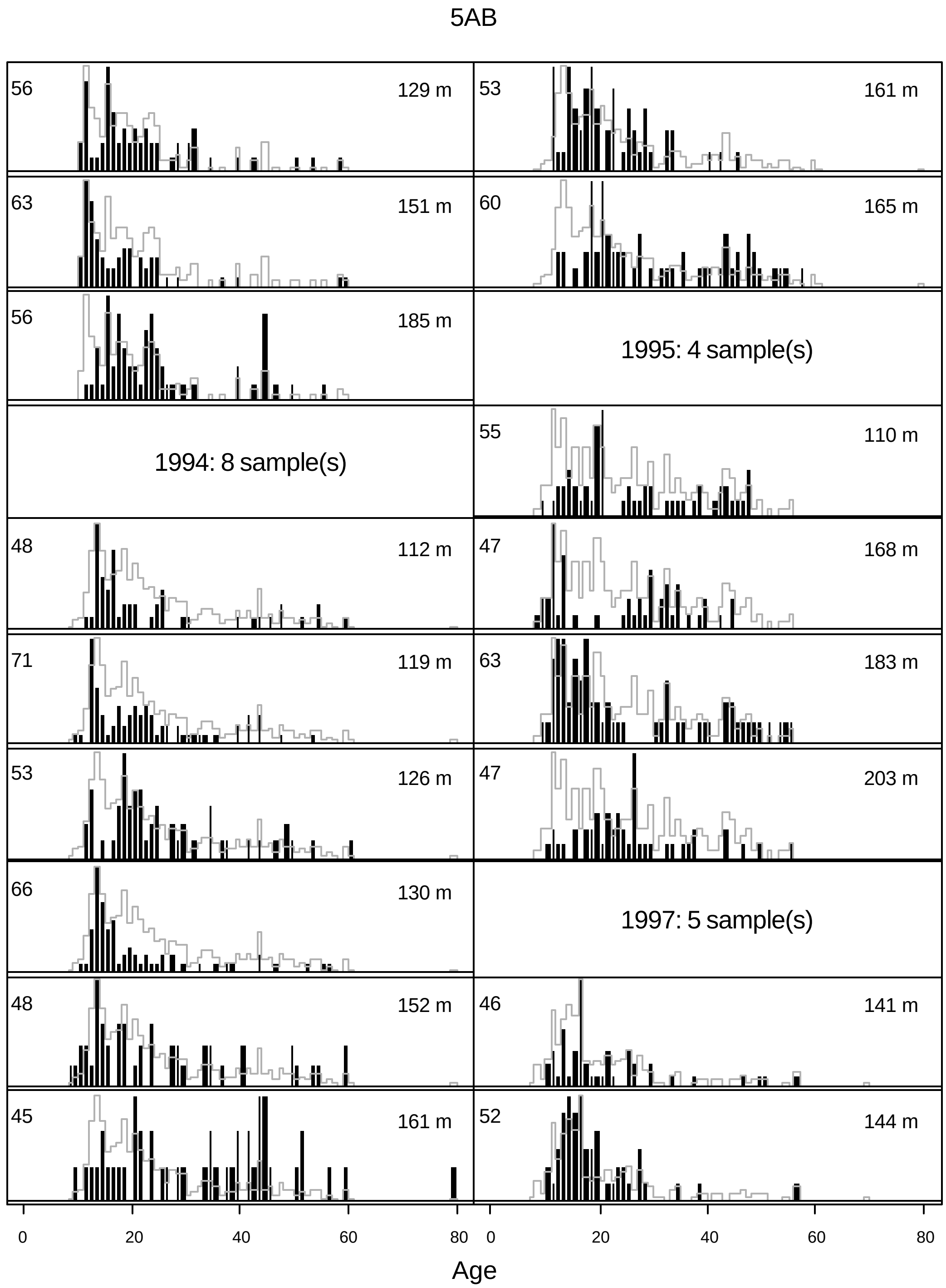


Figure 16. Sample age frequency histograms for Area 5AB (1992-1997). Gray-line indicates histogram of all data pooled for that year

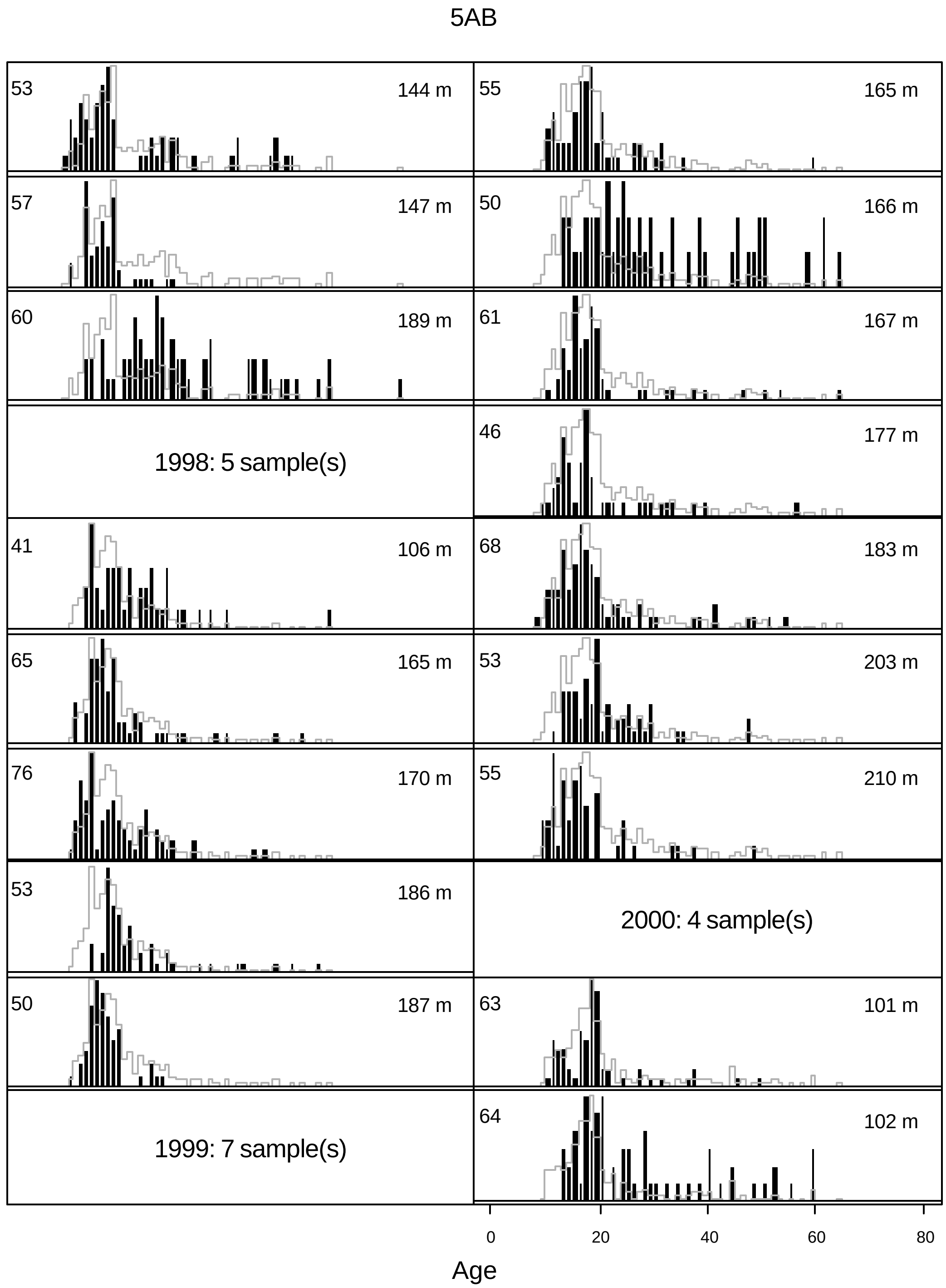


Figure 17. Sample age frequency histograms for Area 5AB (1997 continued-2000). Gray-line indicates histogram of all data pooled for that year

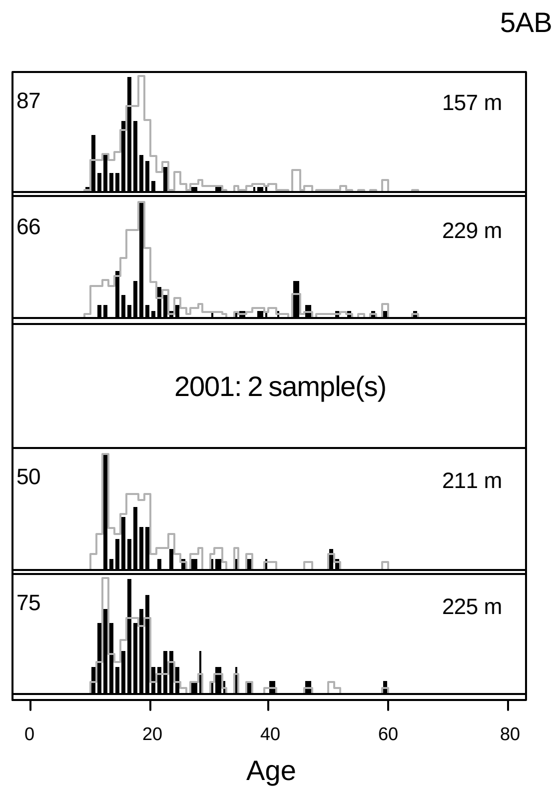


Figure 18. Sample age frequency histograms for Area 5AB (2000 continued – 2001). Gray-line indicates histogram of all data pooled for that year

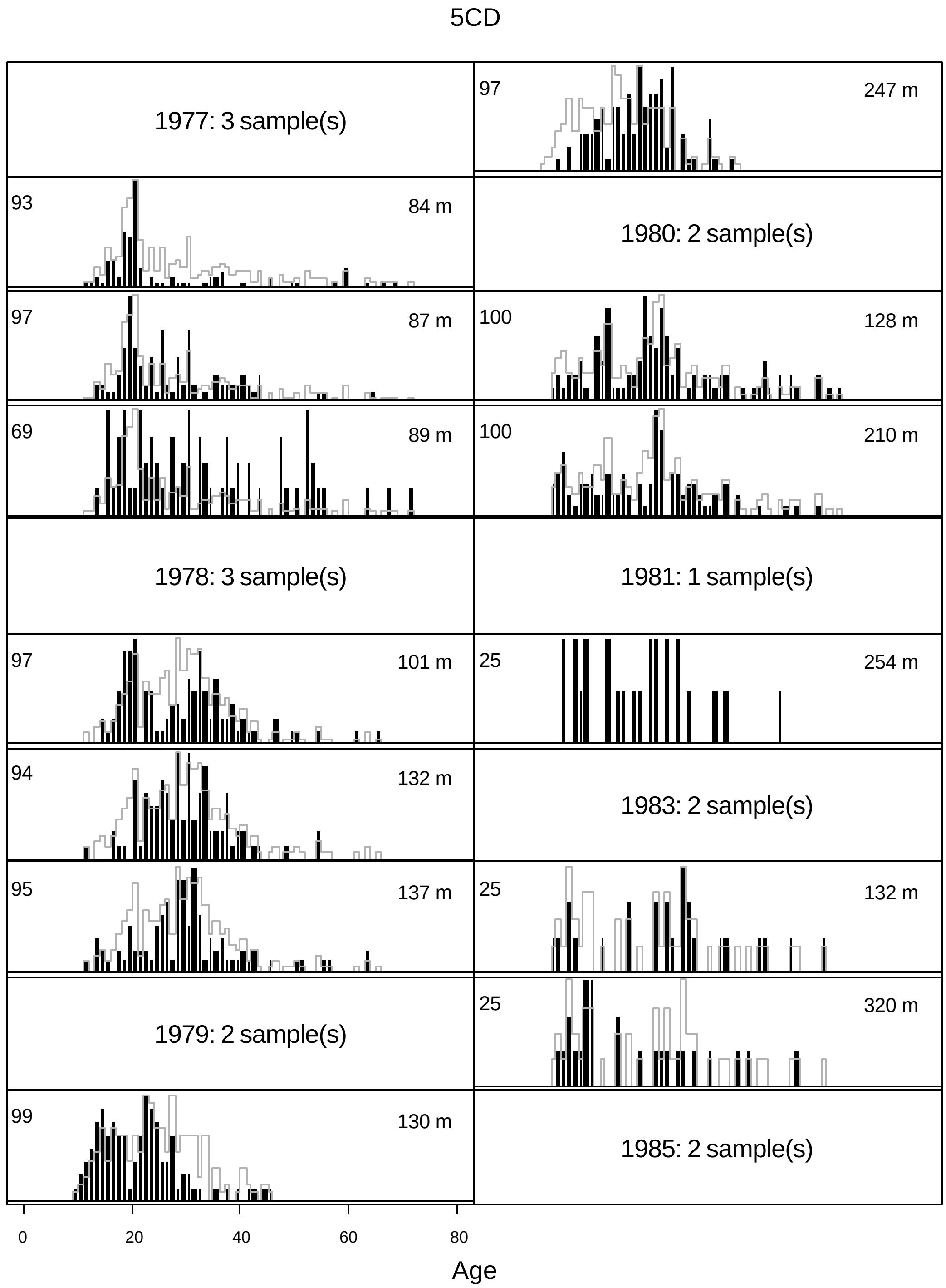


Figure 19. Sample age frequency histograms for Area 5CD (1977 - 1983). Gray-line indicates histogram of all data pooled for that year

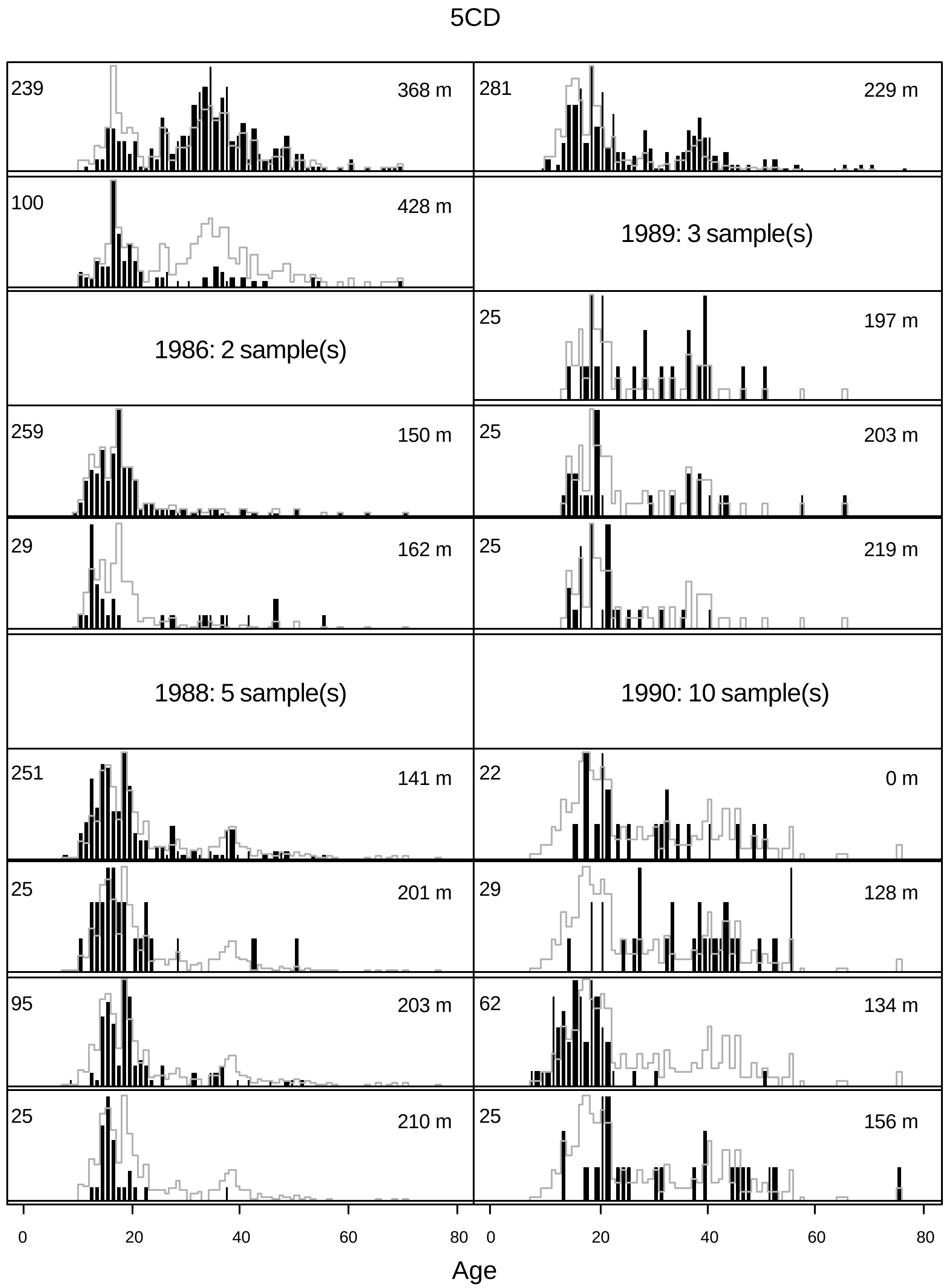


Figure 20. Sample age frequency histograms for Area 5CD (1985 - 1990). Gray-line indicates histogram of all data pooled for that year

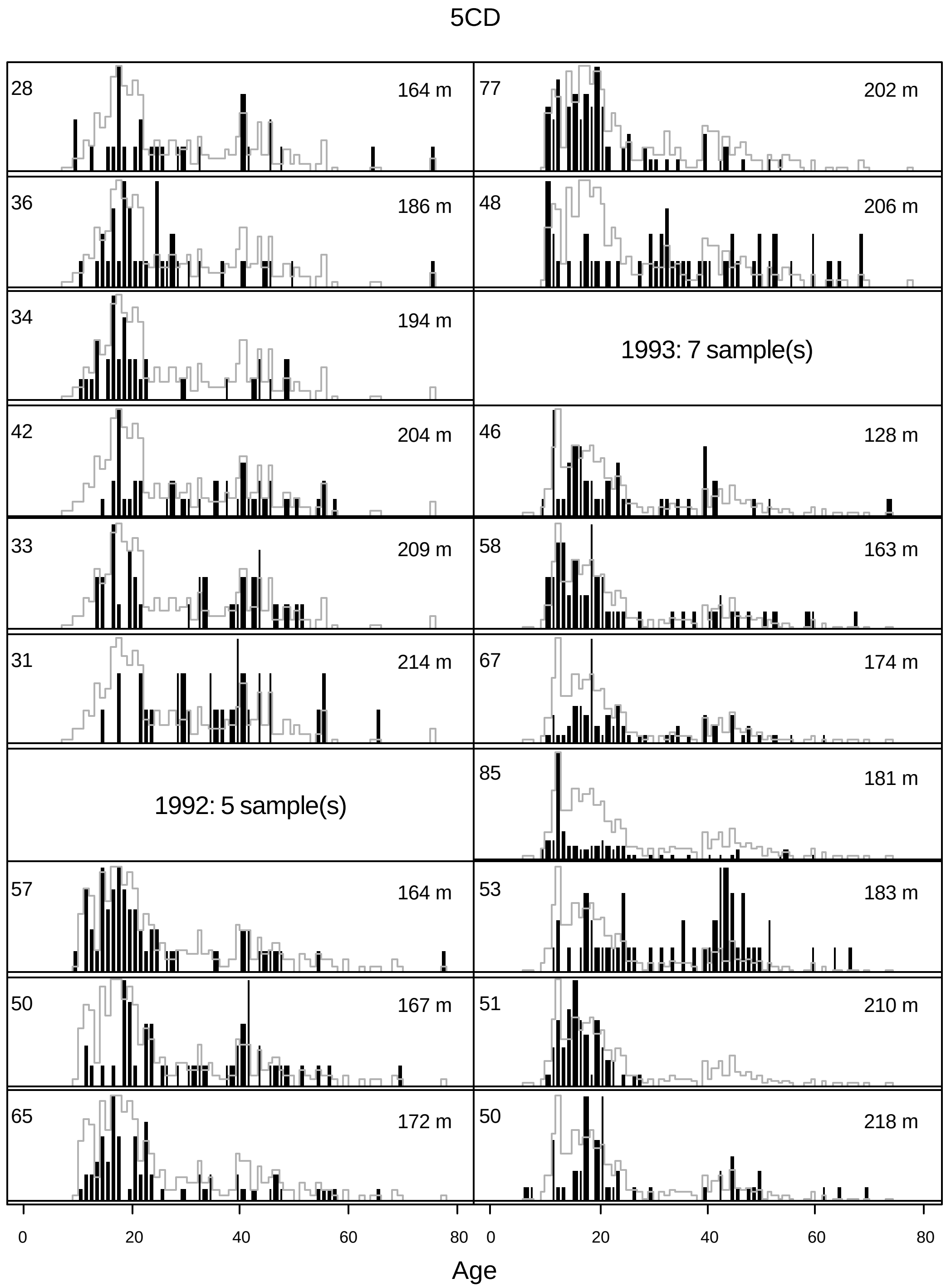


Figure 21. Sample age frequency histograms for Area 5CD (1990 continued - 1993). Gray-line indicates histogram of all data pooled for that year

