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Silvergray rockfish (*Sebastes brevispinis*) assessment for 2000 and recommended yield options for 2001/2002

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Abstract

This document summarises the available information on the stock status of silvergray rockfish (*Sebastes brevispinis*) in British Columbia waters and provides yield recommendations for the 2001/2002 fishing year. It also summarises biological and historical fishery information so that future researchers will be able to use this document as the starting point for their assessment work on silvergray rockfish.

The available biological data are analyzed to provide recommended harvests. We provide harvest recommendations for silvergray rockfish based on three alternative harvest strategies (*F*=0.5*M, *F*=0.75**M* and *F*=1.0**M*). These estimates are not directly comparable to the previous low-risk and high- risk yield options. The *F*=0.75**M* and *F*=1.0**M* estimates are attempts to estimate a midpoint harvest option as opposed to a “bracketing” of possible harvests.

Our best estimate of *M* is 0.06. Data for each of four stocks, corresponding to PMFC Areas 3CD, 5AB, 5CD and 5E, were examined using catch-at-age analysis. Each stock analysis examined three general cases, where Case 1 examined the impacts of tuning with commercial CPUE and/or survey estimates; Case 2 fitted proportion-at-age data only, with variable recruitment and; Case 3, which was similar to Case 2, but forced recruitment to be constant to mimic simple catch curve analysis.

For Area 3CD, quota recommendations are based on the model tuned to a U. S. triennial survey which surveyed part of the area. The three recommended harvest levels were 152, 228, and 296 t corresponding to three target levels of *F*. Previous documents provided a “low-risk” and “high-risk” recommendation of 150-425 t. Quota recommendations for the remaining stocks 5AB, 5CD and 5E, are based on Case 2 model runs which fits ageing data, allows variable recruitment but lack a survey tuning index. The recommended options for 5AB were 214, 319 and 422 t, as compared with the previous range of 350-700 t. For 5CD, the recommended options were 146, 217, and 288 t as compared with a previous range of 125-400 t and for 5E the recommended options were 137, 204, and 270 t as compared with the previous range of 175-300 t.

Résumé

Ce document fait la synthèse de l'information disponible sur l'état des stocks de sébaste argenté (*Sebastes brevispinis)* dans les cours d'eaux de la Colombie-Britannique et fournit des recommandations de rendement pour l'année de pêche 2001-2002. Il résume aussi l'information biologique et historique sur la pêche afin que les prochains chercheurs puissent s'en servir comme point de départ pour leurs travaux d'évaluation sur le sébaste argenté.

On a analysé les données biologiques disponibles afin de fournir les quotas recommandés. Nos recommandations de capture pour le sébaste argenté s'inspirent de trois différentes stratégies de capture (F=0,5*M, F=0,75*M et F=1*M). Ces estimations ne peuvent être comparées directement aux options précédentes de rendement à faible risque et à risque élevé. Les estimations F=0,75**M et F*=1*M visent à établir un niveau de capture médian, plutôt qu'une « plage » des captures possibles.

Notre meilleure estimation de M est 0,06. À l'aide de l'analyse des prises selon l'âge, on a examiné les données de quatre stocks se rapportant respectivement aux zones de gestion des pêches du Pacifique 3CD, 5AB, 5CD et 5E. Chaque analyse de stock portait sur trois cas d'ordre général : le premier a examiné les répercussions de l'ajustement aux CPUE commerciales et/ou aux estimations par relevé; le deuxième a seulement cadré les données sur la proportion des poissons selon l'âge, avec un recrutement variable; et le troisième s'apparentait au deuxième, mis à part le fait qu'il ait forcé le recrutement à être continuel dans le but de reproduire l'analyse de la courbe des prises simples.

Pour la zone 3CD, les recommandations en matière de quotas s'inspirent du modèle adapté à un relevé triennal des États-Unis qui porte sur une partie de la zone. Les trois niveaux de capture recommandés étaient de 152, 228 et 296 t et correspondaient à trois niveaux cibles de F. Dans les documents précédents, on recommandait un niveau « à faible risque » et « à risque élevé » de 150 à 425 t. Les recommandations en matière de quotas pour les stocks de 5AB, de 5CD et de 5E s'inspirent de l'exécution du modèle du deuxième cas qui cadre les données sur l'âge en plus de permettre le recrutement variable, mais qui n'a pas d'indice d'ajustement de relevé. Les options recommandées pour 5AB étaient de 214, 319 et 422 t, comparativement à 350 à 700 t dans le passé. Pour 5CD, elles étaient de 146, 217 et 288 t, comparativement à 125 à 400 t dans le passé. Pour 5E, elles étaient de 137, 204 et 270 t, comparativement à 175 à 300 t dans le passé.

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1 Introduction

This document summarises the information available on the stock status of silvergray rockfish (*Sebastes brevispinis*) in British Columbia waters and provides yield recommendations for the 2001/2002 fishing year. The assessment follows from previous Pacific Scientific Advice Review Committee (PSARC) documents for shelf rockfish (Westrheim 1977, Ketchen 1980b, Stocker 1981, Leaman and Stanley 1985, Stanley 1986a, 1988b,1989-1991, 1993, 1995, 1997, 1999-2000, Stanley and Haist 1997). A brief history of quota yield recommendations, quotas, and landings for silvergray rockfish is provided in Table 1. Details are provided in Appendix A and Appendix Tables A1-A3.

This document has two objectives: (1) to provide harvest advice for the 2001/2002 fishing year and (2) to summarise the available biological and historical fishery information so that future researchers will have sufficient detail to use this document as the starting point for their assessment work on silvergray rockfish. This document therefore provides more background information on the management, assessment and biology than is customary for a stock assessment document. The harvest advice is provided under the assumption that the primary regulatory management tool is an annual quota.

2 General biology

Silvergray rockfish have been reported from southern California to the Bering Sea (Eschmeyer *et al*. 1983). They represent a minor component of groundfish landings from northern Washington to the Gulf of Alaska. Adults (>40 cm) are most common over bottom depths of about 35-450 m (Nagtegaal 1983). Trawl and hook-and-line fishing locations extend for most of the coast at the edge of the continental shelf over depths of 100-400 m (Fig. 1). Rosenberg *et al*. (1982) reported scuba observations of adults in 18-46 m off Baranof Island in Southeastern Alaska. They are often caught with other rockfish, in particular canary (*S. pinniger*) and yellowtail (*S. flavidus*) rockfish and Pacific ocean perch (*S. alutus*), as well as lingcod *(Ophiodon elongatus).* Fishers report that adult silvergray rockfish appear to aggregate and can show as small "haystacks" on their sounders, often in proximity to extreme bottom relief. They also can be indicated on the sounders as a light "fuzz" over gravel bottoms which may be associated with large tows. Silvergray rockfish are rarely caught in large quantities by midwater trawl.

Maximum size of silvergray rockfish from Canadian landings is 73 cm (fork length) and 5 kg (Sections 7.1 and 7.2). Burnt-section ageing of otoliths (MacLellan 1997) has indicated maximum ages from Canadian waters of 82 years (n=7,036) for males and 81 years (n=6,684) for females. They first appear in the trawl fishery in small numbers at age eight and just under 40 cm. Since they are marketable at this size, there are no discards of small silvergray rockfish in the domestic groundfish trawl fishery.

Silvergray rockfish are livebearers with internal fertilisation. Insemination occurs from September to January, with a peak in October. Females release the live young (parturition) from May to August, with a peak from June to July (unpublished data). Large females can produce over 1.5 million larvae, although fecundity estimates are based on egg counts prior to internal hatching and larval development (Section 7.3 and 7.4). Few immature specimens have been encountered in the fishery landings, thus it is difficult to estimate the size at 50% maturity. Based on samples from the commercial fishery, it appears that a few female silvergray rockfish are mature by age 8, but most are mature by 9. Most males are mature by age 10.

Little is known about juvenile life history. O'Connell (pers. comm.)[1] reported that juvenile silvergray rockfish (20 cm) have been observed on the margins of kelp beds in Southeastern Alaska. In B. C. waters, two 3-year olds specimens (17 cm) were captured with midwater trawl over a 115 m pinnacle (Gillespie *et al.* 1993). The low viability of captured specimens, owing primarily to gas embolism, precludes large-scale tagging programs, thus nothing is known about longer-term migration behaviour.

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[1] Victoria O'Connell, Alaska Department of Fish and Game, 304 Lake Street, Rm. 103, Sitka, Alaska 99835.

3 Stock boundaries

Following previous assessment documents, we provide recommendations for five putative stocks (Fig. 1). These included a west coast Vancouver Island stock (Pacific Marine Fisheries Commission Areas 3C and 3D), a Queen Charlotte Sound stock (Areas 5A and most of 5B), a Hecate Strait-Moresby Trough stock (Areas 5C and 5D, and a small part of 5B), the southwestern coast of the Queen Charlotte Island (Area 5E-S) and the northwestern coast of the Queen Charlotte Islands (5E-N).

Initial assessments (1977-1988) treated Areas 3C and 3D separately, with Area 3C assumed to be part of a trans-boundary stock (Table 1). However, as landings from Area 3C declined following Extended Jurisdiction in 1977, it seemed pointless to maintain the distinction between the two areas. Assessments since 1988 have treated Areas 3C and 3D as one stock (Area 3CD).

The populations of Areas 5A and 5B have always been treated as one stock because most of the landings originated from a relatively small area on either side of Sea Otter Trough (Goose Island Gully) and from the northern edge of Goose Island Bank. They were assumed to be separate from Area 3CD because of the spatial gap in catches west of Triangle Island. Few silvergray rockfish have been caught trawl fishing between an area north of Quatsino Sound, on the northwest coast of Vancouver Island, and the edges of Sea Otter Trough in Queen Charlotte Sound (Fig. 1). However, this discontinuity probably reflects the difficulty of bottom trawling in the intervening grounds rather than the actual distribution of silvergray rockfish. The official boundary between the Areas 5AB and the 5CD was modified slightly for stock assessment to correspond to the midpoint of Reed Trough between Goose Island and Middle Banks. Thus, landings on each side of Reed Trough were allocated separately.

Quota recommendations were provided separately for Area 5C and 5D for 1981 to 1984 and combined since that time (Area 5CD). Quota recommendations were separate for 5E-S and 5E-N for 1980 to 1990. No recommendations were proposed for silvergray rockfish for the west of the Queen Charlotte Islands from 1992-1995; they were treated as incidental catches to the Pacific ocean perch (POP) fishery. Quota recommendations have been combined since for Area 5E (1997 to 2000). We emphasise that there is little biological basis for any of the current stock boundaries. No genetics or tagging studies have been conducted on this species that might assist in the biological delineation of stocks boundaries.

4 Landings History

4.1 Landings from Canadian waters

The U.S. trawl fishery moved northward to Area 3CD in the 1950's and reached Area 5AB in the early 1960's. The U.S. fleet dominated the early trawl fishery for rockfish in Canadian waters, but landings were not recorded by species until 1967. Westrheim (1977) suggested that total U.S. rockfish landings, excluding POP, from Area 3CD for 1950-1966 were approximately equal to U.S. landings from 1967-1974 (Tables 2 and 3). Forrester and Smith (1973) reported that mean annual Canadian landings of total rockfish, other than POP, for the entire coast, were 176 t for 1950-1954, 363 t for 1955-1959, 855 t for 1960-1964 and 2,881 t for 1965-1969. Following Extended Jurisdiction in 1977, Canadian trawlers gradually replaced the U.S. fleet. Harvest of rockfishes by U.S. trawlers in Canadian waters had ceased by 1982.

Soviet and Japanese vessels conducted significant trawl fisheries in B.C waters from 1965 to 1976. Based on total rockfish catch figures, aerial surveys of tow locations of Soviet fishing, and observer reports of Japanese vessels, most of the landings were estimated to be POP (Ketchen 1980a). For this report, we have attempted to provide estimates of silvergray rockfish that were removed in these fisheries (Tables 1, 4 and 5). The proportions of silvergray rockfish in the rockfish catches were estimated from observer data collected on Japanese vessels in 1977. Japanese and Soviet total landings were reported for the whole Vancouver Region, encompassing Canadian Area 3CD as well as a portion of northern Washington waters. Based the proportion of the area fished in B. C. waters, we assumed that 75% of these landings came from Canadian waters.

These calculations indicate that from 1965 to 1976, the cumulative catch of silvergray rockfish by these fleets was approximately 200-300 t from Area 3CD, 800 t from Area 5AB and 5C and 7,000 t from Area 5E. Most of the latter catch was from Area 5E-N. Since 1982, there have been no foreign fisheries for silvergray rockfish other than a negligible bycatch in the midwater trawl fisheries for hake.

The Canadian fishery in Area 5CD was originally a small fishery based on occasional landings from the western edge of Moresby Trough in the central part of Hecate Strait. Coincident with the development of the POP fishery in the late 1970's, the fishery began to provide significant landings from the southern part of the edge as well as the both sides of Middle Bank (Fig 1, Table 2). The 5E fishery for the Canadian fleet also started as incidental to a developing POP fishery in the late 1970's.

Prior to the 1990's, trawling completely dominated foreign and domestic rockfish fishing. Landings of silvergray rockfish from hook-and-line fishing has increased in the 1990's as a bycatch for the developing fisheries for other species of rockfish, but have remained small (Table 2). Preliminary estimates of total hook-and-line silvergray rockfish landings for the coast were 56 t in 1999. A significant amount of rockfish may be discarded in the specific hook-and-line fishery for halibut, but we assume logbooks would not provide a meaningful estimate of the discarding. The amount of silvergray rockfish discarded appears negligible in that surveys conducted in 1998 by the

International Pacific Halibut Commission indicated an incidental catch of 82 fish while capturing 580,619 lb of marketable halibut in Canadian waters (I.P.H.C.[2]).

Catches in the aboriginal fisheries are assumed to be low (Frank Crabbe pers. comm.[3]) but there are no estimates. Bycatch in the hake fishery is negligible (source: GFBIO database). Bycatch is also negligible in the shrimp trawl (Hay *et al.* 1999) and recreational fisheries (T. Gjernes, pers. comm.[4]).

In summary, landings of silvergray rockfish were initiated by U.S. vessels in the mid-1950's and reached a few hundred tons by the early mid-1960's, mostly from the south and central areas of the coast. By 1965, Japanese and Soviet fishing in combination with U.S. vessels was probably catching up to 2,000 t/y, coastwide, much of that from Area 5E. Coastwide landings then declined as Japanese fishing stopped. The foreign fishery was then replaced by growing U.S. landings which approached 2,000 t in the late 1970's from Areas 3CD and 5AB. Landings again declined to 1,000 t as U.S. fishing ceased by 1982, but was eventually replaced and then exceeded by Canadian landings of up to 3,000 t in the mid-1980's when the fishery spread up the coast to Areas 5CD and 5E. Total coastwide landings by the Canadian fleet have averaged about 1,800 t/yr during the 1990's, under restrictive quotas and trip limits.

Landings in the early 1980's were presumably driven by market conditions and abundance or availability. Since then landings have been determined primarily by regulation. Fishers reported that dumping at sea and mis-reporting was prevalent from the mid 1980's to mid 1990's to avoid exceeding trip limits. There is no way to estimate these landings so recorded landings can be assumed to be minimum estimates of harvest for that period. We noted that for landings from 1996-1999, summary values from dockside monitoring (DMP) are 5-9% higher than those from observer estimates. While we can assume the DMP data are more accurate, they cannot be classified by area. To derive the final estimate of landings by stock in the analyses, we have multiplied landings by stock for each year by the overall ratio of DMP landings to observed landings for each year (1996-1999: 6.6%, 5.0%, 8.4%, 7.4%).

4.2 Landings from U.S. waters

Landings of silvergray rockfish from Oregon and Washington waters reached over 1,000 t from 1977 to 1979, declined abruptly in the early 1980's then rose to over 600 t in the mid 1980's (Table 6). They have since declined steadily and are now less than 50 t/y. Most of the landings have come from the outer coast of northern Washington State.

Total landings for Alaska have varied from 277 to 1,248 t from 1990-1998. Most are captured in Southeastern Alaska by hook and line [5].

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[2] International Pacific Halibut Commission P. O. Box. 95009. Seattle, WA. 98145-2009.
[3] Aboriginal Fisheries Strategy (AFS) Officer, Fisheries and Oceans, Canada. Pacific Biological Station, Nanaimo, B. C. V9R 5K6
[4] Fisheries and Oceans, Canada. Pacific Biological Station, Nanaimo, B. C. V9R 5K6
[5] AKFIN database, Pacific States Marine Fisheries Commission, Alaska Fisheries Information Network.

5 Silvergray rockfish management

Trawl management plans have been provided for Canadian waters since 1980 (Table 1) (e.g. Fisheries and Oceans Canada 2000a and b). From 1982 to the present, a complex and varying array of landings and effort restrictions have increasingly constrained landings as management and industry struggled to obtain the benefits of stock-specific (area-specific) management while maintaining the viability of the fishery. Quotas have varied from area-specific (1980-1985), to coastwide (1986), to a blend of coastwide and area-specific (1987-1996), and finally back to area-specific for the 1997/98 fishing year (note that as of April 1, 1997 the official fishing year corresponds to April-March, rather than the calendar year).

As quotas became lower in the late 1980's, a request by industry for a 10-month fishery led to the introduction of trawl trip limits in 1986 and restrictions on the number of trips in 1989 to prolong the fishery. In 1986, yearly trip limits were set at 200,000 lb until 60% of the quota was captured and then reduced to 40,000 lb. By 1992, the initial and subsequent trip limits had declined to 10,000 and 2,000 lb. As trip limits became too small to be practical, the management plan made increasing use of aggregate species quotas (Rice and Richards 1995, 1996). The aggregates varied among years and areas and varied from combinations of two species (canary and silvergray rockfish) to six species (Aggregate 1 in 1994).

After exhausting many combinations of time, area, and trip constraints, an Individual Vessel Quota (IVQ) system was implemented for 1997/98. Accompanying the change was the introduction of halibut bycatch caps, a new start date (April 1) for the fishing year and elimination of aggregates.

The hook-and-line sector began harvesting silvergray rockfish in the mid-1990's. In 1995, management permitted an annual catch of silvergray rockfish as part of the aggregate quota of 8,925 t silvergray, yellowtail (*S. flavidus*), canary (*S. pinniger*) and widow rockfish (*S. entomelas*); but overall catch was kept small by restrictive monthly trip limits. The aggregate was altered in 1996 to include only silvergray and canary rockfish. The silvergray rockfish quota was 1,075 t within the aggregate quota of 1,813 t; but small hook-and-line trip limits continued to keep the fishery well below the quota. The Halvorson decision in 1997 established the trawl/hook-and-line rockfish allocation as 92%/8% (Halvorson 1997). The ratio was changed to 95%/5% for the 2000/2001 fishing year for silvergray rockfish. The current hook-and-line management plan includes a 129 t coastwide silvergray rockfish quota managed within a combined canary and silvergray rockfish aggregate quota (Aggregate 3) (Fisheries and Oceans, Canada 2000a).

The U.S. Pacific Fishery Management Council (PMFC) sets harvest quotas for the management areas of US-Vancouver, Columbia and Eureka (Washington-northern California). Silvergray rockfish were lumped within the "Sebastes" complex which has been controlled through by trip limits and trip frequency since 1983 (see Table 1 in Tagart *et al*. 2000).

6 Relative and absolute abundance estimates of silvergray rockfish

6.1 CPUE indices in Canadian assessments

Estimates of commercial catch per unit effort (CPUE) are available for the trawl fisheries from 1967 for both U.S. and Canadian fisheries. In spite of doubt about the relationship between catch rate and abundance for an aggregating species, most previous assessments have presented indices based on CPUE and discussed quota recommendations relative to both the trends and the absolute values of catch rate. Summary tables typically presented a “nominal” CPUE index without any data screening, and “qualified” CPUE which used only those records in which silvergray rockfish represented at least 25% of the retained catch. The intent of the qualified index was to select records that reflected targeted fishing. Starting in 1989, assessments attempted to standardise CPUE trends with respect to fishing power. Catch per unit effort was found to be positively related to vessel horsepower or size (Stanley 1992), however, the relationship was weak and hence resulted in a negligible impact on the indices.

We assumed that the dynamic management regime of 1984 to 1996 led to monthly and yearly variation in fishing strategies that must have compromised the comparability of CPUE over time. For example, the proportion of tows that reflected targeting, non-targeting or avoidance of silvergray rockfish may have varied among years, boats, and seasons. This would certainly have decreased the precision of annual CPUE estimates, and, more importantly, may have introduced bias in the index owing to decreasing trip limits over time, which must have altered the presumed relationship between CPUE and abundance.

Finally, we assumed that the introduction of IVQ’s in 1997 affected fishing strategies which further altered the relationship between CPUE and abundance. Fishers now report that for some areas and times, much of the IVQ’s for silvergray rockfish are subscribed from bycatch while targeting on other species.

Further complicating the utility of commercial trawl CPUE is the evolution in data recording for the fishery. Originally the processing of groundfish trawl catch data relied on a merging of fishing logs and sales slips to obtain the most accurate rendition of the trawl trip (Rutherford 1999). Fisher logs were voluntary from 1954 to 1986; but during the 1980’s fishers began to withhold logbooks to protest management action. This resulted in logbooks becoming mandatory in 1987. As it became obvious that fisher logs were being used for enforcement, data quality deteriorated as fishers were reluctant to record significant trip limit overages or discards that could be self-incriminatory. For example, this led to mis-allocation of catches to incorrect species and areas. It also became obvious by the late 1980’s that the data quality in offload records (sales slips) was deteriorating for the same reasons.

Following the shortcomings in data capture from the mid-1980’s to the mid-1990’s, 100% at-sea observer coverage and dockside validation were implemented. Catch estimates were now based on observer estimates of catch per tow instead of fisher logs. While unquestionably more accurate (greater precision and less bias), the change reduced comparability of the catch series because of the greater detail by species. More of the retained catch could now be attributed to less common species. These were previously unreported and lumped as part of the catches of dominant species.

In addition to changes in the accuracy of the logbooks, data collection and archiving procedures varied over time (Rutherford 1999). Until 1992, each record of landing in the trawl catch database (GFCATCH) could represent the summed catch and effort of one or more tows. Beginning in 1992, each record represented one tow, regardless of whether the record was based on fisher or observer logs.

In summary, for reasons listed above, we assumed *a priori* that commercial CPUE data for the period prior to IVQ (1997) did not index abundance and therefore recommend that they not be used directly for selecting harvest options. They were included in the assessment to allow their impact on the assessments to be evaluated.

6.2 Data extraction to calculate CPUE

For the present assessment, we derived four CPUE indices based on two data extractions and two measures of central tendency (the median and the 10% trimmed mean of the observations of CPUE). We extracted all tows (or grouped tows for pre-1992 data) which contained a catch of silvergray rockfish. Data were extracted from the GFCATCH (1967-1995) and PACHARV1 (1996-1999) databases supported at the Pacific Biological Station (Table 3).

Other extraction criteria included selecting only those records which included an estimate of hours fished (effort), represented standard bottom trawl gear, and identified the location to at least PMFC area. We also ignored tows reported to have been conducted in PMFC Areas 1 and 2 (inside the Strait of Juan de Fuca). Catch per unit effort was estimated for the calendar year.

6.3 Calculation of CPUE by depth strata

The extracted data set of catch and effort related to silvergray rockfish was separated by depth to examine CPUE over time in “optimal” and “marginal” depth ranges for silvergray rockfish. The optimal depth range was described as the 100 m depth range which bracketed the mid-point of the peak catch rate of silvergray rockfish within a bi-monthly period. The marginal fishing depth was defined as the two 20 m depth strata which bracketed either side of the 100-m optimal range by bi-monthly period.

Peak CPUE and most landings are associated with the overall depth range of 100-300 m (Fig. 2). However, as reported by fishers (B. Dickens[6] and R. Gorman[7], pers. comm.), silvergray rockfish show a depth-related movement of up to 80 m from late summer/early fall to late winter/early spring (Fig. 3). We identified the optimal 20 m depth stratum for a 2-month period as the stratum associated with the peak CPUE as determined by applying a non-parametric LOESS smooth function (Cleveland 1979) to the CPUE against depth. The analysis shows that, averaged over the entire coast, peak

[6] Brian Dickens. 1678 Admiral Tryon Blvd, Qualicum Beach, B. C.
[7] R. Gorman. 6648 Hersham Ave., Burnaby. B. C. V5E 3K8

catch rates are observed in the 100-200 m depth zone in late summer/early fall but, depending on the stock, as deep as 180-280 in the late winter/early spring. This presumably is caused by a seasonal depth migration, although other explanations are plausible. Modest differences in this seasonal movement among stocks were apparent so we estimated the depth strata separately by stock. We omitted the analysis for Area 5E because there were too few tows shallow of 200 m and, instead, used Area 5CD depth extractions for Area 5E.

After identifying depth strata of maximal density for each bi-monthly period, we allocated observations to either an "optimal" depth zone of 100 m centred on the 20 m stratum of peak density and a "marginal" depth zone composed of the two 20-m strata bracketing the optimal 100 m zone (Table 7-8 and Fig. 4). We thus derived optimal depth and marginal depth CPUE indices, adjusted for seasonal variation in depth of peak density.

The choice of optimal and marginal measures of CPUE represent an attempt to accommodate the "basin model" suggested by MacCall (1990). He suggested that the most sensitive measure of abundance may be presence in sub-optimal habitat as the population "spills" out of optimal habitat through density dependent effects. This thinking is consistent with perceptions of fishers who often suggest that abundance may have increased because they have observed elevated catch rates in unusual depths for a given species of groundfish. Tows in which no silvergray rockfish were caught are assumed to be in unsuitable habitat.

These indices were expressed as median CPUE and trimmed (10%) mean CPUE and generated for each stock (Fig. 5). Catch per unit effort was computed using the average of individual catch rates for each fishing event (a tow), the so-called mean of ratios estimator,

$$CPUE_{td} = \frac{1}{n_{td}} \sum_{i=1}^{n_{td}} \frac{D_{tdi}}{E_{tdi}} \quad ,$$

where D_{tdi} is the catch (kg) for the fishing event *i* in depth stratum *d* and year *t*. Similarly, E_{tdi} is effort (hours) for each fishing event. Trimming observations from each tail of the distribution of catch rates, D_{tdi}/E_{tdi} within each depth stratum and year, can increase the robustness of the estimator to outliers.

This methodology can be altered as we identify more realistic criteria of silvergray rockfish habitat. While we hope that the fishery will remain stable enough to provide comparability of CPUE over time, this may be wishful thinking. It may be more realistic to assume the fishery will never again approach the relative stability of the 1970's. Implementation of marine protected areas, radical changes in gear design to impose selectivity, or compliance for full retention of all catch, are examples of changes possible in the short-term that will have an impact on comparability of CPUE.

The specifics of the trends for each stock are discussed below. In general, we found little difference in overall trend between the 10% trimmed mean and median indices. The 10% trimmed mean was adopted to impart a degree of robustness to the computed indices. We plan to examine the sensitivity of the derived trends to the degree (%) of trimming in the next assessment.

The indices exhibit a marked decline with the beginning of 100% observer coverage in 1996. The transition from using fisher logs to observer logs meant that tows with very small catches of silvergray rockfish, that would not have been included in fisher log data (pre-1996), were now being recorded by observers. Thus, the indices decline because of the increased number of small catches. We therefore divide the indices into two time series, pre-observer (<1996) and post-observer (>1995). While more complex data extractions might have mitigated this impact, we also have to accommodate the shift from pre-IVQ to post-IVQ in the 1997/1998 fishing year. As can be seen below, additional manipulation of the CPUE indices for these years would have little impact on the advice.

6.4 CPUE estimates in U.S. assessments

There have been no U.S. stock assessments of silvergray rockfish. They plan to conduct the first assessment of this species for the population off California to Washington waters in 2001. The results of U.S. biomass surveys are reported below.

6.5 Canadian silvergray rockfish biomass surveys

Since 1960, there have been over 50 research cruises in Canadian waters in support of rockfish stock assessment, however, the main focus of most of these trips was POP, which co-exists with silvergray rockfish in the deeper part of the silvergray rockfish habitat. Exceptions include an observer trip in 1984 and two 1-week test cruises in each of 1985 and 1986 (Stanley 1988a). The objective was to provide age samples of canary and silvergray rockfishes and to explore the potential for swept-area surveys for these two species. Results indicated that while swept-area surveys were inappropriate for canary rockfish (Stanley 2000), the concept appeared feasible for silvergray rockfish. However, the concept did not seem feasible for other rockfish that were co-habitants in the same depth range. Since yellowtail and widow rockfish tend to be more pelagic or semi-pelagic animals, shelf rockfish surveys would only be able to focus on the one species. The concept did not appear to be cost-effective. The only subsequent cruise to focus on the “shelf” species of rockfish was a sampling trip to Queen Charlotte Sound and the west coast of Vancouver Island to supplement the shelf rockfish samples obtained through port sampling (Gillespie and Stanley 1989).

We note that during a panel discussion of trawl fishers concerning the efficacy of trawl surveys for rockfish, the consensus was that the reliability of surveys for silvergray rockfish would be “Poor+”, owing to the “patchy and variable nature of their distribution” (Schnute *et al*. 1999).

While there have been no surveys in Canadian waters directed at biomass estimation of silvergray rockfish, some researchers have attempted to derive abundance estimates of silvergray rockfish parenthetically to their estimation of POP biomass (Leaman and Nagtegaal, 1982 and 1986, Leaman *et al*. 1988) (Table 9). These estimates have typically indicated unreasonably small biomasses, probably due in part to the focus on depths appropriate for POP and the difficulty in extrapolating estimating biomass to untrawlable bottom.

There have been numerous bottom trawl surveys for POP surveys conducted in Queen Charlotte Sound (Area 5AB). In hopes that the "bycatch" of silvergray rockfish in these trips might provide an abundance index, we collated silvergray catch rates from all the cruises (Hand *et al.* 1995; Harling and Davenport 1977; Harling *et al.* 1970, 1973, 1971; Nagtegaal *et al*. 1986; Westrheim 1967, Westrheim et al. 1968, 1969, 1973, 1976; Yamanaka 1996). However, the estimates were highly variable, probably owing to the low average catch rates of silvergray rockfish in the survey. The index was highly influenced by 1-2 successful tows. We did not use the index in the assessment.

6.6 U.S. rockfish surveys

U.S. assessment staff have been more persistent in their attempts to provide swept-area estimates of all commercial species groundfish species. They have conducted random stratified coastwide surveys from southern California to at least the U.S.–Canada border off northern Washington every three years from 1977-1998 (Wilkins *et al*. 1998, Shaw et al. 2000) and 1999 and 2000 (data not yet available). The initial focus was on shelf rockfish species but shifted in the 1980's to other species owing to frustration over the low precision and the obvious bias since the estimated biomass for some rockfish species was regularly exceeded by annual catches.

