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Canary rockfish assessment for 1999 and recommended yield options for 2000/2001

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Abstract

This document provides an analysis of the available stock assessment information on canary rockfish *(Sebastes pinniger*) in Canadian waters and harvest recommendations for the 2000/2001 fishing year. For Areas 3C+3D (west coast of Vancouver Island), this review proposes minimum and maximum harvests of 350-700 t, an increase from the 350-550 t range proposed the previous year. The document recommends a range of 175-350 t for Areas 5A+5B (Queen Charlotte Sound) down slightly from the 200-400 t range proposed a year earlier. There is little basis for determining optimal harvest levels for Areas 5C+5D (Hecate Strait) or 5E, (west coast of the Queen Charlotte Islands). However, for Areas 5C+5D; the document suggests consideration of a harvest range of 50-150 t. This brackets historical landings. A harvest range of 100-200 t is proposed for Area 5E, but note that the hook-and-line fishery is providing significant landings from this area. The document summarises the history of Canadian and U.S. landings, management and assessment history for canary rockfish.

Assessment methodologies continue to follow recommended procedures for “data poor” stocks. Historical mean harvests are evaluated as quota guidelines subject to: observed trends in age composition, catch curve analysis, CPUE trends and comments from fishers. We include a discussion of the information content of each data source. Also included is a brief review of a canary rockfish assessment provided by Walters and Bonfil (1999) and incorporation of those authors’ concerns in the quota recommendations. Yield recommendations are discussed relative to current perceptions of decadal scale variation in groundfish recruitment.

Résumé

Ce document présente une analyse des données disponibles sur l'évaluation des stocks de sébaste canari *(Sebastes pinniger*) dans les eaux canadiennes et contient des recommandations pour les récoltes de l'année de pêche 2000-2001. Pour les régions 3C+3D (côte Ouest de l'île de Vancouver), les récoltes minimales et maximales proposées sont respectivement de 350 t et de 700 t, ce qui représente une hausse par rapport aux niveaux proposés l'an dernier (350 t et 550 t). Pour les régions 5A+5B (Queen Charlotte Sound), la gamme recommandée est de 175 t à 350 t, ce qui est légèrement inférieur à la gamme proposée l'année précédente (de 200 t à 400 t). Il existe peu de données pour déterminer les niveaux de récolte optimaux dans les régions 5C+5D (Hecate Strait) ou 5E (côte Ouest des îles de la Reine-Charlotte). Cependant, pour les régions 5C+5D, la gamme suggérée pour les récoltes est de 50 t à 150 t. Ces niveaux correspondent aux données des années antérieures sur les débarquements. La gamme suggérée pour les récoltes dans la région 5E est de 100 t à 200 t, mais il faut tenir compte du fait que la pêche avec lignes et hameçons produit des débarquements importants dans cette région. Le document résume l'évolution des débarquements, de la gestion et de l'évaluation du sébaste canari au Canada et aux États-Unis.

Les méthodes d'évaluation continuent à être conformes aux procédures recommandées pour les cas où l'on dispose de peu de données sur les stocks. Les données historiques de récoltes moyennes sont évaluées en terme de lignes directrices des quotas selon : les tendances observées dans la composition selon l'âge, l'analyse de la courbe de prises, les tendances des prises par unité d'effort (CPUE) et les commentaires des pêcheurs. L'information que contient chaque source de données est commentée. L'évaluation du sébaste canari par Walters et Bonfil (1999) est passée en revue brièvement. Les préoccupations de ces auteurs sont incorporées dans les recommandations en matière de quotas. Finalement, les recommandations ayant trait au rendement sont examinées par rapport à la perception actuelle de la variation à l'échelle décennalle du recrutement du poisson de fond.

Table of Contents

Introduction

This document summarises the information available on the stock status of canary rockfish in British Columbia waters and provides yield recommendations for the 2000/2001 fishing year. The assessment follows from previous PSARC assessment documents for shelf rockfish (Westrheim 1977, Ketchen 1980, Stocker 1981, Leaman and Stanley 1985, Stanley, 1986a, 1988-1991, 1993, 1995, 1997, Stanley and Haist 1997, Stanley 1999).

The intent is not only to provide harvest advice for the coming fishing year, but also to summarise the available biological and historical fishery information such that future researchers will have sufficient detail to use this document as the starting point for their assessment work on canary rockfish. It differs from previous assessments on shelf rockfish in that we confine the document to one species and provide greater detail on:

- the history of canary rockfish management and assessment in B. C. waters;
- a summary of assessments for U. S. waters;
- previous biomass and sampling surveys;
- the biology of the species;
- the status of relevant data bases;
- additional research pertaining to stock assessment of this species.

We have adopted a more retrospective tone than was typical in previous assessments and attempt to include all pertinent background information. The document is also intended to provide a more convenient platform for creation of derivative documents such as Stock Status Reports, Integrated Fishery Management Plans, and PSARC Subcommittee Reports. The three to four year cycling of full assessments for this species represents the assumption of a low interannual variability in biomass for a long-lived species. It also recognises that directed research on this species will be infrequent given its relatively low priority.

Canary rockfish biology

Canary rockfish are common from British Columbia to central California and are reported to range from Southeast Alaska to the Baja peninsula, Mexico (Eschmeyer *et al*. 1983). Adults are most common over bottom depths of 80-160 m but can be found to depths of 274 m (Milton Love[1], unpublished data). Longline catches off the west coast of the Queen Charlotte Islands indicated that mean size increased with depth of catch (McCarter 1980). Juveniles can be found to nearly sub-tidal depths. Adults are often caught with other rockfish, in particular silvergray (*S. brevispinis*), and yellowtail (*S. flavidus*) rockfish, as well as lingcod *(Ophiodon elongatus).*

Adult canary rockfish appear to aggregate. Fishers report that they show as small "haystacks" on their sounders often in proximity to high relief and over untrawlable bottom. They are rarely caught by midwater trawl. Maximum size of canary rockfish is about 67 cm and 5 kg. Burnt-section ageing of otoliths (MacLellan 1997) has indicated maximum ages from Canadian waters of 84 for males and 77 for females, although females rarely exceed 50 years. They first appear in the trawl

[1] Milton Love. Univ. Cal. Santa Barbara. Marine Science Institute, Santa Barbara. Calif. 93106-6150

fishery in small numbers at age five or six and about 30 cm. They are marketable at this size thus there are few discards in the domestic groundfish trawl fishery.

Adult canary rockfish probably consume a mix of planktonic invertebrates and small fishes. Euphausiids dominated in the stomach contents of specimens collected during the 1980 U. S. triennial survey (Brodeur and Pearcy 1984). Canary rockfish have internal fertilisation and are livebearers. Insemination occurs in late summer or fall; release of the live young (parturition) occurs in late winter (Wylie Echeverria 1987). A few female canary rockfish are mature by age six, 50% are mature by age 14 and most are mature by 18. Males mature at similar ages to females (unpublished data).

Juvenile life history is unknown. Carr (1983) reported that canary rockfish in central California recruited to a giant kelp forest in May. A tagging study of juveniles on the Oregon coast found that some individuals moved up to 236 km (Bill Barss[2], unpublished data). Little is known about adult canary rockfish movement. The low viability of captured specimens precludes large-scale tagging programs.

Stock boundaries

Stock boundaries have not been adequately defined. Electrophoretic work by Wishard *et al*. (1980) showed some evidence of restricted gene flow between populations of northern California and northern Washington; but the results were inconclusive.

Recent assessment documents provided recommendations for two putative stocks: a west coast Vancouver Island stock (Pacific Marine Fisheries Commission Areas 3C+3D), and a Queen Charlotte Sound stock (PMFC Areas 5A+5B). The Areas 3C+3D stock may be continuous with Washington State populations. Initial assessments (1977-1988) treated Areas 3C and 3D separately with Area 3C assumed to be part of a trans-boundary stock. 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.

The Areas 5A+5B population has always been treated as one stock because most of the landings originated from a relatively small area on either side of Goose Island Gully or from the northern edge of Goose Island Bank. They were assumed to be separate from Areas 3C+3D because of the spatial gap in catches. Few canary rockfish have been caught trawl fishing between Quatsino Sound, on the northwest coast of Vancouver Island, and Cape Scott spit of Queen Charlotte Sound. However, this discontinuity probably reflects the difficulty of bottom trawling in the intervening grounds rather than low abundance. Hook-and-line fishers have reported a significant presence of canary rockfish during the summer on un-trawlable bottom west of Triangle Island, midway between the two regions. We suspect the distribution is more continuous than is reflected in the distribution of trawl catches.

Areas 5C, 5D and 5E have yielded small annual landings of canary rockfish. Assessment documents for 1979-1989 included “guideline” quotas in anticipation of a fishery. Depending on the management regime, and the status of the Langara Pacific ocean perch (*Sebastes alutus*) experiment (Leaman and Stanley 1993), recommendations were provided for Area 5C and 5D

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separately (1981-1986) or combined (1979-1980, 1987-1989) and for 5E-S and 5E-N, either separately (1979-1980, 1982-1986) or combined (1981, 1987-1989, 1998). We emphasise that there is little biological basis for any of the current stock boundaries.