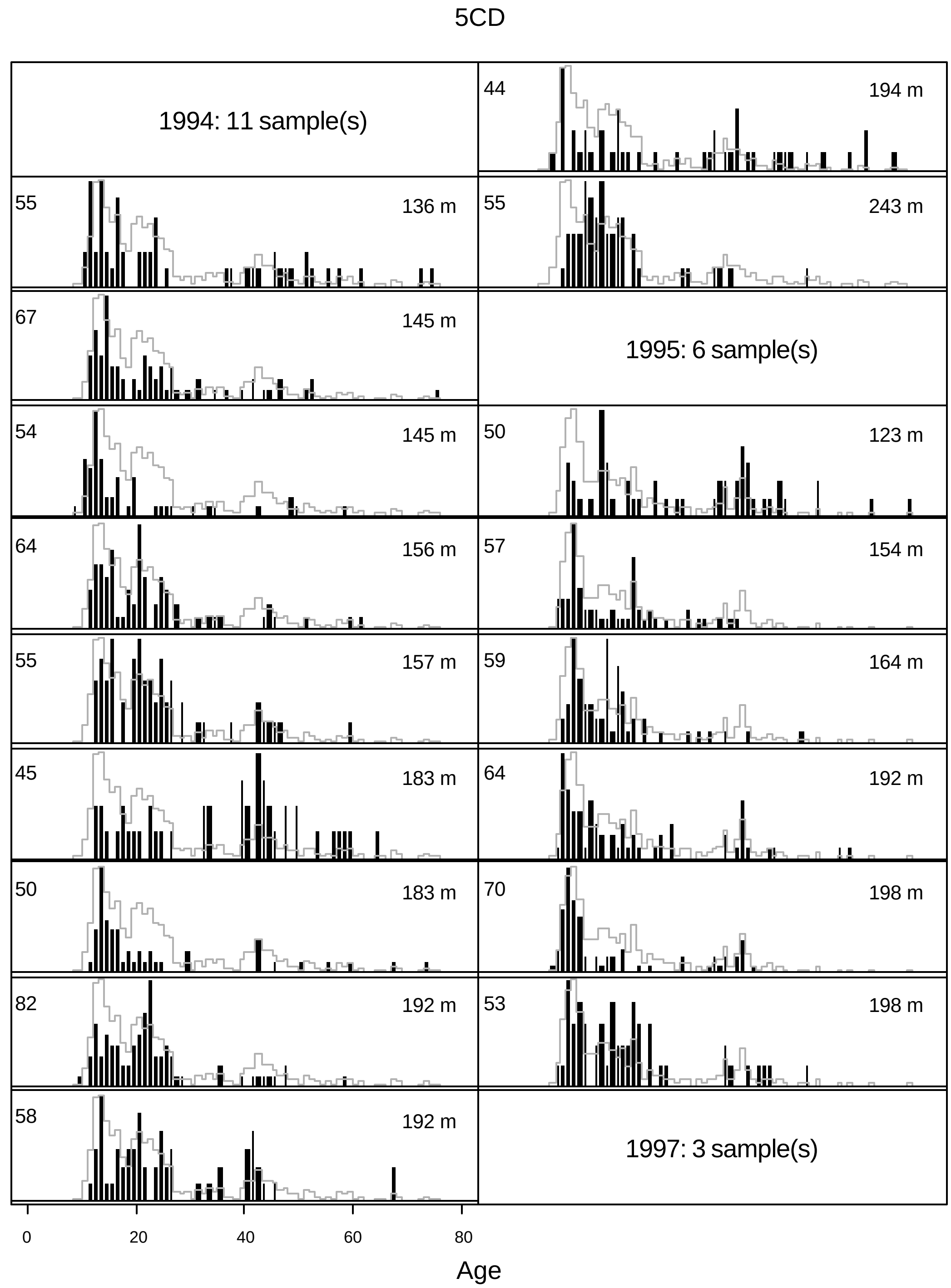


Figure 22. Sample age frequency histograms for Area 5CD (1994 - 1996). Gray-line indicates histogram of all data pooled for that year

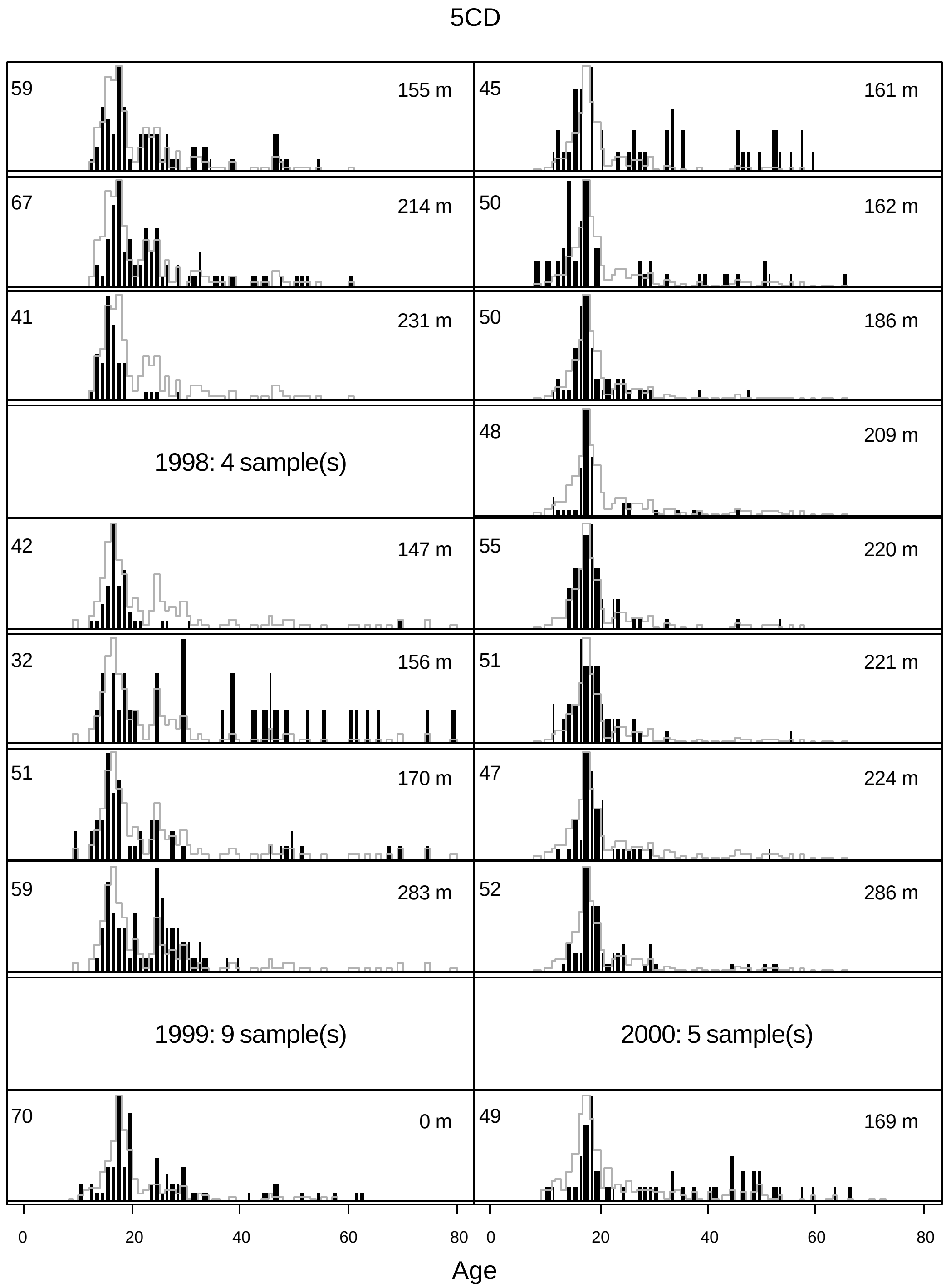


Figure 23. Sample age frequency histograms for Area 5CD (1997 - 2000). Gray-line indicates histogram of all data pooled for that year

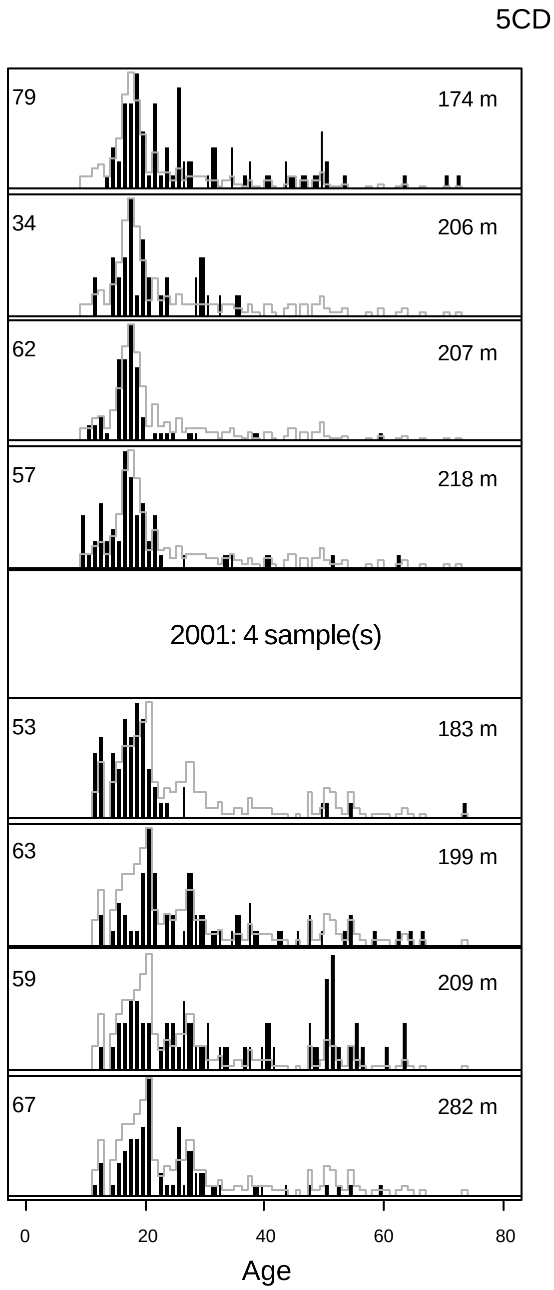


Figure 24. Sample age frequency histograms for Area 5CD (2000 continued - 2001). Gray-line indicates histogram of all data pooled for that year

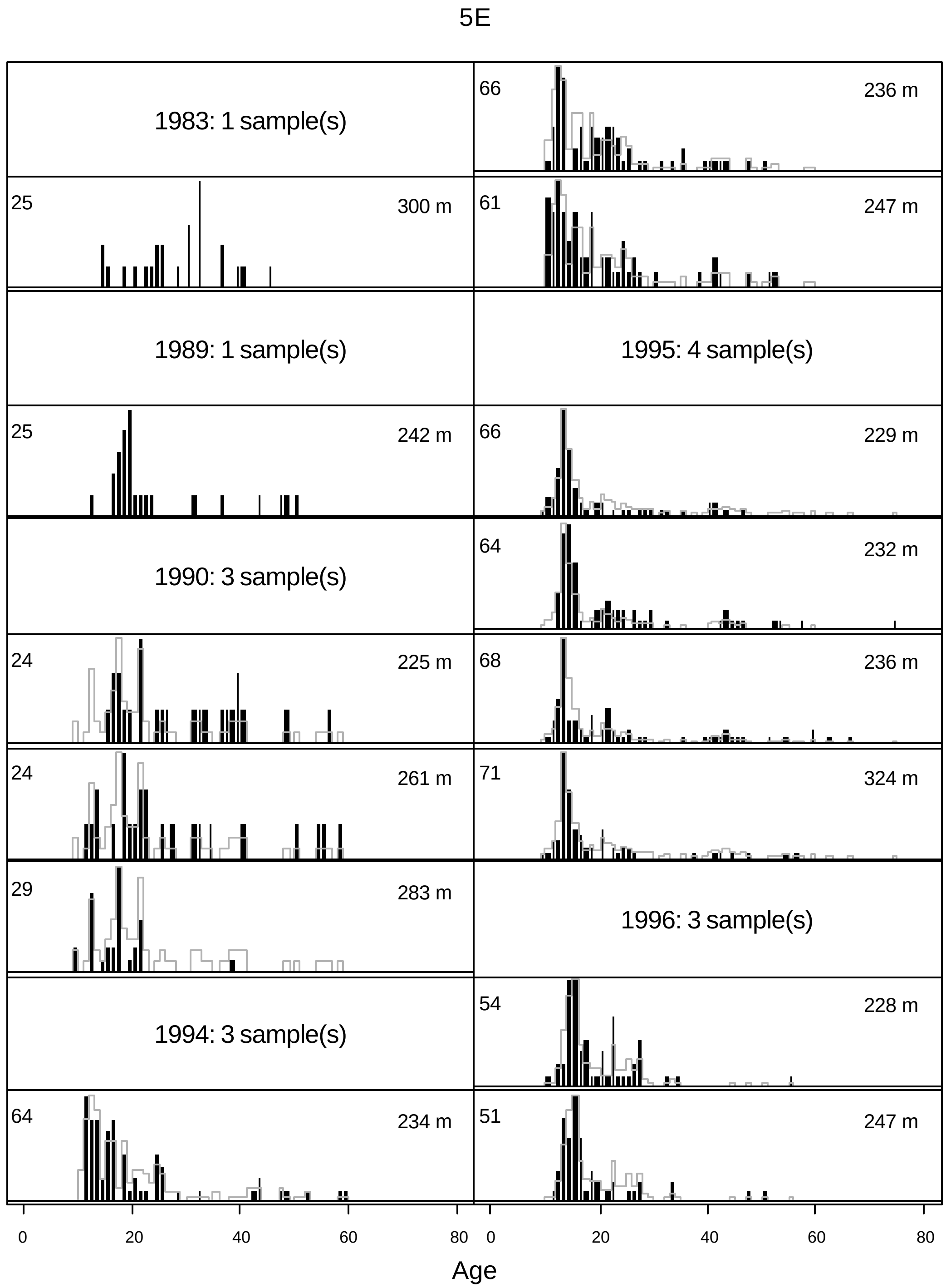


Figure 25. Sample age frequency histograms for Area 5E (1983 – 1996). Gray-line indicates histogram of all data pooled for that year

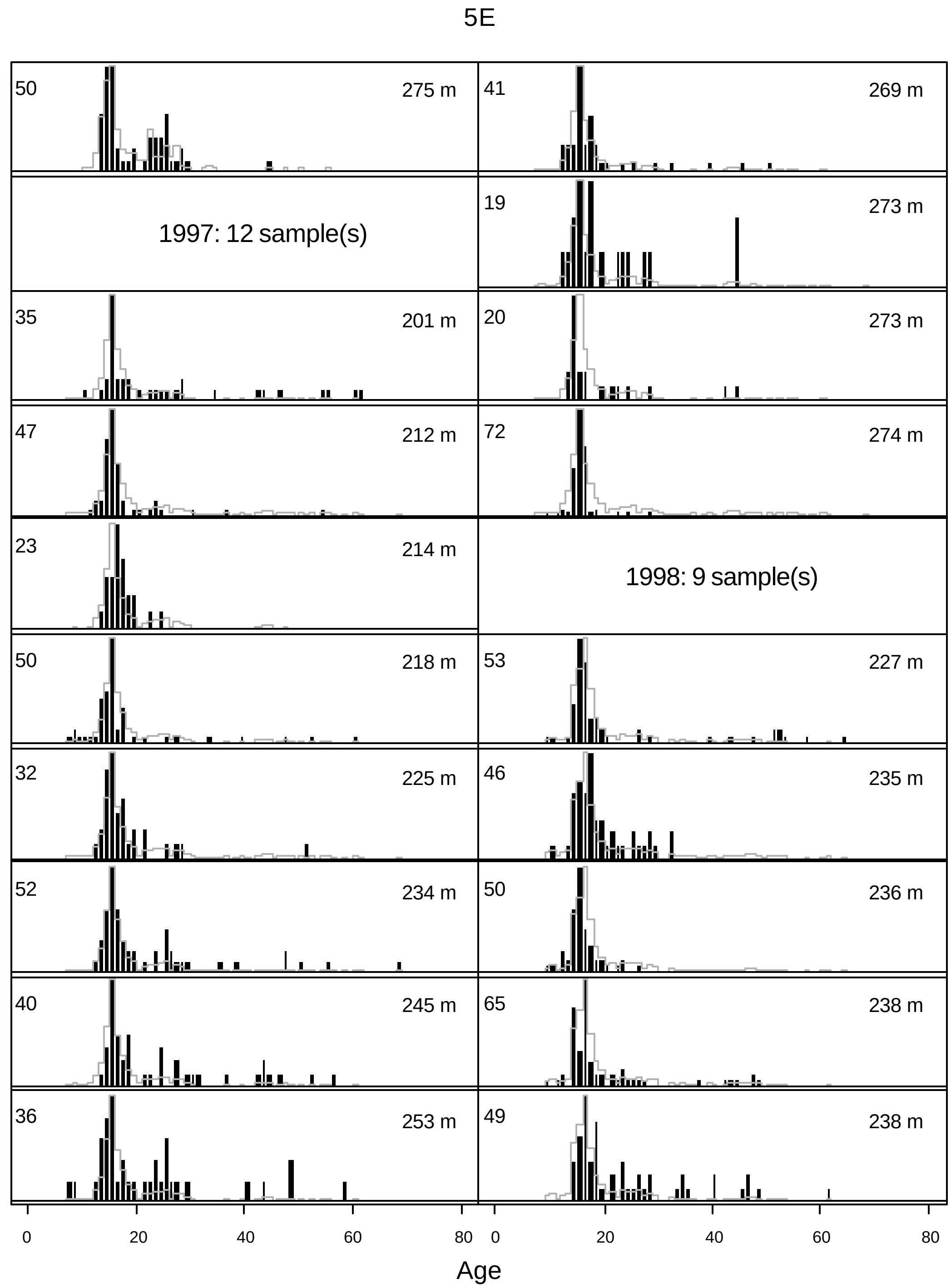


Figure 26. Sample age frequency histograms for Area 5E (1996 continued - 1998). Gray-line indicates histogram of all data pooled for that year