Nevertheless, the survey results have been used to tune many rockfish assessments including those for yellowtail and canary rockfish. For the most recent examples, see Crone *et al*. 1999, Sampson 1996, and Sampson and Stewart 1994 for canary rockfish and Tagart *et al.* 2000 for yellowtail rockfish. The triennial frequency has continued through the 1998 survey. The survey was completed with a modified format again in 1999 and 2000, but did not occupy Canadian waters. The trend for U.S. waters indicates a significant decline in silvergray rockfish biomass from estimates of 1,337-14,622 t 1977-1983 to current estimates of 102-595 t (1992-1998) (estimates from M. Wilkins[8], pers. comm) (Table 10, Fig. 6).

Some of the surveys extended into Area 3CD in Canadian waters (Fig. 1) for which separate biomass estimates have been provided. Excluding the largest estimate of over 7,000 t in 1980, these estimates range from 647-2,445 t, for an area that corresponded to Area 3C (49^{o} 15' N)(1977 and 1983) or included Area 3C and Area 3D to 49^{o} 40' N (Nootka Island) (1989, 1992, 1995 and 1998). If the 1980 estimate is included, the decline in Area 3CD is similar to that implied for U.S. waters.

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[8] M. Wilkins. National Marine Fisheries Service. Bldg: 3 Rm: 2067 7600 Sandpoint Way, NE Seattle, WA 98115-6349.

The U.S. National Marine Fisheries Service has also conducted surveys in the Gulf of Alaska[9] (Table 11, Fig. 7). The variance estimates are large, but the point estimates indicate a significant population which appears to have increased over the last decade. The current total estimate for the Gulf of Alaska is almost 40,000 t, of which about two-thirds was reported from Southeastern Alaska which is adjacent to Area 5E.

[9] Harold Zenger. U.S. National Marine Fisheries Service. Rm: 1181, 7600 Sandpoint Way, N.E. Seattle WA 98115-6349.

7 Estimation of life history and fishery parameters, and target reference points

7.1 Age composition

The GFBIO database at the Pacific Biological Station (PBS), Nanaimo, British Columbia contains data on 41,726 silvergray rockfish sampled from Canadian waters through 1999. Samples were obtained from port sampling, observer trips and research cruises. Over 20% of the specimens have been obtained from 1998 to 1999 with most of these coming from sampling at sea by contract observers in the trawl fishery. Data not in GFBIO include a small number of "length-only" port and research samples collected from 1977-1996. These data are available in hard copy or on micro-fiche at PBS. An examination of reports from research cruises conducted from 1960-1970 might realise a small number of additional specimens. However, no ageing structures are available from these cruises and the overall number would probably be less than 1,000 specimens.

The dataset includes 13,671 aged specimens, of which 13,534 can be assumed to be representative of commercial catches (Table 12). For calculating proportions-at-age, we removed samples that were stratified or collected during special circumstances (GFBIO Sample_ID's 98975, 99003, 99321, 99537). We included samples collected during charters if the fishing activities which led to the catches were typical of commercial fishing.

All ages were determined using the general otolith burnt section technique (MacLellan 1997) with a minor modification. A charter survey focused on studying juvenile rockfish in July, 1991 captured two 17-cm silvergray rockfish. An examination of these otoliths indicated that the previous methodology had incorrectly missed the first annulus and, therefore, previously aged specimens were probably underaged by one year (S. MacLellan, pers. comm.[10]). The ageing methodology for silvergray rockfish was modified in August, 1992. The faint first annulus is consistent with the mid-summer parturition of silvergray rockfish which apparently precludes significant summer growth in the first year of life. We therefore added one year to all previously aged rockfish in the GFBIO database. The timing of the change in methodology corresponds to samples collected before 1992.

Between reader agreement is poor for silvergray rockfish (Fig. 8). Agreement to ±1 year is 60-80% for ages less than 20 and 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 (Fig. 9). The mode falls between 15 and 20 years for all stocks.

While the number of specimens aged reached the hundreds for many years from 1977-1997, the actual number of aged samples was small and often limited to only 0-4/stock/year (Table 12). As for other groundfish species, specimens for biological measurements were originally collected in batches (sample sizes) of 300 fish. Sample

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[10] S. E. MacLellan. Fisheries and Oceans, Canada. Pacific Biological Station. Nanaimo, B. C. V9R 5K6

size now is typically 50-100 fish. We assigned equal weighting to each sample within a year for preparation of the proportion-at-age tables. We made no attempt to weight among years proportional to number of samples or specimens. We excluded the few observations below 10 years of age. The accumulator age, or plus group, was 30+.

The ageing data indicated that the proportions of 30+ fish have decreased over time (Fig. 10). There is also an indication of one or two recruitment episodes which appear to be centred on approximately the 1981 and 1970 yearclasses. These are most evident in Area 5CD and 5E samples. The degree of ageing imprecision reported earlier makes it plausible that only one, or at most, two cohorts account for these recruitment episodes. However, we have no means for determining the degree to which ageing imprecision blurs the signal from specific strong cohorts. The between reader comparison provides a minimum estimate of among reader variability, but fails to include the imprecision of the ageing methodology. The latter source of error could only be resolved with samples of known age fish. The effects of ageing imprecision can be explored through use of a mis-classification matrix but this was not attempted for the current assessment.

7.2 Growth

We found a modest difference in growth rate between sexes (Fig. 11) but little evidence of difference over time or among stocks (Figs. 12 and 13). Predicted asymptotic size for females is about 61 cm and 55 cm for males. Size at age data were fit according to Schnute (1981) as described in Appendix B. For the catch-at-age model, we assumed a combined-sex growth model, but used a female growth model for calculation of the target reference points (Table 13). We estimated the length/weight relationship for males and females separately and combined from 476 total specimens (Table 13). These represented all weighed silvergray rockfish specimens in GFBIO.

7.3 Age at Maturity

Specimen maturity state was examined macroscopically and classified into one of seven maturity stages (Appendix Table D1) (Stanley 1988a). We classified all stage 1 fish as immature, with stage 2 and greater fish designated as mature. In the previous shelf rockfish document (Stanley 2000), it was assumed that mature fish were stage 3 or greater. However, we found in an examination of maturity stages by month that there was an obvious progression through stage 2 to 3 within the year. We also observed a significant proportion of older females of all age classes as stage 2. We suspect that some stage 2 females, while “maturing” may not actually spawn in the coming reproductive season and thus are “immature”, however, for reasons provided above, Stage 2 seems preferable as indicative of maturity.

The proportion of fish mature at age, m_a, was computed by fitting a generalized additive model (GAM) to the binomial (0=immature, 1=mature) maturity classes as a function of age a (Hastie and Tibshirani 1990). A logistic link with a binomial error structure was applied, with a second-degree non-parametric LOESS smoother. The observed and predicted proportions mature at age are shown in Fig. 14 and Table 14 for both sexes. Only the results for females were used in the calculation of spawning biomass given by equation (D.7) in Appendix Table A.2. Thus, equation (D.7) was modified to produce spawning biomass of females under the assumption of a 50:50 sex ratio:

$$S_t = 0.5\sum_{a=1}^{A} m_a w_{at} N_{at} \quad .$$

However, W_{at}, the sex-pooled mean weight at age, was retained in the calculation.

From the commercial fishing samples, it appears that a few females are mature at age eight, with most mature by age nine. A few males appear to be mature at age five, most are mature by age eight. It is noteworthy that most specimens in the commercial catch are mature by age 10 to12, well before full recruitment at age 20+. It is important to note that age-specific maturity in the fishery samples may not reflect the maturation rate of the overall population. The fractions of mature and immature fish for a given age that recruit to a fishery may not be equal. In other words, for age 9 females, the proportion of *mature* females that recruit at age 9 may be greater than the proportion of *immature* age 9 females that recruit at age 9. This could lead to the apparent knife-edge maturity ogive for silvergray rockfish. If the steepness in the ogive is overestimated, then during a fishing-down period, the rate of decline in spawning biomass would be underestimated. Nevertheless, from the available data, it appears that the trawl fishery for silvergray rockfish does not significantly exploit immature individuals.

7.4 Fecundity

Fecundity estimates were obtained from a sample collected in early April 1989 from southern Queen Charlotte Sound (Area 5AB). Since the results have never been previously published, we have briefly summarized the methods below.

Fish were stored aboard the fishing vessel in refrigerated seawater until unloading and sampling. Sampling was stratified by length to increase the likelihood of obtaining a broad age range. Measurements of fork length, gonad weight, round weight minus gonad weight (somatic weight) and otoliths were obtained from each specimen.

Ovaries to be used for fecundity samples were fixed and stored in modified Gilson's solution (Leaman 1988) and shaken weekly for about one year. Fecundity estimates were derived volumetrically as described by Leaman (1988). Histological sections from samples originally fixed in Smith's solution were imbedded, sectioned, mounted, stained with Harris' hematoxylin and counterstained with alcoholic eosin (Gray 1954).

The histological cross-sections from 11 mature specimens all indicated that the ovaries were in the process of vitellogenesis (late Stage 3 of Echeverria 1987, Stage V of Bowers 1992). The oocytes within an ovary were either large, with diameters ranging of 300-600 µ, or smaller than 150 µ. There was little size variation within ovaries of the larger eggs (±50µ) and no evidence of second batches maturing as has been reported in bocaccio rockfish (*Sebastes paucispinis*) (Moser 1967a,b).

Figure 15 provides plots of fecundity (000s of eggs) against age, relative fecundity (000s eggs/g somatic weight) against age, and fecundity against somatic weight (g). The solid curve in each panel is the result of fitting a generalized additive model (GAM) to each relationship (Hastie and Tibshirani 1990). An identity link with a Gaussian error structure was used in each case. The dashed curves represent the limits of point-wise 95 percent confidence intervals. The “rug” along the x-axis of each plot shows the frequency of observations over age classes. The filled circles indicate three fish that appear to show lower than expected fecundity at age (top panel). Interestingly, the few observations of relative fecundity for the oldest specimens indicates declining relative egg production after the age of 40 (Fig. 15, panel 2).

7.5 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 already been fished for 10-20 years. Estimation of Z from maximum age in the aged samples (Hoenig 1983) indicates estimates of instantaneous natural mortality (M) of 0.056 for males and females. 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.

In the catch-at-age component of this assessment, we entertained three alternative values for “M” of 0.04, 0.06 and 0.08. This range is consistent with the overall range for the genus. The midrange estimate of 0.06 is slightly greater than estimates for POP, which are slightly more long-lived, and much greater than the estimates for more long-lived species like yelloweye rockfish (*S. ruberrimus*) (*M*=0.02) (O’Connell and Carlisle 1996). It is less than estimates that have been published for shorter-lived species like yellowtail, canary and widow rockfishes (Tagart 1991). While we have used a range in our catch-at-age model runs, to demonstrate the sensitivity of the analysis to the choice of *M*, we suggest that the best estimate for *M* for silvergray rockfish is 0.06 and base our advice on that value.

8 Estimation of spawning potential per recruit

We used the estimates of M, growth, and fecundity in conjunction with selectivity at age as indicated in catch-at-age analysis (for example, see Figure 17a) to provide estimates of relative population fecundity of unfished and fished populations of female silvergray rockfish (Fig. 16) (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 apparent early maturity relative to entry to the fishery. However, we doubt the validity of the maturity relationship and suspect that mature specimens within a cohort tend to recruit before immature specimens. Thus, fishery samples underestimate the age of maturity.

The work on target reference points by members of the U. S. west coast groundfish stock assessment team (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 recent declines in widow rockfish, bocaccio and now 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, reference points of at least $F_{50\%}$ are more appropriate for rockfish. They comment that $F_{50\%}$ tends to correspond to a F=0.75*M.

Patterson (1992) and Walters (1998) suggested that an optimal F_{opt} is approximately 0.6*M and within the range of 0.5*M-0.7*M. This represents a more conservative approach than the F=0.75*M reported above. The same U.S. study endorses the comments of Walters and Parma (1996) who suggest that a risk-averse strategy would assume that F_{opt}=0.5*M. They recommend adoption of this strategy unless it can be demonstrated that higher harvest rates are possible. We provide harvest options corresponding to F=0.5*M and F=0.75*M, as well as F=M, the reference point used for previous Canadian assessments.

9 Previous Fisheries and Ocean's assessments of Canadian silvergray rockfish stocks

Previous assessments for Areas 3CD and 5AB generally followed methodologies currently recommended as appropriate for data-poor contexts (Walters 1998, Restrepo *et al*. 1998). The earliest assessments were highly qualitative and emphasised the lack of information available. The process became more rigorous by the early 1980's with use of an equilibrium model to derive quota recommendations for Areas 3C, 3D and 5AB (Ketchen 1980b). Equilibrium biomass was calculated from the U.S. triennial survey for 3C and from a regression of CPUE against cumulative landings ("depletion estimator") to predict starting biomass for areas 3D and 5AB. At that time, CPUE by U.S. vessels was declining and it was assumed that the fishery was still developing. Therefore, a depletion estimator seemed appropriate. Instantaneous natural mortality for both sexes was assumed to be M=0.20, based on surface ageing of other rockfish species.

As discussed earlier, the introduction of the burnt-section method of otolith ageing revealed that silvergray rockfish were more long-lived, and consequently, exhibited a lower M than previously thought (Archibald *et al.* 1981). However, few additional age data were available until 1993. In the interim, assessments were based on estimates of Z from an equilibrium-based length frequency simulator (Rasmussen and Stanley 1988). While there is too little contrast in size at age of silvergray rockfish to decompose length samples into age composition, modelling attempts indicated that the descending (right-hand) limb of a length frequency distribution was relatively stable and could be used to infer Z (Stanley 1986b).

The initial calculations of F, given an assumption of M<0.1, from length frequency analysis (Leaman and Stanley 1985) continued to influence assessments through 1992. For the 1993 assessment, the age samples of 1988-91 were compared with those of 1982-1986 for the first comparison of age composition and catch curves over time (Stanley 1993). These data were updated in subsequent assessments. Although a few samples were collected in most years, data were too sparse to consider catch-at-age analysis. Previous assessments discussed CPUE estimates relative to other rockfish fisheries as well as presenting trends, but little credibility was attached to the trends. A more detailed history of stock assessments is provided in Appendix A.

10 Other assessments of Canadian silvergray rockfish stocks

10.1 Absolute biomass from 1994-1996 CPUE

Walters and Bonfil (1999) assumed a swept-area logic and used commercial CPUE from 1994-1996 to estimate absolute abundance. The catch rates were averaged for 1-nm blocks and converted to biomass with an estimate of the swept area per time trawling, K_s, assumed to be 0.1 nm^2/h. The point estimate for that block was converted to a “best” estimate through a distance and variance weighted averaging which considered adjacent blocks to within 2 nm. The authors generated a coastwide estimate and estimates for 19 core fishing zones (Table 15).

The authors assumed that fishing is random within each 1-nm block because they saw little evidence of non-random spacing in tow locations for POP, and because tows are longer than 2 nm in length. They then stated that the key assumptions involved (i) the swept area value, K_s , (ii) how to estimate biomass for unfished blocks, and (iii) how to combine results within the year given that fish can show seasonal migrations and may, in the extreme case, be double counted.

The authors’ use of the CPUE is innovative and as valid than any other use of commercial catch data for estimating biomass. However, we view the four assumptions as appropriate for species that predominantly inhabit trawlable ground, inhabit portions of the shelf with little depth gradient, and for which a major component of fishing effort, either to target or avoid, is not conducted acoustically. These may include flatfishes, juvenile halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*), or POP and thornyheads (*Sebastolobus* sp.). We suggest that the logic is less applicable to silvergray rockfish.

For example, it was assumed that CPUE of fished blocks are representative of adjacent non-fished blocks. However, adjacent non-fished blocks are either at the same depth and untrawlable (or they would be fished) and therefore a different habitat, or at different depths. If the adjacent unfished blocks are shallower or deeper, they are either untrawlable or have no fish presence, or both. The process therefore extrapolates from one habitat to another. In the case of silvergray rockfish, density on soft bottom is used to infer abundance on hard bottom. While habitat preferences have not been quantified, the many surveys to the east coast Queen Charlotte Islands and traditional tow locations indicate that silvergray rockfish prefer to be near to, or on, hard bottom. Thus the density estimate is based on sub-optimal habitat. To the extent that silvergray rockfish prefer untrawlable to trawlable habitat, the biomass is underestimated in the extrapolated areas. Similarly, as the ratio of untrawlable to trawlable habitat increases, the biomass estimates are also underestimated. This assumption is the same logic flaw that has caused swept-area survey estimates to often produce absolute biomass estimates for shelf rockfish that are less than annual harvest (Tagart 1991).

The second assumption of the model, which relates to estimating silvergray rockfish, is the assumption of random fishing within small areas (1-nm^2). The suggestion that tows must have random coverage since they are often 2 nm in length implies that not only is tow start location random within the block, but so is the tow direction. This is clearly incorrect for most shelf rockfish trawling. Fishers typically tow by following a specific depth contour, precise to a few m, where the bottom slope is significant. They are therefore towing “along the edge. Since depth can easily vary up to 45 m within a nautical mile, the assumption of random towing within each nautical mile block is not true. Therefore, each tow is an attempt to maximize CPUE within the block. Violation of the assumption of randomness incorporates an unknown degree of overestimation bias.

The model also ignores the fact that fishers target on silvergray rockfish after locating the shoals on the sounder. Shoals of silvergray rockfish are typically a few hundred metres in cross-section and related to specific topographic features. Location of targets with sounders also violates the assumption of a random search and tends to produce high CPUE and therefore overestimates of biomass. Conversely, fishers currently report they are often avoiding silvergray rockfish. This argues for an underestimation bias, since fishers will use sounders and their background knowledge to reduce silvergray rockfish CPUE.

In summary, the spatial averaging approach is a brave attempt to provide absolute biomass estimates and may be of use for some species. However, the requisite assumptions of nearly random distribution of fish and fishing effort are incorrect for silvergray rockfish. Furthermore, it is difficult or impossible to determine the direct and extent of the biases. While the authors are probably correct is suggesting they are providing “minimum” biomass, it is not clear how “minimum” the estimates are.

The authors computed coastwide biomass estimates for silvergray rockfish of 13,692, 9,165, and 6,439 t for 1994-1996 respectively, and 5,684 t for 1996 by summing the estimates for selected regions. The selected region approach translates to total biomass estimates of 679 t for Area 3CD, 1,540 t for Area 5AB, 1,953 t for Area 3CD and 1,512 t for Area 5E. Based on the authors estimated F_{opt} =0.119, the implicit “minimum” yield recommendations would range from 76-219 t for the four stocks. “Minimum” harvest recommendations from the two coastwide estimates translate to 638 or 722 t.

10.2 Single-stock bayesian biomass estimation.

Walters and Bonfil (1999) also provide a stock assessment based on a “single-stock Bayesian assessment” procedure. This procedure models populations over various assumptions of starting biomass (B_0) and is tuned with 1980-1996 qualified CPUE. The authors note that their Fig. 7 indicates unrealistic trends in CPUE over very short time periods. Their analysis suggests that the ratio of current biomass (B_{96}) to starting biomass (B_o) ranges from 0.34-0.83 among the 19 areas (combined and weighted by biomass by PMFC Area in Table 15). B_{96} in 7 of 19 areas was less than 50% of B_0. From this analysis, they suggested that the minimum and most probable estimates of MSY are 949 and 1,226 t respectively as compared with the 2000/2001 recommendations of DFO of 800-1825 t (Stanley 1999) and a quota of 1,510 (Fisheries and Oceans, Canada 2000b)

11 Catch-at-age model definition and application

The model used in this assessment was derived from those proposed by Schnute and Richards (1995), Richards *et al.* (1997) and Fargo and Richards (1998). A complete list of model notation and the model definition are provided in Appendix C. Data input to the model included:

(1) Catch (000's tonnes) of silvergray rockfish for each year t ($1 \leq t \leq T$);
(2) Stock indices computed from CPUE data as described in Section 6. With the exception of stocks 3CD and 5AB, the indices (I_{1t}, I_{2t}) consisted of commercial CPUE broken into two periods, 1965-1995 and 1996-1999. For Area 3CD an index derived from the U.S. triennial survey was substituted in some runs instead of CPUE for the 1965-1995 period. Proportions at age, derived from the commercial catch at age data and computed such that each sample had equal weight within a year (Appendix C);
(3) 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;
(4) Proportion of females mature at age using the generalized additive model procedure described in Section 7.3 (Table 14).

Three general cases (described below) of the model were examined with respect to the variance in the index and recruitment. For each general case, we examined the sensitivity of the output to three values of M (0.04, 0.06 and 0.08) but framed our advice based on M=0.06. The basis for selecting among the three cases is provided below.

<u>Case 1</u>: C1 runs were tuned to abundance indices. We achieved this by setting ρ =0.7. This choice modestly favours the tuning index but not enough to force the model to follow short-term variation in the indices. When a survey index was available (for Area 3CD), we examined cases which used both time series of commercial CPUE (C1a) or the survey index and the post-1996 CPUE (C1b).

<u>Case 2</u>: C2 runs were designed to remove the influence of the tuning indices. We achieved this by setting ρ =0.001 and κ = 100.0. This indicated to the model that the index values were unreliable (high variance), effectively leaving the model with only the proportion-at-age data with which to fit the model (see Appendix D for summary of the effect of varying ρ and κ.

<u>Case 3</u>: C3 runs were not index -based and recruitment was forced to be virtually constant. We fixed ρ =0.00001 and raised κ^2 = 1000.0, thereby reducing variance of recruitment (σ^2) to 0.01. We also forced the time series correlation of recruitment to be low by fixing γ =0.1. The intent was to force the model to resemble simple catch-curve analysis by forcing constant recruitment. The C3 constraint of virtually constant recruitment is less reasonable biologically than C2, but was examined as a "last resort" if the ageing data were too limited or had too little structure to provide stable convergence.

The results of each case and choice of *M* for each stock are provided in Tables 16a-19a. We provide graphical summaries of the four runs chosen as the basis for the advice (Figs. 17-20). Included in these graphs, are summaries of the residuals from fits to the ageing data. Provided the model was allowed to fit the selectivity relationship to the ageing, we saw little indication of patterns in the residuals. The only exception was the fit of Area 5E ageing data after constraining the parameters of the selectivity curve.

The model was relatively stable and generally had little trouble converging. The major exceptions were the C2 runs for Area 3CD. Not surprisingly, with very little age data available for this stock, and no tuning index, the model did not converge. The C2 (M=0.06) runs also had trouble converging with Area 5E data. In this configuration, the model had trouble fitting, γ, the degree of auto-correlation in recruitment. We therefore fixed γ using the fitted value (γ=0.828) from the Area 5CD run.

Estimates of the selectivity parameters (α, β_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% recruitment by age 20. The model fit an implausible straight line relationship for Area 5E because the model had to rely almost entirely on samples collected from 1994 to 1999 to provide information on selectivity. The age of full recruitment could not be resolved because so few fish in the samples from those years represented ages that appeared to be fully recruited in other stocks. Therefore, we imposed the Area 5CD selectivity relationship (Case 2: M=0.06) for the 5E runs. This stock is the closest geographically and is based on the most complete series of age data.

When we allowed *M* to be free, the estimates of *M* varied from 0.013-0.077 for most cases. The only exception was an estimate of 0.109 for Area 3CD when tuned to a index that appeared unreasonable (C1a). This model run resulted in an unlikely high biomass of 27,000 t. The estimates were consistent with our options of M=0.04-0.08, although tending to the lower part of this range.

We did not model variable selectivity over time. Age/size specific selectivity is much greater than size of retention for rockfishes, thus gear changes would presumably have little effect on size/age composition. It is possible that there has been spatial/temporal variation in the prosecution of the fishery such that more fishing, and therefore sampling, is being directed at younger or older elements of the population. We do not know of any actual basis for this possibility. We did examine the depth of capture of sampled tows over time and observed no major change.

12 Assessments by stock

12.1 Area 3CD

Since the U.S. initial survey biomass estimate of 7,000 t for about half of the Area 3CD in 1980 (section 6.6), the survey estimates have declined overall (Fig. 6). The two most recent estimates for 1995 and 1998 are 650 and 1,140 t, even though the estimates are based on a slightly larger area. Ageing samples are sparsely distributed over time. The overall age pattern shows less structure than other stocks, but does show a declining proportion represented by older age classes. We provide a graphical summary of Case 1b*, the survey-tuned run, minus the 1980 biomass estimate. A tabular summary of the runs is provided in Table 16a, with a graphical summary of Case 1b* provided in Figures 17a-d. An overall summary table of assessment information is provided in Table 16b.

<u>Case 1a: Tuning index, CPUE only</u>

As with Area 5CD, CPUE in Area 3CD since 1983 reflects the landings history. The decline in the index probably reflects the transition from direct fishing in the mid-1980's to a greater proportion of non-targeted fishing as trip limits were reduced. The correlation implies that CPUE is not a credible reflection of abundance. We note that CPUE has risen over the four years since the introduction of the observer program (1996) and IVQs (1997).

Runs tuned to the CPUE index indicate that the population structure and ageing data are inconsistent with the index. The gradual selectivity curve that fits these data, and the cumulative inertia of over 40 years recruitment in the fishery, make it difficult for a population to match the short-term dynamics implied in the CPUE index. In order to account for the sudden increase in population, the model would have to depict massive incoming recruitment such that the young ages swamped the observations of older fish in the samples. This is contradicted by the ageing samples of the early 1980's (Fig. 17b). Similarly, the rapid decline (1985-1995), although coincident with higher landings, is not associated with recruitment failure or rapid extinction of the cohorts.

The model cannot accommodate the rapid change therefore it averages through the years. It identifies little impact of the higher landings in late 1980's and thus applies low estimates of *F* (0.06-0.08) to these landings and consequently very low estimates of *F* and high estimates of biomass in recent years. This appears to be assisted by stabilizing of pre-1996 CPUE and increasing CPUE since. It interprets the dominance of young fish in recent samples as a result of the 1990's recruitment being the largest ever seen in the stock (Fig. 17c).

We view the runs based on CPUE as spurious. Nevertheless output from these runs indicated a range of B_{1999}'s from 14,000-56,000 t for M's of 0.04, 0.06, and 0.08 (Table 16a). Implied quotas would be 658, 979 and 1,296 t based on M=0.06.

<u>Case 1b and 1b*: U.S. survey and CPUE (1996+)</u>

We conducted runs with Area 3CD ageing data tuned to the U.S. triennial survey and the 1996+ observer CPUE index. All three runs with varying *M* indicated a significant decline in biomass and high F_{1999}'s ranging from 0.19-0.14. Current spawning biomass based on *M*=0.06 was estimated to be 47% of 1980 spawning biomass (SpB_{1999}/SpB_{1980}). B_{1999} was 2,200 t with a CV of 58%. Quotas options for these runs would be 65, 97 and 128 t.

We know of no reasons why this trend should be biased except that the two most recent surveys provide estimates for a slightly larger area. However, since the impact of the survey estimates would appear to be leveraged by the high anomalous biomass estimate of over 7,000 t in 1980, we ran the model excluding this point (Case 1b*) (Table 16a, Figs. 17a-d). This configuration provided an F_{1999} of 0.070. The SpB_{1999}/SpB_{1980} was 84% and the estimate of B_{1999} was 5,190 t with an estimated coefficient of variation (CV) of 27%. Target reference quotas for this run were 152, 228 and 302 t.

<u>Case 2: No tuning index, variable recruitment</u>

When the emphasis on CPUE was minimised, the model did not converge. The limited ageing data for this stock and relative lack of structure, as compared with other stocks, appeared to provide too little information to guide the model to a solution.

<u>Case 3: No tuning index, constant recruitment</u>

When we forced model to simulate simple catch-curve analysis, by assuming constant recruitment, model runs indicate F_{1999}'s of 0.057-0.062 The variation in *M* lead to scenarios ranging from overfishing to risk-neutral fishing. For *M*=0.06, The SpB_{1999}/SpB_{1980} was 87% and the estimate of B_{1999} was 4,250 t with an estimated CV of 31%. Recommended quotas based on this run were 126, 187 and 248 t.

Recommendation

We suggest that the model runs tuned with the triennial survey minus the large 1980 estimate (C1b*), provides the most reasonable basis for a harvest recommendation for 2001/2002 (Table 16b). We also suggest that the 1980 biomass estimate was probably an anomaly of a change in availability of the fish to the gear in 1980. The three harvest recommendations are 152, 228 and 302 t.

12.2 Area 5AB

Three or more samples were obtained from Area 5AB in years 1978-1979, 1981, 1986, 1988, 1990-1992, 1994-1995, and 1997-1999 (Fig. 18b). The overall trend indicates a recent episode of recruitment centred on about the 1981 cohort that is now fully recruited. The ageing data also indicates a gradual reduction over time in the proportion represented by the 30+ age group. A graphical summary of Case 2 is provided in Figures 18a-d. The model runs are summarized in Table 17a and a summary table of quota recommendations for Area 5AB is provided in Table 17b.

<u>Case 1: Tuning index, CPUE only</u>

Over the 30 year time series, CPUE indicates a declining trend through 1995. No trend is apparent since 1996. While this CPUE index can obviously be consistent with the inherent population dynamics of silvergray rockfish, the same biases discussed in general terms above (Section 6.1) and restated for Area 3CD may also apply to this stock. The decline in the index may be the result of a trend away from targeted fishing. In spite of the decline, however, the runs based on the index provide optimistic reconstructions. The fit to the CPUE index indicates large recruitment from the entire 1980's decade. The run based on M=0.06 indicates an F_{1999} of 0.039, less than the target reference point, a SpB_{1999}/SpB_{1980} ratio of 88% and a B_{1999} of 15,303 t with a CV of 9%. Target reference quotas based on these runs were 452, 673 and 891 t.

Case 2: No tuning index, variable recruitment

The fit to age data alone indicates a more pessimistic scenario (Fig. 18a-d). While the results suggest better than average recruitment for the 1980's yearclasses, these are not enough to compensate for the impact of fishing and poor recruitment from the late 1970's. For the run based on M=0.06, F_{1999}=0.084, the SpB_{1999}/SpB_{1980} ratio equals 65% and the B_{1999} equals 7,246 t with a CV of 36%. Target reference quotas correspond to 214, 319 and 422 t.

Case 3: No tuning index, constant recruitment

The constant recruitment case indicates a more optimistic reconstruction relative to the Case 2 runs. The model run indicates an F_{1999}=0.058, a SpB_{1999}/SpB_{1980} ratio of 78% and a B_{1999} of 10,270 t with a CV of 16%. Target reference quotas correspond to 304, 452 and 598 t.