Landings History in Canadian Waters

The U.S. trawl fishery moved northward to Areas 3C+3D in the 1950's and probably reached Areas 5A+5B in the early 1960's. These fishers dominated the early trawl fishery for rockfish in Canada, but landings were not recorded by species until 1967. Westrheim (1977) suggested that U.S. rockfish landings from Areas 3C+3D for 1950-1966 (excluding Pacific ocean perch) were approximately equal to U.S. landings from 1967-1974 (Tables 1-4, Figs. 1-2), thereby implying that these populations have been exploited since the 1950's. Following Extended Jurisdiction in 1977, Canadian trawlers gradually replaced the U. S. fishery and by 1982 the U. S. rockfish fishing had stopped in Canadian waters. Since 1982, there have been no foreign fisheries for canary rockfish other than a negligible bycatch in the hake fishery.

Prior to the 1990's, harvests were almost exclusively bottom trawl (>99%). The hook-and line fishery has slowly increased in recent years (Table 1). Preliminary estimates of hook-and-line canary rockfish landings for the coast were 188 t in 1998. There may have been a modest bycatch in the halibut fishery since the 1940's, but no data are available. Reported annual landings were less than 1 ton in 1996-1998 (Archipelago Marine Research[3]). Surveys conducted in 1998 by the International Pacific Halibut Commission indicated an incidental catch of 13 fish while capturing 186,386 lb of halibut for a bycatch weight ratio of less than 0.0003 (I.P.H.C.[4]).

Catches in the aboriginal fisheries are assumed to be low (Frank Crabbe pers. comm.[5]) but there are no estimates. Bycatch in the offshore hake fishery has ranged from 2-4 t/yr, 1991-1998. Bycatch is negligible in the shrimp trawl fishery (Hay *et al.*1999). It is reputed to be negligible in the recreational catches, except in the Strait of Georgia.

Prior to the imposition of catch restrictions of the 1980's, coast wide landings varied from 350-2,000 t, were primarily trawl-caught and were presumably driven by market conditions and abundance or availability. Landings since 1980 were determined primarily by regulation and secondarily by availability. Total landings varied from 580-1,800 t from 1981 to 1998. Fishers reported that dumping at sea was prevalent from the mid 1980's to mid 1990's. Fish were discarded to avoid trip limit overages. There is no way to estimate these landings so recorded landings can be assumed to be "minimum" estimates of harvest. There is dispute over the magnitude of the underestimate. Many fishers argue that the discards were large relative to the total amount landed. However, during this period we observed many cases of landed overages that were simply misreported to species. Thus, while often misreported, these catches were landed and attributed to some species of rockfish.

Catch record indicate that canary rockfish have yielded annual landings of about 1,140 t coastwide since 1967. Of this, Areas 3C+3D have yielded about two thirds and Areas 5A+5B, one third. Fishers currently state that even though canary rockfish have a high market value, the low quotas

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and therefore low Individual Vessel Quotas (IVQ's), cause canary rockfish to become a "nuisance" fish, particularly, in Areas 3C+3D. They cannot target cohabitants of the same depth without exceeding their canary rockfish limits. Nevertheless, the consensus among fishers appears to be that canary rockfish are "more" abundant during the latter years of the 1990's over most of the B.C. coast.

Landings history in U. S. waters

U.S. landings from northern California to the Washington/B.C. border have varied from 800–5,137 t/y and averaged about 2,300 t from 1967-1998 (Crone *et al.* 1999). Landings off the U. S. Pacific coast began in the early 1940's. After significant wartime landings, the landings decreased until the 1960's and then began to increase. In response to fishers' comments in 1993 and 1994 regarding decreasing catch rates and a pessimistic assessment in 1994 (Sampson and Stewart 1994), the recommended harvests were reduced to about 1,000 t for 1995-1998. Landings are currently constrained by restrictive trip limits. The majority of past landings originated in Oregon and Washington trawl fisheries; however, canary rockfish are becoming increasingly important in hook-and-line and recreational fisheries. There are no significant fisheries for canary rockfish in Alaska.

Canary rockfish Management

Trawl management plans have been produced since 1980 (Table 5) and began to constrain harvests by 1982. From 1982 to the present, an increasingly complex array of landings and effort restrictions have further constrained the fishery as management and industry struggled to obtain the benefits of stock-specific (area-specific) management while maintaining the viability of the fishery. Harvest 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: as of 1997, the official trawl year corresponds to April-March).

As quotas became lower in the late 1980's, the request by industry for a 10-month fishery led to the introduction of 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 most 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. Not only did the trip limits change among years, but since quotas became fully subscribed at different times of the year, the initial trip limit was converted to the smaller incidental limit at varying times of the years in different areas. As trip limits became too small to be practical, the management plan made increasing use of aggregate species quotas. The aggregates varied among years and areas and varied from combinations of two species (canary and silvergray rockfish) to six species (Aggregate 1:1994) (Table 5).

The rate of change of the management environment peaked in the 1996-1997 period. After exhausting every imaginable combination of time/area/trip management, an IVQ system was implemented for 1997/98. Accompanying the change was the introduction of halibut bycatch caps, 100% observer coverage for offshore bottom trawling, a new start date for the fishing year (April 1) and elimination of aggregates.

The hook-and-line sector began harvesting canary rockfish in the mid-1990's (Tables 1, 5 and 6). In 1995, management permitted an annual catch of canary rockfish as part of the aggregate quota of 8,925 t (silvergray, yellowtail, canary and widow rockfish) 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 canary rockfish quota was 738 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 1998 hook-and-line management plan included a 74 t canary rockfish limit within a combined canary and silvergray rockfish quota of 213 t.

The U.S. Pacific Fishery Management Council adopts Acceptable Biological Catches (ABC) for the management areas of US-Vancouver, Columbia and Eureka (Washington-northern California). The combined ABCs were initially 2,700 t from 1983-1985, 3,500 t for 1986-1990, 900 t for 1991-1994, 1,250 t for 1995-1997 and 1,045 t for 1998.

Relative and absolute abundance estimates of canary rockfish

CPUE indices in Canadian assessments

Estimates of commercial CPUE are available for the trawl fisheries from 1967 for both U. S. and Canadian fisheries. In spite of misgivings about catch rate as a meaningful index of 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 canary rockfish represented at least 25% of the retained catch (Tables 1-2). 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. CPUE was found to be positively related to vessel horsepower or size (Stanley 1992). However, the effect was weak and caused only a modest adjustment to the indices.

The dynamic management regime of 1984-1997 led to monthly and yearly variation in fishing strategies that must have corrupted the comparability of CPUE over time. The proportion of tows that reflected targeting, non-targeting or avoidance of canary rockfish would have varied among years, boats, and seasons. This would act to decrease precision and introduce bias in CPUE owing to underlying trends in trip limits. Finally, we suggest that the management changes of 1996-1997 were significant enough that they produced such an entirely different fishing environment that it is unrealistic to assume comparability between pre- and post-IVQ CPUE. For example, fishers now report that very little of the annual landings comes from targeted fishing on canary rockfish. Fishers can fill their canary rockfish IVQ’s as the bycatch of target fishing on other species.

Further complicating the usability 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 offload slips to obtain the most accurate rendition of the trawl trip (Rutherford, 1999). Fisher logs were voluntary from 1954-1986 but during the 1980’s fishers began to withhold logbooks to protest management action. This resulted in logbooks becoming mandatory in 1987. However, as it became obvious that fisher logs were being used for enforcement, the data quality deteriorated. Thus, for example, the accuracy of logbook information for 1987-1996 was poorer than for preceding years. Similarly, it became obvious by the late 1980’s that the data quality in offload records (sales slips) was deteriorating as landing records were altered to conform to regulations. Some entire unloadings were deliberately mis-classified. Furthermore, fishers argued that discards at sea during this period were much higher; thus reported landings underestimated true harvests and CPUE.

Following the shortcomings in data capture in the mid-1980's to the mid-1990's, 100% at-sea observer coverage and dockside validation were implemented by 1996. Catch date estimates can now be based on observer estimates of catch per tow instead of fisher logs. While unquestionably more accurate (lower precision and bias), the change reduced comparability because of the greater detail by species. More of the retained catch is now being attributed to the less common species, which previously were unreported and lumped as part of the catches of dominant species.

We hope that the introduction of IVQ's will lead to a more stable period. This may allow us to develop comparable time series of CPUE. In support of using CPUE indices in the future, we have proposed a group of CPUE indices (Table 7). Estimates are based on observer data (1996-1998) and include discards. We present six indices based on different extractions from the observer data and expressed either as "total" CPUE (total catch divided over total effort) or median CPUE. Total CPUE provides an index weighted by catch or effort whereas median CPUE reflects an equal weighting among all tows that contain canary rockfish.