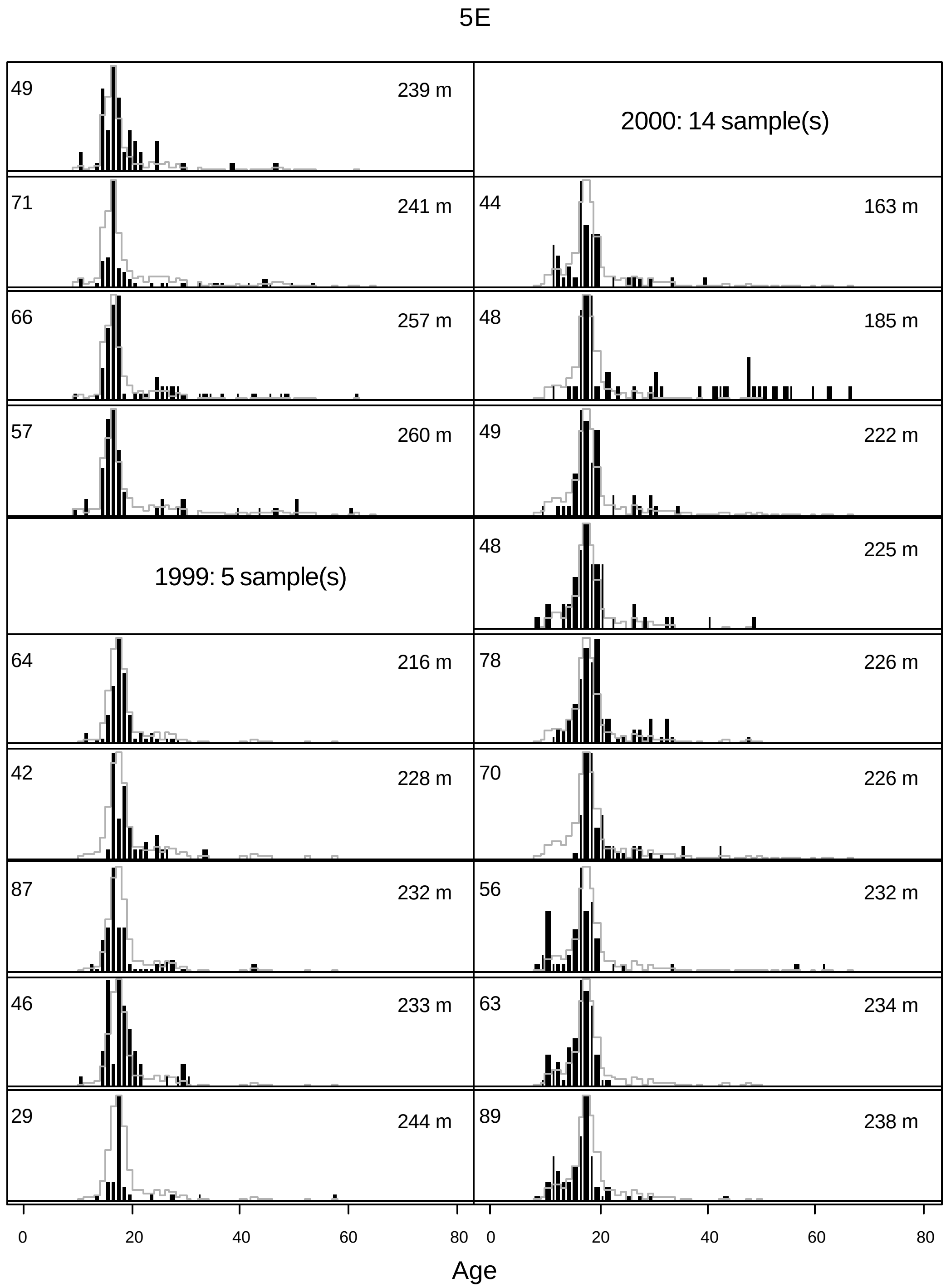


Figure 27. Sample age frequency histograms for Area 5E (1998 continued - 2000). Gray-line indicates histogram of all data pooled for that year

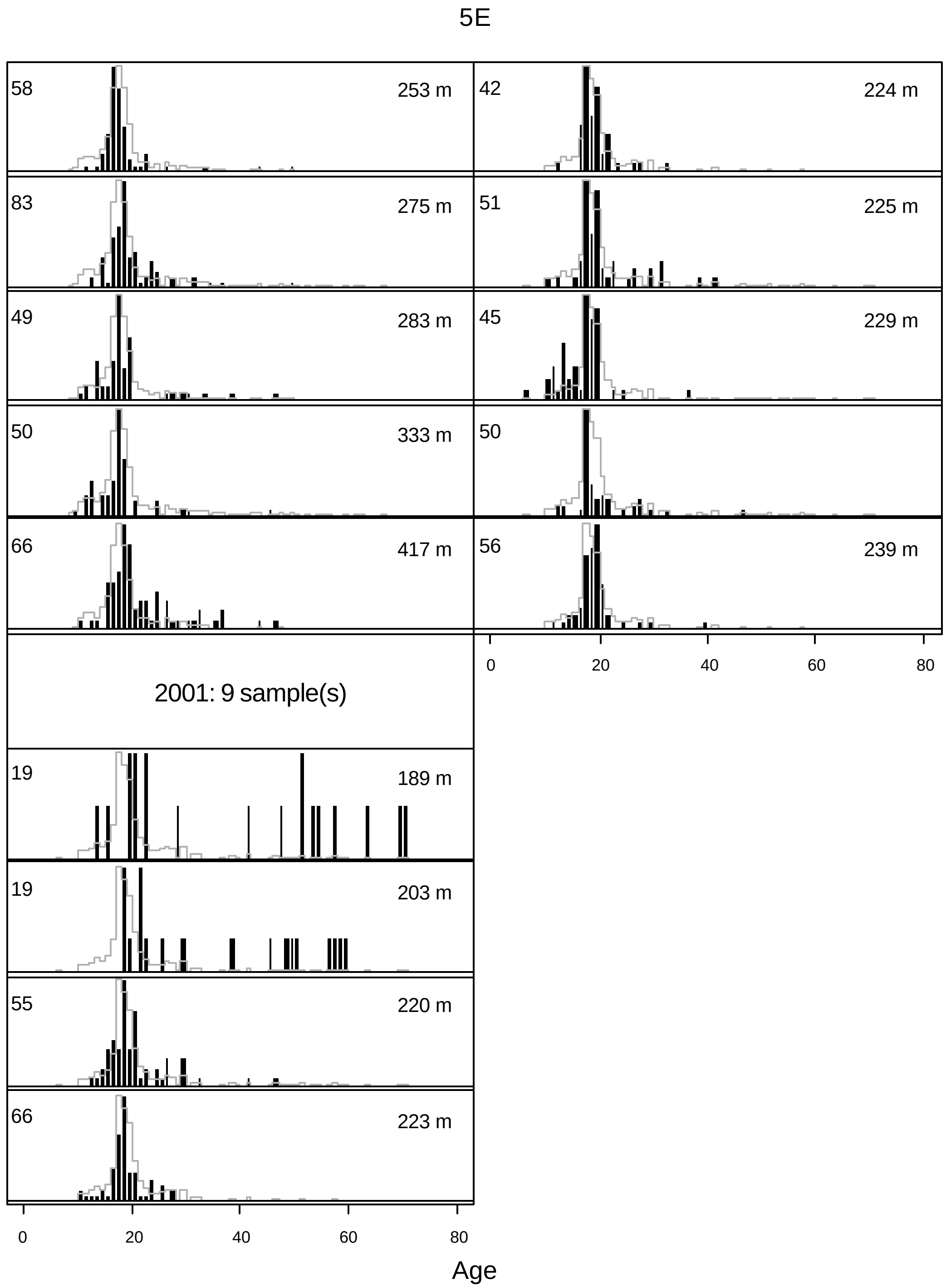


Figure 28. Sample age frequency histograms for Area 5E (2000 continued - 2001). Gray-line indicates histogram of all data pooled for that year

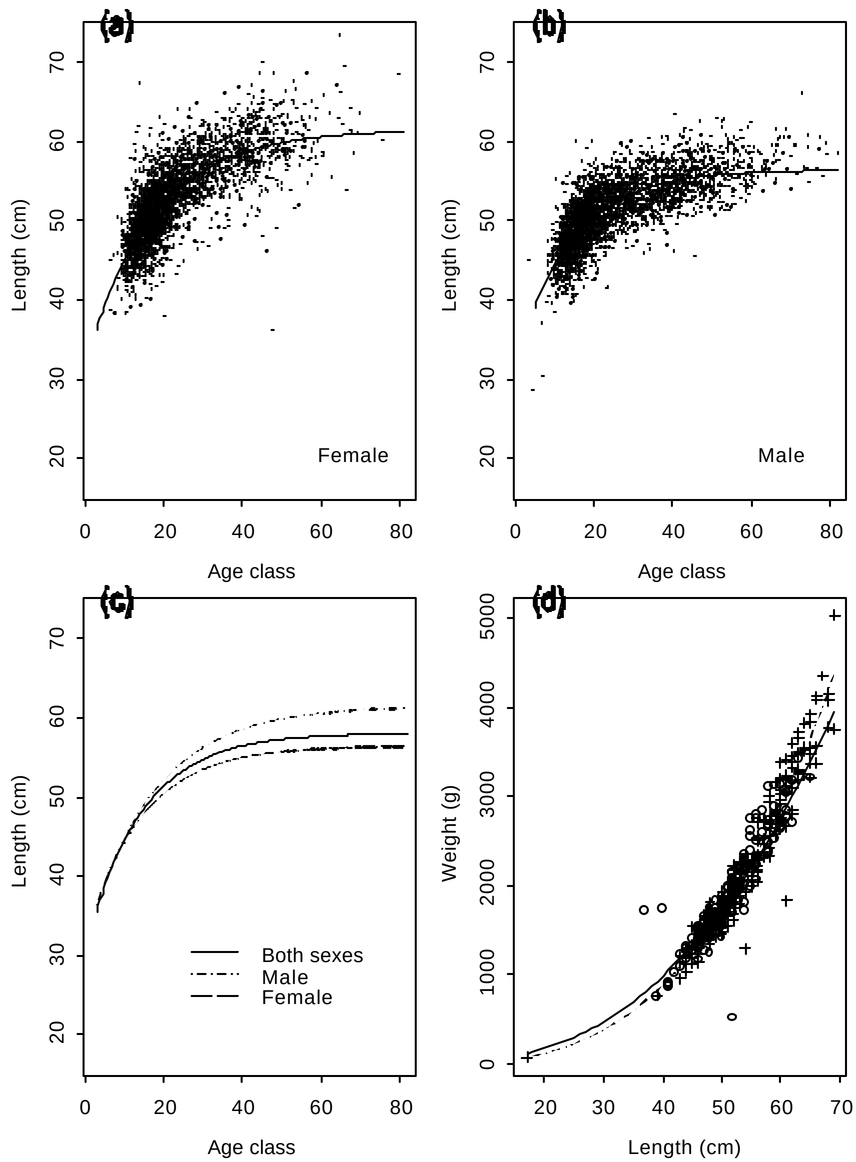


Figure 29. Overall size at age plots for females (a), males (b), comparison of derived growth curves for males and females (c), and length/weight relationship, males=”o” and females=”+” (d).

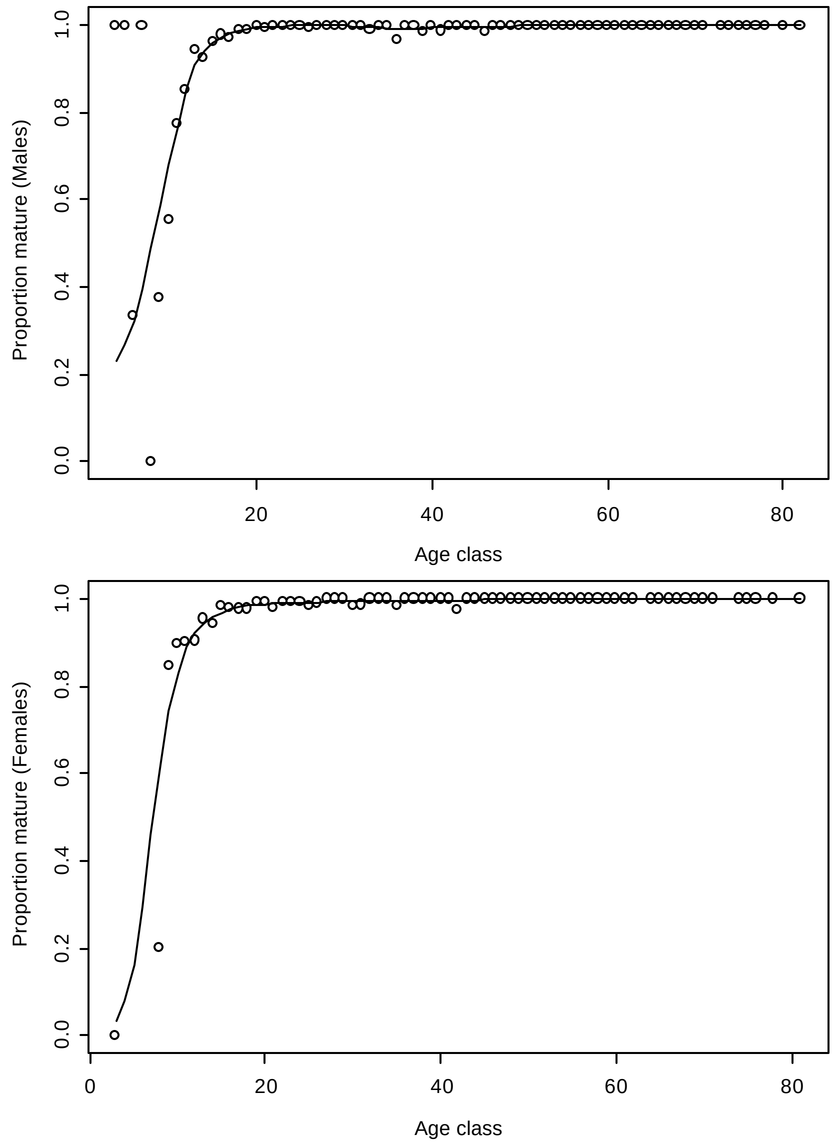


Figure 30. Observed and predicted age at maturity for male (top panel) and female (bottom panel) silvergray rockfish.

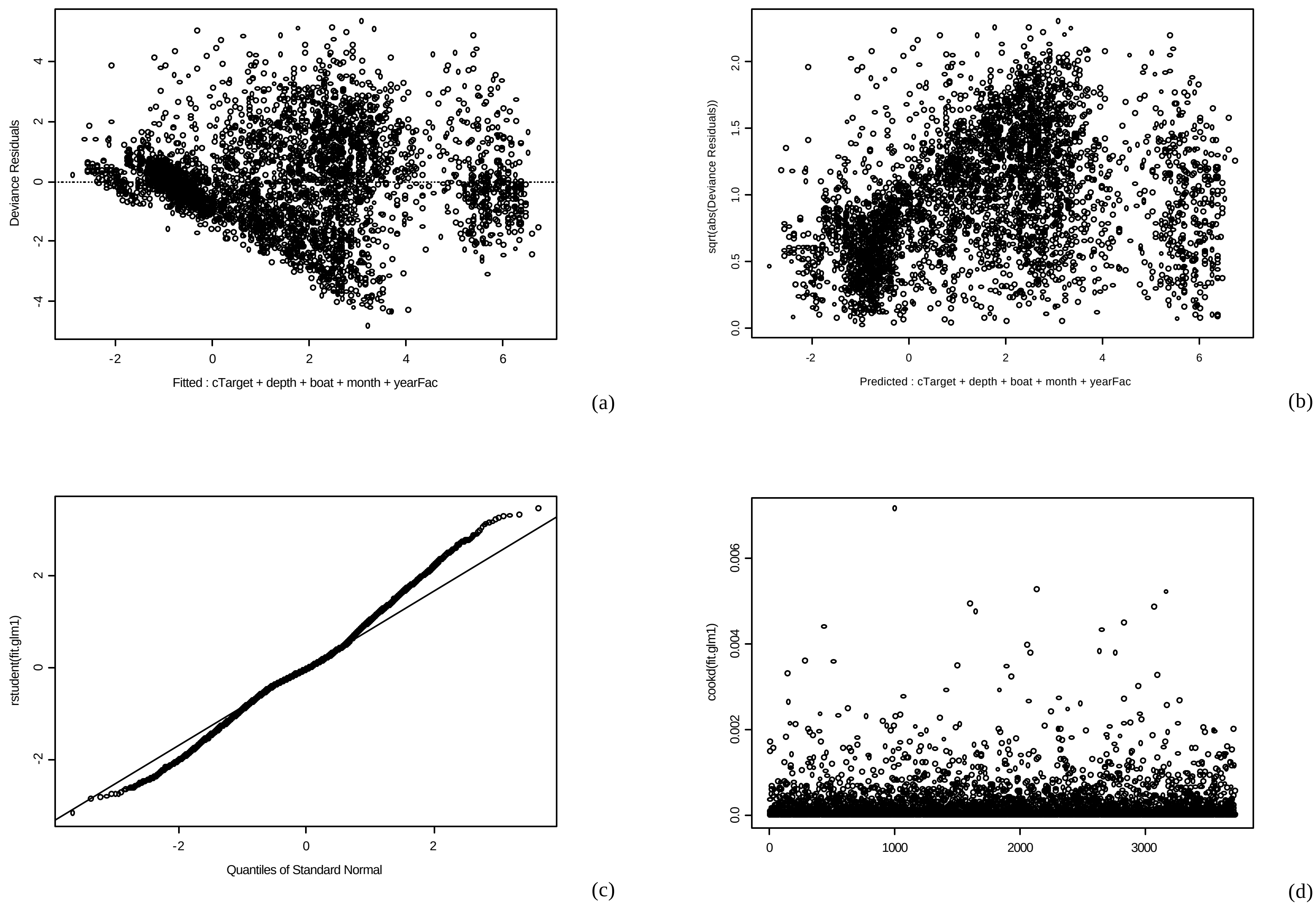


Figure 31. GLM diagnostics for area 3CD; panel (a): deviance residuals, panel (b): square root of the absolute value of the residuals, panel (c): studentized residuals, panel (d): Cook's distance residual plot.