Recommendation

We assume that the decreasing trip limits during the early 1990's have imparted a negative bias to the latter part of the series. Yet, in spite of the trend and presumed bias, the runs tuned to CPUE provide the most optimistic scenario. Case 1a run indicates that current harvests could be increased to 640 t, almost equivalent to the long-term historical mean of 700 t. However, we are reluctant to recommend a return to harvest levels that were associated with the continued reduction in the proportion of older fish.

The Case 2 run indicates quotas of 214, 319 and 422 t. While the Case 3, which assumes constant recruitment, implies larger quotas of 304, 452 and 598. From estimation of the error in terminal biomass (B_{1999}), it is clear that there is overlap in the estimates. The Case 2 and 3 runs are congruent with respect to the overall trend, but differ in determination of the magnitude of the decline.

Since the Case 2 runs are based on the more reasonable biological premise of variable recruitment, we endorse the outcome of this run as a basis for choosing the harvest and recommend quota options of 214, 319 and 422. We note that fishers have not reported a major decline in silvergray rockfish abundance.

12.3 Area 5CD

Ageing data for Area 5CD is more extensive than for the other stocks, but as elsewhere on the coast, the samples indicate a gradual decline in the proportion of older fish in the population (Fig. 19b). The proportions-at-age show a stronger recruitment pulses than stocks to the south. The successful recruitment event centred on the 1970 and

1981 cohorts is more obvious than for other stocks. We provide a graphical summary of the Case 2 run in Figure 19a-d and a summary of statistics for all runs in Table 18a. The assessment information for Area 5CD is summarized in Table 18b.

Case 1: Tuning index, CPUE

Similar to the situation in Area 3CD, the CPUE index in Area 5CD appears to mimic the landings history. The index probably reflects the transition from small incidental fishery to targeted fishing during the 1980's, as the fishers learned to target on silvergray rockfish under relatively high quotas. Catch rates then mirror the decline in landings, as smaller quotas/trip limits may have led to less targeted fishing. We infer from the close correlation between CPUE and landings that CPUE in Area 5CD does not reflect relative abundance over time. The index since 1996 is does not indicate any particular trend.

Case 1 runs indicate the same response as observed for Area 3CD. The model cannot accommodate the implied rate of change in biomass in the late 1980's, without an accompanying age distribution in which the recruiting ages overwhelm older ages. It also cannot reflect the rapid decline in CPUE without rapid extinction of the recruited age classes. The model predicts a constant biomass through the centre of the observed data. We note the extraordinary sensitivity of the model to varying M such that implied risk-averse quota for M=0.08 exceeds 1 million tons (Table 18a). Recommended quotas correspond to 1,983, 4,499 and 5,955 t. These values are far greater than the mean long-term harvest of 557 t.

Case 2: No tuning index (variable recruitment)

Removing the influence of CPUE and relying solely on the fit to the proportions-at-age leads to a pessimistic scenario, regardless of choice of M. The baseline run of M=0.06 indicates an F_{1999} of 0.066, a SpB_{1999}/SpB_{1980} ratio of 54% and a B_{1999} of 4,928 t with a CV of 42%. The population is being supported by the 1981 recruitment event which is estimated to be the largest observed in the time series. However, this cohort is followed by a progression of poor cohorts through to at least 1989. Target reference quotas correspond to 96, 217 and 287 t.

Case 3: No tuning index (constant recruitment)

When we forced the model to mimic constant recruitment, results were similar to the variable recruitment case, with the exception that the model run based on M=0.08 indicated a moderately more optimistic scenario. For M=0.06, the F_{1999} equals 0.073, a SpB_{1999}/SpB_{1980} ratio of 57% and a B_{1999} of 4,928 t with a CV of 27%. Target reference quotas correspond to 103, 199 and 263 t.

Recommendation

We exclude consideration of the CPUE based runs. We note both analyses of the ageing data provide similar scenarios and recommend harvest quotas based on the Case 2 analysis of 96, 217 and 287 t. We note that these scenarios indicate reductions in biomass of almost 50%.

12.4 Area 5E

Early age samples are limited to 1983, 1989 and 1990. However, since 1994, we have obtained at least three age samples per year (Fig. 20b) The proportions-at-age show the same features as that for other stocks by indicating a decline in the proportions of older fish. Note, however, there are fewer early samples than for other stocks. Area 5E data indicate the strongest indication of a large 1981 recruitment episode, and possibly an earlier one centred about 1970. As mentioned earlier, all Area 5E runs fixed selectivity using estimates of α and β_1 from the 5CD run. A graphical summary is provided for the Case 2 run in Fig 20a-d. Table 19a provides the results of all runs and all assessment information is summarized in Table 19b.

Case 1: Tuning index (CPUE)

Unlike Areas 3CD and 5CD, CPUE does not mimic the landings history but indicates a recent and steady increase throughout the time series. Unlike model runs for other stocks, the model can explain the implied change in abundance because it took place over about 10 years. The increase also occurred more recently, thus, unlike other stocks, the change parallels the ageing samples that are almost exclusively young fish. This allows the model to reconstruct massive incoming recruitment centred on the 1981 cohort, above average recruitment since 1981, and overall, an increasing population to 1999. From the M=0.06 run, F_{1999} is 0.023, the SpB_{1999}/SpB_{1980} ratio is 222% and the B_{1999} is 10,688 t with a CV of 15%. Target reference quotas correspond to 316, 470 and 622 t.

Case 2: No tuning index, variable recruitment

The Case 2 runs indicates a stable biomass since 1980 and a F_{1999}=0.055, only slightly above a target reference point (Figs. 20a-d). Historical F's have averaged around the target level. The reconstruction also indicates that the recruitment episode centred around 1981 was very large, but it indicates that recruitment since the 1981 episode is lower than average as opposed to above-average. From the M=0.06 run, the SpB_{1999}/SpB_{1980} ratio is 110% and the B_{1999} is 4,629 with a CV of 50%. Target reference quotas correspond to 137, 204 and 270 t.

Case 3: No tuning index, constant recruitment

Results for the constant recruitment case are similar to those for the Case 2 analysis in that it a stable biomass since 1980 is reconstructed. However, it scales the size of the population lower since it does not indicate a large incoming recruitment event centred on the 1981 yearclass. From the M=0.06 run, the SpB_{1999}/SpB_{1980} ratio is 97% and the B_{1999} is 4,629 with a CV of 45%. Target reference quotas correspond to 83, 123 and 163 t.

Recommendation

We have no objective basis for rejecting the CPUE based runs and note that our *a priori* assumption about the index is that it most likely has a negative bias associated with decreasing trip limits. While the assumption of a large 1981 recruitment episode is consistent with all other stocks, we are reluctant to endorse a stock reconstruction that estimates that all cohorts since 1981 are larger than those observed prior to the 1981-

centred event. Conversely, we view the Case 3 model as overly pessimistic since these results indicate that the only successful cohorts in the last 20 years, were those centred on 1981. Therefore, we support the Case 2 runs which indicate that there has been a gradual fishing down of the older cohorts, although recent recruitment has allowed the stock to recover from a low point in the early 1990's. The harvest recommendations are 137, 204 and 270 t.

13 Summary of environmental considerations and expectation of future recruitment

Examination of groundfish recruitment trends for the north east 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 10 years the silvergray rockfish fishery off B. C. has benefited from a period of good recruitment but is now entering a period that will have to rely on 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 to1994. 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 some suggestion of a regime shift in 1998 but it is too early to evaluate its impact on groundfish stocks and certainly not for silvergray rockfish in particular (McFarlane et al. 2000). Furthermore, its impact on the fishery is a decade away. In summary, current large-scale reviews of environmental change appear to predict poor recruitment from the 1990's cohorts of groundfish.

14 Summary of harvest advice

Based on the available data, we have recommended three harvest options. We note that the two lower options would represent a general reduction in quotas for all stocks, and, in particular, for Area 5AB. The third reference harvest level, *F=M*, would approximately maintain the harvest levels of the last few years. We emphasise that although we suggest that overall biomass most likely has declined since 1980, it has probably been stable since 1990, after the higher landings of the 1980's were reduced. We suggest that the 20-40 year history of landings represents the classic fishing down period. This fishery has been gradually removing the accumulated biomass from the pre-fishery period in addition to the incoming annual production. The fishery is now approximately in equilibrium with incoming recruitment. We caution managers that there is large uncertainty around the estimates as implied in standard deviation of the terminal biomass in each run and the variability in the outcomes from various scenarios.

With respect to the choice of target reference points or harvest rates, we can provide no evidence based on the relatively short time series of information that the traditional reference point of *F=M* represents over-harvesting. Even the lower implied harvest for 5AB in this assessment is not because the stock has declined since the previous assessment. Rather the current assessment suggests that previous quota was slightly larger than it should have been, based on new data and a more thorough anlaysis.

We do not suggest any "harm" to the stocks was done by the overly optimistic quota. Since we estimate that we are harvesting a small proportion of the biomass, 5-10%, differences in the quota equate to only an additional 1-2%/year change in biomass. These differences will have a negligible impact on biomass over the short-term (i.e. 3-4 years). While we currently cannot refute the *F=M* harvest logic and managers may wish to consider using this basis when assigning quotas, we suggest that the general trend in choosing long-term harvests references points seems to be shifting to increasingly conservative viewpoints (see Section 8.).

We provide no forecasting of biomass or quotas., we believe that it will be sufficient to base the next four years' quotas on the status as of 1999. While the biomass will vary modestly over the next four years, we argue that the exercise of forecasting will provide minimal changes to the current year's recommendations because: (1) the incoming large cohort(s) are almost fully recruited, (2) there are no large cohorts on the horizon and (3) our estimate of *M* and recommended *F* are so low as to imply a stable biomass for at least four years.

The increased number of aged samples being generated by at-sea observers and our ability to observe the progression of the 1981 cohort should improve the basis for assessment. However, we expect only a marginal improvement in the "certainty" of our advice. Unless we can treat commercial CPUE as a credible abundance index, or develop an alternative index, the analyses will always confound recent recruitment with overall biomass. We recommend that silvergray rockfish be re-assessed in four years.

With this document we have attempted to improve the knowledge base on the population dynamics of silvergray rockfish in Canadian waters. It is our belief that this knowledge will be useful in selecting among harvest options. We suggest, however, that the presentation of this information would be much improved if the management objectives for this resource were formally stated. As commented by a reviewer, without a clear statement of the fishery management objectives, it is not possible to evaluate the merits of alternative strategies.

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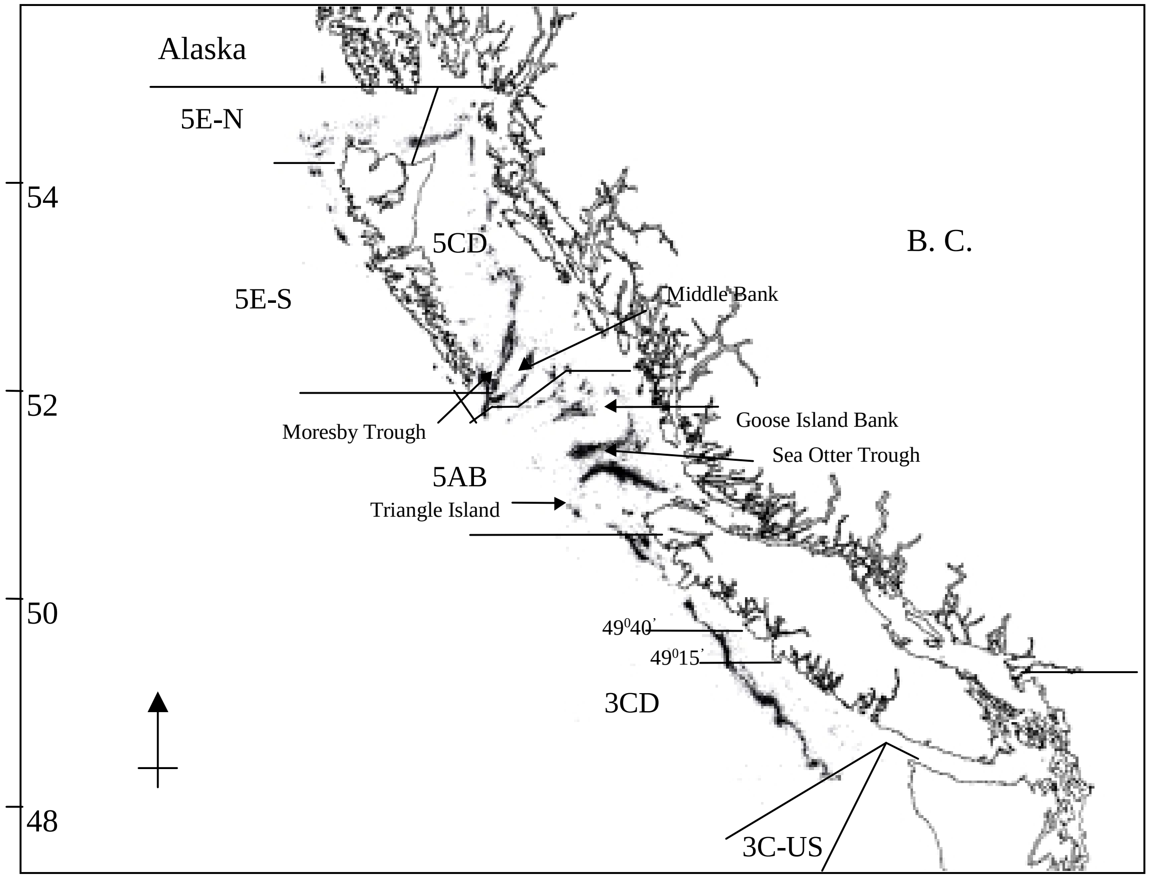

Figure 1. Silvergray rockfish stock boundaries, latitudes of the northern extent of U. S. triennial surveys and bottom trawl locations with >25 kg of silvergray rockfish, 1996-1999.

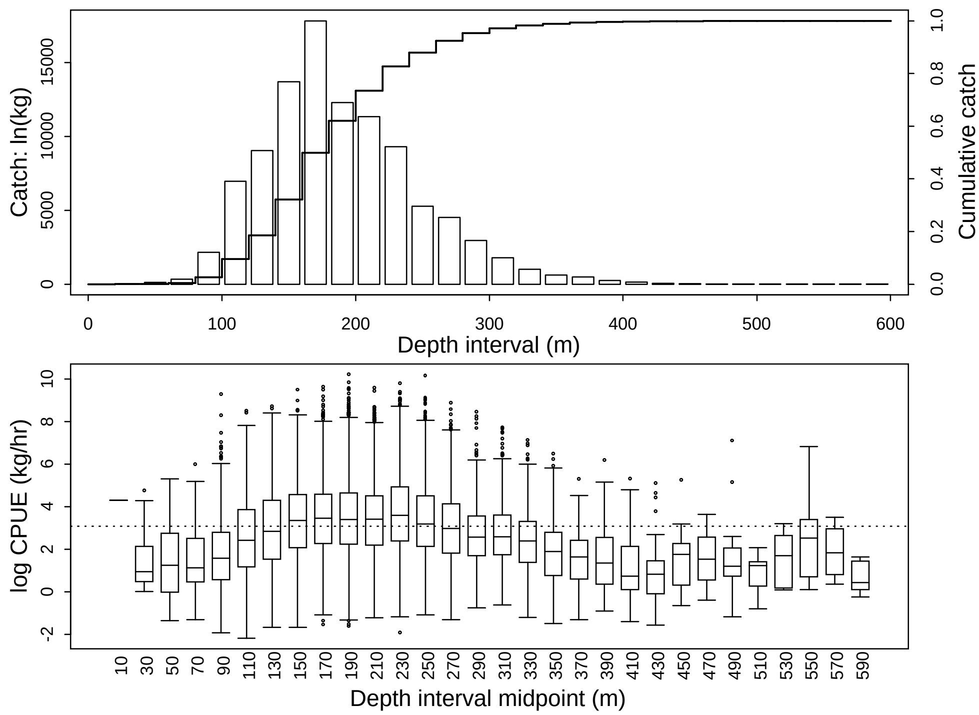

Figure 2. Total catch and log CPUE by 20m depth interval for silvergray rockfish from observer data 1996-1999.

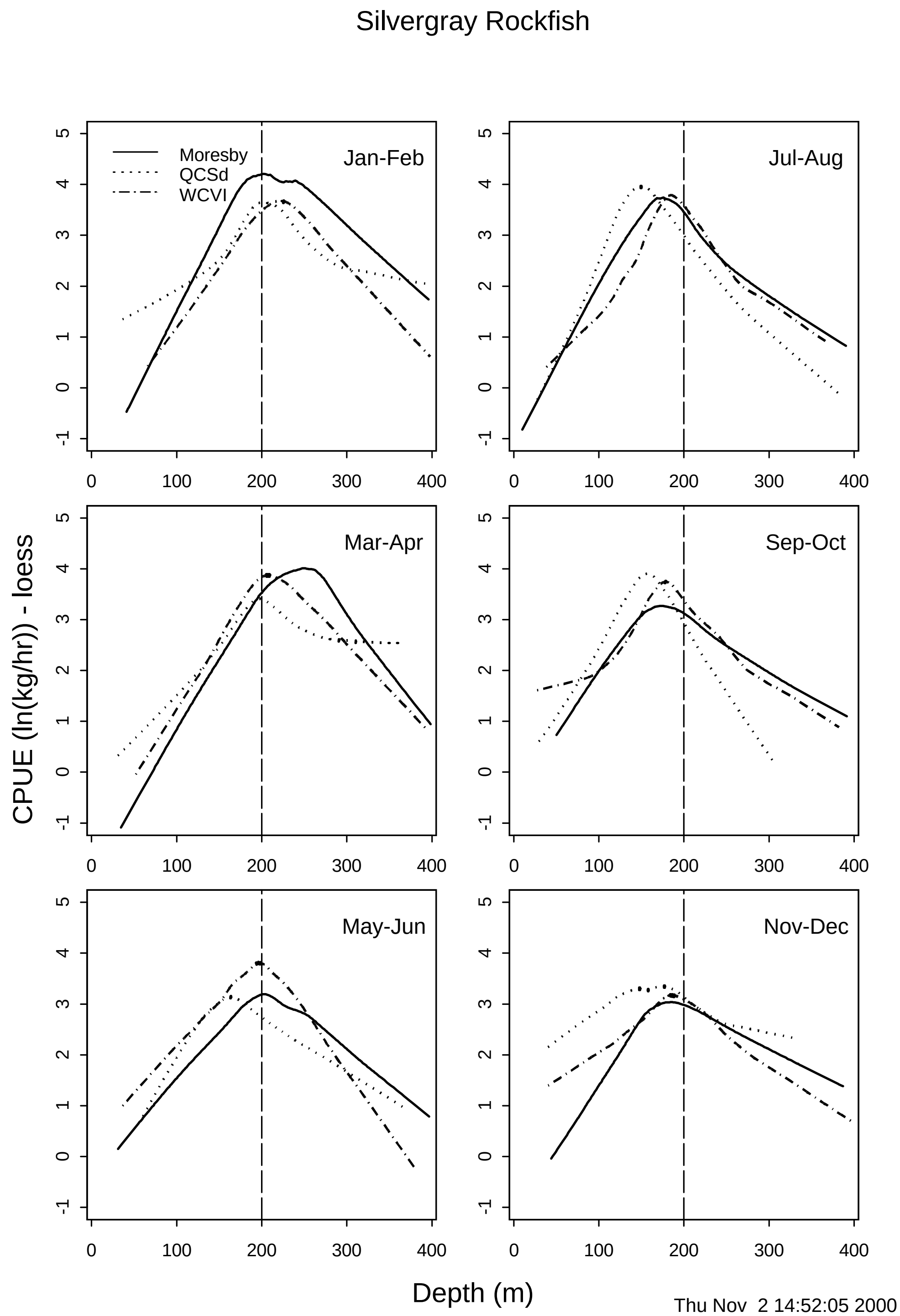

Figure 3. LOESS fit to ln CPUE by depth, stock and bi-monthly period for silvergray rockfish from 1996-1999 observer data for Moresby (5CD), Q. C. Sd. (5AB), and W.CVI (3CD).

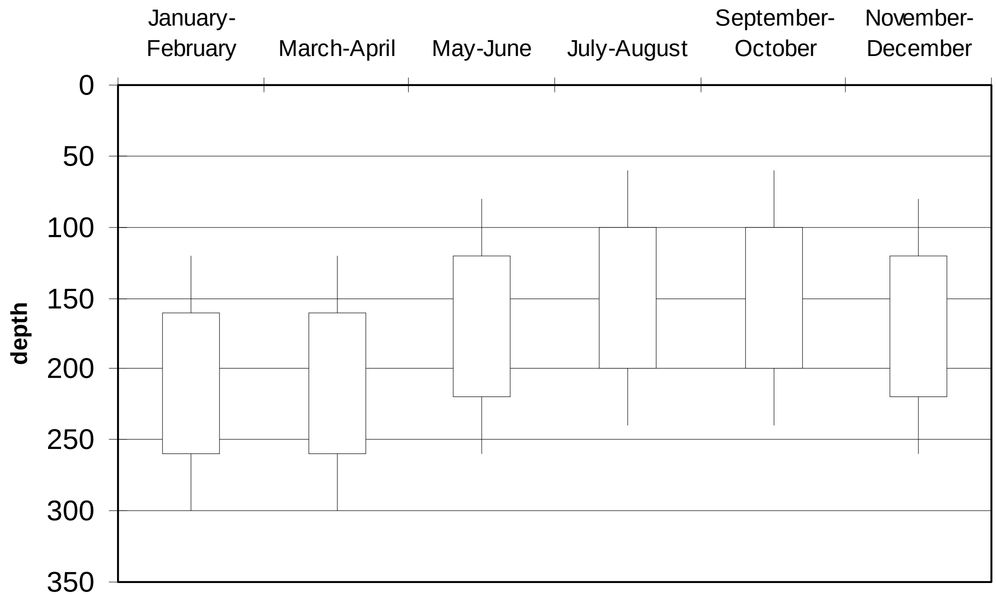

Figure 4. Optimal (box) and marginal (vertical bars) depth strata by bi-monthly period for Area 5AB

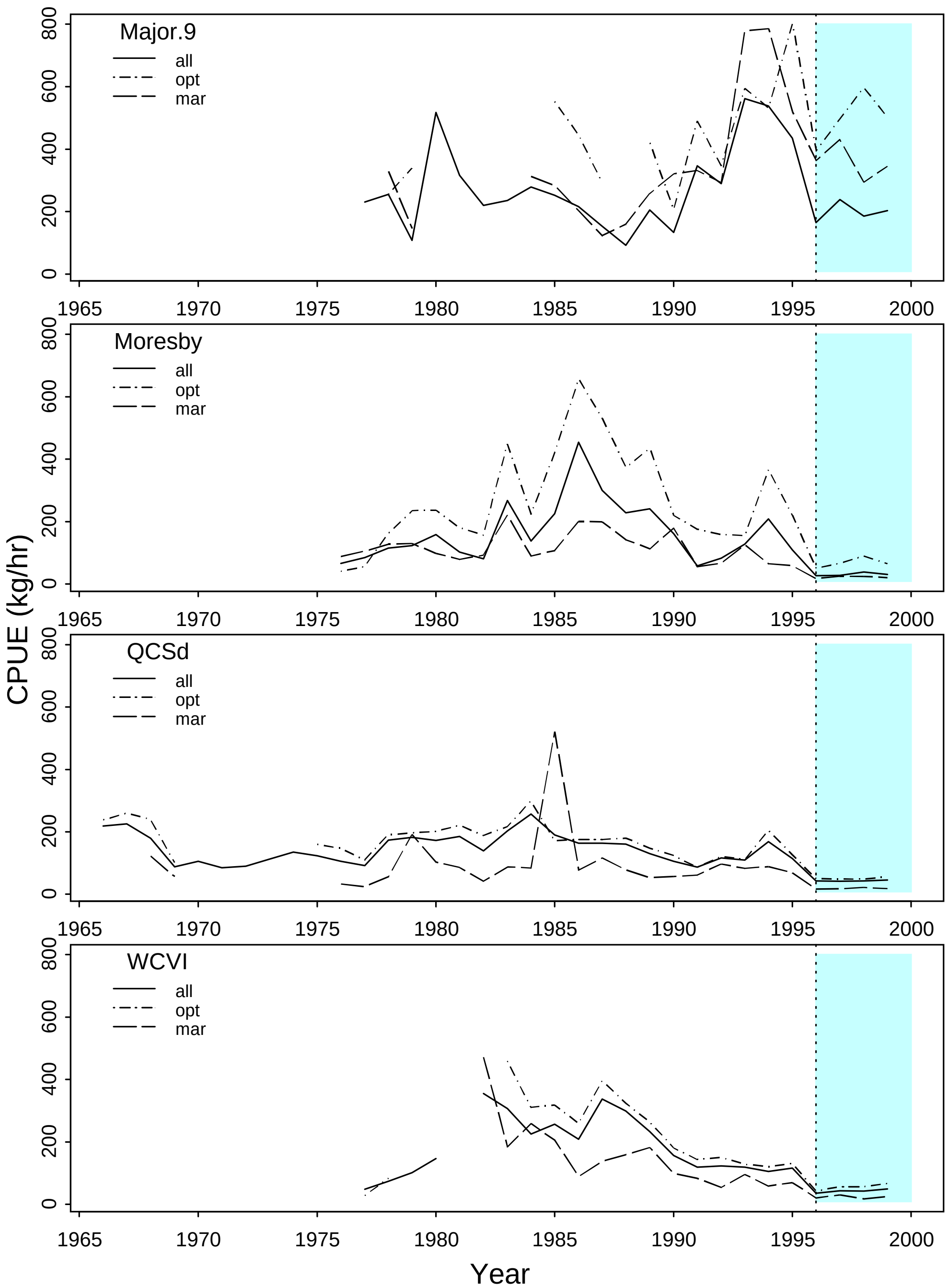

Figure 5. CPUE (10% trimmed mean) by year, stock and data extraction. Shaded area indicates data from 100% observer coverage (Major 9 (5E), Moresby (5CD), Q. C. Sd. (5AB), and W.CVI (3CD) ("all" refers to all optimal and marginal depths combined).

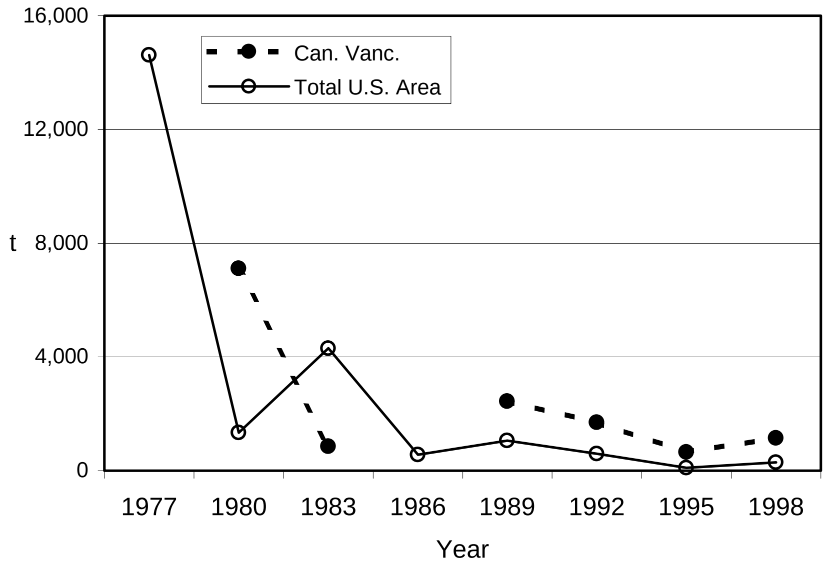

Figure 6. Biomass estimates for U.S. waters off Washington and California, and in approximately the southern half of Area 3CD.

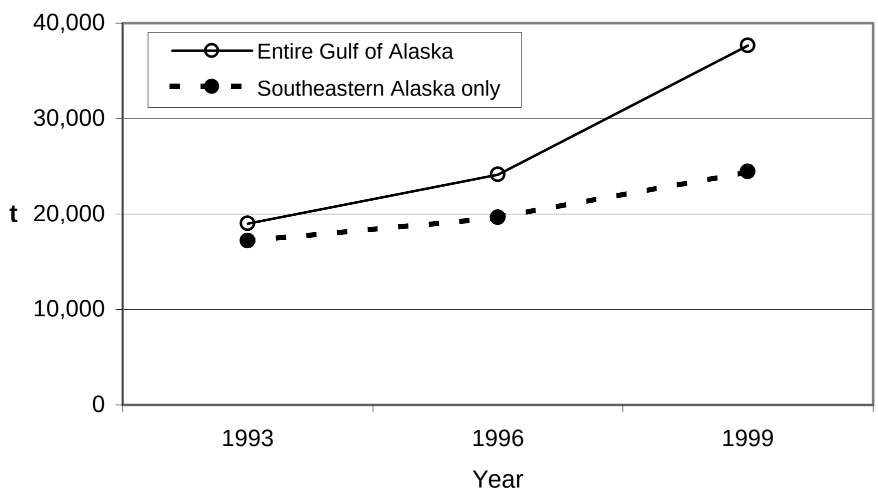

Figure 7. Biomass estimates for silvergray rockfish in the Gulf of Alaska.

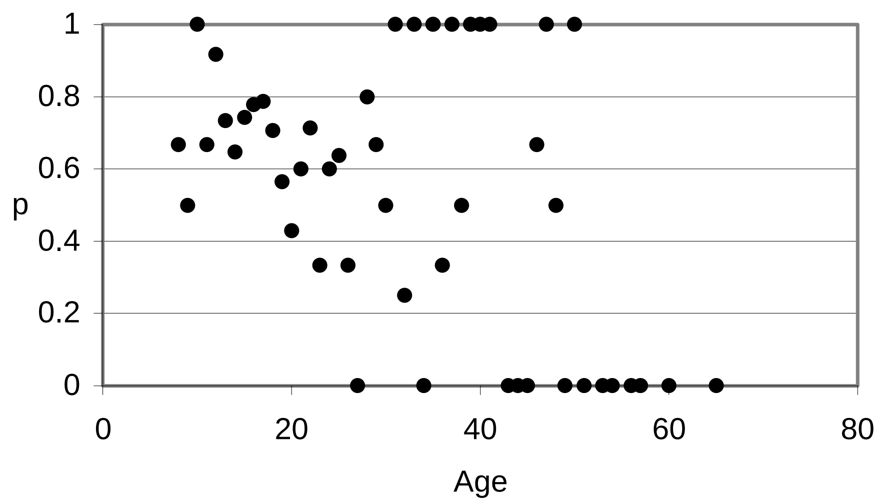

Figure 8. Proportion of agreement between two age readers versus resolved age for silvergray rockfish from 1998 samples.