We apply the two measures of central tendency to three data extractions. The first extraction is used to calculate a nominal CPUE based on all tows in the observer data. For the median version, we restrict the tows to include those with canary rockfish. The second and third extractions relate to preferred-depth and marginal-depth indices. These are 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. The core depth range of 71-100 f (130-183 m) accounted for 67% of the landings from 1967-1995, while the "marginal" depth ranges of 51-70 f (93-128 m) and 101-120 f (185-220 m) combined, provided 25%. Furthermore, by selecting only those catch records with at least one canary rockfish, we are attempting to implicitly constrain the records to suitable habitat within those depth strata.

These selection criteria can be altered as we identify more realistic criteria of canary rockfish habitat. Subsequent assessments will include variance estimates of annual CPUE. While we hope that the fishery will remain stable enough to provide comparability 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. Since 1996, we have already seen significant concentration of IVQ's (Table 8) such that the active bottom trawling fleet has been reduced by almost 50% while catching the same amount of fish. This implies twice the area specific quota for each vessel and therefore an impact on CPUE. This process of concentration may be ending, but we can foresee implementation of Marine Protected Areas, radical changes in gear design to be more selective, and demands for full retention, on the not-so-distant horizon.

Recent estimates of CPUE for Areas 3C+3D appear to be higher than elsewhere on the coast and to have risen over the last three years, consistent with comments from industry. The effect is slightly greater in the marginal depths. CPUE also appears to have risen for Areas 5A+5B. For Areas 5C+5D, CPUE has been stable in the preferred depths and declined in marginal depths. There are too few data to comment on Area 5E. Over the whole coast, CPUE has increased in marginal depths and remained stable in the preferred depths since the introduction of IVQ's.

CPUE estimates in U. S. assessments

Golden and Wood (1990) used a CPUE index to tune their catch-at-age analysis. The index was based on Oregon bottom trawl logbooks for fishing effort from 50-100 fm. The 1994 and 1996 assessments did not use CPUE (Sampson and Stewart 1994, Sampson 1996), arguing that the index could not be adjusted for the evolution in fishing power or spatial distribution of fishing effort. Species composition was summarised by aggregate in the landings data, thus they could not distinguish actual tows that contained canary rockfish.

Crone *et al.* (1999) did not use a commercial CPUE index for the same reasons as Sampson and Stewart (1994). They noted that improvements in collection and storage have now improved the fishery data but the current the time series (1995-1998) is still too short to be useful. Williams *et al.* (1999) used a CPUE index based on California trawl landings. Aggregate catches were decomposed to species through application of port sample data. Overall catch rates were standardised using a general linear model (GLM) to account for year, month, vessel and area fished effects (Ralston 1999).

Canadian and U. S. Canary rockfish surveys

Since 1960, there have been over 50 research cruises in Canadian waters in support of rockfish stock assessment. The main focus of most of these trips was Pacific ocean perch and thus focussed on fishing grounds deeper than those typically inhabited by canary rockfish. Notable exceptions include charter cruises in 1978 and 1979 to the northwest coast Vancouver Island and the west coast of the Queen Charlotte Islands (Barner *et al*. 1978, Nagtegaal *et al*. 1980, Leaman and Nagtegaal 1982). In these five trips, researchers attempted to fish depths as shallow as 55 m and estimate biomass for all rockfish species they encountered. While the target depth range for these cruises was adequate for canary rockfish, none of the surveys provided meaningful abundance estimates for the shallower strata owing to the difficulty in finding trawlable bottom. Researchers did comment that there was significant acoustic sign of rockfish at canary rockfish depths, particularly off the west coast of the Queen Charlotte Islands. A subsequent longline survey to the same region, confirmed that canary rockfish were present in the 55-194 m stratum (McCarter 1980). A slope rockfish biomass survey conducted in 1997 also confirmed the presence of canary rockfish off the west coast of the Queen Charlotte Islands but this survey also had difficulty finding trawlable bottom.

Assessment staff of the Department of Fisheries and Oceans, Canada conducted an observer trip in 1984 and two 1-week charter cruises in each of 1985 and 1986 (Stanley 1988a). The objective was to provide age samples of canary and silvergray rockfish and to explore the potential for swept-area surveys for these two species. However, while fishing captains were given freedom to fish traditional tows and search new sites during the charters, in over four weeks of fishing only seven tows caught significant amounts of canary rockfish. Overall catch rates were 0.07 t/hr and 0.05 t/hr in 1985 and 1986, respectively, in spite of targeted fishing partially on canary rockfish.

The cruises of the 1970's and mid 1980's led assessment staff to abandon attempts at swept-area biomass estimates for canary rockfish. Given that the survey results would be highly leveraged by a few successful tows and that availability would be subject to substantial interannual variability, it was felt that the low precision did not justify the expense. The only subsequent cruise to focus on canary 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).

U. S. biologists have been more persistent in their attempts to survey canary rockfish. They have conducted a coastwide survey from southern California to at least the U.S.–Canada border off northern Washington every three years from 1977-1998 (Wilkins *et al*. 1995). They attempted to estimate all important groundfish species on the continental shelf. The initial focus was on shelf rockfish species but the focus shifted in the 1980's to other species owing to frustration over the low precision and obvious bias in that estimated biomass for some species was often exceeded by annual catches. Nevertheless, the survey results have been used to tune canary rockfish assessments (Crone *et al*. 1999, Sampson 1996, Sampson and Stewart 1994).

Tagart (1991) commented that in one case involving yellowtail rockfish, surveys tows were replicated a few weeks later and generated an estimate 16 times greater than the previous estimate. Wilkins *et al*. 1995, in reference to canary and yellowtail rockfish concluded:

> "Despite efforts to improve precision of rockfish abundance estimates over the first four iterations of the triennial survey, the large variances remained a problem. We concluded that precise estimates of rockfish abundance were not possible using current trawl survey methods and realistic sampling levels. It was clear that a higher priority should be given to obtaining the information that our survey was able to provide well. Consequently, beginning in 1989 the triennial bottom trawl survey was designed to monitor a broad range of demersal species and also focus on providing precise estimates of the demersal component of the Pacific hake stock and sablefish."

The triennial survey has continued through 1998. The 1995 survey extended to 50^{o} N (Nootka Island) and indicated 246 t in Canadian waters and 3,393 t for the whole coast. The 1998 survey extended only to the northern boundary of Area 3C and but indicated a biomass of 1,834 t (CV=27%) in Canadian waters and 3,342 t for the coast (Mark Wilkins, unpublished data[6]). In response to growing concerns over groundfish populations of California-Washington, a modified version was conducted in 1999. The National Marine Fisheries Service is considering increasing the frequency to every year (Waldo Wakefield[7], pers. comm.).

[6] Mark Wilkins, National Marine Fisheries Service, 7600 NE Way, BIN C15700/2067/3, Seattle, Washington. 98155-0700

[7] Waldo Wakefield, National Marine Fisheries Service, 2030 S. Marine Drive. Newport, Oregon. 97365.

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

Biological data and age composition

The GFBio database at the Pacific Biological Station (P.B.S.), Nanaimo, contains the data on canary rockfish sampled from Canadian waters through 1998. These data were obtained from port sampling, observer trips and research cruises. Data not in GFBio includes a small number of "length-only" port and research samples collected from 1977-1996. These data are available in hard copy or on fiche at P.B.S. An examination of reports from research cruises conducted from 1960-1970 might realise a small number of additional specimens. However, no ageing materials would be available and the overall number would probably be less than 1,000 specimens.

As of October 1, 1999, GFBio contains data on 21,737 specimens of canary rockfish, of which 7,756 have been aged (Table 9). Approximately 60% of the ages have been obtained in the last nine years (1990-1998). The increased number of specimens in 1998 reflects additional samples now being obtained from at-sea observers. While the number of aged specimens numbered in the hundreds for many years from 1977-1997, the actual number of aged samples was small and often limited to only 0-4 per region each year. We excluded from the extraction any samples that could not be assumed representative of commercial bottom trawl fishing.

All ages were determined by using the otolith burnt section technique (MacLellan 1997). Ageing agreement between two readers is over 50% for ages 5-9 and over 30% for ages 10-19. There is 0% agreement for ages 20-29, although most observations are within 2 years (Table 10). Precision is very low for ages 30+.

Maximum ages observed in Canadian samples are 84 and 77 for males and females respectively. The estimate of 77 for females is suspect since the next oldest female in the dataset is 61 and the age corresponding to the 99th percentile is 33 years. It may have resulted from ageing error or mis-reporting of sex. The $A_{99\%}$ for males is 66 years. Overall age composition and age composition by year and stock are shown in Figs 3-7. We see little evidence of exceptional year classes; however, the lack of ageing precision would dampen any signal. Trends in mean and median age are shown in Fig. 8.