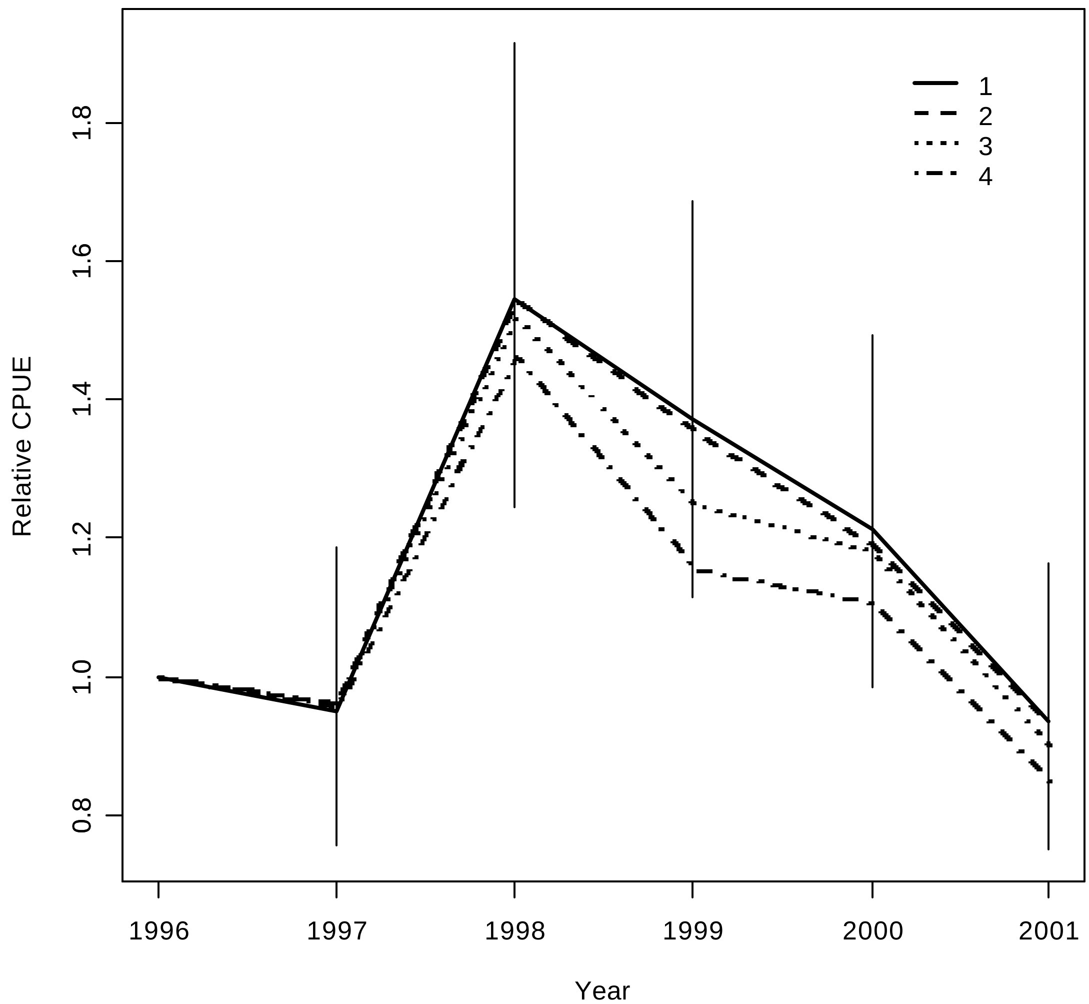


Figure 32. Area 3CD commercial CPUE. 1=baseline GLM with removal of coldspots (<5kg/h) and 95% confidence limits; 2=same as 1 but with removal of *catch-targets* associated with significant catch rates of silvergray rockfish (silvergray, canary and redstripe rockfish, and lingcod); 3= same as 1 but with removal of hotspots (>700 kg/h); 4=same as 1 but removal of hotspots (>200 kg/h).

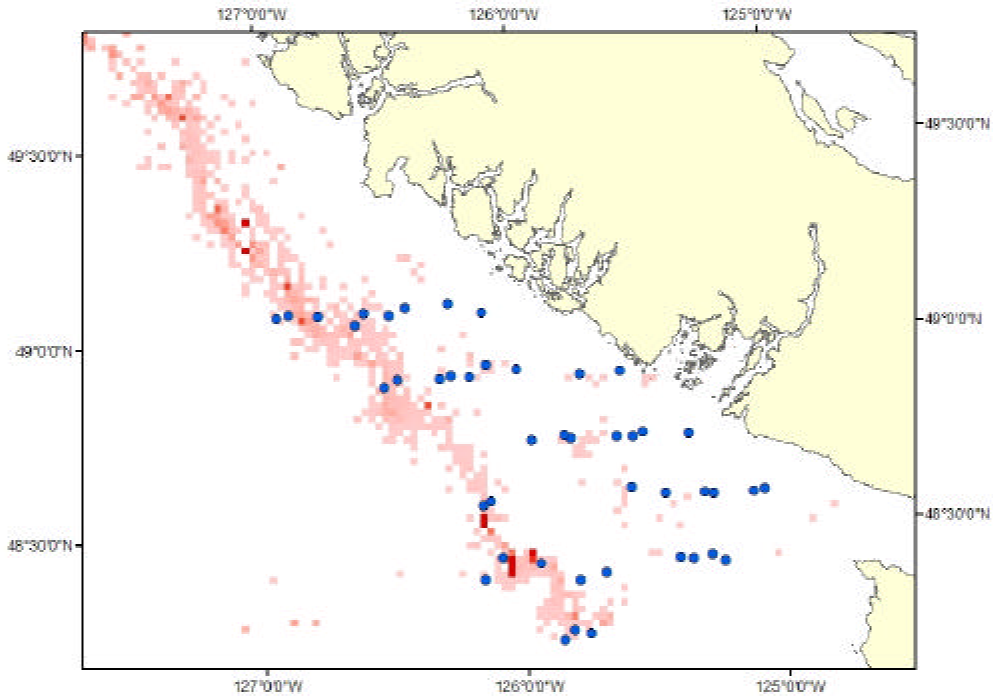


Figure 33. U.S. triennial survey set locations conducted in 2001 (dots). The shaded squares are commercial trawl “hotblocks” for silvergray. The intensity of shading in each 2km^2 block varies in proportion to the mean commercial trawl CPUE of silvergray caught between 1996 and 2001, inclusive.

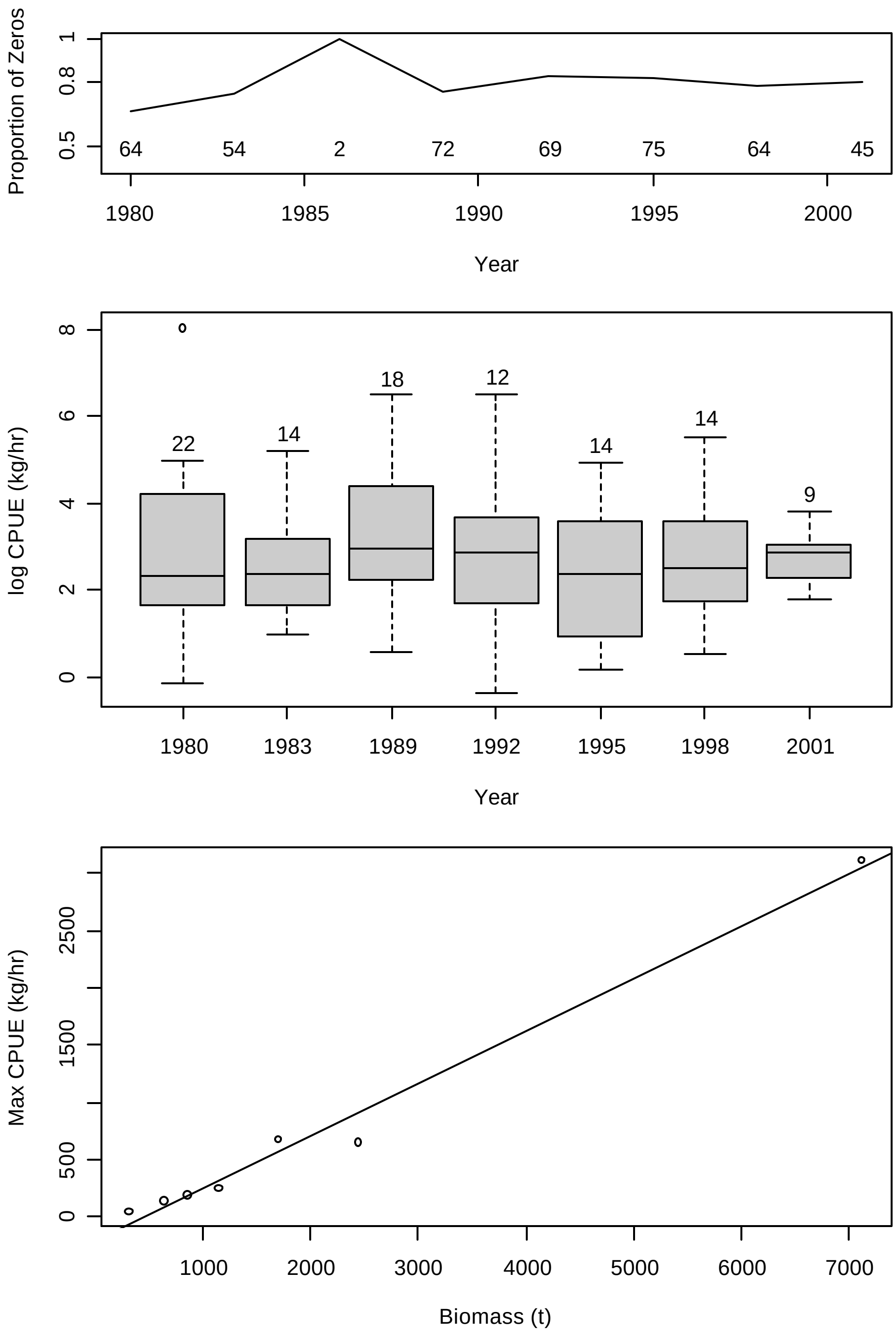


Figure 34. Silvergray rockfish catch in the U.S. triennial survey. Top panel: proportion of sets per year having zero silvergray catch. Middle panel: boxplots of log CPUE. Refer to Figure 2 for a description of boxplots. Bottom panel: Log of the CPUE of the largest sivergray set in each survey plotted against the biomass estimate for the same survey.

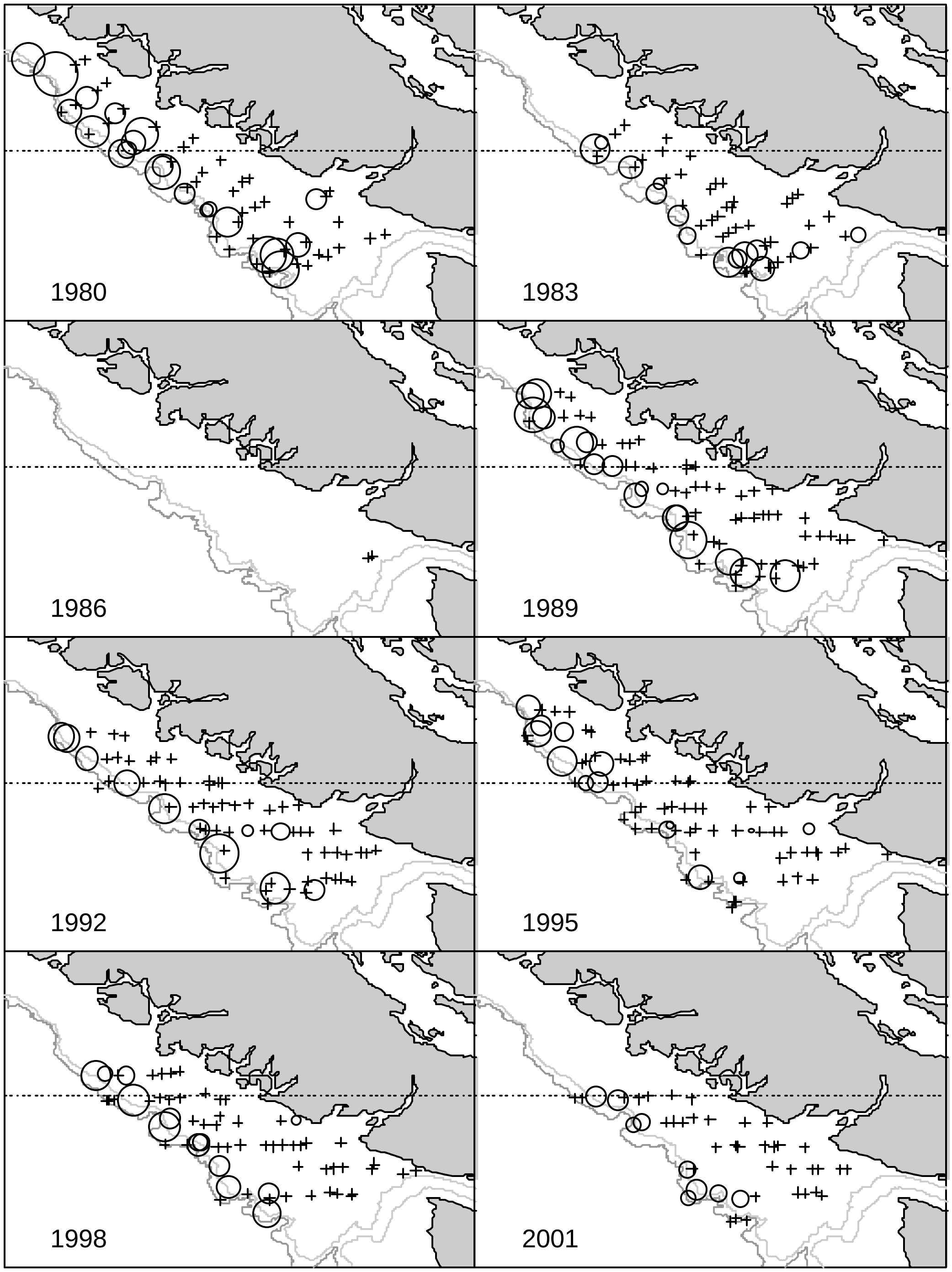
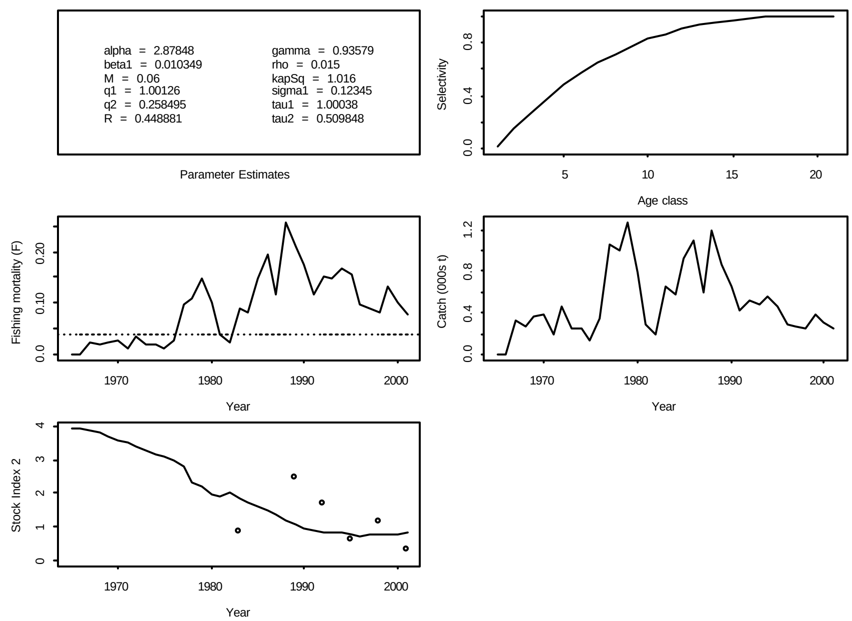
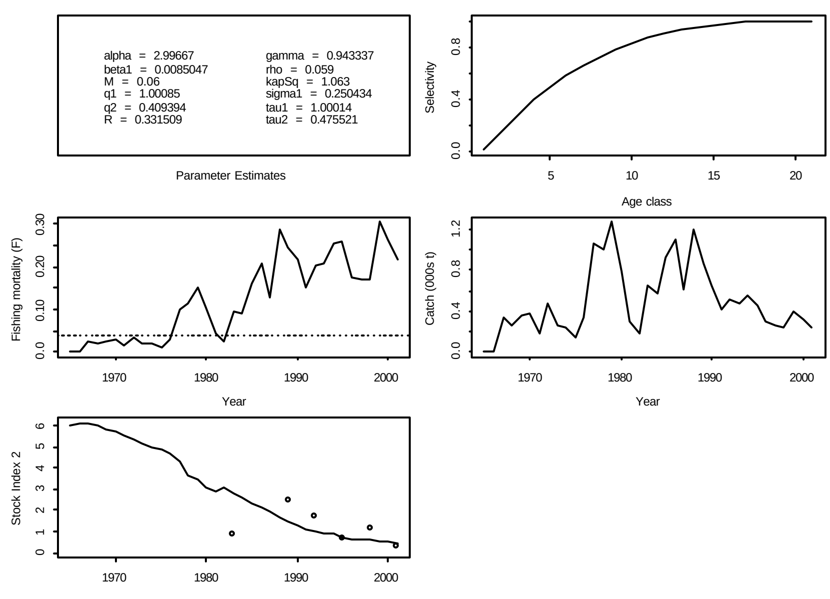


Figure 35. Location of U.S. triennial survey sets conducted in Canadian waters, 1980 – 2001. "+"s indicate the location of sets that caught no silvergray. The location of sets that captured silvergray are indicated by open circles where the area of the circle is proportional to the silvergray CPUE. The dotted line is drawn at a latitude of 49° 5'N.



(a)



(b)

Figure 36. 3CD catch at age model output for (a) Run #1 (b) and Run #5.

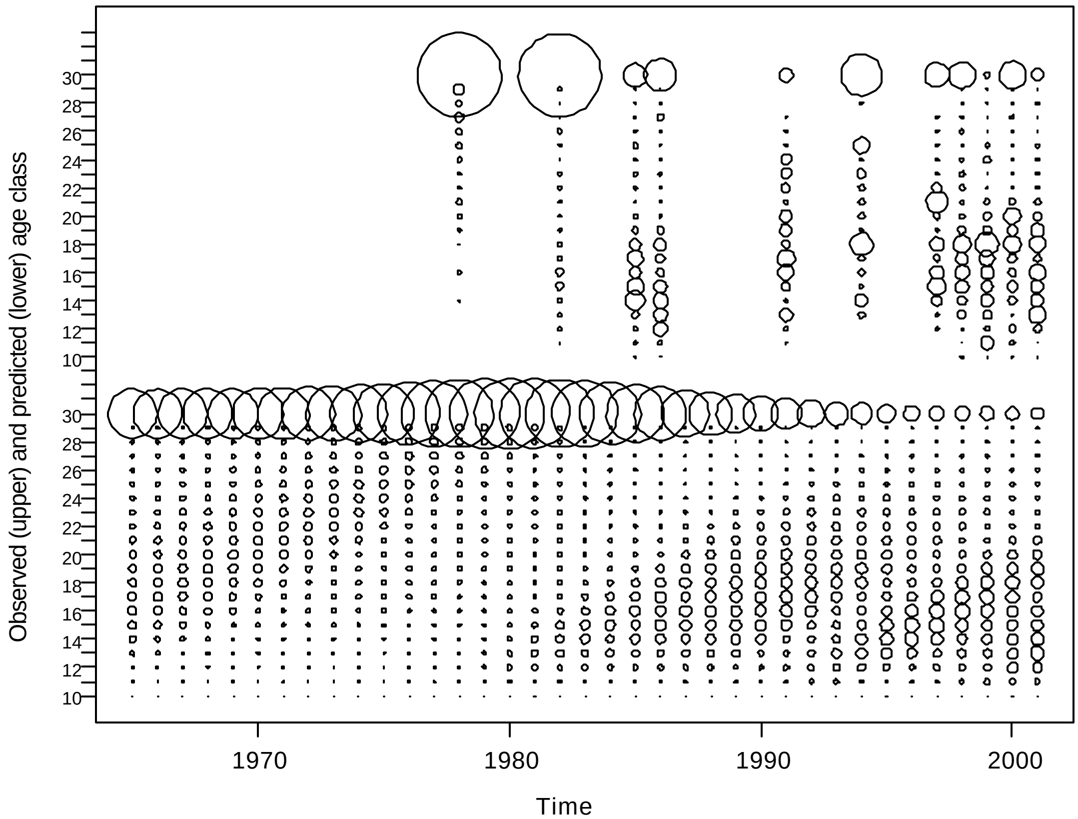


Figure 37. 3CD model showing predicted and observed proportions at age from Run #1.