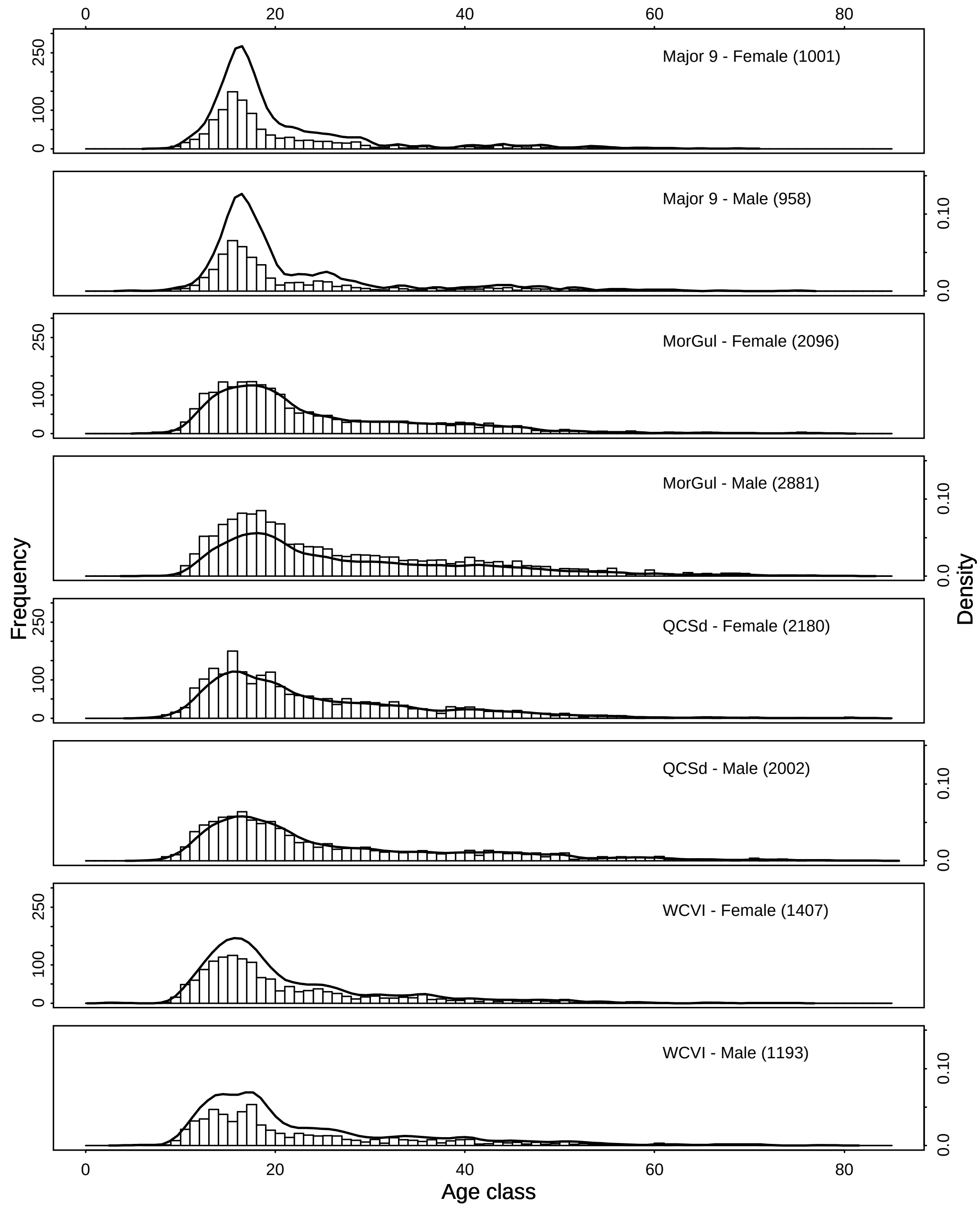

Figure 9. Total histograms by sex and stock for all observations used in catch-at-age model (curved line represents a kernal density estimator).

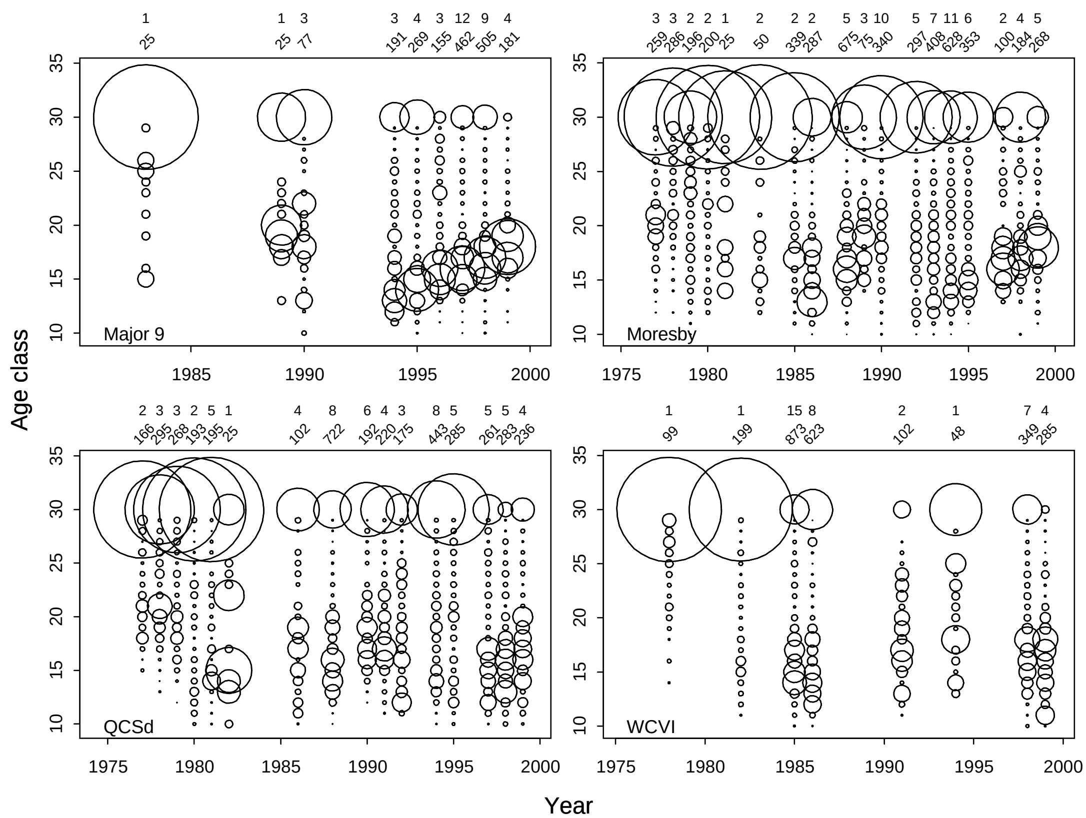

Figure 10. Proportions at age by stock, sexes combined with number of samples and number of specimens for Major9 (5E), Moresby (5CD), Q. C. Sd. (5AB), and WCVI (3CD).

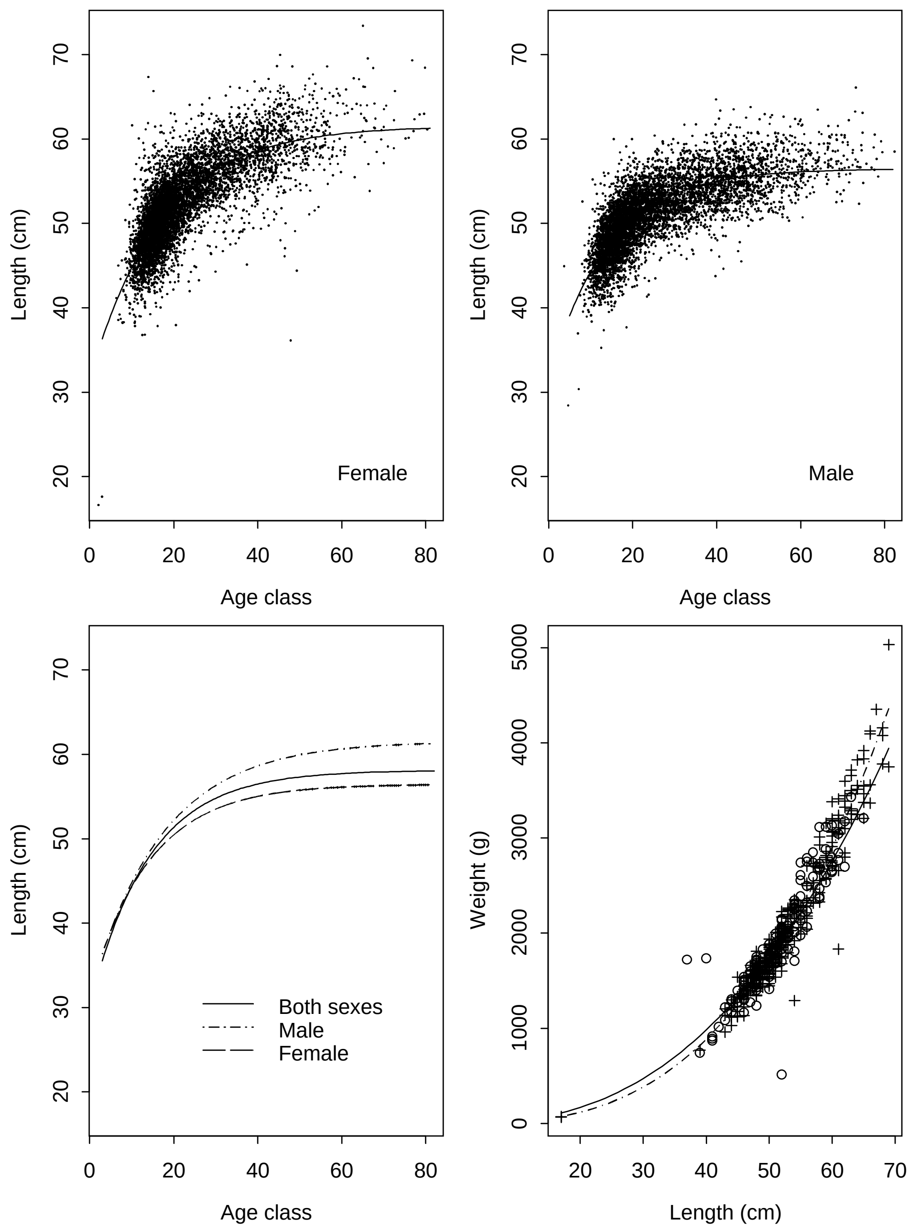

Figure 11. Overall size at age plots for females (a), males (b), comparison of derived growth curves for males and females, and length/weight relationship

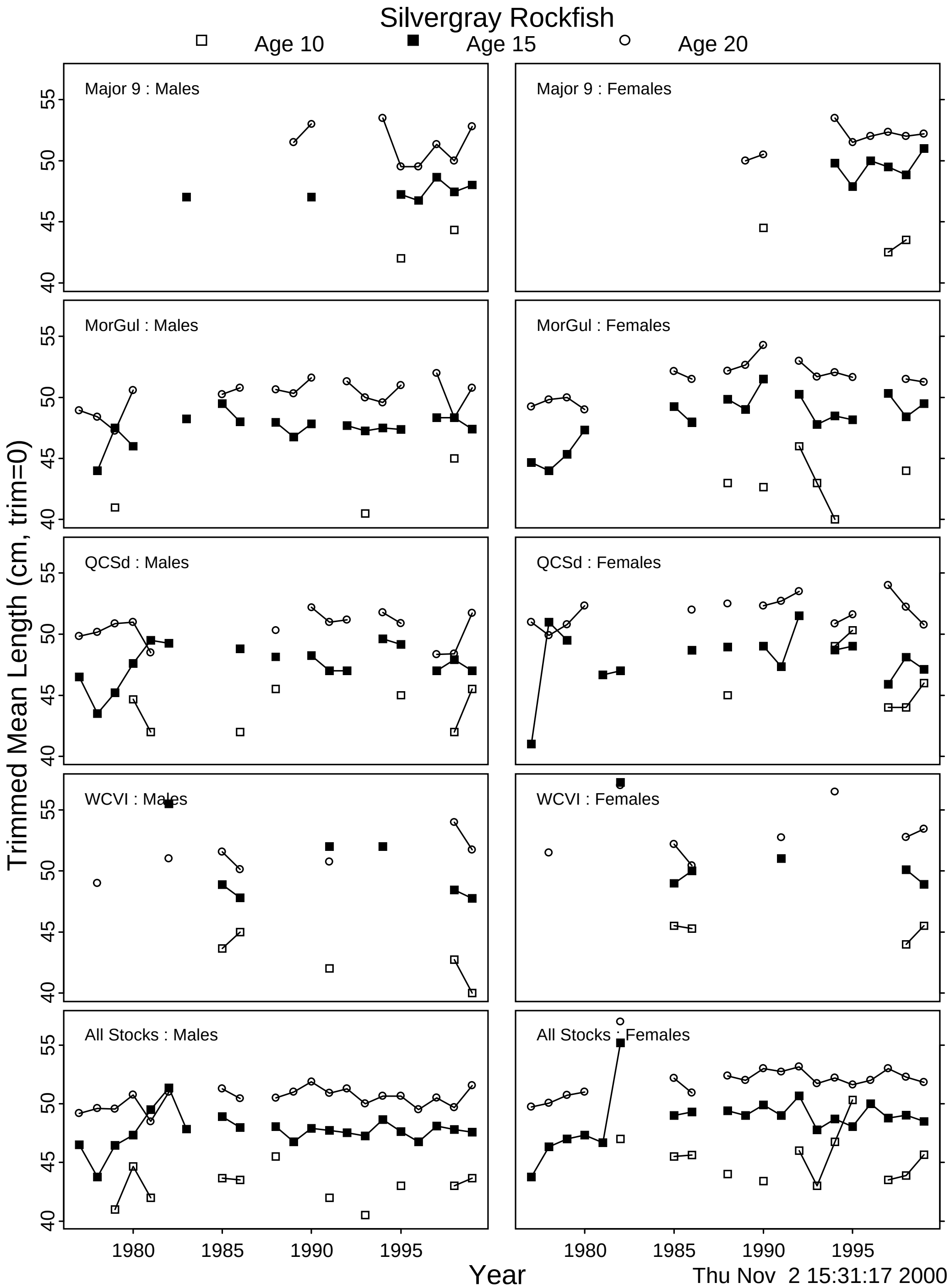

Figure 12. Size at age for ages 10, 15, and 20 year-olds, males and females for Major9 (5E), Moresby (5CD), Q. C. Sd. (5AB), and WCVI (3CD).

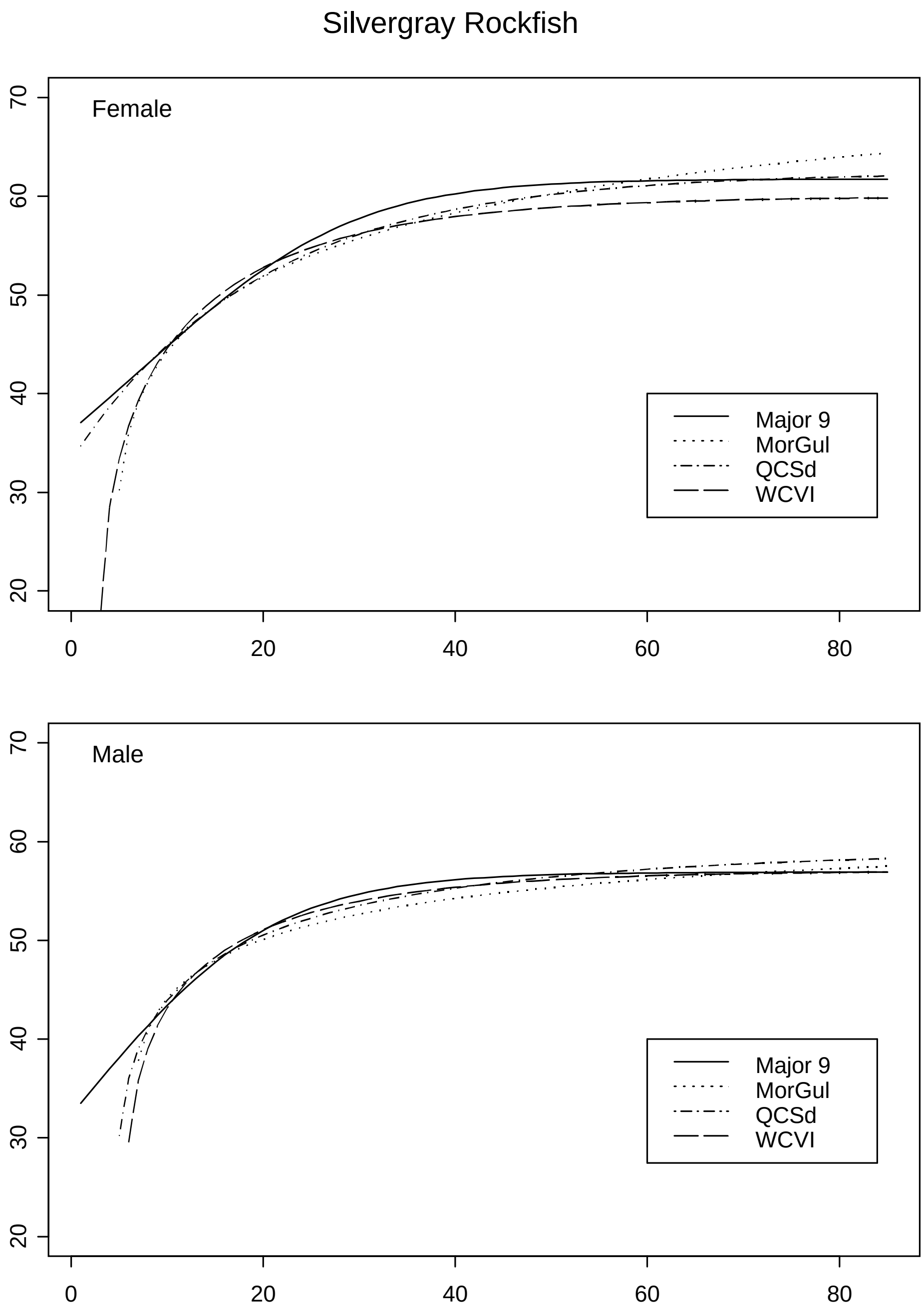

Figure 13. Estimated growth curve by stock and sex for silvergray rockfish for Major 9 (5E), MorGul (5CD), Q. C. Sd. (5AB), WCVI (3CD).

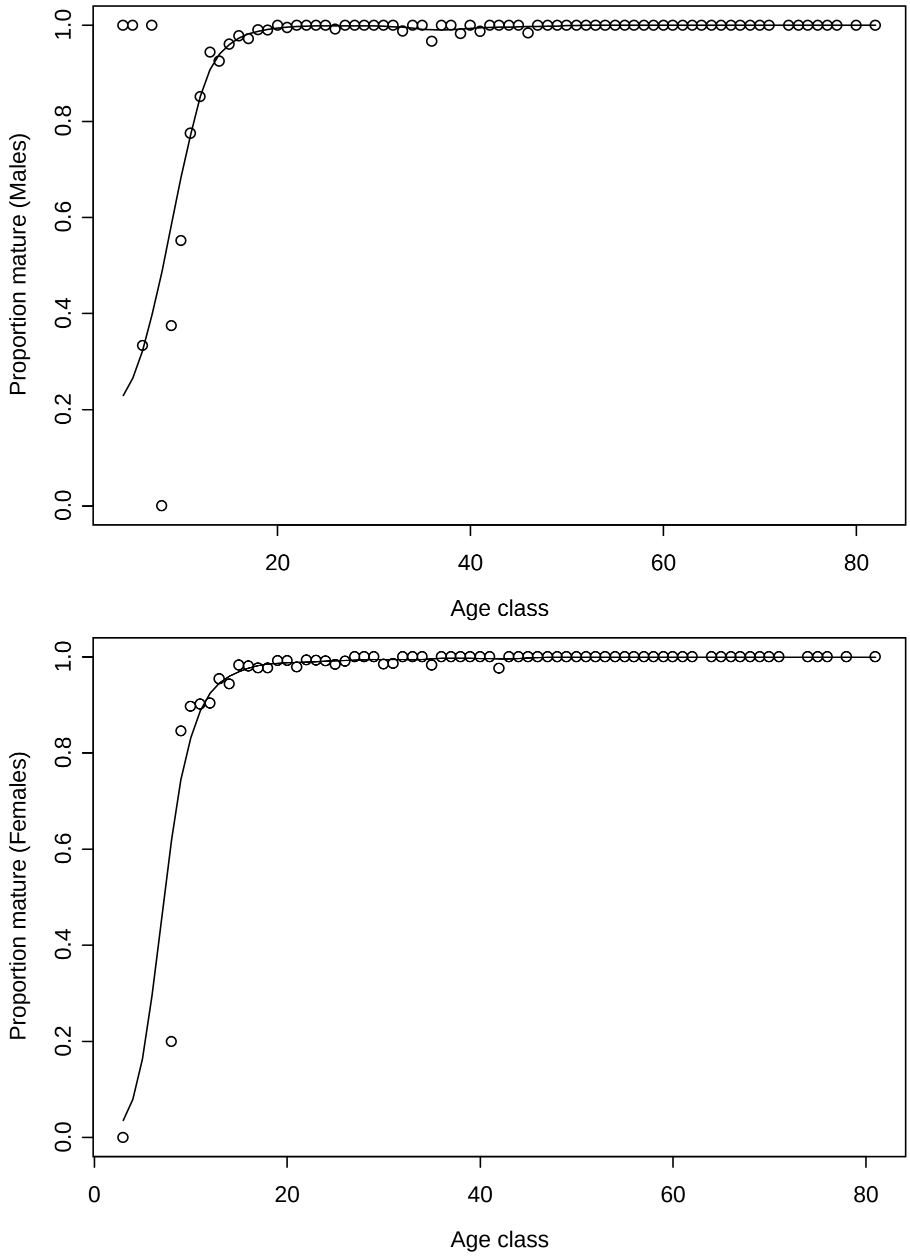

Figure 14. Observed and predicted size at maturity for male (top panel) and female (bottom panel) silvergray rockfish.

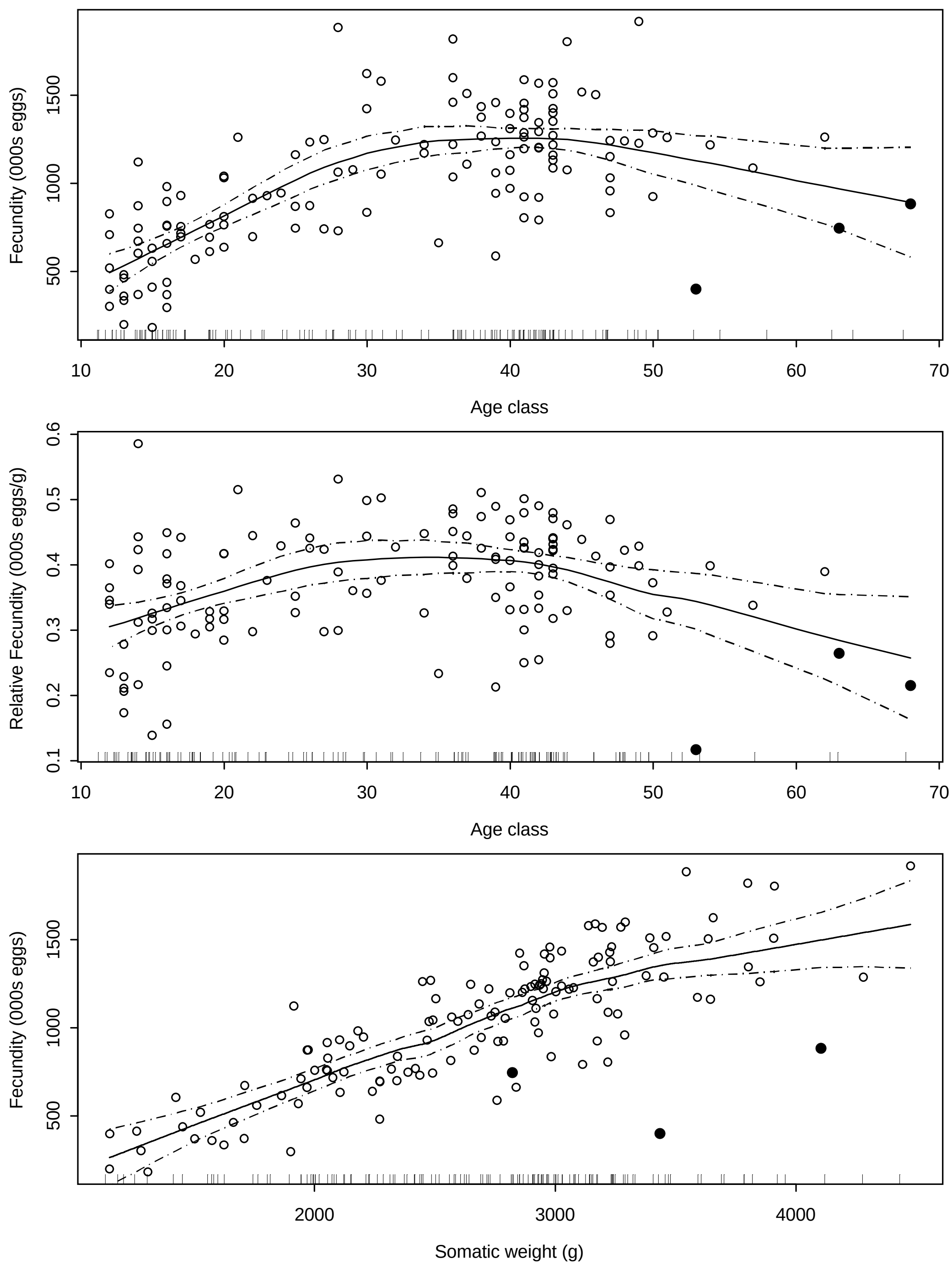

Figure 15. Silvergray rockfish fecundity versus age (a), relative fecundity versus age, and fecundity versus somatic weight (black circles indicate specimens with unexpectedly low fecundity for body size).

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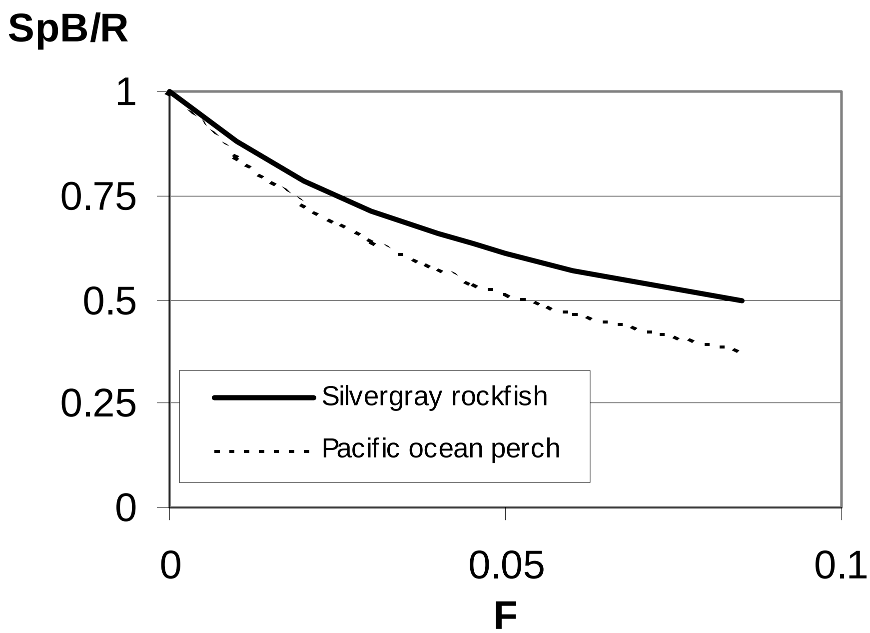

Figure 16. Spawning potential per recruit expressed relative to an unfished population (*F*=0.0, *M*=0.06)