Catch curve analysis

We examined the catch curves by combining the aged samples within five-year periods (1977-1980, 1981-1985, 1986-1990, 1991-1995, and 1996-1998) for the overall coast and for each region. (Fig. 9-14 and Table 11). The exception was Areas 5C+5D wherein we used the 1990-1992 and 1994-1998 periods to make better use of the available samples. We assumed an age of 14 for full recruitment for both sexes (Fig. 3) and the obvious assumption of no trend in recruitment. Estimates of Z_m (instantaneous male total mortality rate) appear to increase from 0.00-0.05 to 0.05-0.07 in the 1990's, while Z_f increased from 0.03-0.065 to approximately 0.10.

Estimation of life history parameters

We estimated male and female growth rates from 1998 samples. There is sufficient background information to compare growth rates over time and among areas, but this was not completed for this assessment. Aged samples of young fish from the 1991 juvenile surveys are in GFBio and would assist in fixing the initial part of the growth curve. However, some of these samples came from gillnet catches and thus would introduce a curious mix of gear-specific selectivity to overlay on similar biases in the trawl samples. I used all samples from 1998 port and observer samples. The data were fitted to the Schnute (1981) growth model (Case 1) (Fig. 15, Table 13). We have too few weight measurements in the historical database to derive a length/weight relationship from Canadian catches, so used estimates based on specimens from U.S. waters (Crone *et al.* 1999) (Tables 12-13).

To calculate age at maturity, we used all aged females in GFBio collected during the months of January-April. While females can be identified as stage 3 from May to December, and are apparently preparing for parturition in the following year, it cannot be determined during field sampling whether they spawned the previous spring. Thus maturing fish in the later months of year are a combination of females which had spawned and virgin females preparing to spawn when they are one year older. Females were considered mature if classified as stage 3 or greater (Table 14). Observations were fit to a logistic model (Tables 12-13). Age at 50% maturity for females is 14.02 (Fig. 16, Table 12-13).

Based on the maturity ogive and age composition data, we note that the percentage of mature females in commercial samples from all regions combined has declined from 48.9% in pre-1996 samples to 44.2% for 1996-1998. Proportions for Areas 3C+3D and 5A+5B decreased from 48.4 to 46.9% and 52.7 to 31.8%, respectively.

We have no fecundity information from B.C waters. Following Williams *et al* (1999) we assumed that fecundity was proportional to body size. We examined this assumption by converting a fecundity/length relationship based on U. S. specimens (Gunderson *et al*. 1980) to fecundity/weight, using the growth curve presented herein. This result implied a linear relationship.

Estimates of natural mortality

Archibald *et al*. (1981) was the first to estimate instantaneous mortality rates for canary rockfish from ages derived from the otolith burnt-section technique. Based on samples collected in 1977-1979, they estimated total instantaneous mortality rates (Z_m and Z_f) for males of 0.03-0.05 and for females of 0.11-0.34, but noted that sample sizes were small. Z_m and Z_f for Area 5E were estimated to be 0.01 and 0.11 respectively.

Crone *et al.* (1999) reviewed the estimation of M for canary rockfish in U.S. assessments. Golden and Demory (1984) initially used an estimate of 0.10 for both sexes but then, based partially on Archibald *et al*. (1981), lowered the estimates for both sexes to 0.06 (Golden and Wood 1990). They also entertained a second natural mortality scenario wherein M_f was allowed to increase to 0.15 for older females. Subsequent U. S. assessments have entertained the dual approach of either setting M_f constant while allowing selectivity to decline with age for females, or, allowing M_f to increase with age while selectivity is constant.

Canadian rockfish assessments have also entertained the dual approach in yellowtail rockfish assessments (Stanley 1993). Yellowtail rockfish exhibit the same truncated age composition and reduced relative abundance for older females. In subsequent Canadian assessments, however, the "refugium" scenario, while theoretically possible, was viewed as an untestable assumption and not supported by any evidence (Stanley and Haist 1997). Crone *et al.* (1999) noted that the two hypotheses, while leading to very different stock reconstructions, resulted in similar harvest recommendations. The lower M_f in the refugium model does not indicate as rapid a decline in abundance, but this is compensated by being associated with a more conservative target reference point, since M_f is assumed to be lower.

Baseline runs of the canary rockfish catch-at-age model assumed M_f to be 0.06 through age 10 and then linearly increasing to 0.20 by age 25+. Variations on the age dependent theme were examined with little impact on the reconstructions. Crone *et al.* (1999) also used the empirical formula of Hoenig (1983) (Table 12). He used $A_{99\%}$ for males and females of 47 and 31years to estimate M's of 0.096 and 0.145 for males and females. Canadian estimates of $A_{99\%}$ are 66 and 33 years for males and females for estimates of M of 0.069 and 0.136, respectively. The maximum observed ages of 84 and 77 years for males and females provide estimates of 0.054 and 0.059, respectively.

Since 1978, we have obtained six additional aged samples from the west coast of the Queen Charlotte Islands. Two of these samples were from research surveys in 1997; four were from on-board observers in 1998. This area has a negligible history of canary rockfish landings through 1998 (Table 1). Recorded trawl landings have been low, and much of the landings of 1986-1993 were probably mis-reported by area. Hook-and-line landings have only recently become significant. If we assume that populations from this area have not been fished, then we can assume that M=Z for this region. Catch curve analysis, with a terminal age of 30, reported above, indicated a Z_m of 0.011 and Z_f of 0.058 (Figs. 7 and 13). The slope is obviously affected by the arbitrary choice of maximum age, since the limited sampling older age classes ensures older classes will be absent. I explored the sensitivity of the estimates by using an alternative logic. I chose terminal age as the age prior to first two consecutive ages with no observations. The procedure follows Archibald *et al.* (1981), except I used two ages instead of five. This resulted in the estimates changing to 0.019 and 0.068 for males and females, respectively. Additional manipulation of the terminal ages caused minor variation in the estimates.

While this estimate of M_m is lower than assumed or derived elsewhere, it can be argued that all previous attempts, except that of Archibald *et al.* 1981, have attempted to estimate it from stocks that had already been exposed to at least 1-2 decades of exploitation. The early harvesting of 1950-1967 would have truncated the male age composition. If the birth rate and juvenile mortality are equal for both sexes, an M_m one-third to one half that of females would have produced an exploitable population dominated by males in the early years of the fishery. This is now the case in Area 5E samples where the ratio in samples is over 2:1. While landings may have been small in the early years, over two-thirds would have been males.

Among stocks and 5-year periods, estimates of Z_m ranged from -0.006 to 0.067 (Table 11). Estimates from collections of more than 10 samples, ranged from 0.041-0.061. It should be noted, however, that the estimate from 5E could easily be biased downwards from a large recruitment event 20-40 years ago. Estimates of Z_f ranged from 0.030-0.107. The estimates based on larger samples sizes were clustered at 0.10. The 5E estimate, presumed to be from an unfished stock, was 0.060-0.070. Estimates of M_f in excess of 0.10 seem unrealistic given the difficulty in finding a estimate of Z for any place or period that exceeds 0.10. We suggest that realistic estimates of M for Canadian waters are 0.02-0.04 for males, and 0.06-0.08 for females.

Estimation of spawning potential per recruit and target reference points

We generated a selectivity ogive from the overall age frequency distribution (Fig. 3). We smoothed log abundance with a 5-point moving average and standardised to full selectivity at age 19. Log abundance for ages less than 19 was extrapolated from a least squares regression of log (n+1) against age for ages 19-30 (Fig. 17). We expressed selectivity for ages less than 19 as observed frequency over predicted frequency. We used the estimates or assumptions of natural mortality, growth, selectivity, fecundity and equilibrium conditions reported above to provide the relative population fecundity of unfished female canary rockfish (Fig. 18) (Gabriel *et al*. 1989). We then provide the relationship between equilibrium fishing mortality rate and spawning output under both assumptions of natural mortality. (Fig. 19).

Recent recommendations on target references points for data poor assessments relate either to the optimal choice of F relative to M, or target spawning per recruit reference points (SPR). Work by Patterson (1992), Walters (1998), and Walters and Bonfil (1999) suggest that an optimal F (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=M logic of earlier work and previous Canadian canary rockfish assessments. These F_{opt} recommendations translate to target Z values for canary rockfish of 0.03-0.06 for males and 0.10-0.13 for females.

Preliminary research on "spawning biomass/recruit" (SPR) target reference points by members of the U. S west coast groundfish stock assessment team (Martin Dorn[8] and Alec MacCall[9], pers. comm.) has paralleled the changing perceptions regarding $F_{opt.}$ Earlier work by Clark (1991) recommended target reference points of $F_{35\%}$. The recent declines in widow rockfish (*S. entomelas*), bocaccio (*S. paucispinis*) and now canary rockfish have prompted a review of this recommendation. Work in progress indicates that, while $F_{35\%}$ may be appropriate for dover sole and other groundfish, reference points of at least $F_{50\%}$-$F_{60\%}$ are more appropriate for rockfish. From Fig. 19, the $F_{50\%}$-$F_{60\%}$ target reflects a target reference point for F_f (instantaneous female fishing mortality) of 0.05-0.08 and therefore a target Z_f (instantaneous female total mortality) of 0.11-0.16. We suggest that managers use the target reference point for females.