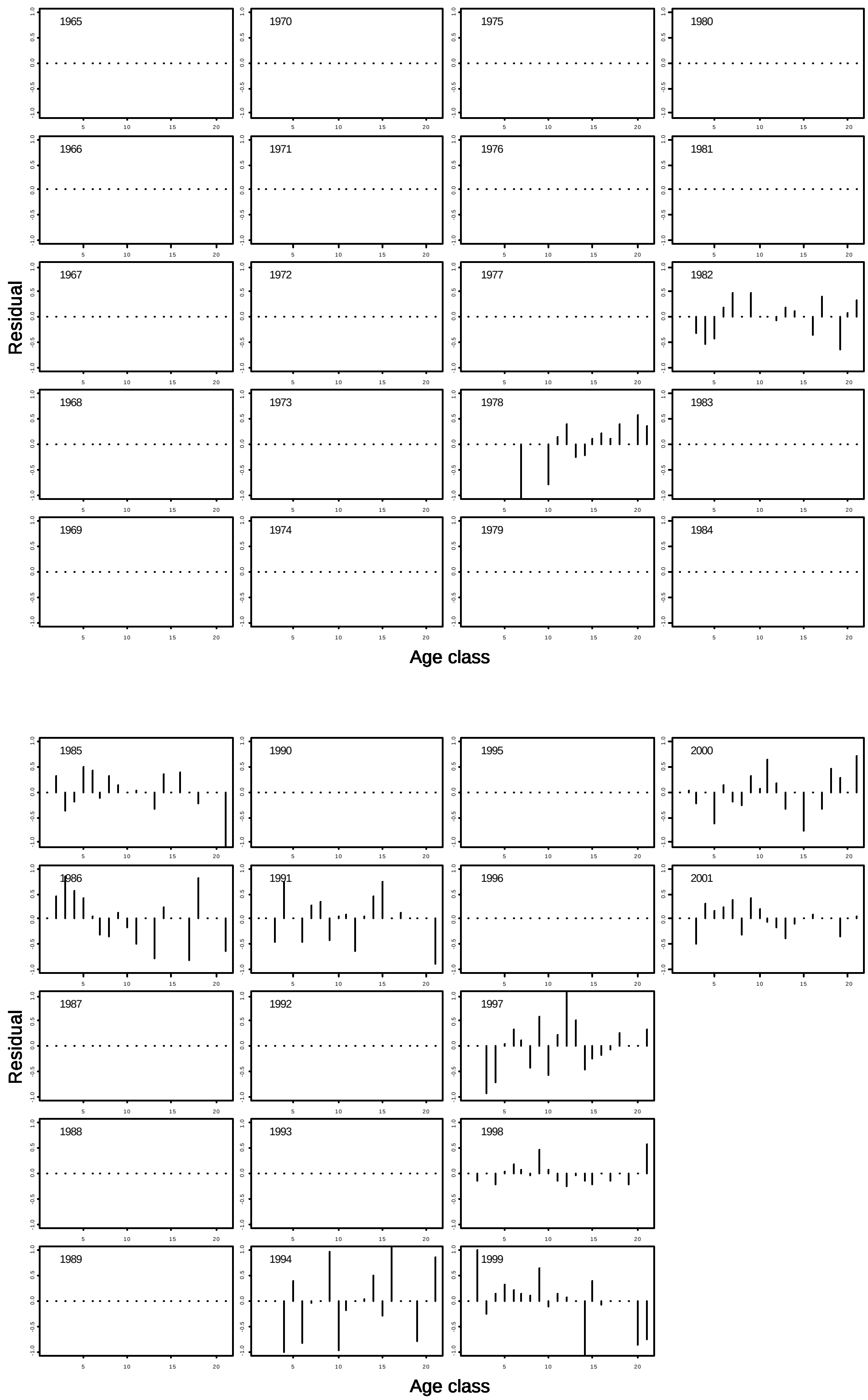


Figure 38. Plot of proportion at age residuals for 3CD model output (Run #1).

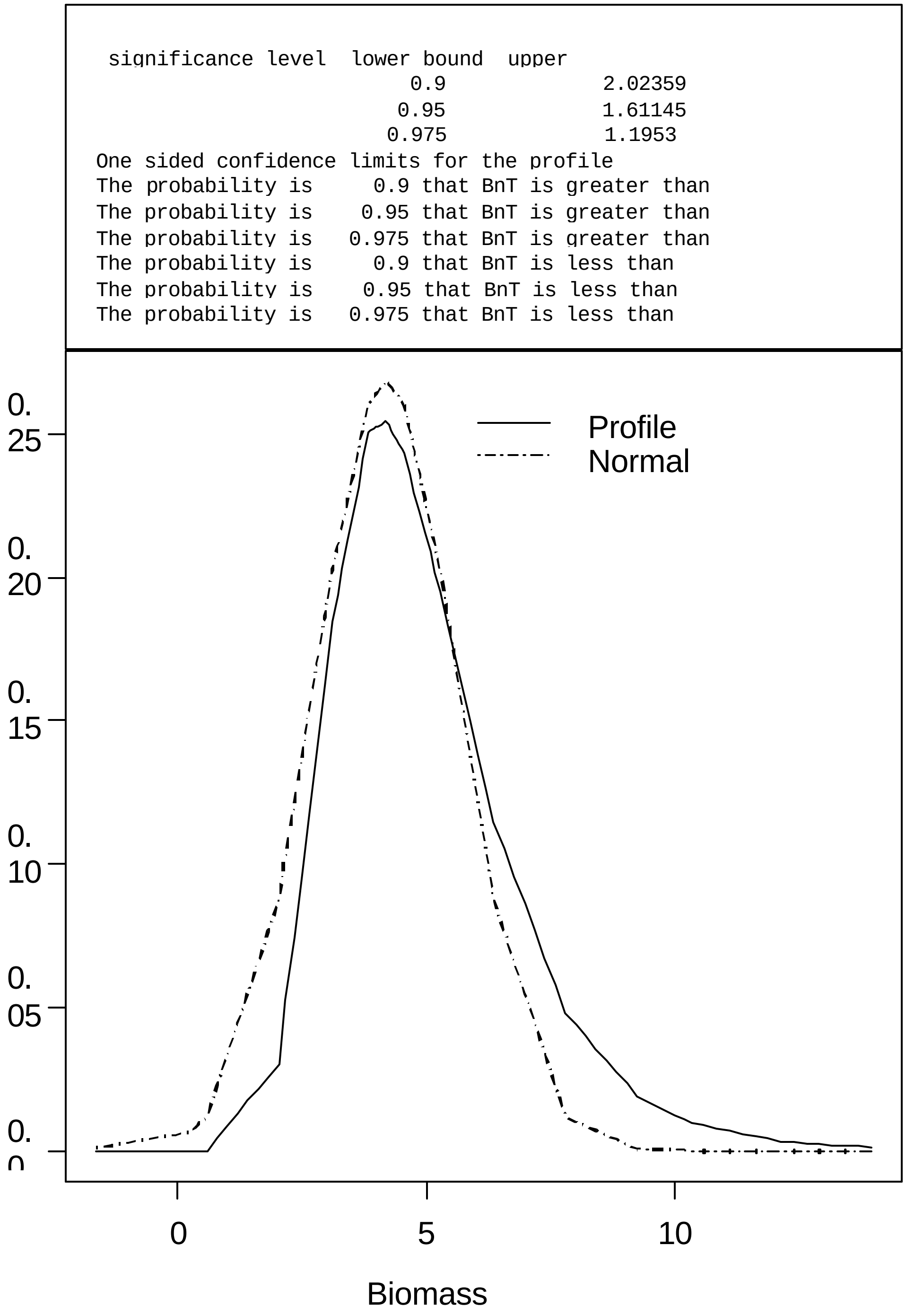


Figure 39. Likelihood profile of predicted biomass (‘000 t) from Area 3CD based on Run #1.

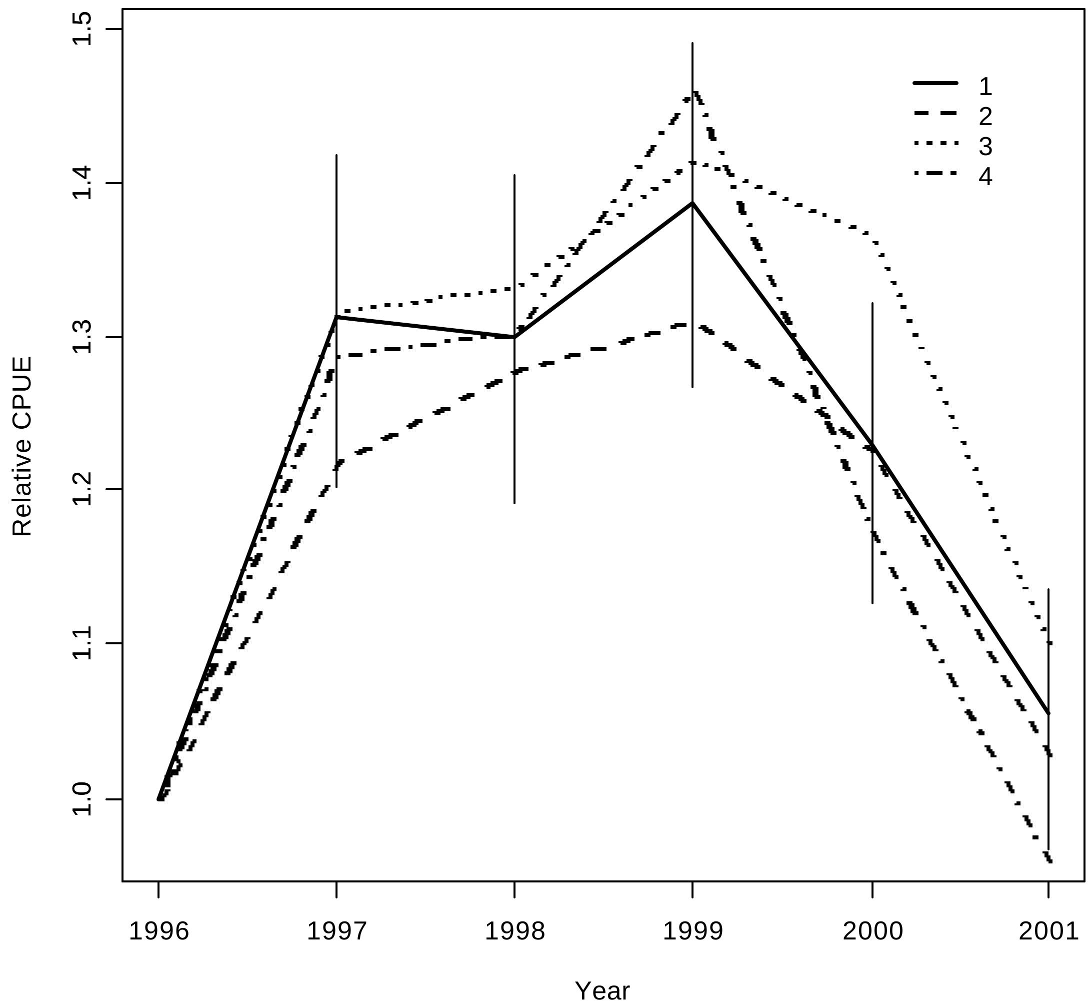
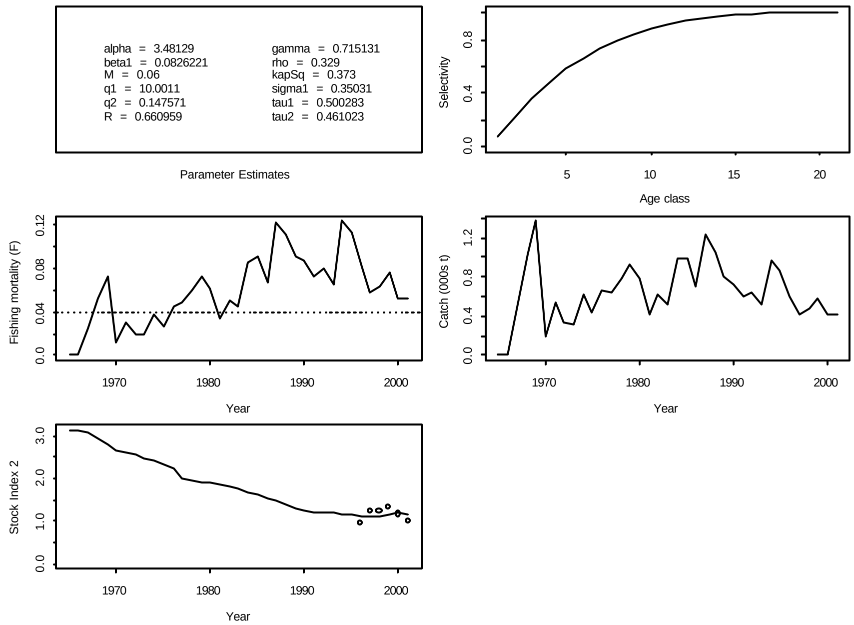
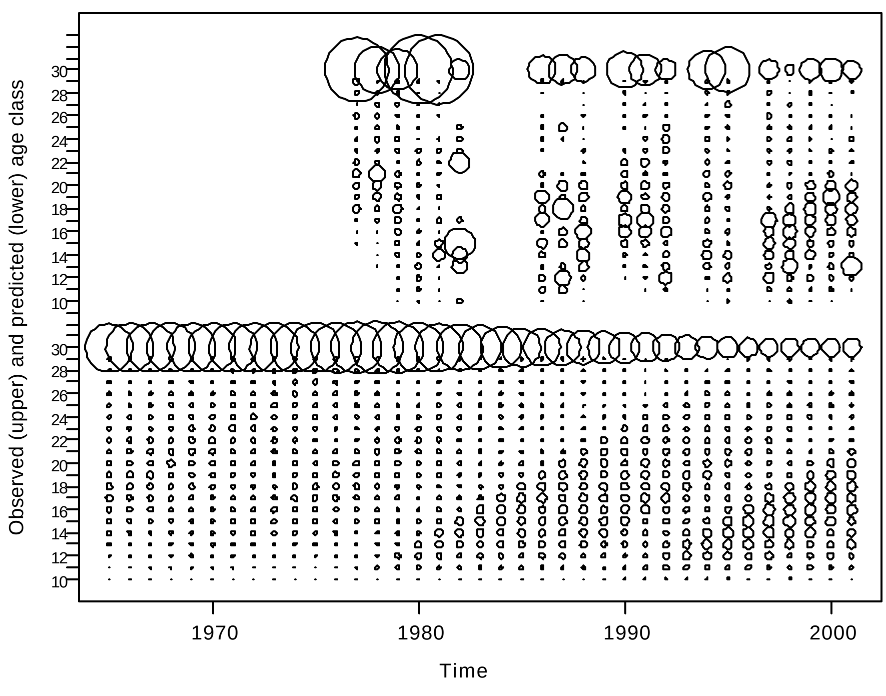


Figure 40. Area 5AB commercial CPUE from GLM. 1= baseline GLM with removal of coldspots (<5kg/h) and 95% confidence limts; 2=same as 1 but with removal of hotspots (>200 kg/h)); 3=same as 1 but with removal of hotspots (>700 kg/h); 4=same as 1 but with removal of *catch-target* as a factor.

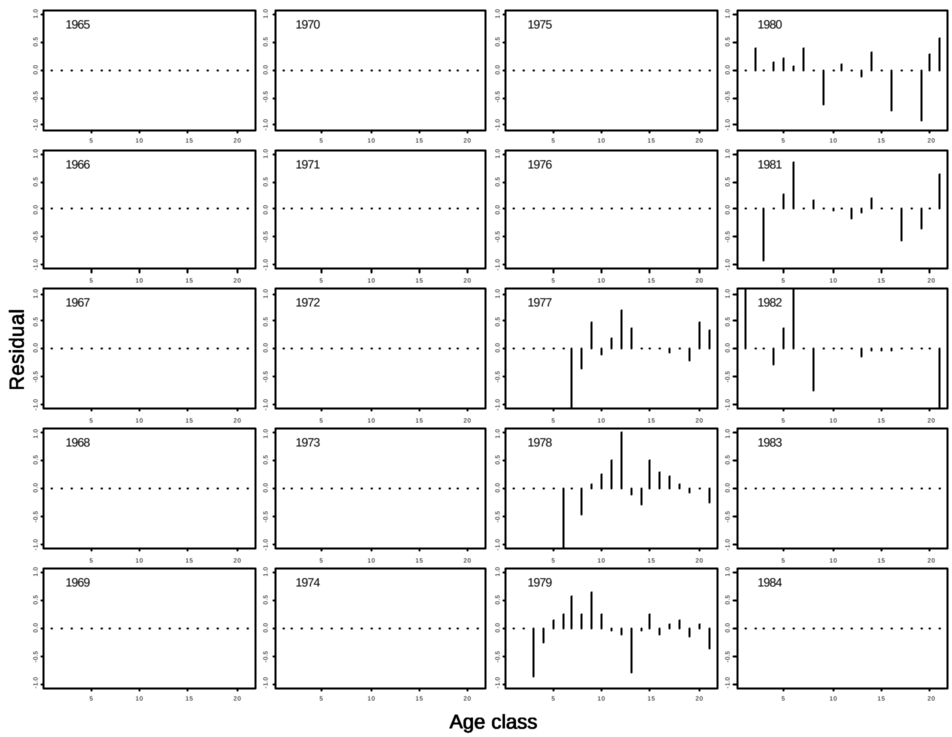


(a)



(b)

Figure 41. 5AB catch at age model output for Run #5 (a), 5AB model output showing predicted and observed proportions at age (Run #5) (b).



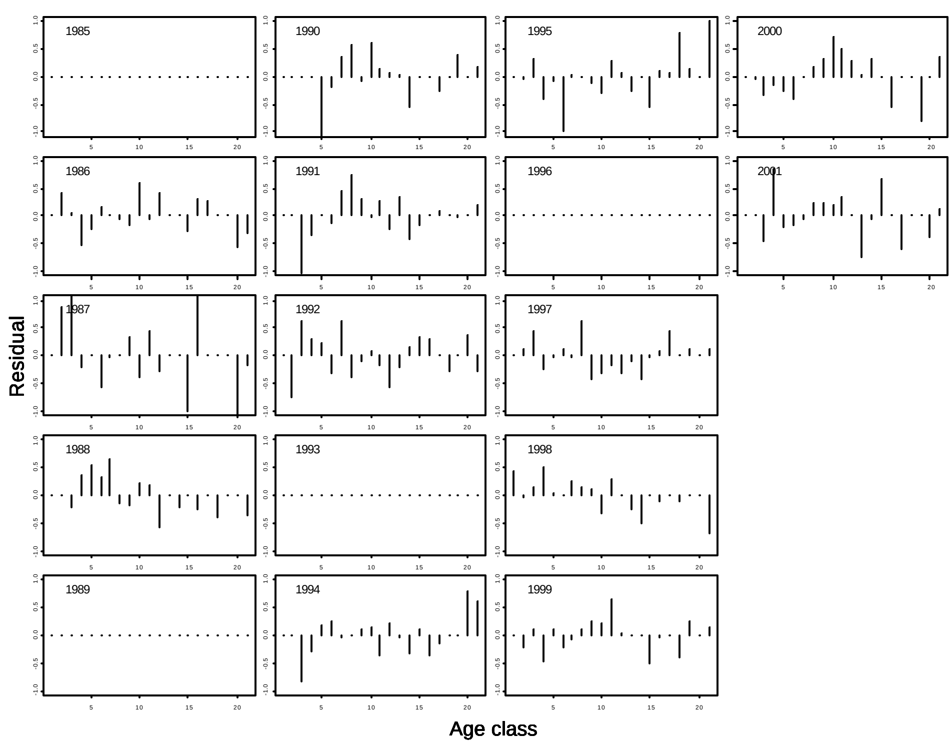


Figure 42. Plot of proportion at age residuals for 5AB model output (Run #5).