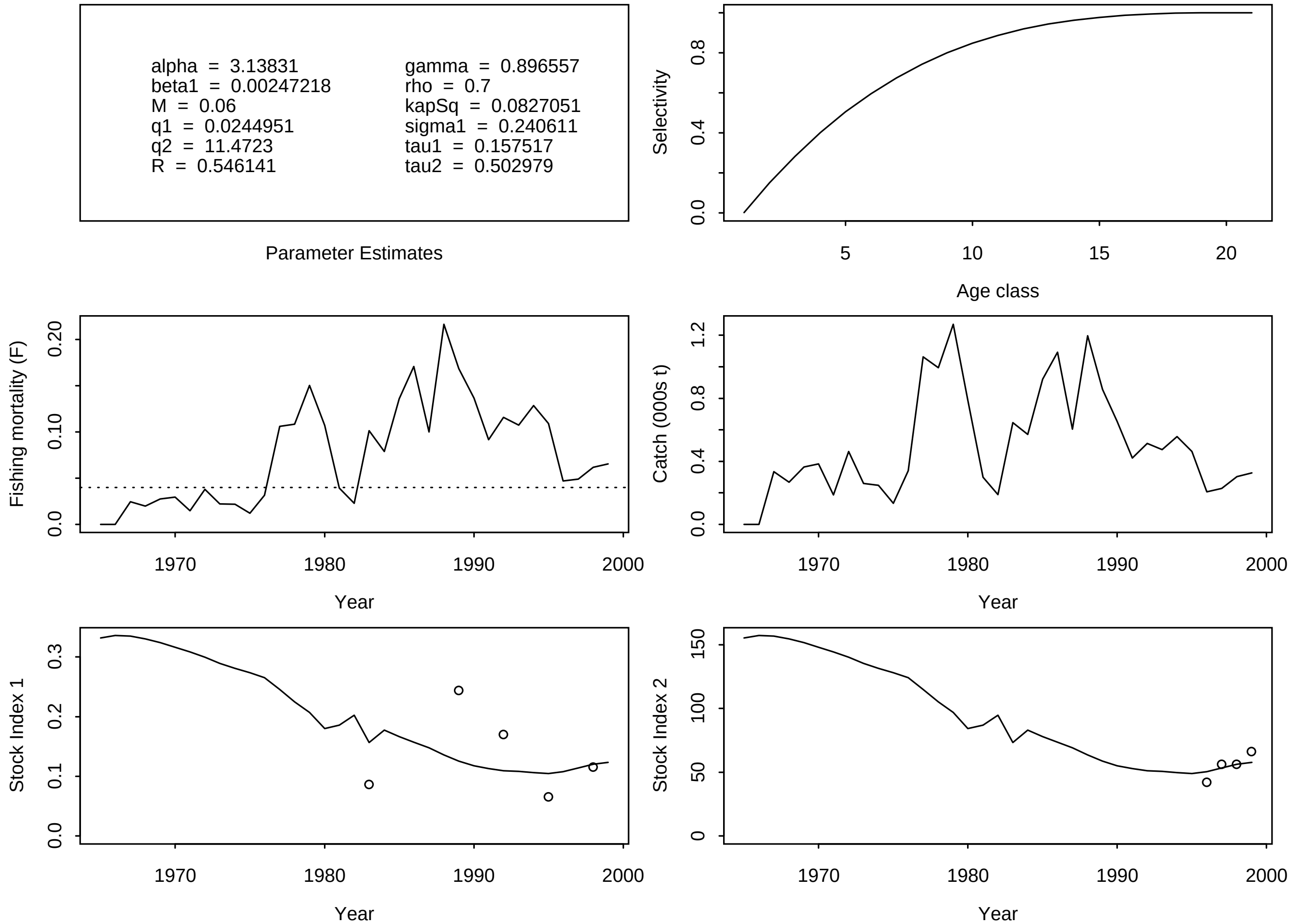

Figure 17a. Summary of input and output from Case 1b* run of Area 3CD

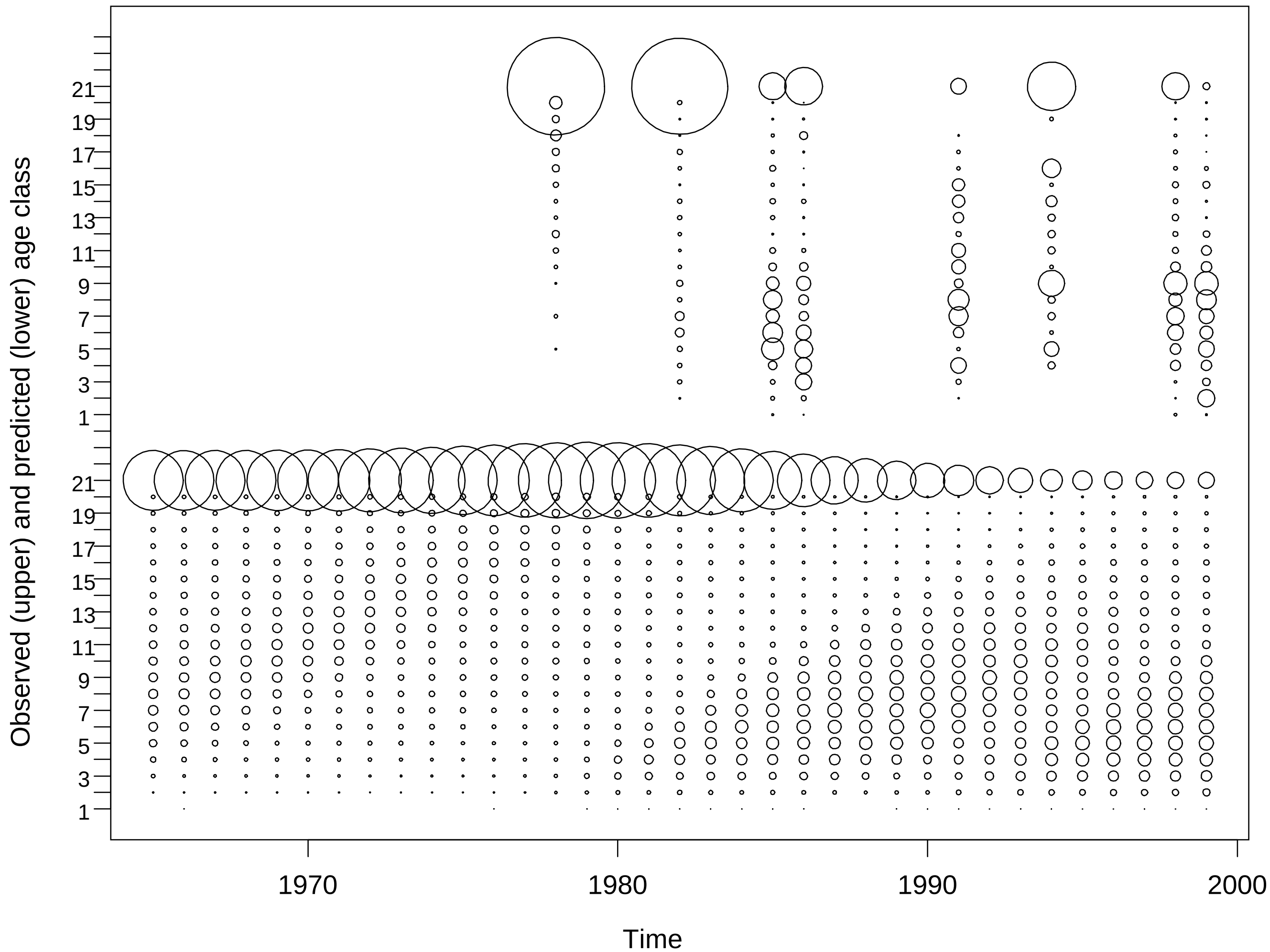

Figure 17b. Comparison of observed and predicted proportions-at-age for Case 1b* run for Area 3CD.

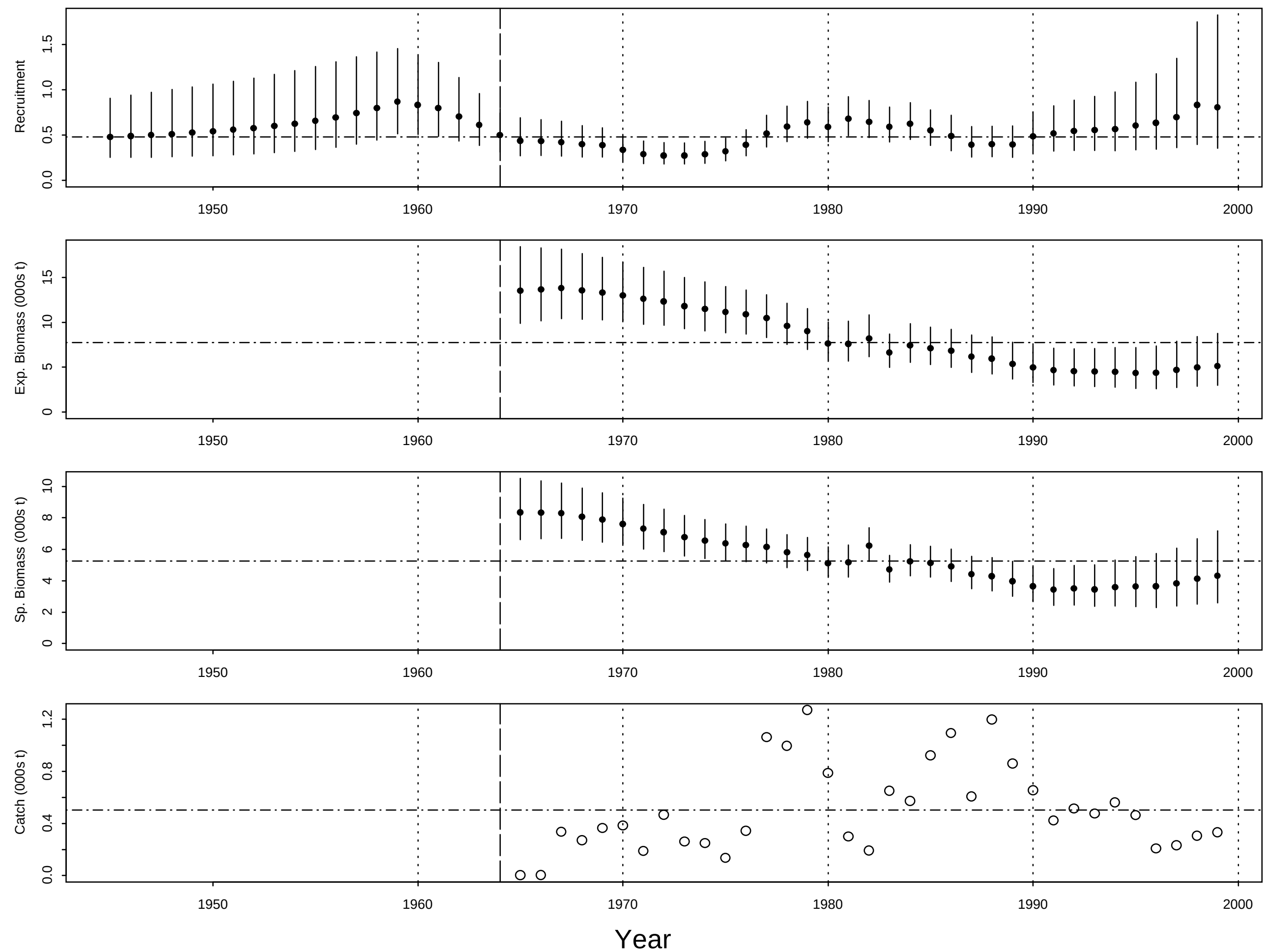

Figure 17c. Population trajectories for Case 1b* run Area 3CD.

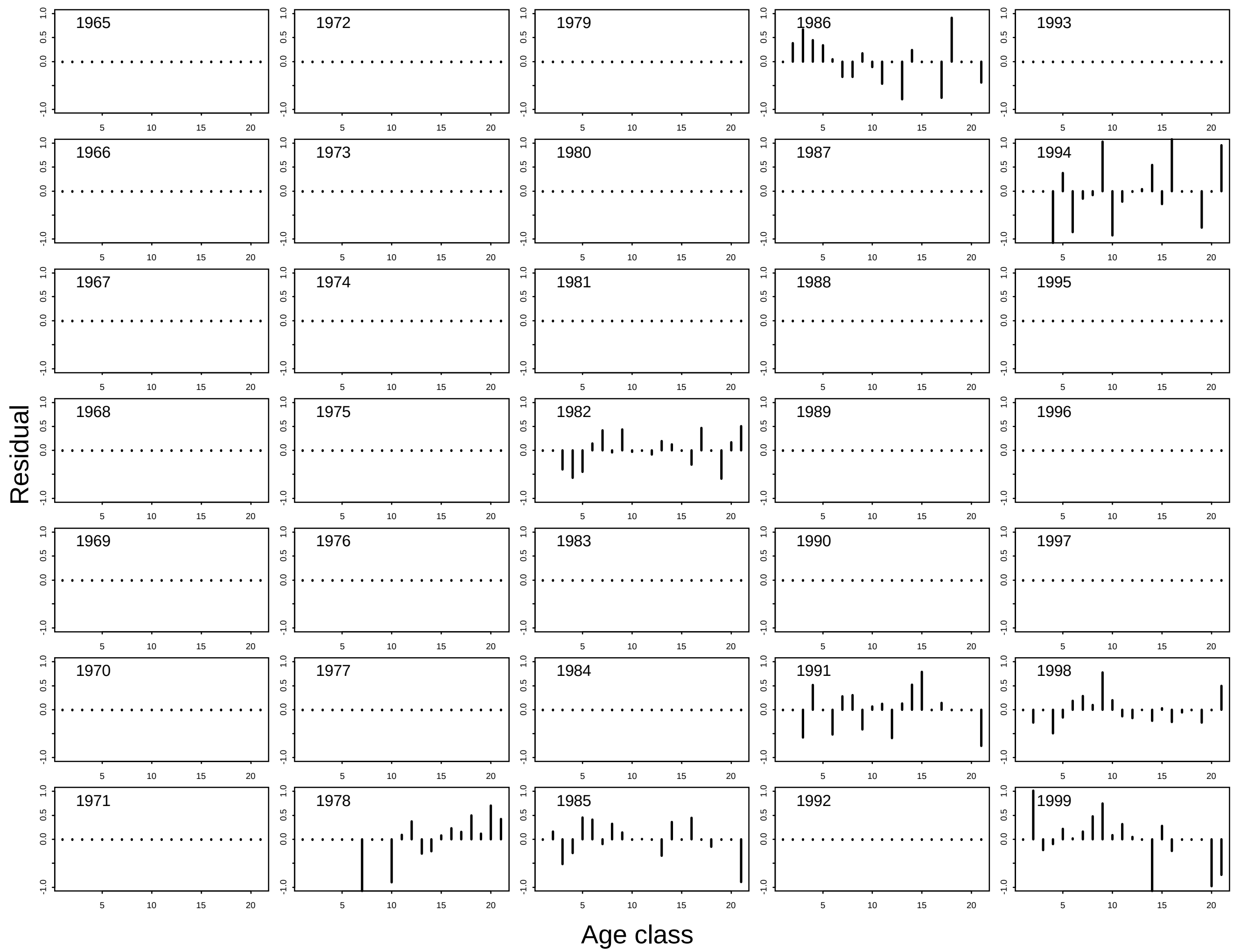

Figure 17d. Proportion-at-age residuals from Case 1b* run for Area 3CD.

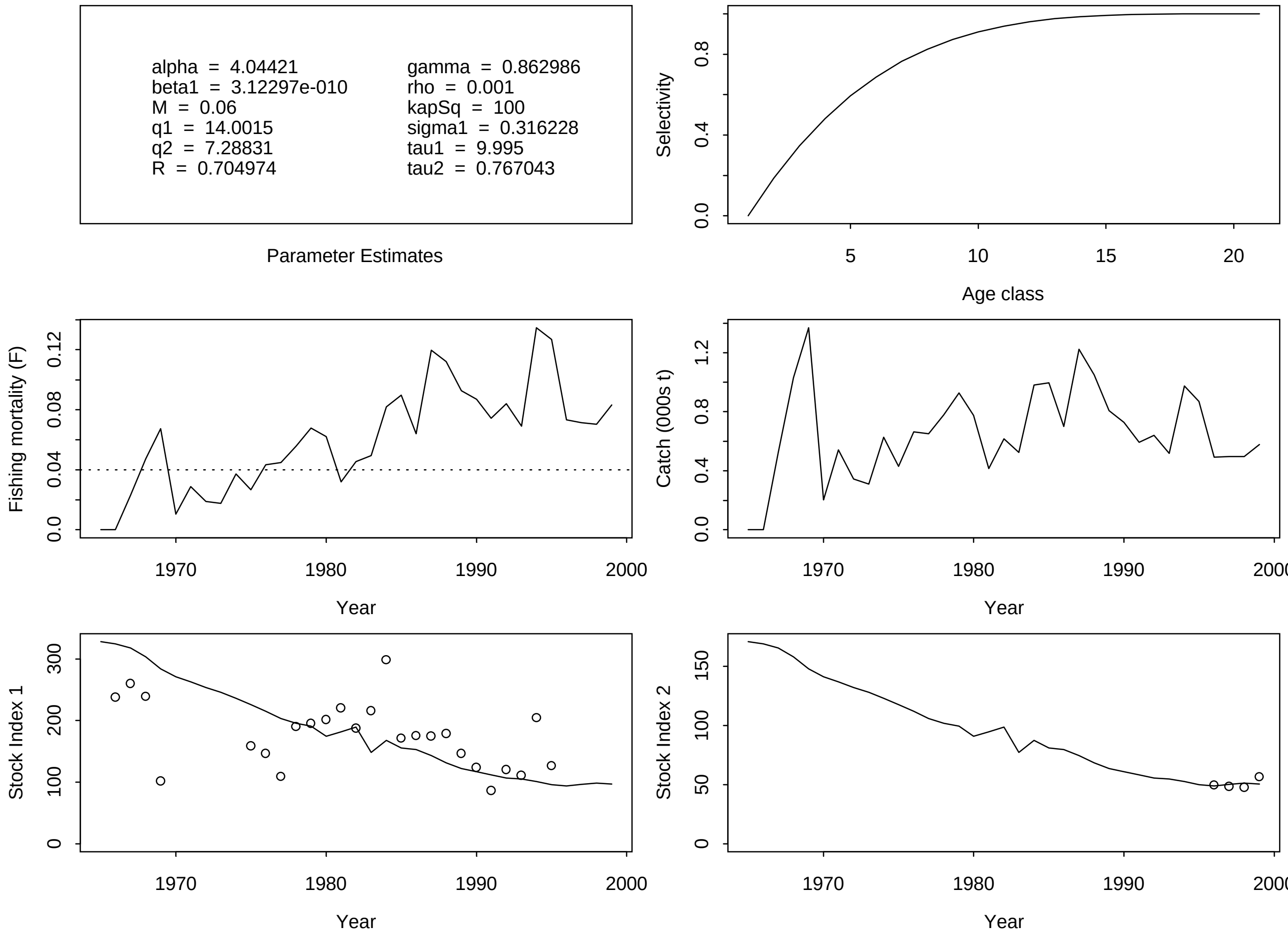

Figure 18a. Summary of input and output from Case 2 run of Area 5AB.

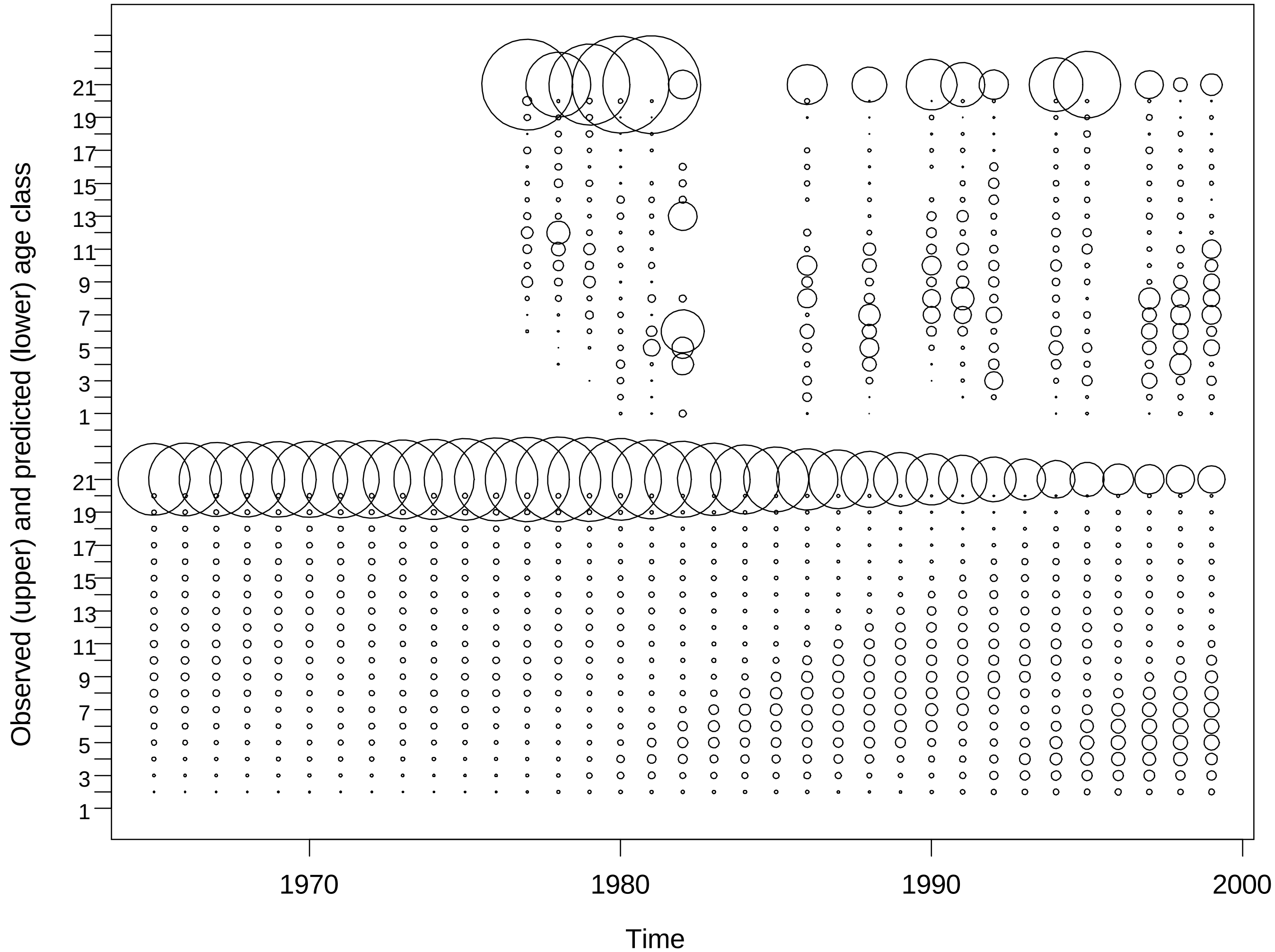

Figure 18b. Comparison of observed and predicted proportions-at-age for Case 2 run for Area 5AB.

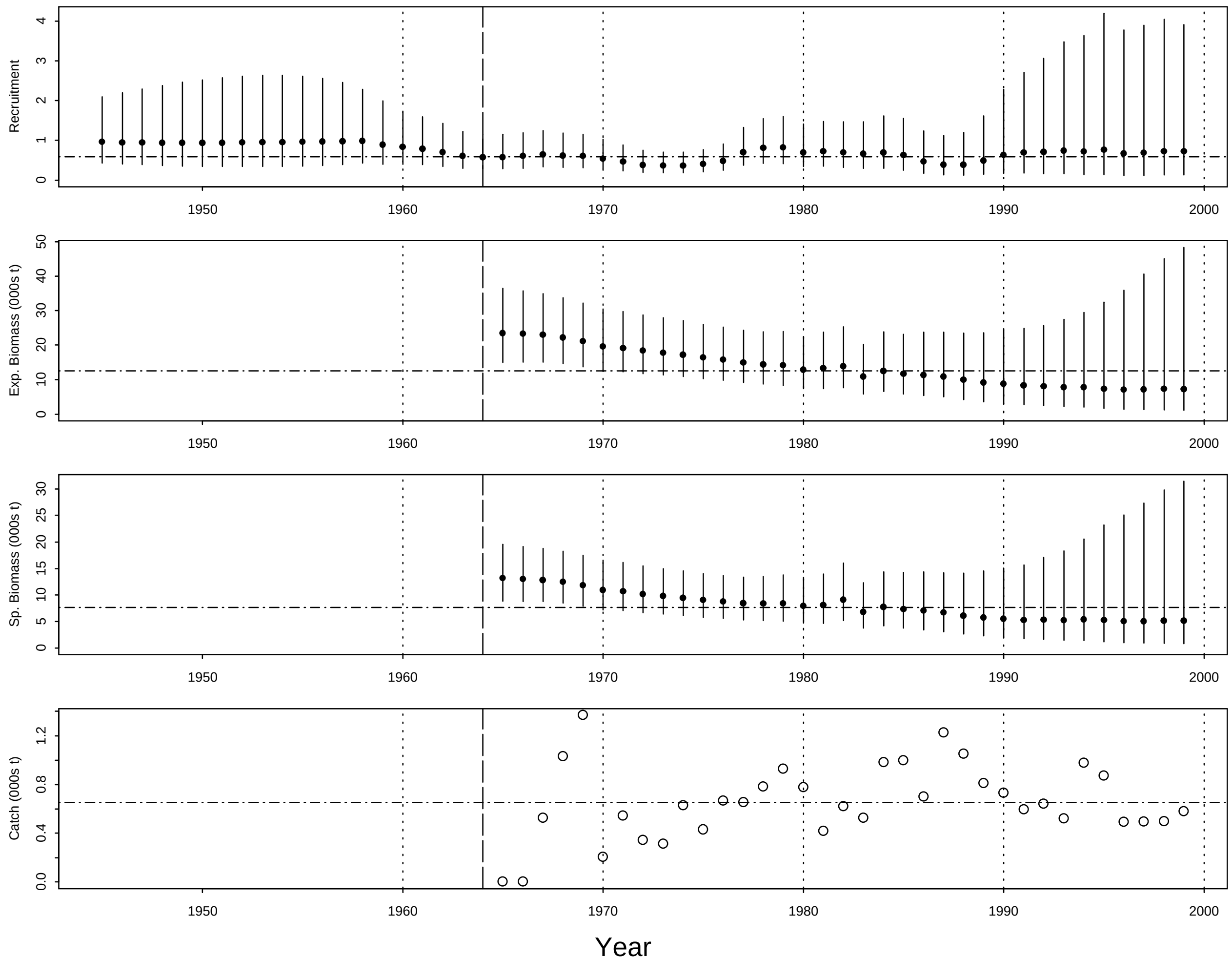

Figure 18c. Population trajectories for Case 2 run for Area 5AB.

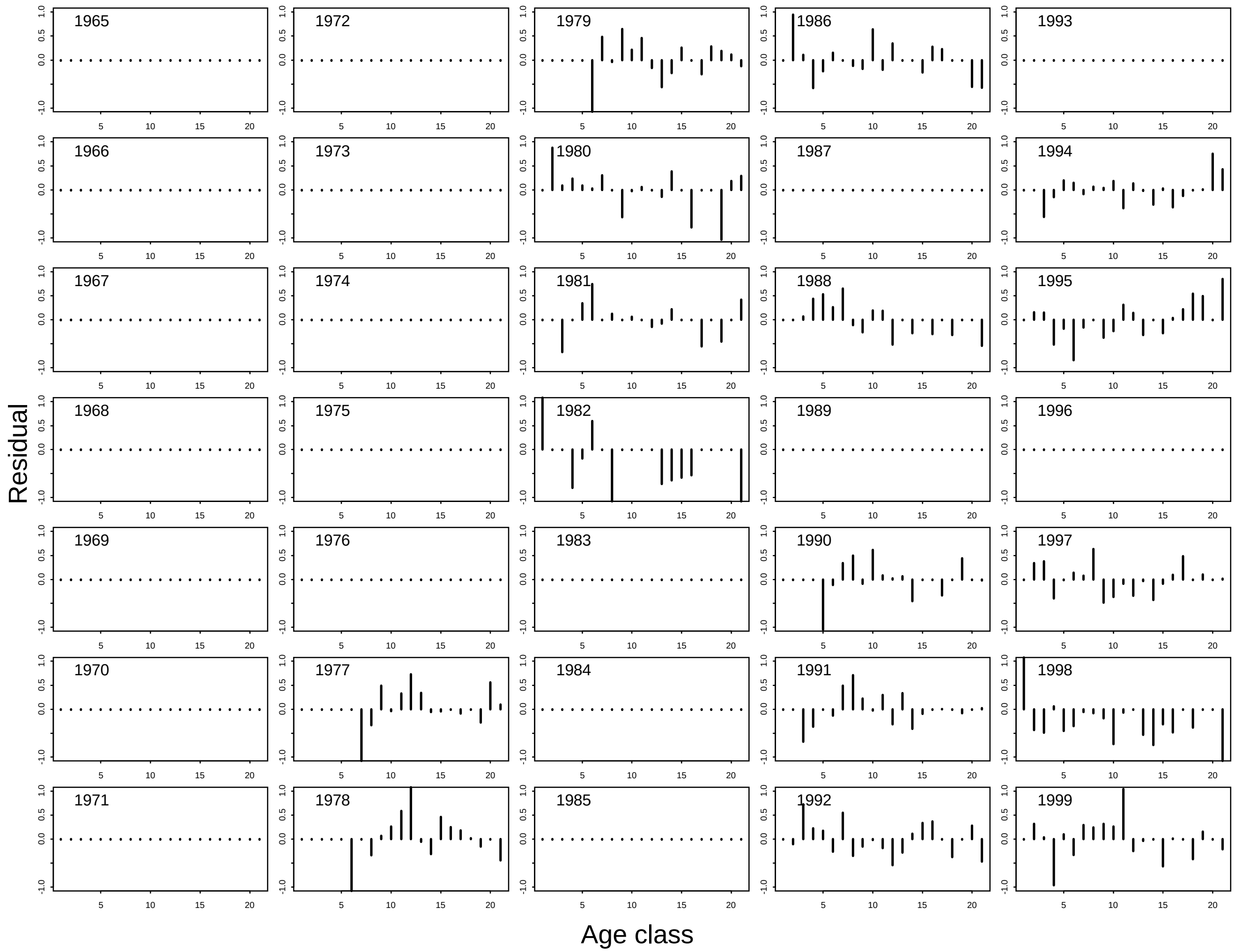

Figure 18d. Proportion-at-age residuals from Case 2 run for Area 5AB.

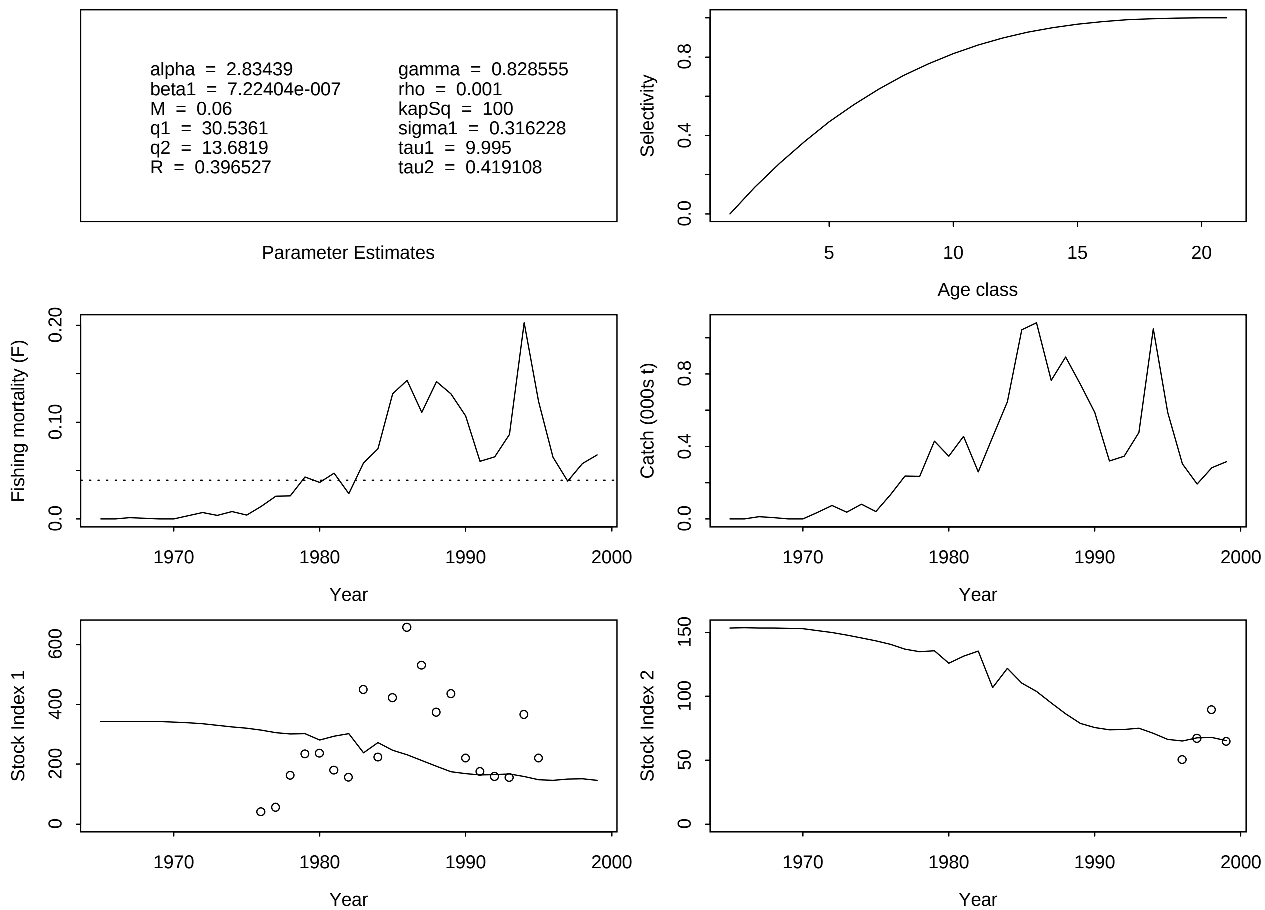

Figure 19a. Summary of input and output from Case 2 run of Area 5CD.