History of canary rockfish assessments by Fisheries and Oceans, Canada

With some exceptions, noted below, previous assessments for Areas 3C+3D and 5A+5B have followed methodologies currently recommended as appropriate for data-poor contexts (Walters 1998, Restrepo *et al*. 1998). The assessments presented mean yield over time and then provided reviews of trends in CPUE and size or age composition, for indications of overfishing or declining abundance. Quota recommendations were then expressed as proportions of the mean yield (Restrepo *et al*. 1998) depending on whether there were any symptoms of varying abundance. Target reference points evolved from the target EY model with M estimated to be 0.2 in the early 1980's, to an F=M target from mid-1980's to late 1990's and an estimated M of less than 0.1.

The earliest assessments were highly qualitative and emphasised the lack of information available or did not comment on canary rockfish stocks. The process became more rigorous by the early

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1980's with use of an equilibrium model to derive quota recommendations for Areas 3C, 3D and 5A+5B (Ketchen 1980). Equilibrium biomass was calculated from the U.S. triennial survey for 3C and from a regression of CPUE against cumulative landings to predict starting biomass for areas 3D and 5A+5B. At that time, CPUE by U. S. vessels was declining and it was assumed that the fishery was still developing; thus a depletion estimator seemed appropriate. M for both sexes was assumed to be 0.20 from surface ageing of other rockfish species.

As reviewed earlier, the burnt-section method of otolith ageing revealed that canary 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 F and Z from an equilibrium-based length frequency simulator (Rasmussen and Stanley 1988). While there is too little contrast in size at age of canary rockfish to decompose length samples into age composition, modelling attempts indicated that the descending (right-hand) limb of a length composition distribution was relatively stable and could be used to infer Z (Stanley 1986b).

The initial calculations of F 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, especially without a reliable tuning index. Previous assessments discussed CPUE estimates relative to other rockfish fisheries as well as presenting trends, but little credibility was attached to the trends, as discussed above.

Areas 3C+CD Harvest Recommendations

In the first stock assessment of Areas 3C+3D canary rockfish, the authors suggested that the stock was probably in "reasonable" condition (Westrheim 1977). Ketchen (1980) conducted regression analysis of CPUE and landings to project a biomass in 3D of 5,200 t and recommended a quota of 500 t for Area 3C (Table 5). The combined quota recommendation for Areas 3C+3D was 600 t. Concerns over declining CPUE in 3C then led to decrease in the overall recommendation to 450 t (3C=100 t, 3D=350 t) by 1982 (Stocker 1981).

Advice was modified in 1985 to include a high and low recommendation (Leaman and Stanley 1985). The range of 250-950 for Areas 3C+CD canary rockfish was large in recognition of the lack of information. The range was increased to 300-1100 t for 1986 (Stanley1986). It was changed to 500-700 t (Stanley 1989); although CPUE was declining, length data indicated that old fish were still present, thus leading to a "compression" of the recommended yield range. 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 1990). The range was further lowered to 175-550 for 1993-1995 owing to an indication of truncation in the age composition (Stanley 1993). The lower range was raised to 350 t for 1996-1999/2000 after additional age samples showed that, while the age composition remained truncated, the degree of truncation did not increase (Stanley 1995).

Areas 5A+5B harvest recommendations

The initial harvest recommendation for Areas 5A+5B was provided in Ketchen (1980). After a summary of catch rates, the authors recommended a quota of 600 t based on historical yields. This was lowered to 500 t for 1980 (Ketchen 1980) and converted to a high and low range of 250-1000 in 1985 (Leaman and Stanley 1985). The range was reduced to 250-750 t for 1986-1987 owing to concerns over lack of information (Stanley 1986b). It was changed to 350-500 t for 1988-1992 to more closely bracket historical yields (Stanley 1988b) and further reduced to 200-375 for 1993-1995 owing to continued absence of older fish in the samples and chronically low CPUE (Stanley 1993). The upper range was changed slightly to 200-400 for 1996-1999/2000 to accommodate the increase in the estimate of the mean yield (Stanley 1995).

Areas 5C, 5D and 5E harvest recommendations

The first quota recommendation for canary rockfish in Areas 5C+5D was provided in 1979 (Ketchen 1980) and recommended 150 t under the argument that it was an incidental fishery. The authors commented that the few biological samples indicated a much smaller size composition than elsewhere. In anticipation of a fishery developing in this area, assessments for 1981-1986 recommended a range of "ceiling" quotas from 150-500 t. When a significant fishery failed to develop; subsequent shelf rockfish assessments omitted recommendations for this area.

The first recommendation regarding area 5E was also provided in 1979 in which a quota of 100 t was suggested (Ketchen 1980). The fishery was assumed to be incidental to the deeper water Pacific ocean perch fishery. Surveys of Area 5E during the 1970's indicated significant acoustic sign of what was thought to be canary rockfish. In anticipation that a fishery would develop, assessments for 1979-1990 recommended various "ceiling" quotas ranging from 200-950 t. No comment was made in assessments of the early 1990's. For the 1998 fishing year, in response from industry that assessments should provide some commentary on this area, a "ceiling" yield of 200-300 t was proposed.

Alternative Assessments of Canadian Stocks: Walters and Bonfil (1999)

Recent work by Walters and Bonfil (1999) provides alternative stock assessments and harvest recommendations for canary rockfish in Canadian waters. They provided two methods for estimating current stock size. The first uses recent bottom trawl CPUE data to generate estimates of absolute biomass. The second method is a "single-stock bayesian biomass estimation".

Absolute biomass from 1994-1996 CPUE

Walters and Bonfil (1999) assumed a swept-area logic and used commercial CPUE from 1996-1998 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 see little sign of non-random spacing in tow locations for Pacific ocean perch and because tows are longer than 2 nm in length. They then state that the key assumptions involve (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 flatfish, juvenile halibut and sablefish, or Pacific ocean perch and thornyheads. We suggest that the logic is not applicable to canary rockfish.

For example, the authors assume that CPUE of fished blocks are representative of adjacent non-fished blocks. Adjacent non-fished blocks are either at the same depth and untrawlable (or they would be fished) and therefore a different habitat, or 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 canary rockfish, density on soft bottom is used to infer abundance on hard bottom. While habitat preferences has not been quantified, the many surveys to the east coast Queen Charlotte Islands and traditional tow locations indicate that canary rockfish prefer to be near or on hard bottom. Thus the density estimate is based on sub-optimal habitat. To the extent that canary 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 causes 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 authors, which relates to estimating canary rockfish, is the assumption of random fishing within small areas (1-nm^2). The suggestion by the authors that tows must have random coverage since they are often 2 nm in length implies that they believe that not only is tow start location random within the block but so is tow direction. This is clearly incorrect for most shelf rockfish trawling. Fishers typically tow along “the edge”. Fishing for canary rockfish and many other species commonly takes place where the bottom has a significant gradient. Fishers rarely tow from deep to shallow for obvious reasons. Most tows attempt to follow a specific depth bracket, often as fine as 2-4 m. Since depth can easily vary up to 45 m within a nautical mile, the assumption of random towing is not true. It can be assumed that during targeted fishing for canary rockfish, CPUE is maximised within a nm. This assumption incorporates an unknown degree of overestimation bias.

The authors ignore the fact that when the fishers target on canary rockfish they trawl after locating the shoals on the sounder. Shoals of canary rockfish are typically a few hundred metres in cross-section and related to specific topographic features. Searching by sounders violates the assumption of random searching and would lead to overestimates. Conversely, fishers currently report they are often avoiding canary rockfish. This argues for an underestimation bias, since fishers will use sounders and their background knowledge to reduce canary rockfish CPUE.

In summary, the spatial averaging approach by Walters and Bonfil (1999) is a brave attempt to provide absolute biomass estimates and may be useful for some species. However, the requisite assumptions of nearly random distribution of fish and fishing effort are incorrect for canary 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 intuitively clear how "minimum" the estimates are. Nevertheless, the authors provide a coastwide biomass estimate of 1996 of 3,246 t, or 2,788 t, by summing the analysis of their selected regions. The selected region approach translates to total biomass estimates of 1,420 t for Areas 3C+3D and 912 t for Areas 5A+5B. Based on the authors estimated F_{opt} =0.095, the implicit "minimum" yield recommendation would be 129 and 83 t for Areas 3C+3D and 5A+5B, respectively and no directed fishery elsewhere (<30 t). Minimum" harvest recommendations from the two coastwide estimates translate to 294 t and 253 t, as compared with annual mean harvests of over 1,100 t.

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. As stated above, we assume that CPUE is not comparable over the long term. While the authors have provided a useful contribution by indicating the impact those trends would have as a tuning index for stock assessment, we suggest that the results are useful only as a "worst case" scenario. Their analysis suggests that the ratio of current biomass (B_{96}) to starting biomass (B_o) ranges from 0.29-0.77 among the 19 areas (combined and weighted by biomass by PMFC Area in Table 16). B_{96} in 10 areas was less than 50% of B_0. They suggest that the minimum and most probable estimates of MSY are 416 and 542 t coastwide, respectively. These compare with 550 t, the sum of the recent minimum F&O recommendations for Areas 3C+3D and 5A+5B combined.