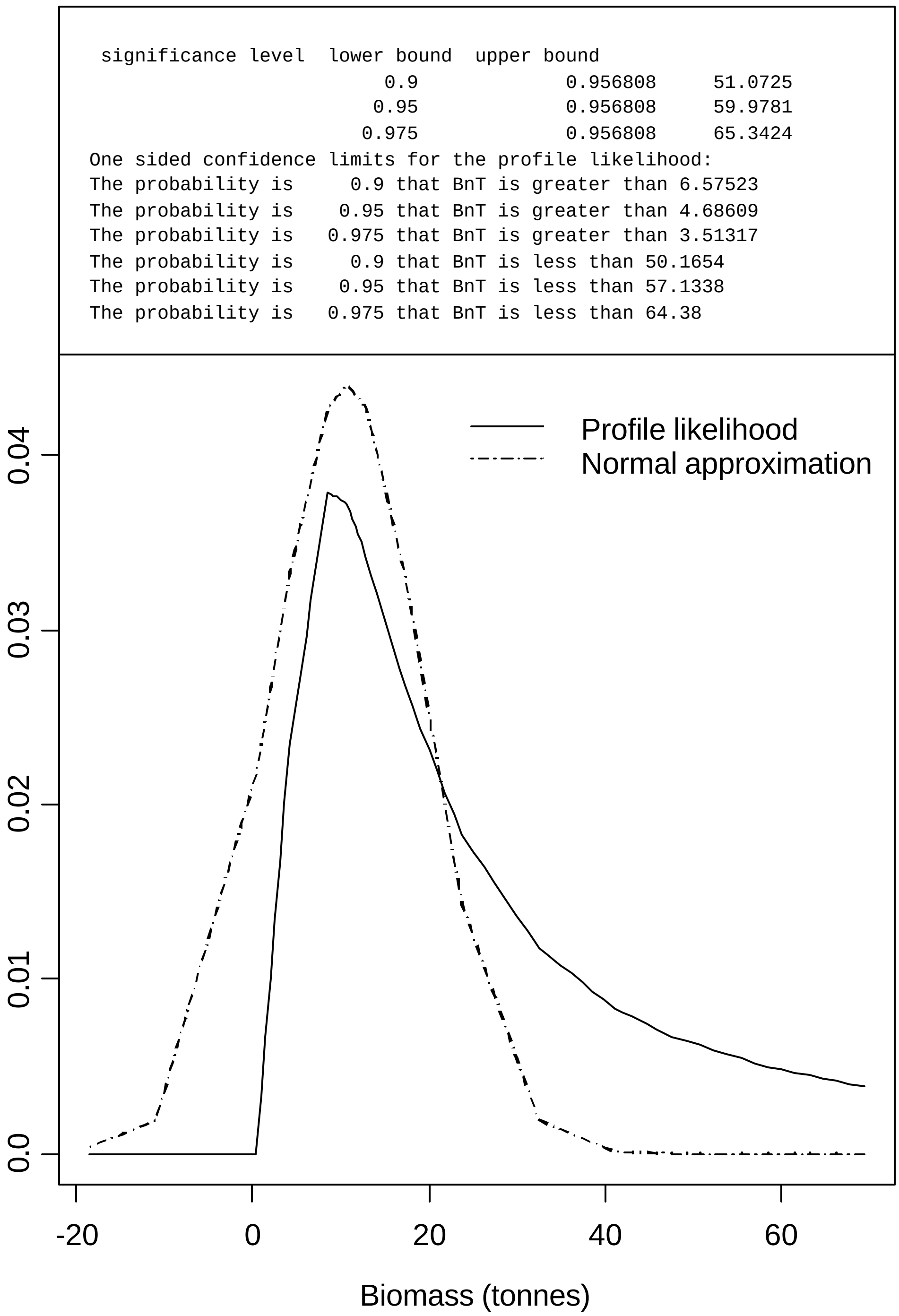


Figure 43. Likelihood profile of predicted biomass (‘000 t) from Area 5AB based on Run #5.

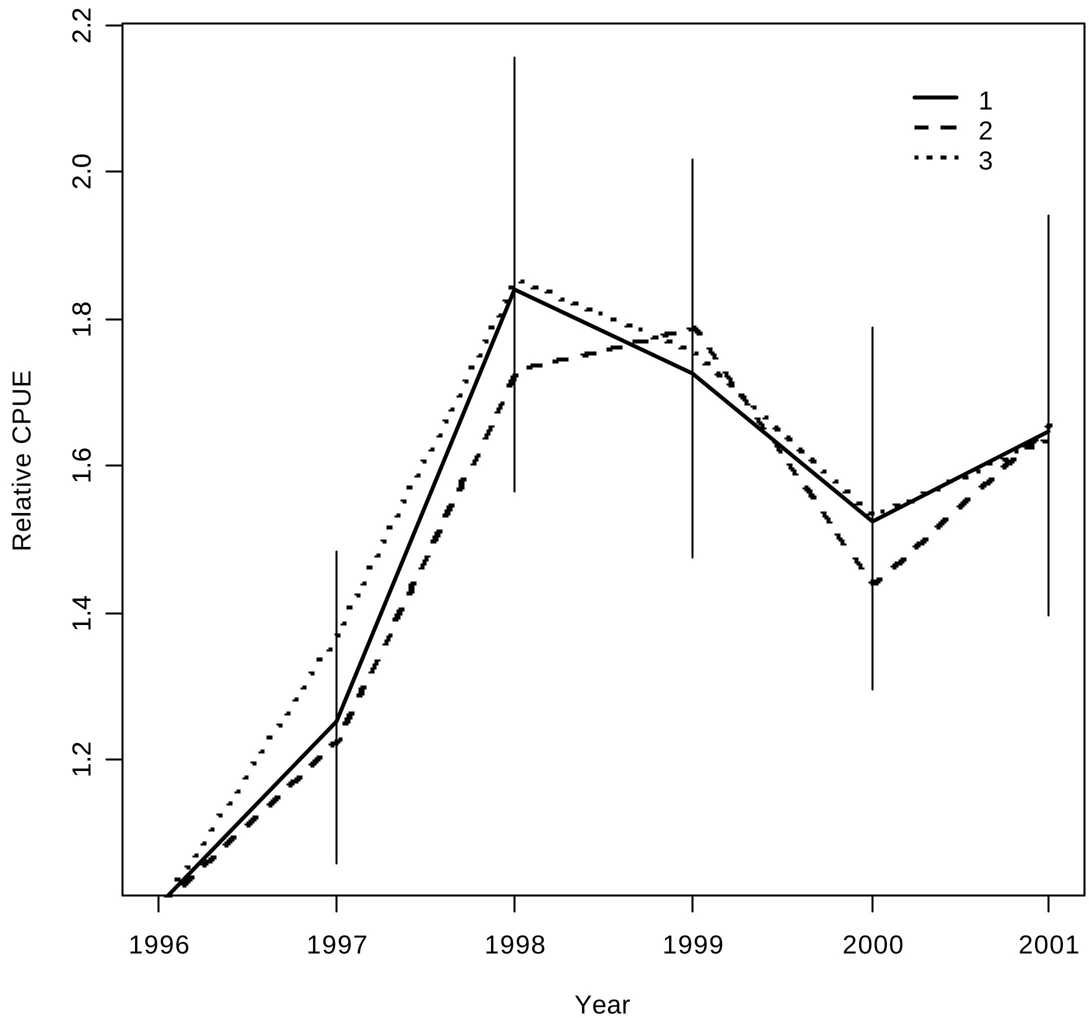
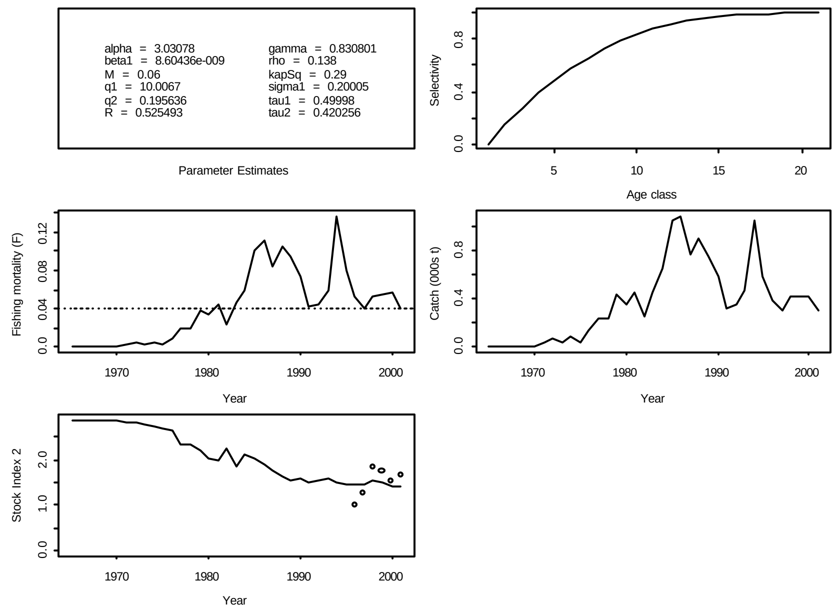
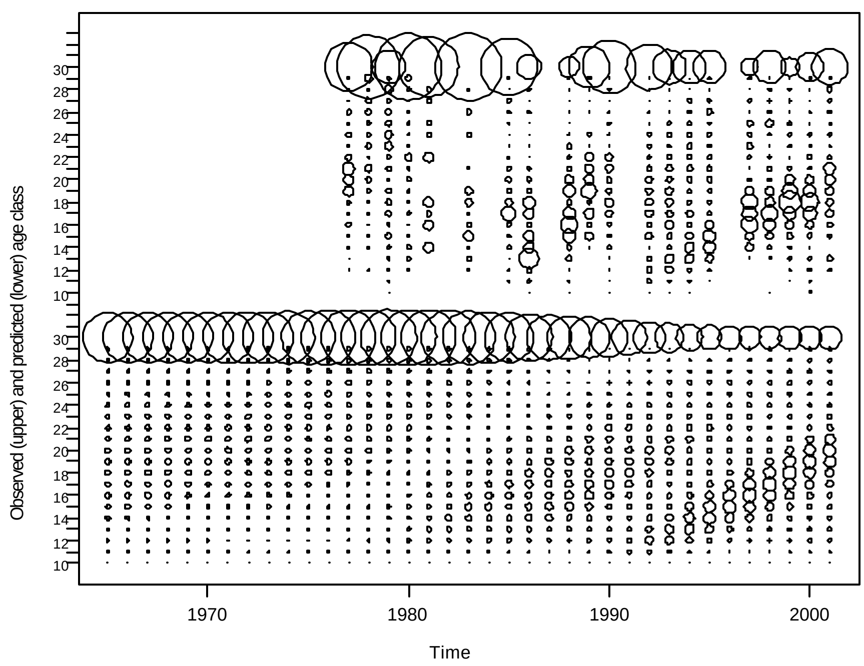


Figure 44. Area 5CD commercial CPUE from GLM. 1=baseline GLM with removal of coldspots (<5kg/h) and 95% confidence limits; 2=same as 1 but with but with removal of hotspots (>200 kg/h); 3=using all tows (no removal of coldspots or hotspots).

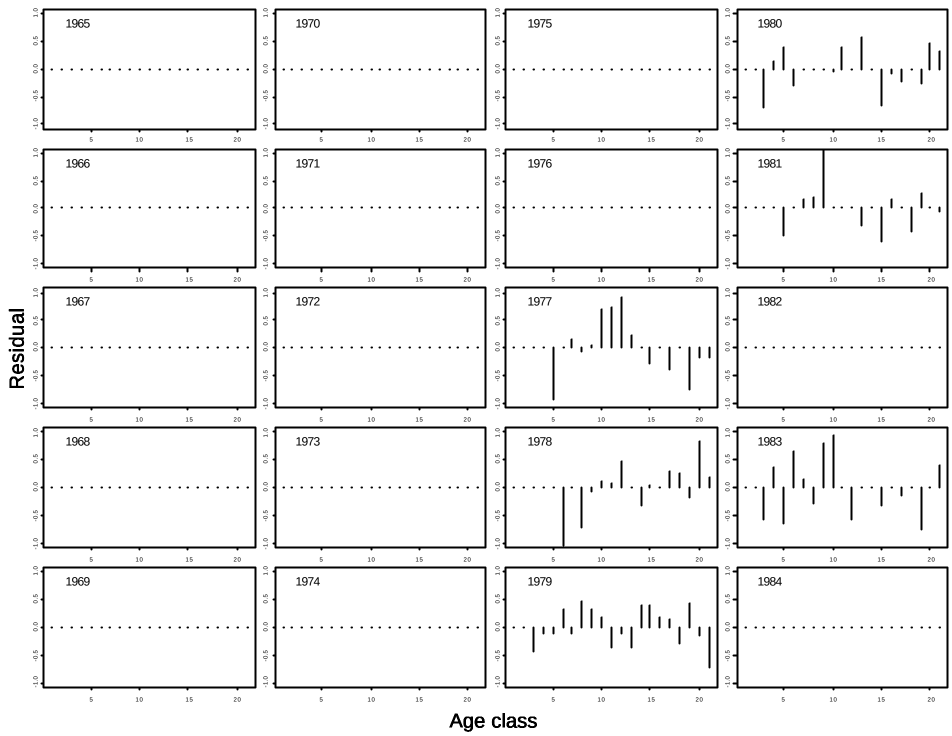


(a)



(b)

Figure 45. Area 5CD catch at age model output for Run #5 (a), 5CD model output showing predicted and observed proportions at age (Run #5) (b).



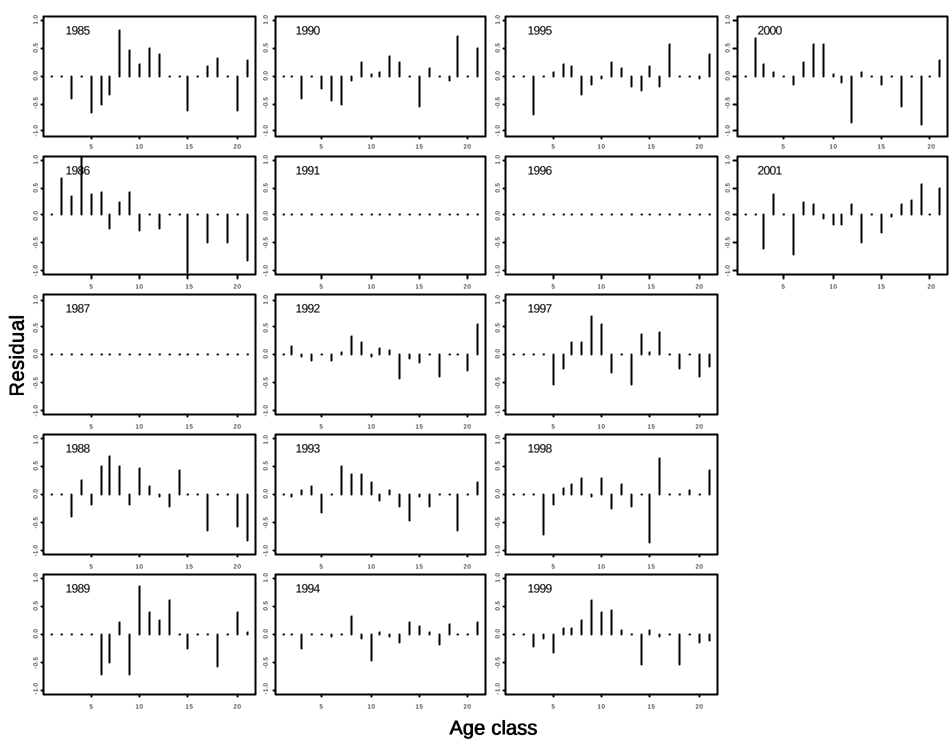


Figure 46. Plot of proportion at age residuals for 5CD model output (Run #5).

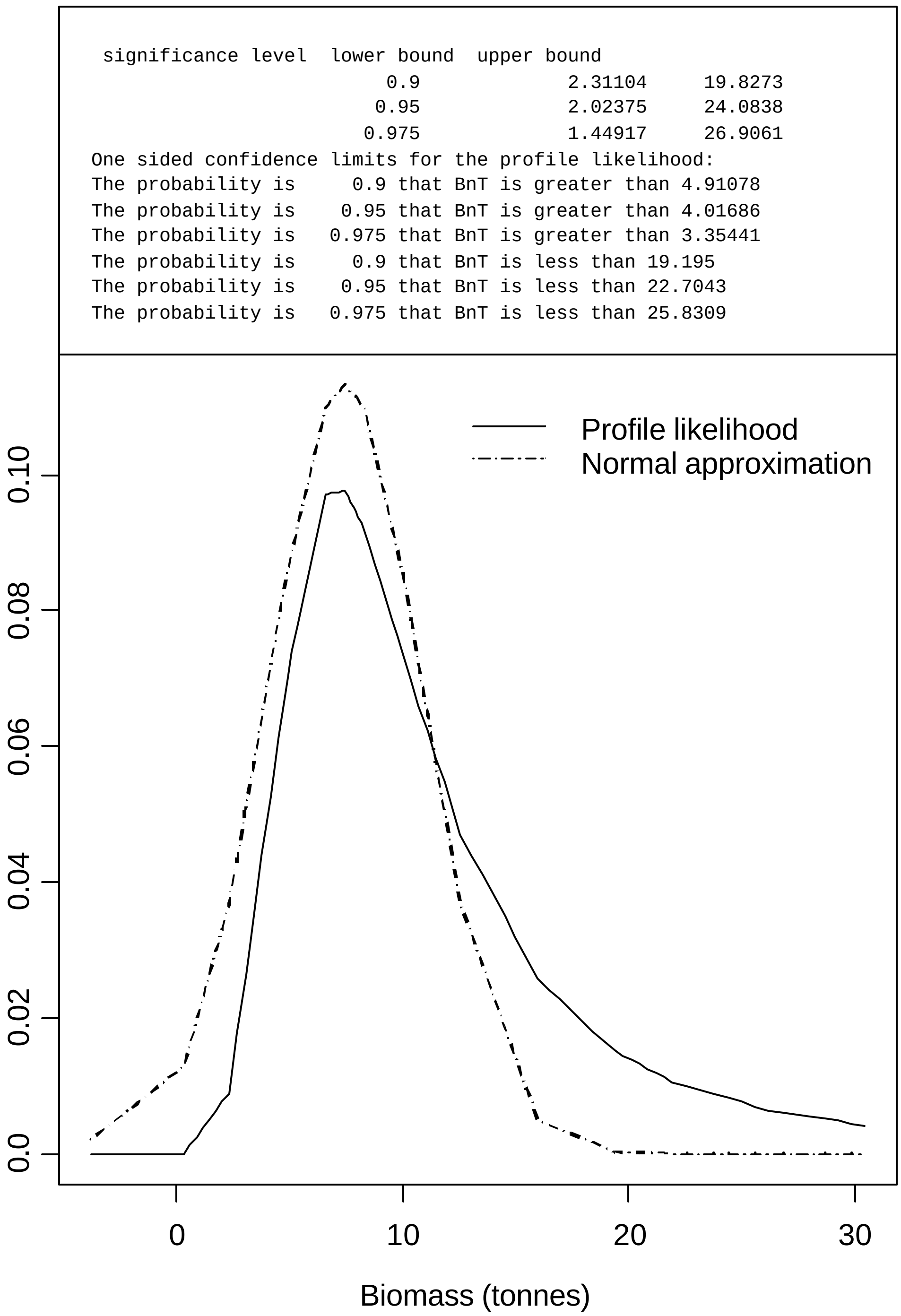


Figure 47. Likelihood profile of predicted biomass ('000 t) from Area 5CD based on run #5.