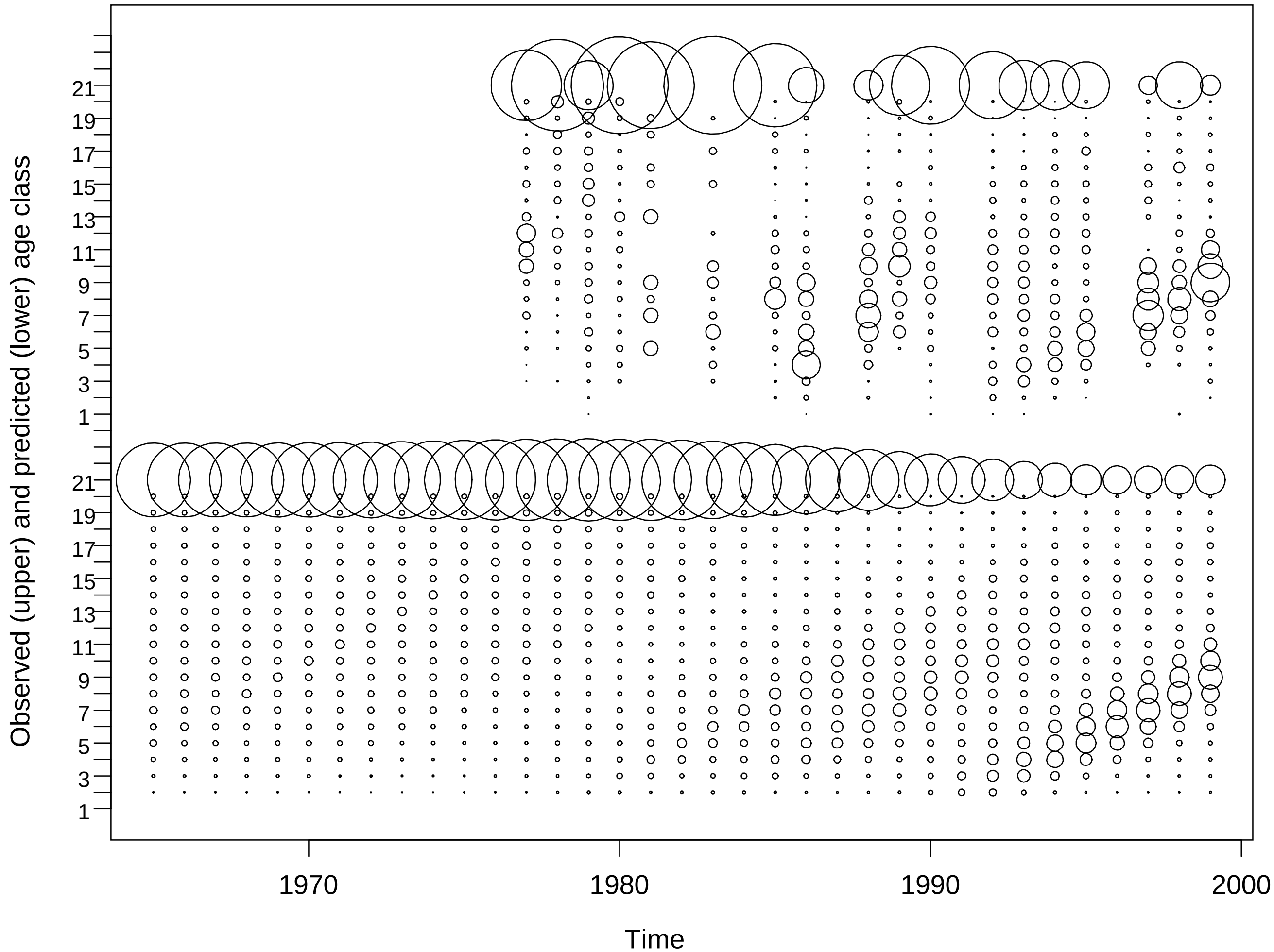

Figure19b. Comparison of observed and predicted proportions-at-age for Case 2 run for Area 5CD.

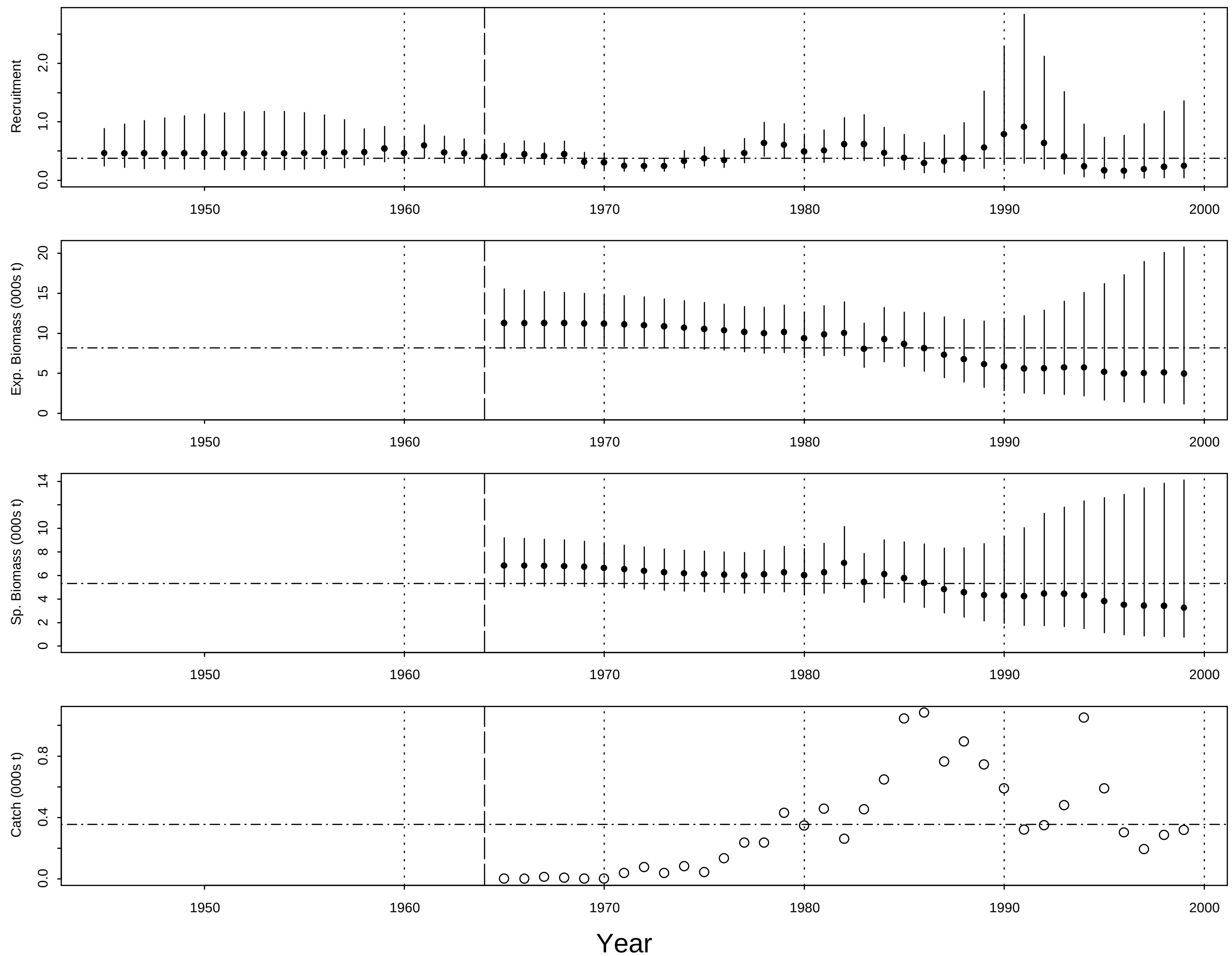

Figure 19c. Population trajectories for Case 2 run for Area 5CD.

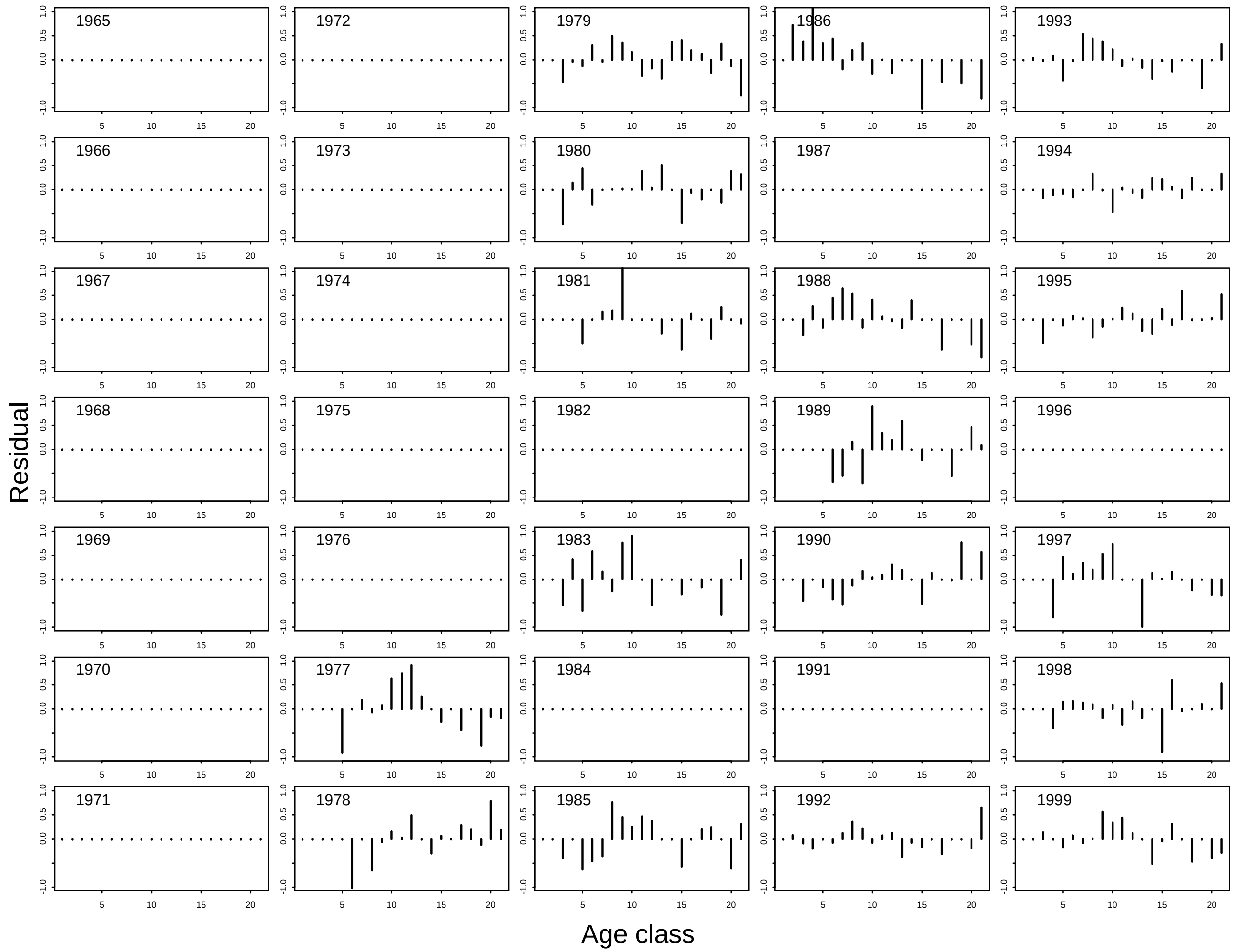

Figure 19d. Proportion-at-age residuals from Case 2 run for Area 5CD.

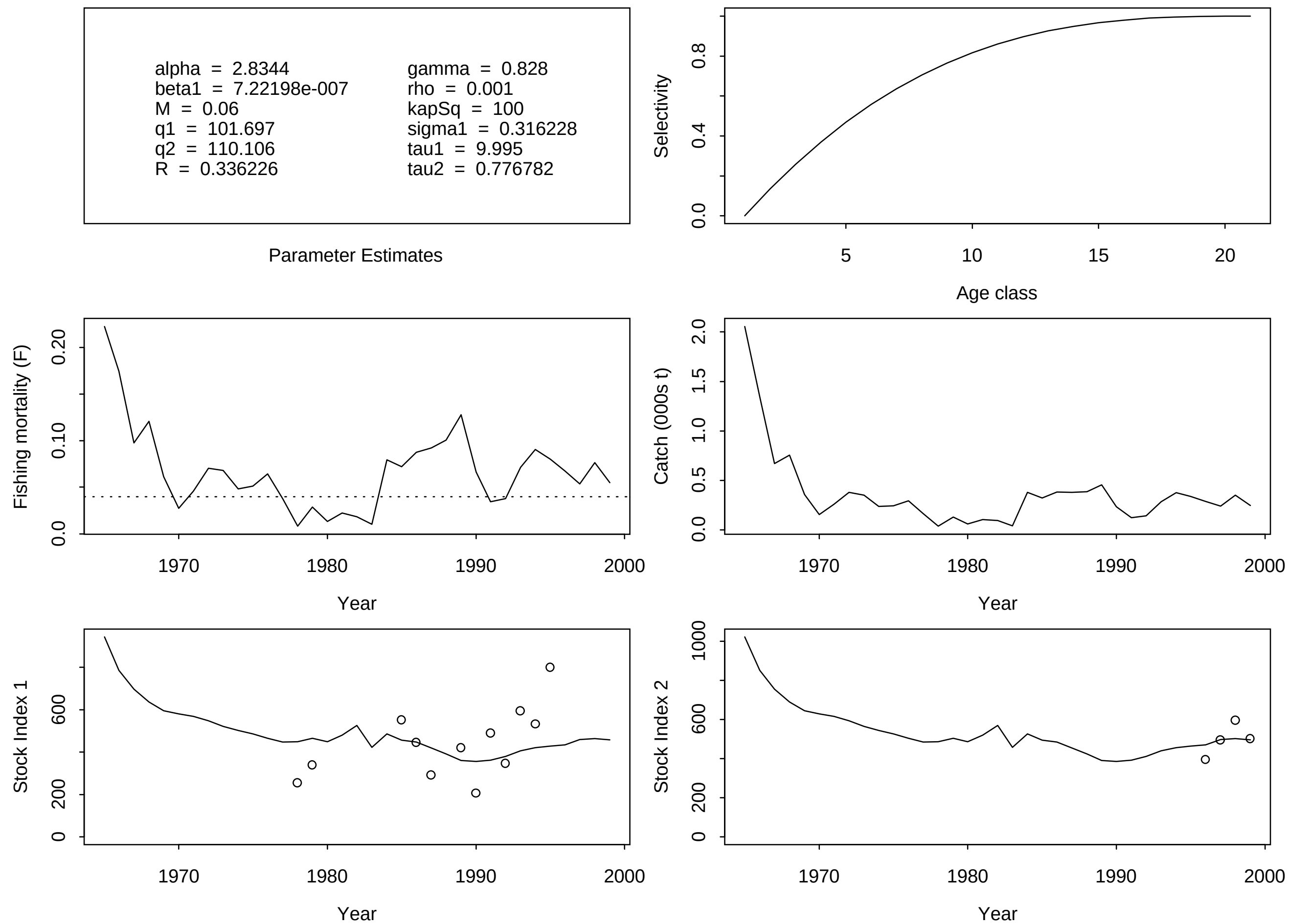

Figure 20a. Summary of input and output from Case 2 run of Area 5E.

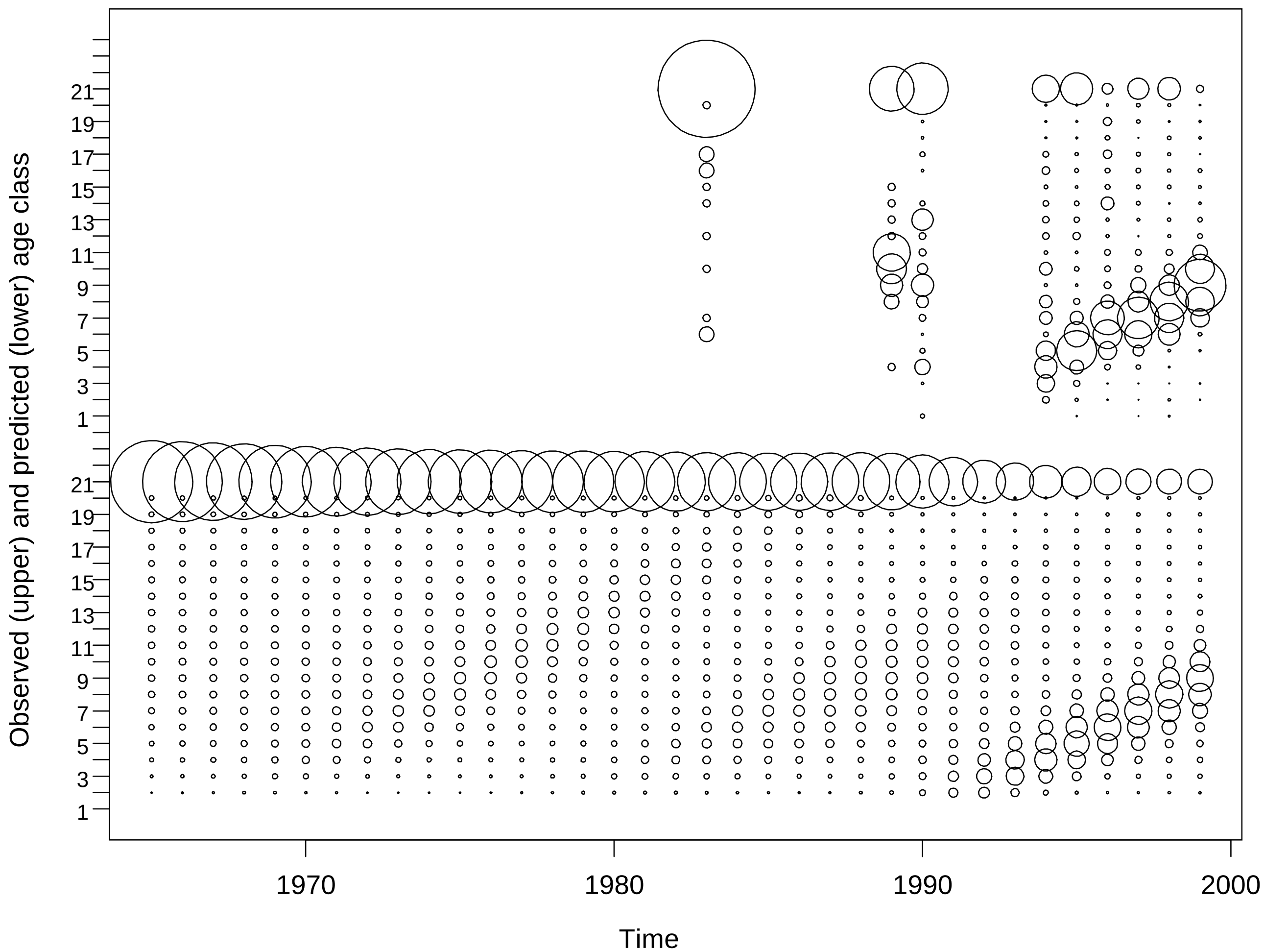

Figure 20b. Comparison of observed and predicted proportions-at-age for Case 2 run for Area 5E.

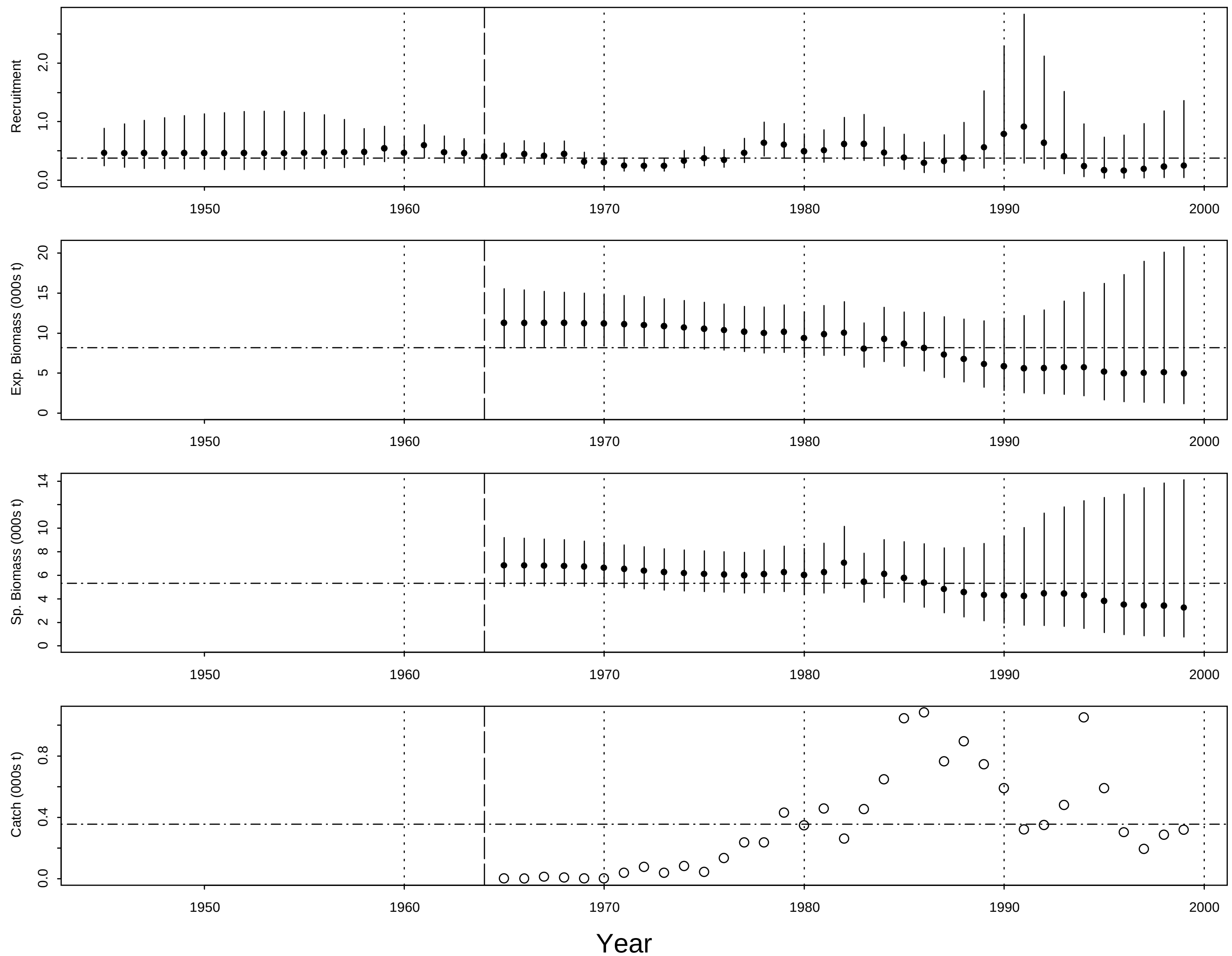

Figure 20c. Population trajectories for Case 2 run Area 5E.

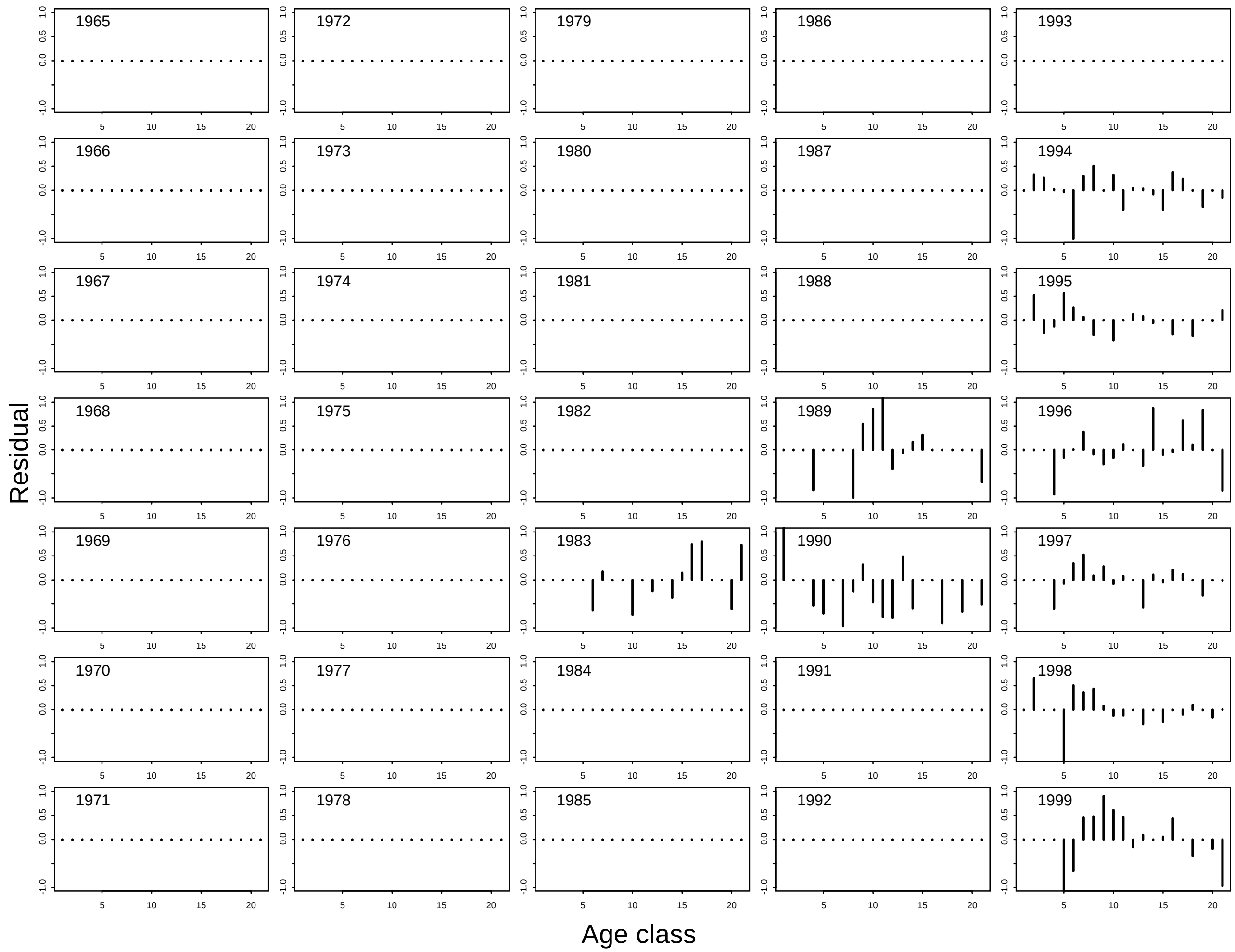

Figure 20d. Proportion-at-age residuals from Case 2 run for Area 5E.

Table 1. Summary of quota recommendations, quotas and total landings of silvergray rockfish (nr=no recommendation, na=not available). Trawl quotas are included for combined areas only (see Appendix Tables A1-A3 for additional details).

Year	3CD			5AB			5CD			5E			Coastwide		
	Rec.	Trawl quota	Total Ldgs.	Rec.	Trawl quota	Total Ldgs.	Rec.	Trawl quota	Total Ldgs.	Rec.	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
1996	150-425		207	350-700		493	125-400		303	nr		288		1,075	1,291
1997	150-425	331	229	350-700	604	495	125-400	302	192	175-300	273	242			1,157
1998	150-425	331	302	350-700	604	496	125-400	302	283	175-300	273	349	138		1,430
1999	150-425	328	328	350-700	599	579	125-400	300	316	175-300	271	248	137		1,472
2000	150-425	301		350-700	549		125-400	275		175-300	248		129		

Table 2. Total landings (t) of silvergray rockfish from B. C. waters.

	3CD					5AB					5CD				5E				B.C.		
Gear:	Trawl	Trawl	Trawl	HL	Total	Trawl	Trawl	Trawl	HL	Total	Trawl	Trawl	HL	Total	Trawl	Trawl	HL	Total	HL	Trawl	Total
Year	Can	U.S.	Other	Can		Can	US	Other			Can	Other	Can		Can	Other	Can				
1965																2,053		2,053		2,053	2,053
1966																1,344		1,344		1,344	1,344
1967		196	139		335	87	397	41		525		13		13		669		669		1,542	1,542
1968		205	62		267	78	933	19		1,030		6		6		755		755		2,059	2,059
1969		334	29		363	78	1,291	0		1,369		0		0		359		359		2,091	2,091
1970	2	371	11		384	14	189	0		203		0		0		157		157		744	744
1971	5	161	20		186	16	521	6		543	34	2		36		258		258		1,023	1,023
1972		442	22		464	54	251	38		343	61	13		74		378		378		1,259	1,259
1973		227	32		259	40	189	82		311	10	27		37		349		349		956	956
1974	1	236	11		248	45	377	205		627	13	68		81		239		239		1,195	1,195
1975	4	113	18		135	31	306	94		431	11	31		42		245		245		853	853
1976	5	326	10		341	172	443	49		664	118	16		134		294		294		1,433	1,433
1977	28	1,035			1,063	198	440	14		652	232	4		236		166		166		2,117	2,117
1978	22	972			994	723	57			780	235			235	36			36		2,045	2,045
1979	22	1,248			1,270	629	298			927	429			429	132			132		2,758	2,758
1980	23	764			787	629	147			776	346			346	59			59		1,968	1,968
1981	15	284			299	415				415	456			456	106			106		1,276	1,276
1982	129	60			189	618				618	259			259	95			95		1,161	1,161
1983	646				646	524				524	451			451	43			43		1,664	1,664
1984	570				570	982				982	647			647	378			378		2,577	2,577
1985	921				921	997				997	1,043			1,043	323			323		3,284	3,284
1986	1,093				1,093	700				700	1,082			1,082	384			384		3,259	3,259
1987	604				604	1,224				1,224	763			763	380			380		2,971	2,971
1988	1,197				1,197	1,051				1,051	893			893	386			386		3,527	3,527
1989	857				857	809				809	743			743	453			453		2,862	2,862
1990	654				654	730				730	587			587	232			232		2,203	2,203
1991	421				421	595				595	320			320	123			123		1,459	1,459
1992	514				514	641				641	347			347	141			141		1,643	1,643
1993	474				474	520				520	478			478	285			285		1,757	1,757
1994	509			48	557	974			2	976	1,046		3	1,049	324		51	375	104	2,853	2,957
1995	426			36	462	866			4	870	567		21	588	221		116	337	177	2,080	2,257
1996	199			8	207	491			2	493	276		27	303	225		63	288	100	1,191	1,291
1997	218			11	229	493			2	495	190		2	192	217		25	242	40	1,117	1,157
1998	301			1	302	480			16	496	271		12	283	326		23	349	52	1,378	1,430
1999	321			7	328	568			11	579	298		18	316	228		20	248	56	1,416	1,472
5-y mean	293			13	306	580			7	587	320		16	336	243		49	293	85	1,436	1,521
10-y mean	505				415	636				640	438			446	232			262		1,710	1,763
20-y mean	505				566	715				725	553			557	246			261		2,082	2,109

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 1996-1999 stored in SQL-Server database, Assessment Methods Section, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station.