U.S. assessments

The Washington-California population of canary rockfish has been assessed five times. Golden and Wood (1990), Sampson and Stewart (1994) and Sampson (1996) conducted catch-at-age assessment using the Stock Synthesis Model (Methot 1990). Sampson (1996) treated the U.S. population as one stock. Reviews by Crone *et al.* (1999) for the Oregon and Washington fisheries and Williams *et al.* (1999) for the northern California fishery provide the most recent assessments.

Crone *et al.* (1999) tune their catch-at-age analysis with the results of the U. S. triennial survey. The analysis entertained two scenarios to accommodate the absence of older females in the sample data. Scenario 1 assumed declining selectivity with age for females (constant M_f). Scenario 2 assumed increasing natural mortality with age (age-dependent M_f). The exploitable biomass of 1998 declines to 8% for Scenario 1, and 18% for Scenario 2, relative to the 1967 biomass. The authors used a target reference point of $F_{40\%}$, (changed from $F35_{\%}$, in Sampson, 1996) to project an ABC for the 2000 fishing year of 391-418 t depending on the scenario.

Williams *et al.* (1999) analysed fishery and survey data for the Eureka, Monterey and Conception PMFC areas (California). The review was necessitated since the Crone *et al.* (1999) analysis was limited to Oregon and Washington waters. However, they suggest that there is no basis for assuming a separate stock and suggest that recruitment to California waters may depend on the spawning biomass off Oregon and California. The California landings represent a small subset of coastwide U.S. landings. Peak landings were 330 t in 1980.

The authors developed a complex model that uses three abundance indices including the triennial survey for the California area, California bottom trawl CPUE, and a pre-recruit survey, to tune an age- and length-based sequential population analysis. Results are similar to the analysis for Oregon and Washington waters. The authors comment that the resource appears to have reached a historically low level by 1993 and has increased slightly since. The 1999 spawning biomass was estimated to be 6.6% of the unfished level. They conclude that the stock is at a very low level and probably overfished. In summary, recent U. S. assessment indicate a severe decline in abundance from poor recruitment and possibly, overfishing.

Summary of environmental considerations

Examination of groundfish recruitment trends for the north east Pacific Ocean suggests a period of overall good recruitment from 1977-1989 followed by poor recruitment in the 1990's (Beamish *et al*. in press). This implies that the last 10 years for the canary rockfish fishery off B. C. have benefited from a period of good recruitment for groundfish but the fishery is now entering a period that will rely on relatively poor recruitment from the 1990's. These conclusions roughly correspond to recruitment trends for 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. There is some suggestion of a regime shift in 1997 (McFarlane, pers. comm.[10]), but it is too early to evaluate its impact on groundfish stocks overall and certainly not on canary rockfish. 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 for groundfish overall.

Recapitulation of assessment analyses and indicators of exploitation status

The coastwide population of canary rockfish has yielded approximately 1,150 t/y from B. C. waters over for over 30 years with the possibility of lower but still significant yields extending back to the late 1950's. The population has persisted without noticeable depletion by industry. The current perception in industry is that canary rockfish are as plentiful and as large as always. Areas 3C+3D have produced 700 t/y and Areas 5A+5B have produced about 400 t/y since 1967. Under assumptions of equilibrium recruitment conditions, a first assumption is that the resource has demonstrated it can continue to withstand harvests at these levels.

Catch curve analysis of 5-year blocks of age samples, indicates a trend to increasing total mortality rates (Z) of males from about 0.03 to 0.06 if compared among decades. The change is notable in Areas 3C+3D and 5A+5B. The trend is weak or non-existent for females with most of the well sampled age groupings indicating a value of about 0.10. The estimates of 0.10 only slightly exceed the assumed M_f of 0.06-0.08, thus indicating modest exploitation. Of concern is the trend towards a reduction in the proportion of mature females in the landings, but the delayed entry into the fishery would seem to ensure a significant number of females reach maturity (Myers and Mertz 1998).

Z_m estimates coastwide and for Areas 3C+3D and 5A+5B vary from 0.04-0.07 in comparison with the proposed range of M_m of 0.02-0.04. A target harvest rate of $F=0.6*M$ implies a target Z_m of

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0.03-0.06. Thus, while males indicate more exploitation than females, catch curve analysis indicates harvests slightly above optimum, under the assumption of no trend in recruitment. It should be noted that the trends in age composition could, however, be generated by gradually decreasing recruitment since the 1960 in combination with declining overall abundance. This reflects the weakness in analysing age composition in the absence of a tuning index or estimate of absolute abundance.

Walters and Bonfil (1999) provide analyses that assume that the CPUE trends have reflected abundance over the long term to suggest stock abundance has declined to about 50% of prefishery biomass. The analysis suggests a coastwide minimum MSY of 416 t and “most likely” MSY of 542. These analyses exclude the potential yield that might come from Area 5E.

Walters and Bonfil (1999) and U.S triennial surveys both attempt to estimate absolute abundance through CPUE. The former attempt is considered unsuccessful by the authors, in that for most species, the estimates were similar to annual landings. However, they present the values as possible minimum estimates. The coastwide estimates varied from 4,932 t in 1994 to 4,452 t in 1995 and 3,246 t in 1996. Area specific “minimum” biomass estimates were 1,420 t, 912, and 413 t for Areas 3C+3D, 5A+5B, and 5C+5D, respectively, based on 1996 data.

The U. S. triennial surveys indicated a biomass of 246 t for the lower half of the west coast of Vancouver (Area 3C and southern portion of 3D) in 1985 and 1,834 t for the 1998 survey, which surveyed a smaller area.

Yield Recommendation

While the variety of conclusions is disappointing, they are consistent in indicating there is no massive underexploited stock of fish in the traditional grounds of 3C-5B. We see no basis for arguing for increased harvests in the traditional canary rockfish fishing grounds of Areas 3C+3D and 5A+5B. The cumulative effect of harvesting 1,150 t/yr has made an exploitation imprint. The imprint can be argued from being modestly expressed in females, based on age analysis, to overfishing based on the Walters and Bonfil (1999) CPUE analysis. We suggest that managers do not consider yields in excess of historical levels for these traditional fishing areas. Therefore, maximum recommended yields for Areas 3C+3D and 5A+5B are 700 and 350 t, respectively.

In view of the expected poor 1990’s’ yearclasses, declining U. S. populations of canary rockfish, the dependency of the age analysis on the assumption of stable recruitment and the low estimates generated by Walters and Bonfil (1999), we suggest a minimum harvest no more than 50% of the average yield. This translates to 350 t and 175 t for Areas 3C+3D and 5A+5B, respectively.

We cannot provide an objective basis for setting quotas in Areas 5C-5E. While fishers report increased availability in Area 5C in recent years, we have no information on where the stock boundary may lie. These may be a separate stock or they may be Areas 5A+5B fish moving northward in response to warmer ocean temperatures. We can only comment that an annual harvest of over 100 t does not seem to have truncated the age composition or led to inflated estimates of Z. For Areas 5C+5D, we suggest a low and high yield recommendation of 50-150 t, which brackets historical yields. Managers may wish to “test” this stock with higher harvests but we note the sources of concern reviewed above. We also emphasise that we cannot rely on age composition data to provide early warning should "test" quotas not be sustainable (Walters 1998).

Area 5E remains the most enigmatic of the putative canary rockfish stocks. The extended age composition implies a separate stock or stocks. Fisher comments and previous surveys suggest significant abundance but distributed on untrawlable bottom. We assume that this region could support at least a minor fishery, but note that the hook-and-line sector is beginning to fill this niche. We note the general trend towards declining historical yields for this species from south to north in B. C. waters, as the species nears the northern limit of its proven production. We suggest that it is unlikely that 5E could sustain the long-term production of Areas to the south and therefore recommend that harvest not exceed 75% of Area 5A+5B. This translates to a recommended yield range of 100-200 t. We note, however, that there is currently no monitoring of hook-and-line age composition from 5E catches.