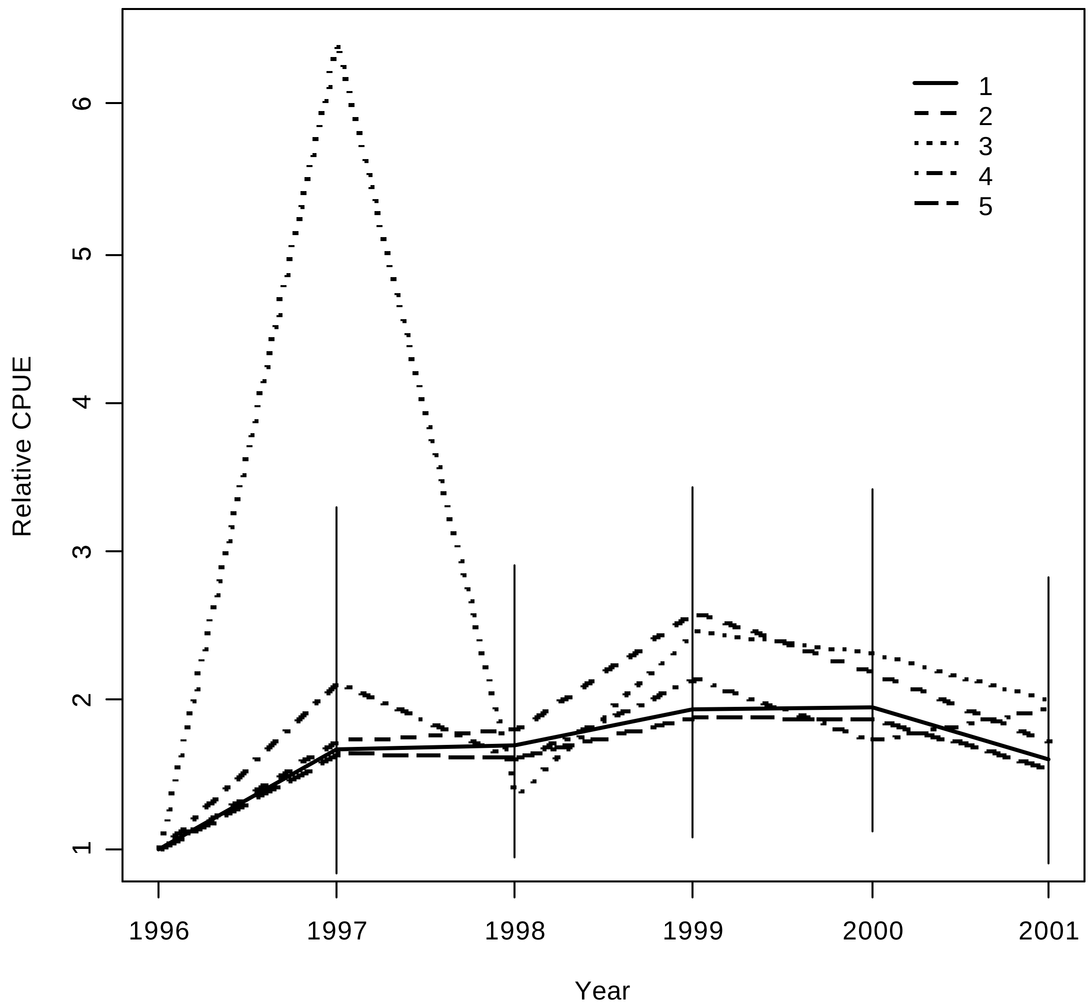


Figure 48. Area 5E commercial CPUE from GLM. 1=baseline GLM with removal of coldspots (<5kg/h) and 95% confidence limits; 2=same as 1 but with removal of hotspots (>200 kg/h); 3= same as 1 but with removal of hotspots (>200 kg/h); 5= used all tows.

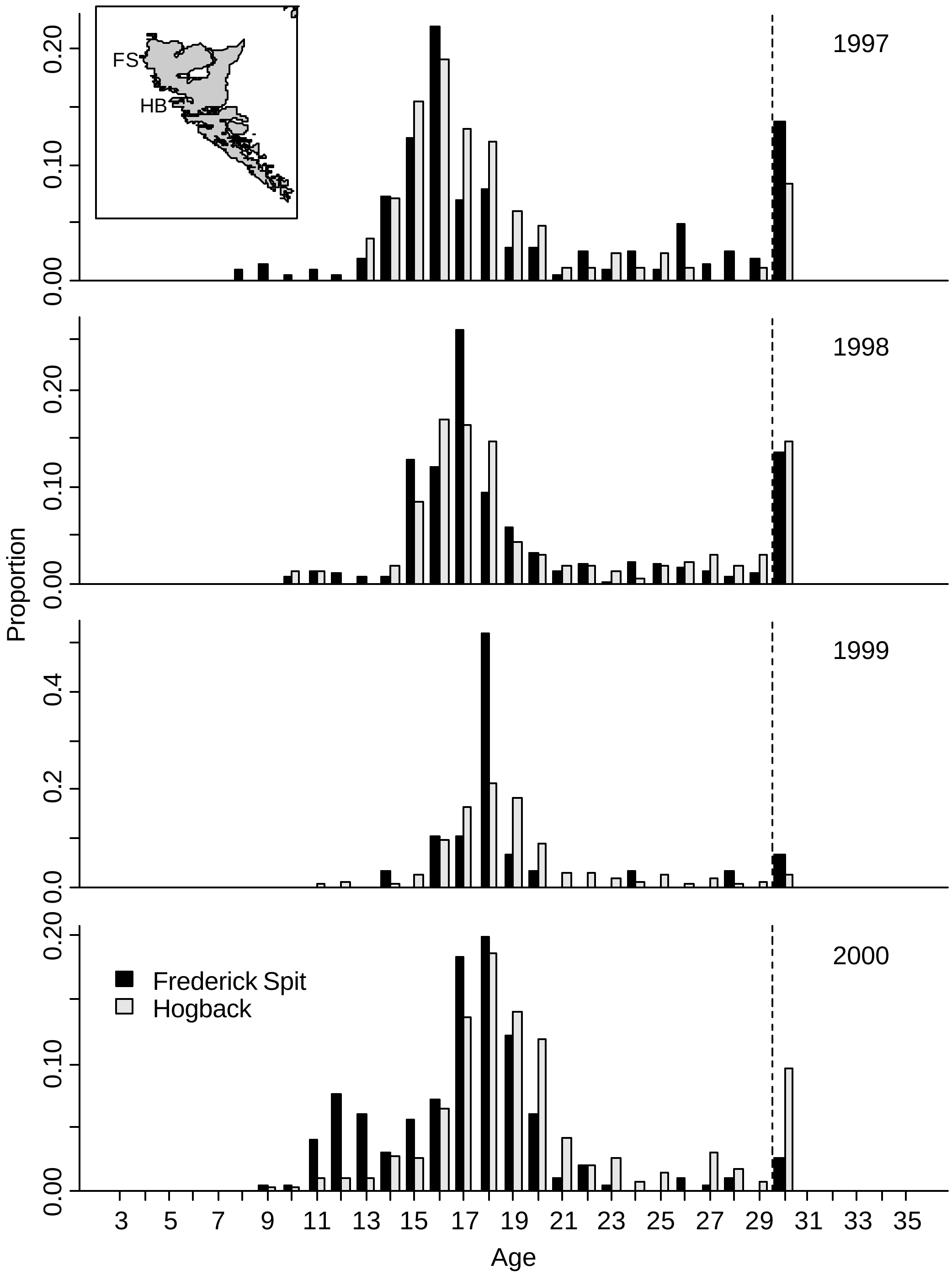
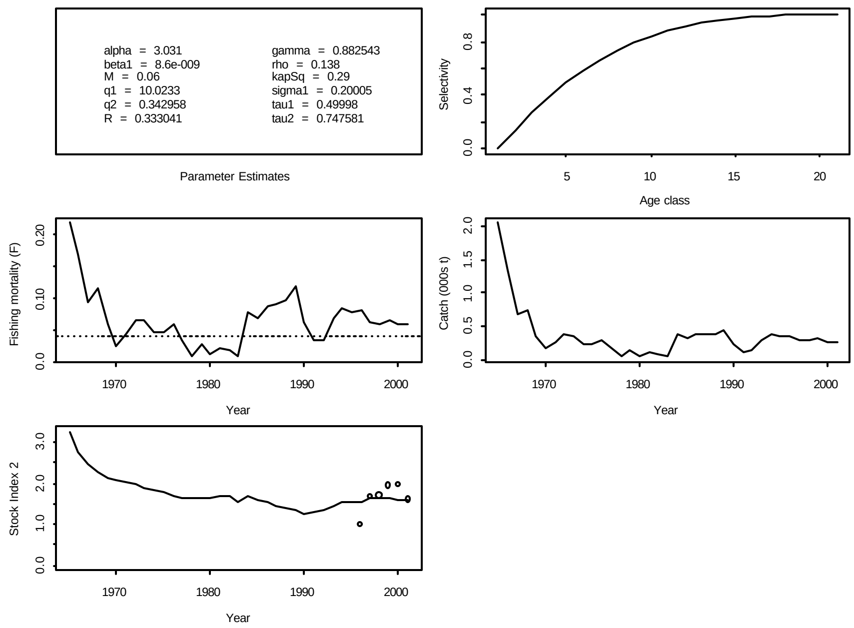
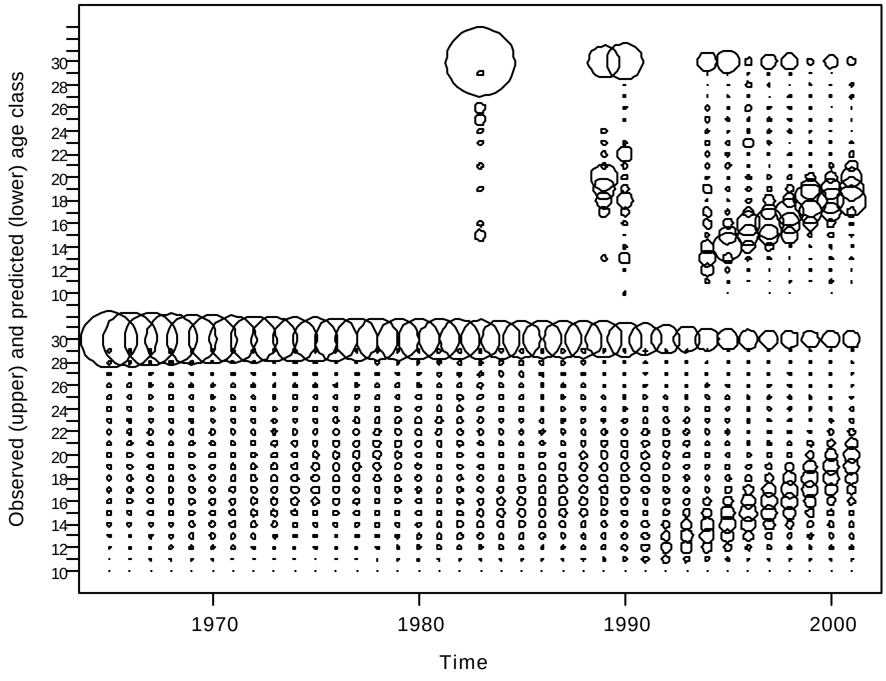


Figure 49. Comparison of age composition between Frederick Spit and Hogback samples. Inset map shows the approximate sample locations (FS = Frederick Spit; HB = Hogback).

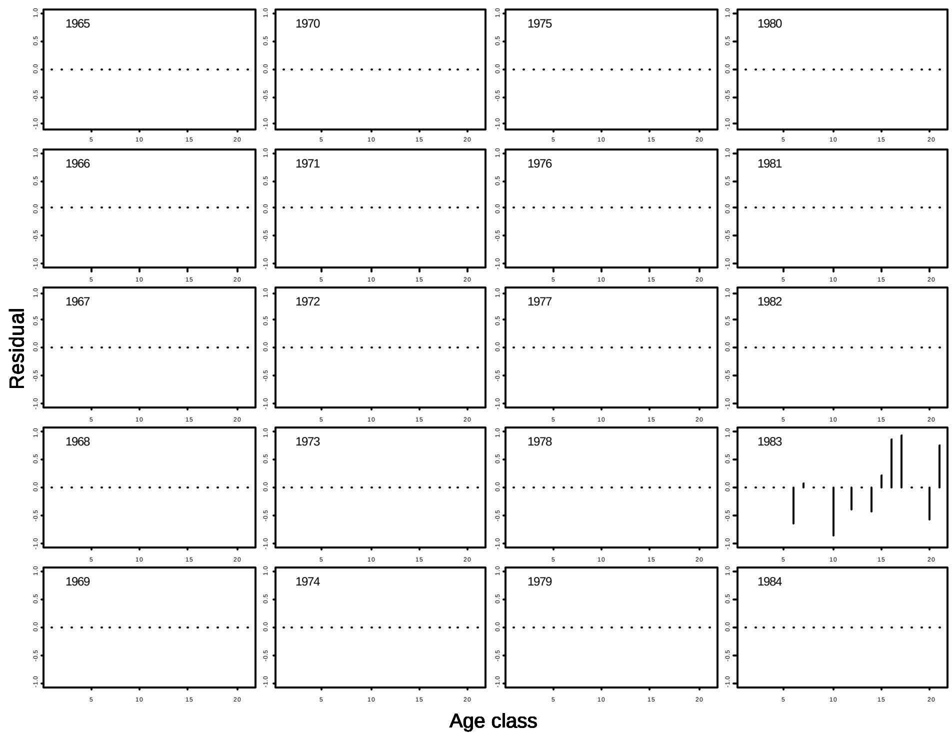


(a)



(b)

Figure 50. (a) 5E catch at age model output for Run #5 (b) 5E model output showing predicted and observed proportions at age (Run #5).



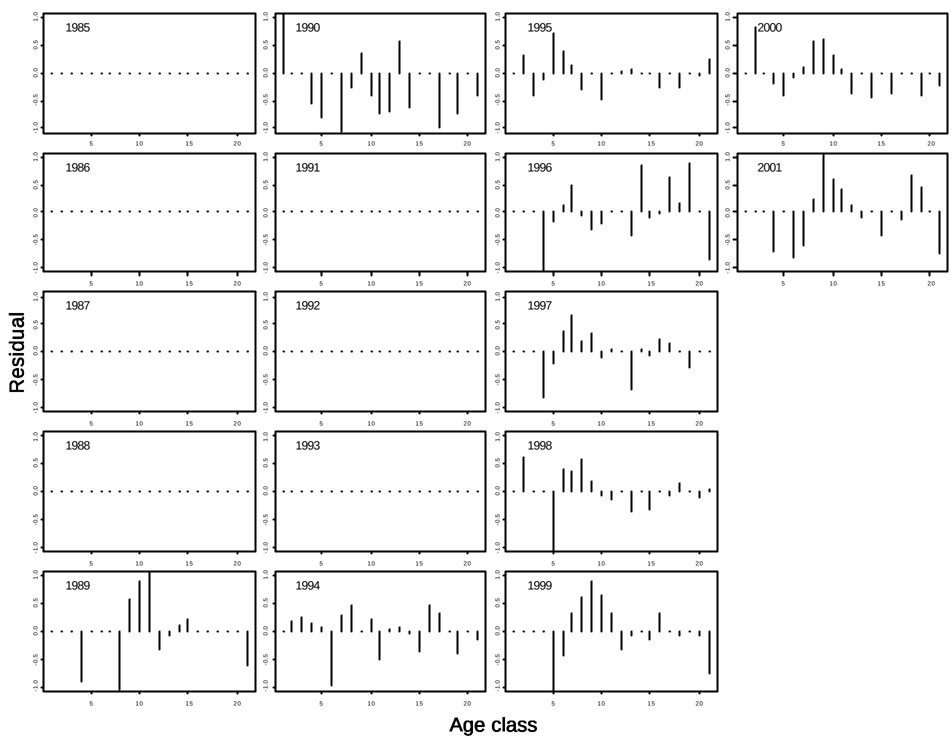


Figure 51. Plot of proportion at age residuals for 5E model output (Run #5).

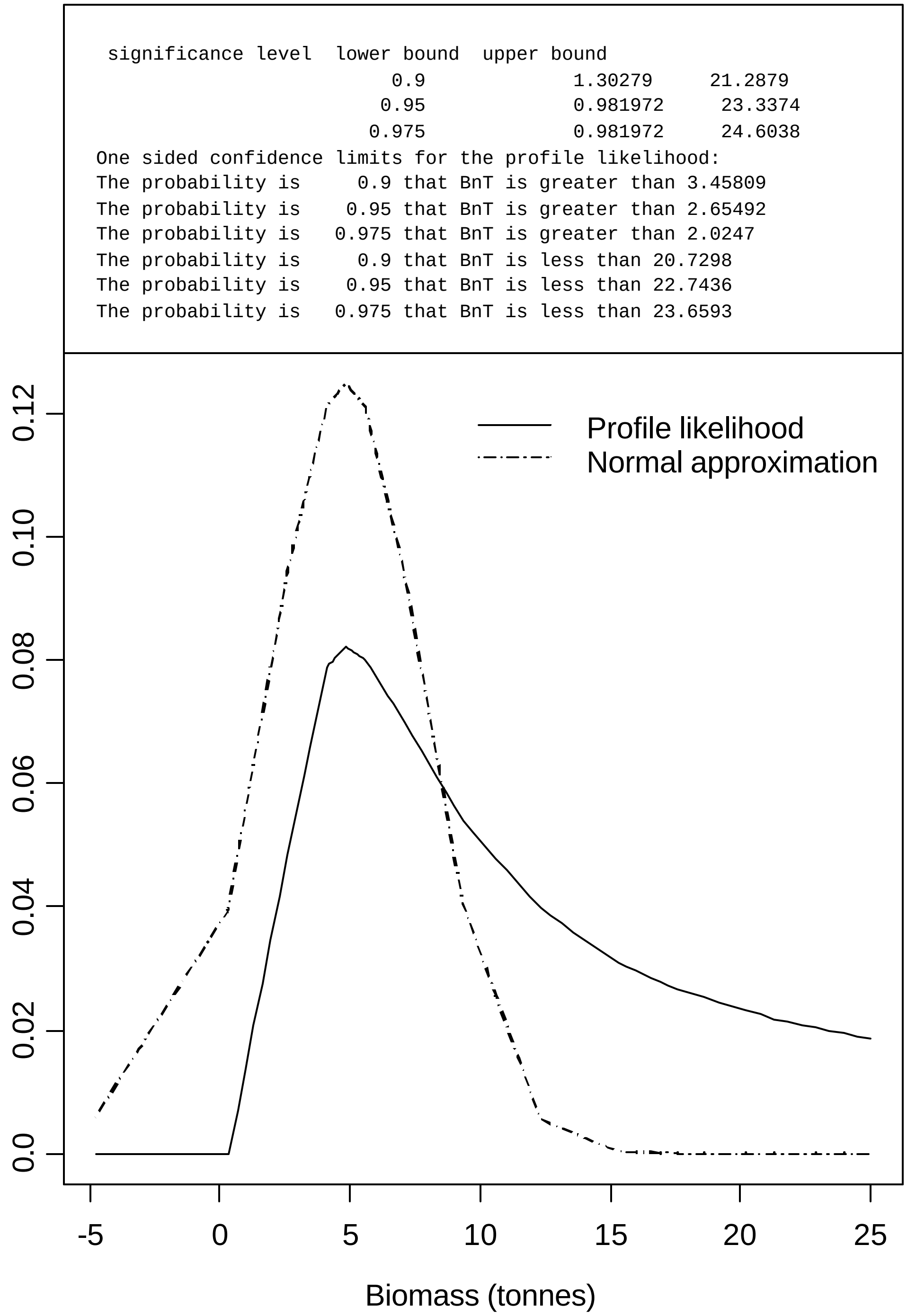


Figure 52. Likelihood profile of predicted biomass ('000 t) from Area 5E based on Run #5.