4) Foreign fishing pre-1976, see Tables 4 and 5

Biological data used in catch-at-age analysis

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

Table 4. Estimation of silvergray rockfish catches (t) by Soviet and Japanese Vessels from 1967-976 for the INPFC Vancouver Region translated to Area 3CD.

	Soviet			Japanese			Total
Year	Total rockfish[1]	% Silvergray rockfish (1.8%)[2]	75% in Canadian Portion	Non-POP rockfish[3]	% Silvergray rockfish (2.6%)[4]	75% in Canadian Portion	
1967	10,263	185	139	0	0	0	139
1968	4,602	83	62	0	0	0	62
1969	2,143	39	29	0	0	0	29
1970	814	15	11	0	0	0	11
1971	1,145	21	15	272	7	5	21
1972	878	16	12	490	13	10	21
1973	793	14	11	1,069	28	21	32
1974	*	*	*	543	14	11	11
1975	239	4	3	752	20	15	18
1976	313	6	4	308	8	6	10

* not available

[1]Fraidenburg et al. (1977) and Forrester *et al*. (1983)

[2]Based on proportion of silvergray rockfish in Japanese trawl catches of all rockfish in Q. C. Sound 1977 (Ketchen 1980b)

[3]From Forrester *et al.* (1983) (3% from longline)

[4]Based on proportion of silvergray rockfish in Japanese trawl catches of all non-POP rockfish in Q. C. Sound 1977 (Ketchen 1980b)

Table 5. Estimation of silvergray rockfish catches (t) by Soviet and Japanese vessels from 1967-1979 for Area 5AB (including Cape St. James area of 5CD) and 5E

	5AB						5E		
	Soviet				Japanese[3]	Total silvergray rockfish	Soviet	Japanese	Total silvergray rockfish[4]
Year	Total rockfish[1]	%POP[2]	Other rockfish	silvergray rockfish[3] (1.8%)			Total rockfish	Total rockfish	
1965	6,870	0.85	1,031	19		19	24,740	0	2,053
1966	20,910	0.82	3,764	68		68	15,896	300	1,344
1967	13,560	0.79	2,848	51		51	2,847	5,216	669
1968	5,650	0.76	1,356	24		24	1,054	8,042	755
1969	70	0.74	18	0		0	159	4,169	359
1970	0	0.71	0	0		0		1,894	157
1971	120	0.68	38	1	6	7		3,113	258
1972					48	48		4,559	378
1973					102	102		4,208	349
1974					256	256		2,883	239
1975					117	117		2,954	245
1976					61	61		3,538	294
1977					17	17		2,000	166

[1]Fraidenburg et al. (1977) and Forrester et al. (1983)

[2]From Ketchen (1980a) (Table 14)

[3]Based on proportion of silvergray rockfish in Japanese trawl catches in Q. C. Sound 1977 (Ketchen 1980b, Table 2.6)

[4]Based on proportion (8.3%) of silvergray rockfish in Japanese trawl catches in W.C.Q.C.Is. 1977. Total rockfish estimates for 1965-1970 from Westrheim 1980, Table 1.4, silvergray rockfish estimates for 1971-1977, from Ketchen, 1980b, Table 2.5.

Table 6. Landings (t) for silvergray rockfish from U. S. waters.

Year	Washington and Oregon Coast[1,2,3]		Alaska[4]
	Northern Washington	Total Washington	
1967	29	29	
1968	20	62	
1969	6	21	
1970	19	22	
1971	29	51	
1972	5	5	
1973	1	1	
1974	0	0	
1975	22	22	
1976	16	16	
1977	991	1,022	
1978	967	1,011	
1979	1,078	1,115	
1980	na	na	
1981	147	244	
1982	72	74	
1983	456	643	
1984	556	623	
1985	414	565	
1986	398	502	
1987	398	491	
1988	201	316	
1989	234	339	
1990	305	334	277
1991	301	367	377
1992	245	316	611
1993	99	157	590
1994	44	124	1248
1995	72	110	745
1996	127	253	572
1997	65	90	576
1998	112	135	644
1999	28	47	

[1] 1967-1979, Tagart and Kimura 1982

[2] 1980, B. Culver, pers. comm. Washington Department of Fisheries

[3] 1981-1999, PACFIN database

[4] AKFIN database

Table 7. Optimal and marginal depth strata (m) by stock (Note: Area 5CD results used for Area 5E)

Stock	Bi-monthly period	Optimal		Marginal			
		min	max	min1	max1	min2	max2
3CD	Jan-Feb	160	260	120	160	260	300
	March-April	160	260	120	160	260	300
	May-June	140	240	100	140	240	280
	July-August	140	240	100	140	240	280
	September-October	140	240	100	140	240	280
	November-December	140	240	100	140	240	280
5AB	Jan-Feb	160	260	120	160	260	300
	March-April	160	260	120	160	260	300
	May-June	120	220	80	120	220	260
	July-August	100	200	60	100	200	240
	September-October	100	200	60	100	200	240
	November-December	120	220	80	120	220	260
5CD	Jan-Feb	160	260	120	160	260	300
	March-April	180	280	140	180	280	320
	May-June	160	260	120	160	260	300
	July-August	120	220	80	120	220	260
	September-October	120	220	80	120	220	260
	November-December	120	220	80	120	220	260
Overall	Jan-Feb	160	260	120	160	260	300
	March-April	180	280	140	180	280	320
	May-June	120	220	80	120	220	260
	July-August	100	200	60	100	200	240
	September-October	120	220	80	120	220	260
	November-December	120	220	80	120	220	260

Table 8. Number of observations of CPUE by stock and year.

Year	3CD		5AB		5CD		5E	
	Opt.	Marg.	Opt.	Marg.	Opt.	Marg.	Opt.	Marg.
1966	1	0	13	10	0	0	0	0
1967	0	2	23	6	3	2	0	0
1968	0	4	21	17	0	4	0	0
1969	6	5	41	13	0	1	0	0
1970	1	2	4	6	1	2	0	0
1971	1	2	10	6	2	1	0	0
1972	0	0	9	11	3	6	0	0
1973	0	0	8	4	4	4	0	0
1974	0	2	8	5	0	1	0	0
1975	0	3	11	4	3	6	0	0
1976	1	1	50	22	11	36	0	0
1977	11	5	70	20	22	69	4	5
1978	14	9	153	18	28	40	17	21
1979	10	8	155	25	55	76	17	19
1980	5	12	154	35	77	49	1	8
1981	1	6	105	30	57	34	3	6
1982	9	11	133	57	27	38	3	9
1983	43	29	133	32	47	21	5	10
1984	55	14	153	25	55	44	6	12
1985	67	29	123	18	59	36	18	29
1986	145	35	144	15	72	26	26	14
1987	92	16	219	44	67	45	23	11
1988	172	21	205	26	102	71	4	21
1989	126	18	202	25	70	45	23	24
1990	143	20	219	45	83	60	14	22
1991	287	104	689	163	312	215	21	12
1992	937	155	1,233	120	550	241	101	61
1993	1,066	163	1135	94	679	282	110	80
1994	1,146	216	1,078	326	823	342	73	105
1995	941	175	1,507	312	673	396	85	44
1996	1,219	200	2,051	358	962	640	76	122
1997	1,009	227	2,382	327	511	531	98	74
1998	1,245	242	2,327	358	627	638	89	140
1999	1,184	294	2,171	502	841	708	81	108

Table 9. Summary of biomass estimates for silvergray rockfish in surveys conducted by Fisheries and Oceans, Canada (na=not available).

Year	Area	t	CV	Reference	Notes
1979	3C	34	na	Leaman *et al.* (1988)	
1985	3C	197	202%	Leaman *et al.* (1988)	
1978	5E	1,586	162%	Leaman and Nagtegaal (1980)	extrapolated to untrawlable ground
1979	5E	500	57%	Leaman and Nagtegaal (1980)	based only on trawlable ground
1979	5E	500	57%	Leaman and Nagtegaal (1980)	extrapolated to untrawlable ground
1979	5E-N	632	na	Leaman and Nagtegaal (1986)	
1979	5E-N	287	na	Leaman and Nagtegaal (1986)	

Table 10. Silvergray rockfish biomass estimates (t) from the U. S. triennial surveys (1977 and 1986 surveys did not enter Canadian waters).

Year	Eureka	Columbia (Oregon, S. Wash.)	U.S. 3C	**Can. 3CD**	CV %	Total U.S. Area	CV %	Total Survey Estimate	CV %	Northern extent of survey estimate
1977	0	540	14,082			14,622	90			
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			
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'

Table 11. Silvergray rockfish biomass estimates (t) for the Gulf of Alaska.

Year	Biomass estimates			Depth Stratum	CV of stratum estimate
	Entire Gulf of Alaska	Southeastern Alaska only	Southeastern Alaska (dominant depth stratum)		
1993	18,980	17,192	9,831	(100-200 m)	46%
1996	24,128	19,641	16,733	(200-300 m)	36%
1999	37,643	24,441	19,656	(100-200 m)	47%

Table 12. Number of samples (N) and observations (n) of aged silvergray rockfish by stock.

Year	3CD		5AB		5CD		5E		Total	
	N	n	N	n	N	n	N	n	N	n
1977	0	0	2	166	3	259	0	0	5	425
1978	1	99	3	295	3	286	0	0	7	680
1979	0	0	3	268	2	196	0	0	5	464
1980	0	0	2	193	2	200	0	0	4	393
1981	0	0	5	195	1	25	0	0	6	220
1982	1	199	1	25	0	0	1	25	3	249
1983	0	0	0	0	2	50	0	0	2	50
1984	0	199	0	0	0	0	0	0	0	199
1985	15	873	0	0	2	339	0	0	17	1,212
1986	8	623	4	102	2	287	0	0	14	1,012
1987	0	0	0	0	0	0	0	0	0	0
1988	0	0	8	722	5	675	1	0	14	1,397
1989	0	0	0	0	3	75	3	25	6	100
1990	0	0	6	192	10	340	0	77	16	609
1991	2	102	4	220	0	0	0	0	6	322
1992	0	0	3	175	5	297	0	0	8	472
1993	1	48	0	0	7	408	0	0	8	456
1994	0	0	8	443	11	629	3	191	22	1,263
1995	0	0	5	285	6	353	4	269	15	907
1996	0	0	0	0	0	0	3	155	3	155
1997	0	0	5	261	2	100	12	462	19	823
1998	7	349	5	283	4	184	9	505	25	1,321
1999	4	285	4	236	5	268	4	181	17	970

Table 13. Estimate of growth parameters (see Appendix B for explanation of growth model).

Equation	Parameter	Males	Females	Sexes Combined
Length/Weight (ln scale)	α	-2.506	-4.000	-3.634
	β	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
	τ_0	-11.610	-12.362	-10.309
	y_∞	56.462	61.549	58.115
	σ^2	6.0475	8.7500	8.637
	τ_1	15.000	15.000	15.000
	τ_2	60.000	60.000	60.000

Table 14. Proportion mature and fecundity (eggs) at age for silvergray rockfish to age 40 (nd=no data).

	% Mature		Fecundity
Age	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 15. Biomass and quota recommendations for silvergray rockfish from Walters and Bonfil (1999).

Estimate	Method	Year	Region	Min. Biom. (t)	F	B_{1996}/B_0*	Most likely MSY (t)	Min. MSY (t)
Coastwide (Table 2)[1]	absolute est. from CPUE	1994	Coast	13,692	0.16			1,536
Coastwide (Table 2)[1]	absolute est. from CPUE	1995	Coast	9,165	0.18			1,028
Coastwide (Table 2)[1]	absolute est. from CPUE	1996	Coast	6,439	0.17			722
Area (from Table 3)[1]	absolute est. from CPUE	1996	3CD	679				76
Area (from Table 3)[1]	absolute est. from CPUE	1996	5AB	1,540				173
Area (from Table 3)[1]	absolute est. from CPUE	1996	5CD	1,953				219
Area (from Table 3)[1]	absolute est. from CPUE	1996	5E	1,512				170
Area (from Table 3)[1]	absolute est. from CPUE	1996	Coast	5,684				638
Coastwide MSY (Table 7)	CPUE trend	1997	Coast				1,226	949
B_{1996}/B_0[1]	CPUE trend	1996	3CD			0.60		
B_{1996}/B_0[1]	CPUE trend	1996	5AB			0.61		
B_{1996}/B_0[1]	CPUE trend	1996	5CD			0.63		
B_{1996}/B_0[1]	CPUE trend	1996	5E			0.61		

[1]Expanded to regional and coastwide estimates, weighted by biomass estimates

Table 16a. Models runs for Area 3CD (n. c.= no convergence).

3CD	Case 1a				Case 1b				Case 1b*	Case 2	Case 3			
M	fixed	fixed	fixed	free	fixed	fixed	fixed	free	**fixed**	fixed	fixed	fixed	fixed	free
M	0.04	0.06	0.08	0.109	0.04	0.06	0.08	0.077	0.06		0.04	0.06	0.08	0.051
Total -ln L	-40.227	-40.822	-41.430	-42.146	-69.161	-69.632	-69.679	-69.679	**-82.588**	n.c.	-60.124	-60.738	-57.701	-61.208
Recruitment -ln L	-25.253	-26.087	-27.091	-27.841	-54.861	-55.076	-54.913	-54.942	**-70.444**		-122.502	-122.809	-123.001	-122.697
Stock Index -ln L	12.894	12.829	12.568	12.444	12.040	11.956	11.748	11.778	**9.198**		65.629	65.629	65.628	65.629
Age -ln L	-27.868	-27.564	-26.907	-26.749	-26.340	-26.512	-26.513	-26.516	**-21.342**		-3.251	-3.557	-0.329	-4.139
alpha	3.011	2.799	2.594	2.164	2.643	2.533	2.408	2.425	**3.138**		2.931	2.676	2.250	2.811
Beta	3.86E-06	2.76E-06	2.03E-06	1.45E-06	1.20E-02	7.46E-03	3.89E-03	4.31E-03	**2.47E-03**		0.041535	0.036731	0.033833	0.038572
q1	21.961	14.016	5.622	0.011	0.053	0.047	0.042	0.042	**0.024**		43.216	36.475	30.215	39.517
q2	4.555	2.800	1.087	0.002	31.101	27.115	23.627	24.066	**11.472**		22.599	13.870	9.784	16.857
R	0.575	1.118	3.305	2485.530	0.292	0.446	0.691	0.652	**0.546**		0.300	0.490	0.757	0.399
gamma	0.938	0.925	0.922	0.906	0.850	0.885	0.926	0.922	**0.828**		0.01	0.01	0.01	0.01
rho	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	**0.7**		1.00E-05	1.00E-05	1.00E-05	1.00E-05
kapSq	0.454	0.444	0.429	0.420	0.149	0.147	0.146	0.146	**0.083**		1000	1000	1000	1000
sigma1	0.564	0.557	0.548	0.542	0.323	0.321	0.320	0.320	**0.241**		0.1	0.1	0.1	0.1
tau1	0.369	0.365	0.359	0.355	0.212	0.210	0.209	0.209	**0.158**		31.623	31.623	31.623	31.623
tau2	0.475	0.476	0.479	0.480	0.481	0.481	0.481	0.481	**0.503**		0.589	0.588	0.605	0.585
F_{1999}	0.024	0.015	0.006	0.000	0.186	0.162	0.141	0.144	0.070		0.133	0.080	0.057	0.098
B_{1999} (000 t)	13.96	22.26	56.18	26706.40	1.93	2.20	2.49	2.45	5.191		2.63	4.25	5.95	3.52
Rel. Error B_{1999}	14%	11%	10%	0%	65%	58%	52%	70%	27%		49%	31%	24%	39%
S_{1999} (000 t)	12.85	21.32	56.25	30275.40	1.83	2.19	2.62	2.56	4.31		2.08	3.44	5.14	2.80
$Landings_{1999}$ (000 t)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33		0.33	0.33	0.33	0.33
B_{1980} (000 t)	8.11	11.84	27.11	14326.00	6.26	7.03	8.05	7.90	7.72		7.32	7.23	7.58	7.21
S_{1980} (000 t)	5.46	8.24	19.67	11428.10	4.05	4.66	5.47	5.35	5.19		4.47	4.93	5.90	4.67
S_{1999}/S_{1980}	2.36	2.59	2.86	2.65	0.45	0.47	0.48	0.48	0.84		0.47	0.70	0.87	0.60
Quota (F=M)	547	1,296	4,319	2,768,781	76	128	192	183	296		103	248	457	175
Quota (F=0.75M)	413	979	3,271	2,104,732	57	97	145	138	228		78	187	346	132
Quota (F=0.5M)	276	658	2,203	1,422,262	38	65	98	93	153		52	126	233	89

Table 16b. Summary of model biomass estimates and quota recommendations for Area 3CD (M=0.06) and comparable Walters and Bonfil (1999) estimates (B_{1996} , min MSY) (n.c.=no convergence. Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery).

Statistic	Status quo	Case 1a CPUE only	Case 1b Triennial Survey	**Case 1b* Triennial Survey (excl. 1980 estimate)**	Case 2 No index, Variable recruitmen t	Case 3 No index, Constant recruitmen t	Walters and Bonfil
20-y mean harvest (t)	566						
2000/2001 rec. (t)	150-425						
2000/2001 Trawl Quota	301						
B_{1980} (t)		11,840	7,030	**7620**	n.c.	7,230	
B_{1999} (t)		22,260	2,200	**5,190**		4,250	679
St. Dev. (B_{1999})		11%	58%	**26%**		31%	
SpB_{1999}/SpB_{1980}		2.59	0.47	**0.84**		0.70	
F_{1999}		0.015	0.162	**0.070**		0.080	
2001/2002 Options (t)							76
F=0.5M		658	65	**152**		126	
F=0.75M		979	97	**228**		187	
F=M		1,296	128	**296**		248	

Table 17a. Models runs for Area 5AB

5AB	Case 1a				Case 2				Case 3			
M	Fixed	fixed	fixed	free	Fixed	**fixed**	fixed	free	fixed	fixed	fixed	free
M	0.040	0.060	0.080	0.027	0.040	**0.060**	0.080	0.038	0.040	0.060	0.080	0.040
Total -ln L	-31.775	-30.734	-28.599	-31.989	60.934	**61.517**	-56.179	28.703	-5.825	-3.730	-96.553	-5.825
Recruitment -ln L	-72.131	-72.519	-71.609	-71.513	-58.520	**-58.087**	-53.875	-58.526	-123.031	-123.110	-118.886	-123.032
Stock Index -ln L	-16.338	-15.762	-15.435	-16.864	66.779	**66.777**	66.798	34.555	51.810	51.811	51.811	51.810
Age -ln L	56.694	57.547	58.445	56.388	52.676	**52.827**	-69.102	52.673	65.395	67.570	-29.477	65.397
alpha	5.956	5.754	5.284	5.872	4.276	**4.044**	3.397	4.292	4.342	4.514	2.709	4.341
Beta	4.48E-10	4.13E-10	3.63E-10	4.52E-10	3.43E-10	**3.12E-10**	0.0834	3.46E-10	4.37E-10	4.20E-10	0.08443	4.36E-10
q1	1.32E+01	9.488	5.961	15.927	19.021	**14.002**	17.299	4.157	3.885	2.948	2.528	3.878
q2	4.780	3.414	2.094	5.769	12.793	**7.288**	24.917	13.549	11.061	5.060	3.604	10.950
R	0.512	0.913	1.840	0.341	0.385	**0.705**	0.635	0.366	0.402	0.764	1.297	0.405
gamma	0.894	0.804	0.850	0.952	0.761	**0.863**	0.960	0.757	0.01	0.01	0.01	0.01
rho	0.7	0.7	0.7	0.7	0.001	**0.001**	0.001	0.001	1.00E-05	1.00E-05	1.00E-05	1.00E-05
kapSq	0.082	0.083	0.085	0.082	100	**100**	100	100	1000	1000	1000	1000
sigma1	0.240	0.241	0.245	0.239	0.316	**0.316**	0.316	0.316	0.1	0.1	0.1	0.1
tau1	0.157	0.158	0.160	0.157	9.995	**9.995**	9.995	9.995	31.623	31.623	31.623	31.623
tau2	0.780	0.783	0.786	0.779	0.767	**0.767**	0.446	0.767	0.811	0.819	0.532	0.811
F_{1999}	0.054	0.039	0.024	0.064	0.153	**0.083**	0.375	0.163	0.131	0.058	0.041	0.130
B_{1999} (000 t)	11.093	15.303	24.720	9.324	4.083	**7.246**	1.854	3.846	4.713	10.270	14.366	4.762
St. Dev B_{1999}	12%	9%	7%	14%	46%	**36%**	117%	56%	30%	16%	11%	33%
S_{1999} (000 t)	6.695	9.373	15.719	5.656	2.843	**5.130**	1.350	2.678	3.189	6.665	10.380	3.220
$Landings_{1999}$ (000 t)	0.579	0.579	0.579	0.579	0.579	**0.579**	0.579	0.579	0.579	0.579	0.579	0.579
B_{1980} (000 t)	12.964	17.768	27.927	10.784	10.004	**12.884**	11.968	9.825	10.752	13.947	16.291	10.768
S_{1980} (000 t)	7.654	10.707	17.364	6.337	5.986	**7.894**	7.440	5.864	6.259	8.542	11.334	6.274
S_{1999}/S_{1980}	0.875	0.875	0.905	0.892	0.475	**0.650**	0.182	0.457	0.509	0.780	0.916	0.513
Quota (F=M)	435	891	1,901	247	160	**422**	143	144	185	598	1,104	188
Quota (F=0.75M)	328	673	1,440	186	121	**319**	108	108	139	452	837	142
Quota (F=0.5M)	220	452	969	124	81	**214**	73	73	93	304	563	95

Table 17b. Summary of model biomass estimates and quota recommendations for Area 5AB (M=0.06) and comparable Walters and Bonfil (1999) estimates (B_{1996}, min MSY) (Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery).

Statistic	Status quo	Case 1 CPUE only	**Case 2 No index, Variable recruitment**	Case 3 No index, Constant recruitment	Walters and Bonfil
20-y mean harvest (t)	725				
2000/2001 rec. (t)	350-700				
2000/2001 Trawl Quota	549				
B_{1980} (t)		17,768	**1,2884**	13,947	
B_{1999} (t)		15,303	**7,246**	10,270	1,540
St. Dev. (B_{1999})		9%	**36%**	16%	
SpB_{1999}/SpB_{1980}		0.875	**0.083**	0.780	
F_{1999}		0.039	**0.083**	0.058	
2001/2002 Options (t)					173
F=0.5M		452	**214**	304	
F=0.75M		673	**319**	452	
F=M		891	**422**	598	

Table 18a Models runs for Area 5CD

5CD	Case 1				Case 2				Case 3			
M	fixed	fixed	fixed	free	fixed	fixed	fixed	Free	fixed	fixed	fixed	free
M	0.040	0.060	0.080	0.013	0.040	**0.060**	0.080	0.044	0.040	0.060	0.080	0.060
Total -ln L	-108.610	-107.530	-105.863	-109.482	-89.354	**-88.871**	-87.496	-89.383	-65.639	-73.705	-69.381	-73.706
Recruitment -ln L	-26.129	-26.495	-26.052	-25.069	-51.212	**-51.781**	-50.132	-51.422	-114.746	-115.329	-115.947	-115.334
Stock Index -ln L	9.574	9.782	10.285	9.024	55.318	**55.316**	55.332	55.318	82.901	82.900	82.899	82.900
Age -ln L	-92.055	-90.817	-90.095	-93.437	-93.460	**-92.407**	-92.696	-93.278	-33.793	-41.276	-36.334	-41.271
alpha	2.765	2.606	2.387	2.978	3.084	**2.834**	2.923	3.030	3.247	2.676	2.085	2.670
Beta	5.10E-07	4.46E-07	3.93E-07	6.15E-07	9.67E-07	**7.22E-07**	8.31E-07	9.03E-07	2.09E-06	1.48E-06	1.31E-06	1.48E-06
q1	11.625	3.756	0.006	22.577	39.645	**30.536**	31.151	37.748	34.829	31.515	28.274	31.479
q2	2.036	0.678	0.001	3.819	21.209	**13.682**	21.725	19.332	22.723	15.476	11.498	15.422
R	0.676	2.876	2327.000	0.176	0.212	**0.397**	0.458	0.243	0.254	0.438	0.718	0.440
gamma	0.901	0.849	0.798	0.958	0.861	**0.829**	0.954	0.845	0.01	0.01	0.01	0.01
rho	0.7	0.7	0.7	0.7	0.001	**0.001**	0.001	0.001	1.00E-05	1.00E-05	1.00E-05	1.00E-05
kapSq	0.437	0.437	0.449	0.438	100	**100**	100	100	1000	1000	1000	1000
sigma1	0.553	0.553	0.561	0.554	0.316	**0.316**	0.316	0.316	0.100	0.100	0.100	0.100
tau1	0.362	0.362	0.367	0.362	9.995	**9.995**	9.995	9.995	31.623	31.623	31.623	31.623
tau2	0.420	0.422	0.423	0.417	0.417	**0.419**	0.419	0.418	0.530	0.514	0.524	0.514
F_{1999}	0.009	0.003	0.000	0.017	0.104	**0.066**	0.113	0.095	0.109	0.073	0.054	0.072
B_{1999} (000 t)	34.859	102.252	52722.300	19.192	3.190	**4.928**	2.946	3.501	3.053	4.515	6.062	4.531
St. Dev B_{1999}	6%	7%	0%	9%	59%	**42%**	92%	59%	40%	27%	21%	28%
S_{1999} (000 t)	22.357	67.106	36100.900	12.001	2.032	**3.245**	1.917	2.248	2.169	3.478	5.252	3.494
$Landings_{1999}$ (000 t)	0.316	0.316	0.316	0.316	0.316	**0.316**	0.316	0.316	0.316	0.316	0.316	0.316
B_{1980} (000 t)	16.311	49.342	29653.400	8.661	7.528	**9.368**	10.454	7.839	9.225	9.459	9.847	9.463
S_{1980} (000 t)	10.818	33.672	21043.200	5.563	4.695	**6.002**	6.674	4.915	5.340	6.061	7.257	6.070
S_{1999}/S_{1980}	2.067	1.993	1.716	2.157	0.433	**0.541**	0.287	0.457	0.406	0.574	0.724	0.576
Quota (F=M)	1,380	5,955	4,053,483	239	125	**287**	227	151	120	263	466	265
Quota (F=0.75M)	1,030	4,499	3,070,308	180	94	**217**	172	114	90	199	353	200
Quota (F=0.5M)	690	3,014	2,057,106	120	63	**145**	115	76	60	133	236	134

Table 18b. Summary of model biomass estimates and quota recommendations for Area 5CD (M=0.06) and comparable Walters and Bonfil (1999) estimates (B_{1996}, min MSY) (Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery).