We expect to re-assess these stocks in three to four years. By that time we will have seven years of CPUE since introduction of IVQ under, hopefully, a stable fishing environment. We will also continue to accumulate an adequate number of aged samples for most of the stocks. However, while we will be able to produce catch-at-age based analyses, we expect only marginal improvement in stock assessment. We have not identified a reliable means for surveying and doubt that IVQ-based CPUE will be a sensitive indicator of abundance over such a short term. Although we argue that the swept-area logic of Walters and Bonfil (1999) is incorrect for estimating absolute abundance, it may be an improved method for indexing relative abundance. If this were to be investigated, it could be improved by using depth as a secondary factor in combination with distance

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Table 1. Canary rockfish landings[1,2] in B. C. waters (1967-1998)

	3C+3D		5A+5B		5C	5D	5C+5D	5E		Total		Grand Total
Year	Trawl	ZN H&L	Trawl	ZN H&L	Trawl	Trawl	ZN H&L	Trawl	ZN H&L	Trawl	ZN H&L	
1967	582	0	257	0	0	12	0	0	0	839	0	839
1968	957	0	1,083	0	1	8	0	0	0	2,041	0	2,041
1969	825	0	531	0	4	3	0	0	0	1,360	0	1,360
1970	1,008	0	226	0	0	20	0	0	0	1,234	0	1,234
1971	1,077	0	225	0	0	27	0	0	0	1,302	0	1,302
1972	294	0	61	0	0	2	0	0	0	355	0	355
1973	493	0	327	0	0	8	0	0	0	820	0	820
1974	633	0	260	0	0	0	0	0	0	893	0	893
1975	672	0	212	0	0	1	0	0	0	884	0	884
1976	588	0	539	0	3	5	0	0	0	1,130	0	1,130
1977	554	0	409	0	7	8	0	1	0	971	0	971
1978	1,131	0	271	0	98	8	0	8	0	1,508	0	1,508
1979	437	0	370	0	116	9	0	1	0	924	0	924
1980	603	0	364	0	202	3	0	0	0	1,169	0	1,169
1981	315	0	144	0	116	11	0	2	0	577	0	577
1982	449	0	358	0	57	3	0	18	0	882	0	882
1983	853	0	343	0	115	4	0	10	0	1,321	0	1,321
1984	1,189	0	507	0	69	5	0	13	0	1,778	0	1,778
1985	903	0	391	0	187	3	0	9	0	1,490	0	1,490
1986	722	0	262	0	44	0	0	110	0	1,138	0	1,138
1987	695	0	560	0	91	12	0	13	0	1,359	0	1,359
1988	313	0	544	0	80	4	0	79	0	1,016	0	1,016
1989	1,173	0	514	0	111	11	0	20	0	1,818	0	1,818
1990	794	0	519	0	136	19	0	81	0	1,530	0	1,530
1991	652	0	511	0	115	41	0	29	0	1,307	0	1,307
1992	774	0	461	0	108	19	0	34	0	1,377	0	1,377
1993	835	0	184	0	54	22	0	30	0	1,103	0	1,103
1994	755	78	256	6	103	9	5	8	19	1,122	108	1,230
1995	623	23	168	3	54	6	9	3	17	848	52	900
1996	326	19	128	11	63	10	4	7	9	524	43	567
1997	387	12	225	13	26	8	5	10	9	648	39	687
1998	518	42	260	51	41	3	29	17	66	836	188	1,024
Mean	692	35	358	17	95	10	10	23	24	1,128	86	1,142
Years	67-98	94-98	67-98	94-98	78-98	67-98	94-98	77-98	94-98	67-98	94-98	67-98
Mean	684		323		81	15		24		1,111		1,154
Years	89-98		89-98		89-98	89-98		89-98		89-98		89-98

[1]Trawl data includes discards for 1996-1998

[2]Provisional nd-line landings for 1998

Table 2. Areas 3C+3D trawl landings (t), effort (hr) and CPUE (t/hr) for canary rockfish prior to introduction of IVQs in 1996.

Year	Nat.[1]	Total[2] Landings	Interviewed landings			25% Qualified landings		
			Landings	Effort	Nominal CPUE	Landings	Effort	Rolled-up Nominal CPUE
1967	USA	578	575	4,471	0.13	-	-	-
	Can	4	4	41	0.10	1	8	0.12
1968	USA	938	902	2,838	0.32	0	0	-
	Can	19	19	157	0.12	10	12	0.83
1969	USA	779	746	3,647	0.20	-	-	-
	Can	46	46	266	0.17	42	127	0.33
1970	USA	990	938	4,785	0.20	-	-	-
	Can	18	18	96	0.19	17	89	0.19
1971	USA	1,011	962	3,009	0.32	-	-	-
	Can	66	66	533	0.12	52	235	0.22
1972	USA	294	292	2,969	0.10	-	-	-
1973	USA	493	490	2,619	0.19	-	-	-
1974	Can	26	26	461	0.06	15	26	0.58
	USA	607	605	2,666	0.23	-	-	-
1975	Can	14	14	186	0.08	9	10	0.9
	USA	658	658	2,938	0.22	-	-	-
1976	Can	193	193	822	0.23	157	207	0.76
	USA	395	395	3,945	0.10	-	-	-
1977	Can	196	196	1,808	0.12	109	147	0.74
	USA	358	358	5,427	0.07	-	-	-
1978	Can	68	68	434	0.16	40	56	0.71
	USA	1,063	1,063	6,244	0.17	-	-	-
1979	Can	122	114	680	0.17	94	175	0.54
	USA	315	315	4,812	0.07	-	-	-
1980	Can	126	126	1,058	0.12	109	204	0.53
	USA	477	477	3,848	0.12	-	-	-
1981	Can	66	66	929	0.07	42	84	0.5
	USA	249	249	5,424	0.05	-	-	-
1982	Can	316	316	1,415	0.22	286	309	0.93
	USA	133	133	11,819	0.01	-	-	-
1983	Can	853	647	1,723	0.38	593	1,049	0.57
1984	Can	1,189	947	1,079	0.46	916	1,170	0.78
1985	Can	903	611	1,897	0.32	557	779	0.72
1986	Can	722	529	2,841	0.19	344	651	0.53
1987	Can	695	600	2,535	0.24	462	670	0.69
1988	Can	313	291	2,085	0.14	176	516	0.34
1989	Can	1,173	1,154	6,520	0.18	854	1,862	0.46
1990	Can	794	731	6,009	0.12	384	1,180	0.33
1991	Can	652	632	7,287	0.09	302	1,061	0.28
1992	Can	774	763	7,810	0.10	421	1,484	0.28
1993	Can	835	817	8,342	0.09	502	1,347	0.37
1994	Can	765	747	7,564	0.10	508	1,315	0.39
1995	Can	623	603	7,146	0.08	421	900	0.47

[1]U.S. total landings equals Washington and Oregon combined.

[2]U.S. interviewed landings from Washington only (Tagart and Kimura 1982).

Table 3. Areas 5A+5B trawl landings (t), effort (hr) and CPUE (t/hr) for canary rockfish prior to introduction of IVQs in 1996

Year	Nat.[1]	Total[2] Landings	Interviewed landings Landings	Effort	Nominal CPUE	25% Qualified landings Landings	Effort	Rolled-up nominal CPUE
1967	Can	41	41	535	0.08	13	32	0.41
	USA	216	215	9,431	0.02	-	-	-
1968	Can	49	49	576	0.09	31	78	0.40
	USA	1,034	937	8,488	0.11	-	-	-
1969	Can	67	67	733	0.09	37	110	0.34
	USA	464	418	13,557	0.03	-	-	-
1970	Can	6	6	80	0.08	4	12	0.33
	USA	220	220	9,264	0.02	-	-	-
1971	Can	18	18	329	0.05	6	8	0.75
	USA	207	183	7,137	0.03	-	-	-
1972	USA	61	61	9,224	0.01	-	-	-
1973	Can	29	29	119	0.24	23	80	0.29
	USA	298	298	9,625	0.03	-	-	-
1974	Can	3	3	81	0.04	1	7	0.14
	USA	257	257	8,797	0.03	-	-	-
1975	Can	23	23	403	0.06	15	17	0.88
	USA	189	189	5,179	0.04	-	-	-
1976	Can	92	92	1,558	0.06	16	49	0.33
	USA	447	447	4,620	0.10	-	-	-
1977	Can	121	121	2,356	0.05	53	192	0.28
	USA	288	288	5,165	0.06	-	-	-
1978	Can	263	263	2,692	0.10	101	242	0.42
	USA	8	8	909	0.01	-	-	-
1979	Can	308	308	3,070	0.10	211	582	0.36
	USA	62	62	1,696	0.04	-	-	-
1980	Can	276	276	2,157	0.13	198	451	0.44
	USA	88	88	1,146	0.08	-	-	-
1981	Can	144	144	1,636	0.09	69	201	0.35
1982	Can	358	330	3,203	0.10	210	706	0.30
1983	Can	343	299	2,851	0.11	152	454	0.33
1984	Can	507	321	2,506	0.13	228	686	0.33
1985	Can	391	281	2,823	0.10	162	553	0.29
1986	Can	262	211	2,931	0.07	64	253	0.25
1987	Can	560	510	4,248	0.12	245	572	0.43
1988	Can	544	529	5,792	0.09	195	652	0.30
1989	Can	514	501	5,419	0.09	238	611	0.39
1990	Can	519	498	6,526	0.08	149	577	0.26
1991	Can	511	499	8,356	0.06	161	637	0.25
1992	Can	461	449	6,241	0.07	185	588	0.32
1993	Can	184	169	3,582	0.05	59	224	0.26
1994	Can	256	247	4,413	0.06	89	211	0.42
1995	Can	168	146	4,572	0.03	55	213	0.26

[1]U.S. total landings equals Washington and Oregon combined.