Appendix 1. PSARC Stock assessment request

Date Submitted: September 24, 2002
Individual or group requesting advice: Groundfish Trawl Advisory Committee Request (November 2000)
Proposed PSARC Presentation Date: November, 2002
Subject of Paper (title if developed): Stock assessment update for silvergray rockfish.
Lead Author: Rick Stanley
Fisheries Management Author/Reviewer:

Rationale for request:

Following presentation of a silvergray rockfish assessment in November 2000 (Stanley and Kronlund 2000), representatives of the fishing industry suggested that the stated status of these stocks was too conservative. They requested that the data be re-examined prior to any reduction in quotas implied by the analysis. Among other issues, they were concerned about the influence of the age composition data in the analysis given there was no abundance index for three of the four stocks. They commented that the older data (pre-1997) was probably to sparse to be considered "representative" and they suggested that changes in fishing behaviour associated with switch to IVQ's in 1997, made it incorrect to assume comparability over time among the commercial age samples.

While DFO declined to re-examine the material immediately, they agreed to re-do the assessment in two years instead of the tentative four year interval. The influence of the older ageing data on the assessment would then be examined and the assessment would benefit from the additional two years of information.

Question(s) to be addressed in the Working Paper:

The general question of the Working Paper is to examine whether the recommendations provided in the previous assessment should be revised or were the previous recommendations still appropriate.

Objective of Working Paper:

Overall: The general question of the project is to examine whether there is strong evidence that the recommendations provided in the previous assessment should be revised.

Specific questions to examine:

1. Determine the influence of the older (pre-1997) age samples on the current estimates of stock size.
2. Use recent commercial CPUE as a tuning index for the stocks.
3. Through GLM analysis, determine which factors contribute to the variance in CPUE and remove their influence in computing an abundance index. Factors to examine may include:

   a. Depth
   b. Time within the year
   c. Target species (determined by “dominant” retained species)
   d. Vessel
   e. Stock
4. Include the 2001 biomass estimate from the U.S. triennial survey in the estimation of stock abundance for Area 3C/3D.
5. Present variance in estimates of standing stock using MCMC methodology.

Appendix 2. Catch Age Model Description

The catch-age model used for this assessment is derived from those proposed by Schnute and Richards (1995), Richards *et al*. (1997), and Fargo and Richards (1998); all are based on the state-space formulation described by Schnute (1994). The notation for a model tailored to silvergray rockfish (*Sebastes brevispinis*) is presented in Appendix Table 1. The model is stated deterministically in Appendix Table 2. Stochastic variation is introduced in Appendix Table 3 where four sources of variability are contemplated. These components of variation are related to system dynamics (process error) in the recruitment function and survival, and to measurement error in the observation of the stock index and the proportions at age. Appendix Table 4 contains the likelihood functions corresponding to the deterministic model in Appendix Table 2, in which the survival error has been set to zero. The sequential components of the model are described below.

Selectivity

Fishery selectivity $\{b_a\}_{a=1}^{A}$ was allowed by vary with age class as defined by equation (D.2). Selectivity increases from b_1 to 1 as a ranges from age class 1 to accumulator age class A. Age class 1 is defined as the youngest age included in the input data. The accumulator age class A includes all fish equal to, or older than, the designated maximum age in the model. Selectivity is linear when the "slope" parameter $a = 1$ and is convex downwards when $a > 1$ with slope 0 at age a=A.

State moments

The exploitable population P_t, exploitable population biomass B_t, and exploitable age proportions u_{at}, depend on the selectivity vector through equations (D.3-D.5). The catch biomass D_t is assumed to be known without error and is converted to catch numbers C_t by equation (D.6) using the mean weights w_{at}. Spawning biomass B_t is computed using maturity at age m_a by equation (D.7).

Recruitment

Recruitment equations in Appendix Table 3 are derived from a lognormal autoregressive recruitment process

(1) $$\log R_t = \log R + g\,(\log R_{t-1} - \log R) + s_1 d_{1t}$$

with parameters (R, g, s_1) and where the d_{1t} are independent standard normal variates (Schnute and Richards 1995). This function (1) has the property that if $g = 0$ then log R is normal with mean log R and variance s_1^2. As the autocorrelation parameter $g \to 1$ the process approaches a random walk with finite moments

(2) $$E[\log R_t \mid R_{t-1}] = (1-g)\log R + g\,\log R_{t-1} \quad ,$$

(3) $$Var[\log R_t \mid R_{t-1}] = s_1^2 \quad ,$$

but infinite unconditional variance

(4) $$Var[\log R_t] = s_1^2 \big/ (1 - g^2) \quad .$$

Predicted observations

Observed data are related to the underlying biological system by equations (D.14-D.16), where an estimated observation is denoted by a bar over the quantity. Observed data are derived from commercial fishery catch and effort data, and from proportions at age determined from samples of the commercial catch.

Stock Abundance Indices

Stock abundance indices are incorporated through equations (D.14) and (D.15). Commercial catch rates were divided into two time series (I_{1t}, I_{2t}) to reflect the change in management regimes resulting from the implementation of full observer coverage in 1996.

The stock indices are assumed to be proportional to the exploitable biomass after known fractions (f_{1t}, f_{2t}) of the catch are removed. For example, the fraction f_{1t} represents that portion of the annual catch taken at the time the index was measured. For this analysis, $f_{1t} = 0.5,\ t \in \mathbf{T}_1$ and $f_{2t} = 0.5,\ t \in \mathbf{T}_2$.

Proportions at age

The proportions p_{at} are estimated using the exploitable proportions u_{at} calculated in equation (D.16). For silvergray rockfish, the age-class *a*=1 corresponds to fish that recruit at age 10, while the accumulator age class *A*=21 consists of all fish age 30 and older.

The age proportions were computed within each year by averaging across samples. Thus, the proportion at age was estimated as

(5) $$p_{at} = \frac{1}{K_t} \sum_{k=1}^{K_t} \frac{n_{atk}}{\sum_a n_{atk}} \quad ,$$

where n_{atk} is the number of fish at age *a* in year *t* for sample $k = 1, \dots, K_t$.

A multivariate logistic error structure (S.10, L.8) was adopted for the proportions at age for two reasons. First, the observed proportions at age may be suspected to have higher variances than expected if the data were drawn from a multinomial distribution. Second, the logistic distribution provides a simple transformation that ensures the model proportions sum to one but allows model parameters to be unconstrained (Schnute and Richards 1995, Quinn and Deriso 1999, p. 332).

Sequential algorithm

The model described in Appendix Table 2 includes a population state vector $\{N_{at}\}_{a=1}^{A}$ for each year t with system dynamics for these states defined by equations (D.9)-(D.13). These dynamics are a consequence of the parameter vector **Ö** and the control data defined by catch biomass (D_t), mean fish weight at age a and time t (w_{at}), maturity at age a (m_a) and the observed proportions at age a and time t (p_{at}). The parameter vector **Ö** includes the recruitments $\{R_t\}_{t=2-A}^{T}$ that determine the initial states N_{a1} at time t=1 using equations (D.9) and (D.10) and the initial moments from equations (D.3) to (D.8). At time t=2, the states N_{a2} are determined using the dynamic equations (D.11)-(D.13) and the previously computed values (N_{a1}, C_1, u_{a1}). Iterative application of this procedure yields values N_{at} for all values of time $t = 2, \ldots, T$. Estimated observations are produced by application of equations (D.14)-(D.16) to the values of the states and moments determined at each iteration.

Unit analysis

The recruitment vector $\{R_t\}_{t=A-2}^{T}$ determine the units of the numbers of fish N_{at} by equation (D.9-D.13). The catch in numbers C_t is in units of millions of fish since the observed catch biomass D_t, (thousands of tonnes) is divided by the mean weight per fish w_{at} (kilograms). Hence, the recruitment units are millions of fish. Exploitable biomass B_t is in units of millions of kilograms, or thousands of tonnes, by equation (D.4). Spawning biomass is also in millions of kilograms (thousands of tonnes) by equation (D.7).

Sources of error

The sources of error are (1) autoregressive lognormal process error among the recruitments R_t with recruitment standard deviation s_1 (2) lognormal measurement error in the stock indices (I_{1t}, I_{2t}) with index standard deviation t_1, and (3) multivariate logistic measurement error in the observed age proportions p_{at} with standard deviation t_2. We have assumed that the standard deviation t_1 applies to both stock indices. This is reasonable since the index residuals defined by equations (L.6, L.7) are formed from the log of ratios and are therefore dimensionless. Also, error in the survival process represented by equations (S.5, S.7) of Appendix Table C.3 has been ignored by setting $s_2 = 0$.

In order to avoid singularities in the maximum likelihood function (L.11) (Schnute 1994, Schnute and Richards 1995), we reduce the number of parameters by assuming a known variance ratio between recruitment process error and stock index measurement error. Equation (L.2) defines the total variance k^2 resulting from the two error components and r is the proportion of this variance attributable to the recruitment process error. The definition (L.2) re-parameterizes the recruitment and index errors from (s_1, t_1) to (k^2, r), while equation (L.3) reverses the transformation. Note that a given choice of r implies the variance ratio

(5) $$\frac{s_1^2}{t_1^2} = \frac{r}{1-r} \quad .$$

Thus, as $r \to 0$, recruitment becomes more deterministic $(s_1 \to 0)$. Similarly, measurement error assigned to the stock indices diminishes as $r \to 1$ and therefore $t_1 \to 0$.

Likelihood function

Table C.4 defines the likelihood function $L(\mathbf{È})$ for the stochastic model, where the parameter vector **È** includes the vector **Ö** in equation (D.1) plus the parameters (R, g, s_1, t_1, t_2). Computation of the likelihood function begins with the values of $\overline{p}_{at}$ and $\overline{I}_{it}$ from Table C.2 and proceeds through equations (L.4)-(L.12).

Technical issues

Technical details related to model implementation are omitted from the model description in Tables C.2 through C.4 to simplify notation. Implementation details include the following issues.

The state-space formulation accommodates missing information. Missing catch or index data requires that terms be dropped from the product (L.10).

In order to reduce the influence of age class proportions based on only a few fish, the definition of an age class was altered to require that $p_{at} \geq 0.02$ for all *a* and *t* in the manner of Richards et al. (1997). This requirement was implemented in computer code by grouping consecutive ages into a single age class whenever necessary. When a proportion was less than or equal to 0.02 for a given age class *a*, the observed numbers at age *a* were added to the observed numbers at age classes *a*+1, a+2, … until the proportion exceeded 0.02. Thus, years with no age proportion data are not included in the product (L.11).

Removing the effects of the stock indices can be achieved by fixing any two of (r, k^2, s_1^2) appropriately. In particular, fix r at some small value (e.g. 0.0001) and fix s_1^2 at some sensible value by setting $k^2 = s_1^2 / r$ as implied by equation (L.3). As a consequence, k^2 will be large, and hence t_1^2 will be large. This effectively reduces the weight of $L_2(\mathbf{\grave{E}})$ of equation (L.10) in the overall likelihood $L(\mathbf{\grave{E}})$ defined in equation (L.12).

Appendix Table 1. Notation for the silvergray rockfish catch-age model.

Symbol	Description
	Indices and index ranges
a	Age class, where 1<= a <=A and a =1 corresponds to first age class
t	Year, where 1<= t <=T and t =1 corresponds to the first year
A	Accumulator age class
T	Final year
$\mathbf{T}_1, \mathbf{T}_2$	Sets of years for stock index 1 and stock index 2
	Data
D_t	Observed catch biomass in year t
$f_{1t},\ f_{2t}$	Fraction of catch taken prior to measurement of stock indices
I_{1t}, I_{2t}	Observed stock indices in year t
m_a	Proportion of age class a fish that are mature
p_{at}	Observed proportion of age class a fish in the catch for year t
w_{at}	Mean weight of age class a fish in year t
	Parameters
È, Ö	Vectors of model parameters
a	Selectivity slope parameter
b_1	Selectivity of age class a=1, for years $(1 \le t < t')$
d	Difference in selectivity of age class a=1, for years $(t' \le t \le T)$
b_a	Selectivity for age class a
M	Instantaneous rate of natural mortality
q_1, q_2	Scaling factor (catchability) for stock indices
R, g	Autoregressive recruitment parameters
s_1	Standard deviation of recruitment process error
t_1	Standard deviation of stock index measurement error
t_2	Standard deviation of age proportion measurement error
k^2	Total recruitment process error and stock index measurement error
r	Variance ratio s_1 / k^2
	States and state moments
B_t	Exploitable biomass at the start of year t
C_t	Number of fish caught in year t
F_t	Instantaneous fishing mortality rate in year t
N_{at}	Number of age class a fish at the start of year t
P_t	Exploitable numbers at the start of year t
R_t	Age class a=1 recruitment in 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 Table 2. Deterministic catch-age model

Parameters

(D.1) $\mathbf{Ö} = \left(a\ ,\ b_1, d, M,\ q_1, q_2, \{R_t\}_{t=2-A}^{T}\right)$

Selectivity

(D.2) $b_{at} = \begin{cases} 1-(1-b_1)\left(\dfrac{A-a}{A-1}\right)^{a}\ ; & (1 \le t < t') \\ 1-(1-b_1+d)\left(\dfrac{A-a}{A-1}\right)^{a}\ ; & (t' \le t \le T) \end{cases}$

State Moments

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

(D.4) $B_t = \sum_{a=1}^{A} b_{at} w_{at} N_{at}$

(D.5) $u_{at} = b_{at} N_{at} \big/ P_t\ ; \quad (1 \le a \le A)$

(D.6) $C_t = D_t \Big/ \sum_{a=1}^{A} u_{at} w_{at}$

(D.7) $S_t = \sum_{a=1}^{A} m_a w_{at} N_{at}$

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

Initial States $(t = 1)$

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

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

State Dynamics $(2 \le t \le T)$

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

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

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

Predicted Observations $(1 \le t \le T)$

(D.14) $\overline{I}_{1t} = q_1 (B_t - f_{1t} D_t); \quad (t \in \mathbf{T}_1)$

(D.15) $\overline{I}_{2t} = q_2 (B_t - f_{2t} D_t); \quad (t \in \mathbf{T}_2)$

(D.16) $\overline{p}_{at} = u_{at}; \quad (1 \le a \le A)$

Appendix Table 3. Stochastic Simulation Model

Parameters

(S.1) $\grave{\mathbf{E}}_S = (a, b_1, d, M, q_1, q_2, R, g, s_1, s_2, t_1, t_2)$

Recruitment $(2-A \le t \le T)$

(S.2) $R_{2-A} = Re^{\left(s_1/\sqrt{1-g^2}\right)d_{1,2-A}}$

(S.3) $R_t = R^{1-g} R_{t-1}^{g} e^{s_1 d_{1t}}, \quad 2-A < t \le T$

Initial States $(t = 1)$

(S.4) $N_{11} = R_1$

(S.5) $N_{at} = \bar{N}_{at} \prod_{b=2}^{a} \frac{e^{s_2 d_{b,b-a+1}}}{1-e^{-M}+e^{-M}e^{s_2 d_{b,b-a+1}}}, \quad 2 \le a \le A$

State dynamics $(t \ge 2)$

(S.6) $N_{1t} = R_t$

(S.7) $N_{at} = \bar{N}_{at} \frac{e^{s_2 d_{at}}}{1-e^{-M}+e^{-M}e^{s_2 d_{at}}}, \quad 2 \le a \le A$

Observations $(1 \le t \le T)$

(S.8) $I_{1t} = \bar{I}_{1t} e^{t_1 u_t}$

(S.9) $I_{2t} = \bar{I}_{2t} e^{t_1 u_t}$

(S.10) $x_{at} = \log(\bar{p}_{at}) + t_2 e_{at} - \frac{1}{A}\sum_{a=1}^{A}\left[\log(\bar{p}_{at}) + t_2 e_{at}\right]; \quad (1 \le a \le A)$

(S.11) $p_{at} = \frac{e^{x_{at}}}{\sum_{a=1}^{A} e^{x_{at}}}; \quad (1 \le a \le A)$

Appendix Table 4. Likelihood function

Parameters

(L.1) $$\textbf{È} = \left(\textbf{Ö}, R, g, \{R_t\}_{t=2-A}^{T} s_1, t_1, t_2\right)$$

(L.2) $$k^2 = s_1^2 + t_1^2, \quad r = \frac{s_1^2}{s_1^2 + t_1^2}$$

(L.3) $$s_1^2 = r k^2, \quad t_1^2 = (1 - r) k^2$$

Residuals

(L.4) $$x_{2-A} = \log R_{2-A} - \log R$$

(L.5) $$x_t = \log R_t - (1 - g) \log R - g \log R_{t-1}; \quad (2 - A < t \leq T)$$

(L.6) $$z_{1t} = \log I_{1t} - \log \overline{I}_{1t}; \quad (t \in \mathbf{T}_1)$$

(L.7) $$z_{2t} = \log I_{2t} - \log \overline{I}_{2t}; \quad (t \in \mathbf{T}_2)$$

(L.8) $$h_{at} = \log(p_{at}) - \log(\overline{p}_{at}) - \frac{1}{A} \sum_{a=1}^{A} \left[\log(p_{at}) - \log(\overline{p}_{at})\right]$$

Likelihoods

(L.9) $$L_1(\textbf{È}) = \sqrt{1 - g^2} \left(\sqrt{2p}\, s_1\right)^{2-A-T} \exp\left[-\frac{1}{2s_1^2}\left(\left(1 - g^2\right) x_{2-A}^2 + \sum_{t=3-A}^{T} x_t^2\right)\right]$$

(L.10) $$L_2(\textbf{È}) = \prod_{i=1}^{2} \prod_{t \in \mathbf{T}_i} \left[\frac{1}{\sqrt{2p}\, t_1} \exp\left(-\frac{1}{2t_1^2} z_{it}^2\right)\right]$$

(L.11) $$L_3(\textbf{È}) = \prod_{t=1}^{T} \left[\frac{A^{1/2}}{\left(\sqrt{2p}\, t_2\right)^{A-1}} \exp\left(-\frac{1}{2t_2^2} \sum_{a=1}^{A} h_{at}^2\right)\right]$$

(L.12) $$L(\textbf{È}) = \prod_{i=1}^{3} L_i(\textbf{È})$$