Statistic	Status Quo	Case 1a CPUE only	**Case 2 No index, Variable recruitment**	Case 3 No index, Constant recruitment	Walters and Bonfil
20-y mean harvest (t)	557				
2000/2001 rec. (t)	125-400				
2000/2001 Trawl Quota	275				
B_{1980} (t)		49,342	**9,374**	9,459	
B_{1999} (t)		102,252	**4,936**	4,515	1,953
St. Dev. (B_{1999})		7%	**42%**	27%	
SpB_{1999}/SpB_{1980}		1.993	**0.541**	0.574	
F_{1999}		0.003	**0.066**	0.073	
2001/2002 Options (t)					219
F=0.5M		3,014	**146**	133	
F=0.75M		4,499	**217**	199	
F=M		5,955	**287**	263	

Table 19a. Models runs for Area 5E (Note that alpha and Beta fixed for all runs, gamma fixed for C2:M=0.06 runs)

5E	Case 1a				Case 2				Case 3			
M	Fixed	Fixed	Fixed	Free	Fixed	**Fixed**	Fixed	Free	Fixed	Fixed	Fixed	Free
M	0.04	0.06	0.08	0.018	0.04	**0.06**	0.08	0.024	0.04	0.06	0.08	0.0269
Total -ln L	-48.552	-47.161	-45.531	-49.398	9.909	**10.678**	11.173	9.517	-13.345	-16.855	-16.000	-20.356
Recruitment -ln L	-77.044	-76.176	-75.114	-77.232	-55.018	**-54.863**	-54.842	-55.061	-119.325	-123.274	-123.308	-123.367
Stock Index -ln L	-6.435	-5.937	-5.423	-7.075	36.845	**36.842**	36.841	36.848	55.332	55.263	55.263	55.264
Age -ln L	34.928	34.952	35.006	34.909	28.082	**28.699**	29.174	27.730	50.647	51.156	52.045	47.747
alpha	2.834	2.834	2.834	2.834	2.834	**2.834**	2.834	2.834	2.834	2.834	2.834	2.834
Beta	7.22E-07	7.22E-07	7.22E-07	7.22E-07	7.22E-07	**7.22E-07**	7.22E-07	7.22E-07	7.22E-07	7.22E-07	7.22E-07	7.22E-07
q1	98.58	69.22	39.35	128.99	159.33	**101.70**	48.68	201.01	10.43	141.36	88.65	230.19
q2	68.00	49.78	29.42	84.61	210.58	**110.11**	47.52	321.12	12.41	180.35	104.70	573.11
R	0.29	0.48	0.93	0.16	0.18	**0.34**	0.75	0.11	0.19	0.29	0.49	0.12
gamma	0.954	0.937	0.925	0.978	0.839	**0.828**	0.872	0.819	0.01	0.01	0.01	0.01
rho	0.7000	0.7000	0.7000	0.7000	0.0010	**0.001**	0.001	0.001	1.00E-05	1.00E-05	1.00E-05	1.00E-05
kapSq	0.057	0.059	0.062	0.055	100	**100**	100	100	1000	1000	1000	1000
sigma1	0.199	0.204	0.209	0.196	0.316	**0.316**	0.316	0.316	0.1	0.1	0.1	0.1
tau1	0.130	0.133	0.137	0.128	9.995	**9.995**	9.995	9.995	31.623	31.623	31.623	31.623
tau2	0.820	0.820	0.820	0.820	0.773	**0.777**	0.780	0.770	1.052	0.943	0.950	0.915
F_{1999}	0.032	0.023	0.014	0.038	0.109	**0.055**	0.024	0.175	0.148	0.093	0.053	0.358
B_{1999} (000 t)	7.995	10.688	17.711	6.589	2.401	**4.629**	10.655	1.547	1.802	2.792	4.777	0.823
St. Dev B_{1999}	17%	15%	12%	20%	86%	**50%**	44%	134%	72%	45%	28%	184%
S_{1999} (000 t)	5.780	7.766	12.942	4.743	1.712	**3.269**	7.463	1.110	1.412	2.176	3.655	0.722
$Landings_{1999}$ (000 t)	0.248	0.248	0.248	0.248	0.248	**0.248**	0.248	0.248	0.248	0.248	0.248	0.248
B_{1980} (000 t)	3.346	4.758	8.348	2.557	3.191	**4.449**	8.531	2.713	2.470	2.878	4.340	2.503
S_{1980} (000 t)	2.403	3.496	6.266	1.784	2.059	**2.964**	5.764	1.705	1.796	2.252	3.464	1.629
S_{1999}/S_{1980}	2.406	2.222	2.065	2.659	0.831	**1.103**	1.295	0.651	0.786	0.966	1.055	0.443
Quota (F=M)	313	622	1,362	117	94	**270**	819	36	71	163	367	22
Quota (F=0.75M)	236	470	1,031	88	71	**204**	621	27	53	123	278	16
Quota (F=0.5M)	158	316	694	59	48	**137**	418	18	36	83	187	11

Table 19b. Summary of model biomass estimates and quota recommendations for Area 5E (M=0.06) and comparable Walters and Bonfil (1999) estimates (B_{1996}, min MSY) (Note that the trawl quota excludes 129 t coastwide quota for hook-and-line fishery).

Statistic	Status Quo	Case 1a CPUE only	Case 2 No index, Variable recruitment	Case 3 No index, Constant recruitment	Walters and Bonfil
20-y mean harvest (t)	261				
2000/2001rec. (t)	175-300				
2000/2001 Trawl Quota (t)	248				
B_{1980} (t)		10,688	**4,449**	2,878	
B_{1999} (t)		4,758	**4,629**	2,792	1,512
St. Dev. (B_{1999})		15%	**50%**	45%	
SpB_{1999}/SpB_{1980}		2.222	**1.103**	0.966	
F_{1999}		0.023	**0.055**	0.093	
2001/2002 Options					170
F=0.5M		316	**137**	83	
F=0.75M		470	**204**	123	
F=M		622	**270**	163	

Table 20. Summary of silvergray rockfish quota recommendations.

Stock	Previous rec.	B_{1999}	Target reference		
			F=0.50*M	F=0.75*M	F=1.00*M
3CD	150-425	5,190	152	228	302
5AB	350-700	7,246	214	319	422
5CD	125-400	4,936	145	217	287
5E	175-300	4,629	137	204	270
Total	800-1825	22,001	648	968	1,281

16 Appendix A. Summary of previous DFO assessments by stock

Areas 3CD Harvest Recommendations

Ketchen (1980) suggested a 1979 Total Allowable Catch (TAC) of 100 t and 150 t for Areas 3C and 3D respectively. The authors emphasized the lack of knowledge about the fishery but expressed concern over the reported low growth rate. The 3D TAC for was raised for 1980 to 200 t owing to biomass estimates derived from the 1978 biomass survey (Westrheim 1980).

Advice was modified in 1985 to include high (non-sustainable) and low (conservative) harvest recommendations (Leaman and Stanley 1985). Recommended yields were a non-directed fishery to 200 t for Area 3C and 150-700 t for Area 3D. The large ranges were intended to communicate the lack of knowledge about stock status and introduce the concept of risk. The 3D range was changed to 250-350 t for 1988 based on the large proportion of smaller fish in the samples collected during 1985 and 1986 charters and commercial samples (Stanley 1988). The harvest range was combined for 3C and 3D for 1989. Stanley (1989) recommended a range of 400-600 t although the estimates of instantaneous total mortality (Z) from the 1985 and 1986 charters were noted as a source of concern. For 1990-1993, recommendations were lowered to 400-600 t, in response to continued decline in CPUE and high inferred high values of F from length frequency analysis (Stanley 1991). The range was further lowered to 150-425 t for 1993-2000 owing to an indication of truncation in the age composition (high F implied from catch curve analysis) (Stanley 1993).

Areas 5AB harvest recommendations

In the initial harvest recommendation for Areas 5AB, the authors noted the inverse relationship between landings and CPUE in the U.S. targeted fishery (Ketchen 1980). They suggested that the stock may be at maximal exploitation and recommended a TAC of 600 t, equal to historical annual yield. This was converted to harvest range of 400-1,200 t for 1985 (Leaman and Stanley 1985), narrowed to 700-1,000 t for 1988 (Stanley 1988) and further compressed to 700-850 for 1990, owing to length based catch-curve analysis (Stanley 1990). Concern over the high implied estimates of F from age based catch curve analysis led to a lowering of the “conservative” yield to 200 t for a recommended range of 200-700 t for 1990-1992 (Stanley 1991). This range was increased slightly to 375-725 for 1993-1995 owing to continued stability in CPUE in spite of high estimates of F. The range was modified slightly for 1996 to 2000 to 350-700 t in accordance with a change in historical mean yield.

Areas 5CD harvest recommendations

The first quota recommendation for silvergray rockfish in Areas 5CD was provided in 1979 (Ketchen 1980). The fishery had previously been incidental and limited to the central and northern half of Hecate Strait. Landings increased in the late 1970’s from southern Hecate Strait, in association with the development of the POP fishery near Cape St. James. In anticipation of sustained higher landings of silvergray rockfish, the authors recommended a TAC of 300 t, in excess of the early landings, to allow development of the fishery. For 1981, the combined quota was split into TACs of 300 and 200 t for Areas 5C and 5D respectively. The 5C recommendation was further increased to 400 t for 1982 (Stocker 1982). For 1985, harvest recommendations were expressed as a range of 300-900 t (Leaman and Stanley 1985), raised to 400-1,000 for 1988

(Stanley 1988), and lowered slightly to 500-800 for 1989 (Stanley 1989). Yields were lowered again to 400-600 t for 1990-1992 (Stanley 1990), owing to declining CPUE. It was lowered to 150-425 for 1993-1995 in response to high implicit estimates of F from age based catch curve analysis, and modified slightly to 125-400 t for 1996-1999.

Area 5E harvest recommendations

For the 1979 assessment, the authors commented that there was a suspected significant bycatch of silvergray rockfish of 170-350 t/yr by the Japanese fishery in Area 5E in the 1970's (Ketchen 1980). They suggested that this annual harvest may be sustainable and recommended a provisional TAC of 350 t. The fishery was assumed to be incidental to the deeper water POP fishery.

The recommendations were split between 5E-N and 5E-S for the 1980 recommendations. Since the Japanese fishery was thought to have taken most of the bycatch from 5E-N, it was suggested that the southern area might sustain a similar yield for a TAC of 350 t. Concerns over possible over-exploitation of all rockfish in 5E-N, led authors to propose an "all-rockfish" quota of 400 t for 1980 (Westrheim 1980). For the 1982 fishery, the recommended quotas for silvergray rockfish were 100 and 350 t for 5E-N and 5E-S respectively (Stocker 1982). In response to declines in nominal and qualified CPUE, the recommended range for 5E-S was lowered to 100-250 (Stanley 1988). The yield recommendation for 5E-N was 100-150 t.

There were no yield recommendations for 1989. Stanley (1989) commented that the silvergray rockfish continued to be incidental to the POP fishery. Quota or trip limit restrictions would only lead to discarding and fail to provide meaningful information about the fishery. For 1990, Stanley (1990) re-emphasized the impact of restrictive quotas within an incidental fishery but recommended a maximal ceiling of 500 t for 5E-S. An open fishery was recommended for 5E-N to accommodate the continued experimental fishery for POP (Leaman and Stanley 1993). No recommendations were provided for 1991-1996.

Yield recommendations for silvergray rockfish in 5E were proposed for 1997-2000 based on 75% and 125% of the historical mean yield for a proposed range of 175-300 t, applied to south and north areas combined.

17 Appendix Tables A1-A3

Appendix Table A1. History of stock specific assessment recommendations for silvergray rockfish in B. C. waters (nr = no recommendations; na = recommendations not available)

Year	3C	3D	3CD	5AB	5C	5D	5CD	5E-S	5E-N	5E
1978	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr
1979	100	150	250	600	nr	nr	300	nr	nr	350
1980	100	200	300	600	nr	nr	300	350	400	
1981	100	200	300	600	300	200	500	350	400	
1982	nr	200	200	600	400	200	600	350	100	450
1983	na	na	na	na	na	na	na	na	na	na
1984	na	na	na	na			300-1000	350	100	450
1985	nd-200	150-700	150-900	400-1200			300-1000	350	100	450
1986	nd-200	150-700	150-900	400-1100			300-900	350	100	450
1987	nd-200	150-700	150-900	400-1100			300-900	nr	nr	
1988	25-200	250-350	275-550	700-1000			400-1000	100-250	100-150	
1989			400-600	700-1000			500-800	nd	nd	
1990			400-600	700-850			400-600	500	open	
1991			400-600	200-700			400-600	nr	nr	
1992			400-600	200-700			400-600	nr	nr	
1993			150-425	375-725			150-425	nr	nr	
1994			150-425	375-725			150-425	nr	nr	
1995			150-425	375-725			150-425	nr	nr	
1996			150-425	350-700			125-400	nr	nr	
1997			150-425	350-700			125-400			175-300
1998			150-425	350-700			125-400			175-300
1999			150-425	350-700			125-400			175-300
2000			150-425	350-700			125-400			175-300

Appendix Table A2 History of management regulations pertaining to trawling for silvergray rockfish (cs: aggregate of canary and silvergray rockfish; csy: aggregate of canary, silvergray and yellowtail rockfish, n.d.=non directed fishery

Year	Coastwide	3C	3D	5A+5B	5C	5D	5E-S	5E-N	Comments
1982				600					For 5A+5B, incidental limit equals 2 t when quota reached.
1983		n.d.	600-csy	1,100-cs	300				
1984		200-csy	1,000-csy	1,100-cs	600		950-csy		
1985		300-csy	1,000-csy	1,100-cs	600		950-csy		
1986	4,100-cs							Open	200,000 lb limit decreasing to 40,000 lb. limit
1987		250-cs	800-cs	1,100-cs	600		750-cs	Open	Quarterly trip limits but area/specific management Trip limits decreasing from 150,000 to 75,000 to 5,000 lb as quota filled
1988		300-cs	800-cs	1,100-cs	600		750-cs	Open	Quarterly trip limits decreasing from 50,000 to 20,000 lb
1989	2125	500		850	650		650	**Open**	2 trips per month, decreasing from 50,000 to 20,000 Coastwide management but with attention to area quotas
1990	1900						250	Open	Introduction of trip options: A (2 trips/month) and B (3 trips/month) Trip limits 25,000 to 20,000 lb
1991	1575						125	Closed	Trip limits 11,000 to 4,400
1992	1575						125	Closed	No trip options and trip limits 10,000 to 2,200
1993	2105-cs (1275-s)							Closed	Dockside monitoring Limited trips/month and trip limit aggregates with silvergray rockfish
1994	12,574							Closed	6 species in aggregate, A, B or C options, trip averaging and relinquishments
1995	9,716 (1446-s)								New aggregate and early closure of the fishery
1996	1,813-cs (1075-s)								New aggregate and halibut bycatch caps, new option A, B and C At-sea observer coverage for A options.
1997-98	1510	331		604	302		273		No aggregates and new fishing year and IVQ's
1998-99	1510	331		604	302		273		
1999-00	1498	328		599	300		271		
2000-01	1509	331		604	302		273		

Appendix Table A3. History of hook-and-line management of silvergray rockfish

Year	Coastwide limit (aggregate limit)	Comments
1994		• No mention of silvergray rockfish limits but retention permitted as part of ZN license
1995	8,925 t	• Introduction of dockside monitoring • Part of aggregate #3 with canary, yellowtail and widow rockfish • Trip limits of 4,000–10,000 lbs depending on fishing option. Catches not to exceed catch of aggregate #1 (quillback and copper rockfish).
1996	738 t (1,813 t)	• Aggregate #3 with canary rockfish. • Trip limits 3,000-7,000
1997	906 t (2,417 t)	• Aggregate #3 with canary rockfish • Trip limits 2,000-5,000
1998/1999	74 t (212 t)	• Implementation of the Halvorson report. H&L receives 8% of all rockfish • Aggregate #3 with canary rockfish • Trip limit 2,500-7,000
1999/2000	76 t (213 t)	• Aggregate #3 with canary rockfish • Trip limit 1,800-7,000

18 Appendix B. Growth Model

This appendix describes the growth model (Schnute 1981) used to compare growth curves among areas. The model involves six parameters $\Theta = (\tau_1, \tau_2, y_1, y_2, a, b)$, where τ_1 and τ_2 are two arbitrary ages in the life a fish, such that $\tau_2 > \tau_1$. The parameter y_1 is the size of a fish at time τ_1 and y_2 is the size of a fish at time τ_2 with $y_2 > y_1 > 0$. Parameters *a* and *b*, determine the shape of the growth curve by controlling the acceleration (deceleration) in growth from times τ_1 to τ_2. The parameter *a* has units (time^{-1}), while *b* is dimensionless. Although mathematical expression of the model has four cases, these four cases actually represent the limiting forms of a single equation as *a* and/or *b* approach 0. Let $Y(t)$ be the size at time *t*, then:

Case 1: $a \neq 0, b \neq 0$

(1) $$Y(t) = \left[y_1^b + \left(y_2^b - y_1^b \right) \frac{1 - e^{-a(t-\tau_1)}}{1 - e^{-a(\tau_2-\tau_1)}} \right]^{1/b} ,$$

Case 2: $a \neq 0, b = 0$

(2) $$Y(t) = y_1 \exp\left[\ln\left(y_2 / y_1 \right) \frac{1 - e^{-a(t-\tau_1)}}{1 - e^{-a(\tau_2-\tau_1)}} \right] ,$$

Case 3: $a = 0, b \neq 0$

(3) $$Y(t) = \left[y_1^b + \left(y_2^b - y_1^b \right) \frac{t - \tau_1}{\tau_2 - \tau_1} \right]^{1/b} ,$$

Case 4: $a = 0, b = 0$

(4) $$Y(t) = y_1 \exp\left[\ln\left(y_2 / y_1 \right) \frac{t - \tau_1}{\tau_2 - \tau_1} \right] .$$

Suppose that the age and size of a sample of fish are measured to give *n* data points (t_j, Y_j), $j = 1, 2, \ldots, n$. If the ages are determined exactly, then additive or multiplicative errors may be specified

(5) $$\hat{Y}_j = Y_j + \sigma\varepsilon_j; \quad j = 1, \ldots, n ,$$

(6) $$\hat{Y}_j = Y_j e^{\sigma\varepsilon_j}; \quad j = 1, \ldots, n ,$$

where the random variables $\varepsilon_j\left(j=1,\ldots,n\right)$ are assumed to be normally distributed with mean 0 and variance σ^2.

There are compelling reasons to adopt this formulation of growth. The parameters $\mathbf{\Phi}=\left(\tau_1,\tau_2,y_1,y_2,a,b\right)$ always exist even in cases where, for example, the most appropriate model does not include a maximum growth asymptote. Model parameters are expressed as quantities that have direct biological interpretation, and the parameterization has superior statistical properties (Ratkowsky 1986). In any case, Schnute (1981) provided transition equations to convert the parameter set $\mathbf{\Phi}$ to those used in the various specialized growth forms.

We used likelihood ratio tests to compare growth among groups. Suppose size-at-age data are collected for i=1,…,m groups of data. Given that an appropriate growth formulation has been selected, there are four possible situations defined by equal or unequal variances σ^2 and independent or common parameter sets Φ (Quinn and Deriso 1999). The full model is defined by independent parameter sets and unequal variances, all other situations are obtained by reduction in the number of parameters. For example, a reduced model can be specified by assuming a common parameter set and equal variances among groups, i.e., fitting the growth model to the pooled data. Under the assumption of independent, additive normal errors, the likelihood of the data given the parameters for group i is specified by

(7)
$$\mathcal{L}_i\left(\Phi_i,\sigma_i\mid\left\{Y_{ij}\right\}\right)=\left(2\pi\sigma_i^2\right)^{-n_i/2}\exp\left[-\frac{1}{2\sigma_i^2}\sum_{j=1}^{n_i}\left(Y_{ij}-\widehat{Y_{ij}}\right)^2\right] \quad .$$

In practice, parameter estimates $\left(\hat{\Phi}_i,\hat{\sigma}_i^2\right)$ are determined by minimizing the (negative) of the logarithm of the likelihood function, calculated by summation of the log-likelihood components over the m groups:

(8)
$$\ln\mathcal{L}_F=\sum_{i=1}^{m}\ln\mathcal{L}_i\left(\hat{\Phi}_i,\hat{\sigma}_i\mid\left\{Y_{ij}\right\}\right)=\sum_{i=1}^{m}\left[-\frac{n_i}{2}\log\left(2\pi\hat{\sigma}_i^2\right)-\frac{1}{2\hat{\sigma}_i^2}\sum_{j=1}^{n_i}\left(Y_{ij}-\widehat{Y_{ij}}\right)^2\right] \quad ,$$

where

(9)
$$\hat{\sigma}_i^2=\frac{1}{n_i}\sum_{j=1}^{n_i}\left(Y_{ij}-\hat{Y}_{ij}\right)^2 \quad .$$

The likelihood ratio statistic

(10)
$$\mathrm{X}^2=-2\left(\ln\mathcal{L}_R-\ln\mathcal{L}_F\right)$$

can be used to test a hypothesis between a full (F) and reduced (R) model by comparing X^2 to a chi-square critical value χ^2 with degrees of freedom equal to the difference in the number of parameters between full and reduced models.

19 Appendix C. 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 C.1. The model is stated deterministically in Appendix Table C.2. Stochastic variation is introduced in Appendix Table C.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 C.4 contains the likelihood functions corresponding to the deterministic model in Appendix Table C.2, in which the survival error has been set to zero. The sequential components of the model are described below.

Selectivity

Fishery selectivity $\{\beta_a\}_{a=1}^{A}$ was allowed by vary with age class as defined by equation (C.2). Selectivity increases from β_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 $\alpha = 1$ and is convex downwards when $\alpha > 1$ 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 (C.3-C.5). The catch biomass D_t is assumed to be known without error and is converted to catch numbers C_t by equation (C.6) using the mean weights w_{at}. Spawning biomass B_t is computed using maturity at age m_a by equation (C.7).

Recruitment

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

(1) $$\log R_t = \log R + \gamma\left(\log R_{t-1} - \log R\right) + \sigma_1\delta_{1t}$$

with parameters (R, γ, σ_1) and where the δ_{1t} are independent standard normal variates (Schnute and Richards 1995). This function (1) has the property that if $\gamma = 0$ then log *R* is normal with mean log *R* and variance σ_1^2. As the autocorrelation parameter $\gamma \to 1$ the process approaches a random walk with finite moments

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

(3) $$Var\left[\log R_t \mid R_{t-1}\right] = \sigma_1^2 \quad ,$$

but infinite unconditional variance

(4) $$Var\left[\log R_t\right] = \sigma_1^2 \big/ \left(1-\gamma^2\right) \quad .$$

Predicted observations

Observed data are related to the underlying biological system by equations (C.14-C.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 (C.14) and (C.15). Commercial catch rates were divided into two time series $\left(I_{1t}, I_{2t}\right)$ 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 $\left(f_{1t}, f_{2t}\right)$ 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 (C.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 $k = 1, \ldots, K_t$.

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 Table C.2 includes a population state vector $\{N_{at}\}_{a=1}^{A}$ for each year *t* with system dynamics for these states defined by equations (C.9)-(C.13). These dynamics are a consequence of the parameter vector $\mathbf{\Phi}$ 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 $\mathbf{\Phi}$ includes the recruitments $\{R_t\}_{t=2-A}^{T}$ that determine the initial states N_{a1} at time *t*=1 using equations (C.9) and (C.10) and the initial moments from equations (C.3) to (C.8). At time *t*=2, the states N_{a2} are determined using the dynamic equations (C.11)-(C.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 (C.14)-(C.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 (C.9-C.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 (C.4). Spawning biomass is also in millions of kilograms (thousands of tonnes) by equation (C.7).

Sources of error

The sources of error are (1) autoregressive lognormal process error among the recruitments R_t with recruitment standard deviation σ_1 (2) lognormal measurement error in the stock indices (I_{1t}, I_{2t}) with index standard deviation τ_1, and (3) multivariate logistic measurement error in the observed age proportions p_{at} with standard deviation τ_2. We have assumed that the standard deviation τ_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 $\sigma_2 = 0$.

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 κ^2 resulting from the two error components and ρ is the proportion of this variance attributable to the recruitment process error. The definition (L.2) re-parameterizes the recruitment and index errors from (σ_1, τ_1) to (κ^2, ρ), while equation (L.3) reverses the transformation. Note that a given choice of ρ implies the variance ratio

(5) $$\frac{\sigma_1^2}{\tau_1^2} = \frac{\rho}{1-\rho} \quad .$$

Thus, as $\rho \to 0$, recruitment becomes more deterministic $(\sigma_1 \to 0)$. Similarly, measurement error assigned to the stock indices diminishes as $\rho \to 1$ and therefore $\tau_1 \to 0$.

Likelihood function

Table A.4 defines the likelihood function $L(\mathbf{\Theta})$ for the stochastic model, where the parameter vector $\mathbf{\Theta}$ includes the vector $\mathbf{\Phi}$ in equation (D.1) plus the parameters $(R, \gamma, \sigma_1, \tau_1, \tau_2)$. 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.5 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 $(\rho, \kappa^2, \sigma_1^2)$ appropriately. In particular, fix ρ at some small value (e.g. 0.0001) and fix σ_1^2 at some sensible value by setting $\kappa^2 = \sigma_1^2 / \rho$ as implied by equation (L.3). As a consequence, κ^2 will be large, and hence τ_1^2 will be large. This effectively reduces the weight of $L_2(\mathbf{\Theta})$ of equation (L.10) in the overall likelihood $L(\mathbf{\Theta})$ defined in equation (L.12).

Appendix Table C.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
$\mathbf{\Theta}, \mathbf{\Phi}$	Vectors of model parameters
α	Selectivity slope parameter
β_1	Selectivity of age class a=1, for years $(1 \le t < t')$
δ	Difference in selectivity of age class a=1, for years $(t' \le t \le T)$
β_a	Selectivity for age class a
M	Instantaneous rate of natural mortality
q_1, q_2	Scaling factor (catchability) for stock indices
R, γ	Autoregressive recruitment parameters
σ_1	Standard deviation of recruitment process error
τ_1	Standard deviation of stock index measurement error
τ_2	Standard deviation of age proportion measurement error
κ^2	Total recruitment process error and stock index measurement error
ρ	Variance ratio σ_1 / κ^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 C.2. Deterministic catch-age model

Deterministic catch-age model listing recursive calculations that define all states and observations given the parameter vector $\mathbf{\Phi}$.

Parameters

(D.1) $\mathbf{\Phi} = \left(\alpha, \beta_1, \delta, M, q_1, q_2, \{R_t\}_{t=2-A}^{T}\right)$

Selectivity

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

State Moments

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

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

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

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

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

(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) $\overline{I}_{1t} = q_1\left(B_t - f_{1t} D_t\right)$; $(t \in \mathbf{T}_1)$

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

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

Appendix Table C.3 Stochastic catch-age simulation model

Predicted values from Table C.1 are indicated using a bar over the quantity. The standard normal variates $(\omega_t, \delta_{at}, \upsilon_t, \varepsilon_{at})$ are mutually independent.

Parameters

(S.1) $\boldsymbol{\Theta}_S = (\alpha, \beta_1, \delta, M, q_1, q_2, R, \gamma, \sigma_1, \sigma_2, \tau_1, \tau_2)$

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

(S.2) $R_{2-A} = Re^{\left(\sigma_1 / \sqrt{1-\gamma^2}\right)\omega_{2-A}}$

(S.3) $R_t = R^{1-\gamma} R_{t-1}^{\gamma} e^{\sigma_1 \omega_t}, \quad 2 - A < t \le T$

Initial States $(t = 1)$

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

(S.5) $N_{at} = \bar{N}_{at} \prod_{b=2}^{a} \frac{e^{\sigma_2 \delta_{b,b-a+1}}}{1 - e^{-M} + e^{-M} e^{\sigma_2 \delta_{b,b-a+1}}}, \quad 2 \le a \le A$

State dynamics $(t \ge 2)$

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

(S.7) $N_{at} = \bar{N}_{at} \frac{e^{\sigma_2 \delta_{at}}}{1 - e^{-M} + e^{-M} e^{\sigma_2 \delta_{at}}}, \quad 2 \le a \le A$

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

(S.8) $I_{1t} = \bar{I}_{1t} e^{\tau_1 \upsilon_t}$

(S.9) $I_{2t} = \bar{I}_{2t} e^{\tau_1 \upsilon_t}$

(S.10) $x_{at} = \log(\bar{p}_{at}) + \tau_2 \varepsilon_{at} - \frac{1}{A} \sum_{a=1}^{A} \left[\log(\bar{p}_{at}) + \tau_2 \varepsilon_{at} \right]; \quad (1 \le a \le A)$

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

Appendix Table C.4. Likelihood function for the model in Table C.2

Sequential calculations begin with the parameter vector $\mathbf{\Theta}$ and proceed to define $L(\mathbf{\Theta})$.

Parameters

(L.1) $\mathbf{\Theta} = (\mathbf{\Phi}, R, \gamma, \sigma_1, \tau_1, \tau_2)$

(L.2) $\kappa^2 = \sigma_1^2 + \tau_1^2, \quad \rho = \dfrac{\sigma_1^2}{\sigma_1^2 + \tau_1^2}$

(L.3) $\sigma_1^2 = \rho\kappa^2, \quad \tau_1^2 = (1-\rho)\kappa^2$

Residuals

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

(L.5) $\xi_t = \log R_t - (1-\gamma)\log R - \gamma \log R_{t-1}\,; \quad (2 - A < t \le T)$

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

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

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

Likelihoods

(L.9) $L_1(\mathbf{\Theta}) = \sqrt{1-\gamma^2}\left(\sqrt{2\pi}\sigma_1\right)^{2-A-T} \exp\left[-\dfrac{1}{2\sigma_1^2}\left((1-\gamma^2)\xi_{2-A}^2 + \sum_{t=3-A}^{T}\xi_t^2\right)\right]$

(L.10) $L_2(\mathbf{\Theta}) = \prod_{i=1}^{2}\prod_{t\in\mathbf{T}_i}\left[\dfrac{1}{\sqrt{2\pi}\tau_1}\exp\left(-\dfrac{1}{2\tau_1^2}\zeta_{it}^2\right)\right]$

(L.11) $L_3(\mathbf{\Theta}) = \prod_{t=1}^{T}\left[\dfrac{A^{1/2}}{\left(\sqrt{2\pi}\tau_2\right)^{A-1}}\exp\left(-\dfrac{1}{2\tau_2^2}\sum_{a=1}^{A}\eta_{at}^2\right)\right]$

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

20 Appendix D. Sensitivity tests for varying ρ and κ.

We used results from the baseline run for Are 5CD to explore the sensitivity of the quota recommendations to varying ρ and κ. Appendix Table E.1. indicates the affect on B_{1999} of a variety of combinations of values of ρ and κ on terminal biomass for Area 5AB. From estimates of mean recruitment (R), the mean of the abundance index (I), we chose values for ρ and κ which corresponded to relative errors (standard deviation/mean) in R and I of 25%, 50% and 100%. The results indicate little effect on quota recommendations provided relative error in the recruitment index remained below 50%. The sensitivity tests also indicated that our base line model runs for Cases 2 and 3 had been using high enough levels of error in the CPUE index, to remove its impact on the stock dynamics.

Appendix Table D.1. Relative change in B_{1999} with varying relative error in the recruitment index or CPUE. Assumes B_{1999} of baseline run for Area 5AB (Case 2) mean R=0.705 and mean CPUE index =150.

Recruitment		CPUE		κ^2	ρ	B_{1999}	Relative change in B_{1999}
Relative error of σ_1	σ_1	Relative error of τ_1	τ_1	$\kappa^2 = \sigma_1 + \tau_1$	$\rho = \sigma_1 / \kappa^2$		
0.14	**0.100**	**0.67**	**100**	**100.00**	**0.001000**	**7.246**	
0.25	0.176	1.5	225	225.18	0.000783	7.033	-3%
0.5	0.353	1.5	225	225.35	0.001564	6.728	-7%
1	0.705	1.5	225	225.71	0.003124	6.378	-12%
0.25	0.176	3	450	450.18	0.000392	7.015	-3%
0.5	0.353	3	450	450.35	0.000783	6.706	-7%
1	0.705	3	450	450.71	0.001564	6.354	-12%
0.25	0.176	6	900	900.18	0.000196	7.006	-3%
0.5	0.353	6	900	900.35	0.000392	6.695	-8%
1	0.705	6	900	900.71	0.000783	6.342	-12%

21 Appendix Table F. Field classification of maturity stages.

Stage	Males	Females
1	Immature (translucent, string-like	Immature (translucent, small)
2	Developing (swelling, brown-white)	Developing (small, yellow eggs, opaque or translucent)
3	Not used	Developed (large yellow eggs, opaque)
4	Developed (large, white, easily broken)	Fertilised (large, orange-yellow eggs, translucent)
5	Ripe (running sperm)	Embryos or larvae (includes eyed eggs)
6	Spent (flaccid, red)	Spent (flaccid, red ovaries; a few larvae may be present)
7	Resting (ribbon-like, small brown)	Resting (moderate size, firm, red-grey ovaries)