[2]U.S. interviewed landings form Washington only (Tagart and Kimura 1982).

Table 4. Data sources for the canary rockfish assessment

Catch and landings data

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

2) Canadian landings from 1954 to 1995 from GFCATCH (Rutherford 1999);

3) Canadian landings from 1996-1998 stored in SQL-Server database, Assessment Methods Program, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station.

Biological data

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

Table 5. History of management regulations and quotas (t) pertaining to trawling for canary rockfish (cs: aggregate of canary and silvergray rockfish; csy: aggregate of canary, silvergray and yellowtail rockfish)

Year	Coastwide	3C	3D	5A+5B	5C	5D	5E-S	5E-N	Comments
1980-81	-		500						
1982[11]	-		350	500					• For 5A+5B, incidental limit equals 2 t when quota reached.
1983[12]		.	600-csy	1,100-cs	200-cy				
1984[1]		200-csy	1,000-csy	1,100-cs	200-cy	500-csy	950-csy		
1985[1]		200-csy	1,000-csy	1,100-cs	450		950-csy		
1986[2]	4,100-cs							Open	• 200,000 lb limit decreasing to 40,000 lb. limit
1987[2]	3,800-cs	250-cs	800-cs[13]	1,100-cs	300		750-cs	Open	• Quarterly trip limits but area/specific management • Trip limits decreasing from 150,000 to 78,000 to 5,000 lb as quota filled • Mandatory logbooks and sorting of quota rockfish in plants
1988[2]	3850-cs	300-cs	800-cs[3]	1,100-cs	300		750-cs	Open	• Quarterly trip limits decreasing from 30,000 to 11,000 lb
1989[2]	1575	600[3]		425	300		500[14]	Open	• 2 trips per month and coastwide management but with attention to area quotas
1990[2]	1475	[15]	[5]				500[16]	Open	• Introduction of trip options: A and B and trip limits 15,000 to 11,000 lb
1991[2]	1350	[5]	[5]				125[17]	Closed	• Trip limits 11,000 to 4,400
1992[2]	1275	[5]	[5]				50	Closed	• No trip options and trip limits 10,000 to 2,200
1993[2]	2150-cs (850-c)	[5]	[5]					Closed	• Dockside monitoring • Limited trips/month and trip limit aggregates with silvergray rockfish
1994[2]	12,5784[18]							Closed	• Canary rockfish one of 6 species in aggregate • A, B or C options and trip limit averaging and relinquishments allowed
1995[2]	9,716[19] (867-c)								• New aggregate • Early closure of the fishery
1996[1]	2,085-cs (738-c)								• New aggregates, halibut bycatch caps and at-sea observer coverage for A options • New option A, B and C • New fishing period averaging and trimesters instead of quarters
1997-98[2]	929	503		345	81				• No aggregates and new fishing year and IVQ's
1998-99[1]	929	503		345	81				
1999-00[1]	921	499		342	80				

[11] Based on final published management plan
[12] Based on draft of plan
[13] Minor area 127 included in 3D instead of 5A+5B
[14] 250 t included in coastwide quota. If attained, then increased to 500 t.
[15] Winter closure
[16] 250 t included in coastwide quota. If attained, then increased to 500 t.
[17] 125 t included in coastwide quota. If attained, possibly increased.
[18] Included in aggregate with Pacific ocean perch, yellowmouth, rougheye, canary, silvergray and yellowtail rockfish
[19] Included in aggregate with Rougheye, canary, silvergrey, yellowtail and widow rockfish

Table 6. History of hook-and-line management of canary rockfish

Year	Coastwide limit (aggregate limit)	Comments
1994		• No mention of canary rockfish limits but retention permitted as part of ZN license
1995	8,925 t	• Introduction of dockside monitoring • Part of aggregate #3 with silvergray, 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 silvergray rockfish. • Trip limits 3,000-7,000
1997	906 t (2,417 t)	• Aggregate #3 with silvergray 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 silvergray rockfish • Trip limit 2,500-7,000
1999/ 2000	76 t (213 t)	• Aggregate #3 with silvergray rockfish • Trip limit 1,800-7,000

Table 7. CPUE indices from the domestic observer program (1996-1998). "Nominal" includes all tows, median and depth stratified indices include tows with canary rockfish.

Year	Area	All tows	All tows	All tows	71-100			51-70; 101-120		
		# of tows	Nominal CPUE[1] t/h	Median CPUE kg/h	# of tows	Total CPUE t/h	Median CPUE kg/h	# of tows	Total CPUE t/h	Median CPUE t/h
1996	3C+3D	7,362	0.016	18.1	1,148	0.113	25.5	301	0.042	12.4
1997	3C+3D	5,271	0.022	26.7	904	0.141	34.5	303	0.141	20.9
1998	3C+3D	6,174	0.025	27.2	912	0.171	36.3	485	0.134	26.2
1996	5A+5B	7,188	0.010	6.2	563	0.063	8.2	542	0.029	6.0
1997	5A+5B	6,200	0.023	8.8	854	0.076	10.9	755	0.043	8.6
1998	5A+5B	5,899	0.027	8.7	1,016	0.072	10.4	590	0.064	11.3
1996	5C+5D	4,934	0.009	7.1	202	0.117	12.4	246	0.045	6.3
1997	5C+5D	4,256	0.005	5.0	117	0.104	19.3	126	0.031	3.5
1998	5C+5D	4,492	0.006	4.9	133	0.117	9.1	113	0.033	3.9
1996	5E	1,225	0.004	7.8	0	na	na	6	na	na
1997	5E	673	0.011	7.8	0	na	na	4	na	na
1998	5E	785	0.012	26.1	0	na	na	2	na	na
1996	3C-5E	20,709	0.012	11.1	1,913	0.097	16.5	1,095.00	0.036	7.5
1997	3C-5E	16,400	0.018	13.6	1,875	0.105	21.8	1,188.00	0.062	10.2
1998	3C-5E	17,350	0.021	14.3	2,061	0.115	19.0	1,190.00	0.088	15.0

Table 8. Number of vessels landing non-hake bottom trawl catches, 1996-1998

Retained catch	1996	1997	1998
100%	117	83	66
90%	79	51	45
75%	58	35	32
50%	33	18	17
Total (t)	15,791	12,986	14,016

Table 9. Summary of canary rockfish samples in GFBio (sample size variable)

Year	Samples	Samples usable for catch curve analysis	Samples from comm. landings	Aged specimens	Un-aged specimens	Total	Samples by Region			
							3C+3D	5A+5B	5C+5D	5E
1962	1	0	1	0	90	90	0	0	0	0
1969	2	0	2	0	453	453	0	0	0	0
1976	2	0	2	0	269	269	0	0	0	0
1977	3	3	3	214	678	892	2	1	0	0
1978	10	10	10	978	1,870	2,848	1	4	4	1
1979	4	4	4	390	725	1,115	2	1	1	0
1980	6	3	6	300	1,481	1,781	0	1	2	0
1981	1	1	1	24	253	277	0	1	0	0
1982	3	3	3	77	629	706	2	1	0	0
1983	4	3	4	250	872	1,122	2	1	0	0
1984	3	3	3	212	201	413	3	0	0	0
1985	6	5	6	401	998	1,399	4	0	1	0
1986	3	2	3	75	666	741	2	0	0	0
1988	4	3	4	216	709	925	1	1	0	1
1989	1	1	1	25	125	150	1	0	0	0
1990	8	8	5	325	156	481	1	4	3	0
1991	39	8	16	748	245	993	2	4	2	0
1992	3	3	0	157	0	157	0	2	1	0
1993	4	4	0	232	0	232	3	1	0	0
1994	13	11	2	591	102	693	1	7	3	0
1995	5	5	0	261	0	261	4	0	1	0
1996	9	7	3	382	186	568	4	1	2	0
1997	15	13	6	485	63	548	4	5	0	4
1998	43	21	21	1,413	3,210	4,623	16	2	1	2
Total	192	121	106	7,756	13,981	21,737	55	37	21	8

Table 10. Number of times two age readers agreed on age of canary rockfish from 1998 samples.

Age	n	Agreement	Difference in years		
			1	2	3+
5	5	0.80	0.20	0.00	0.00
6	4	0.50	0.50	0.00	0.00
7	4	0.50	0.25	0.25	0.00
8	4	0.75	0.00	0.25	0.00
9	11	0.55	0.27	0.09	0.09
10	18	0.61	0.22	0.11	0.06
11	12	0.50	0.25	0.25	0.00
12	22	0.36	0.36	0.14	0.14
13	23	0.22	0.61	0.17	0.00
14	18	0.56	0.33	0.06	0.06
15	12	0.67	0.33	0.00	0.00
16	10	0.30	0.60	0.00	0.10
17	6	0.33	0.33	0.33	0.00
18	18	0.33	0.11	0.33	0.22
19	5	0.20	0.40	0.40	0.00
20	3	0.00	0.67	0.00	0.33
21	4	0.00	0.50	0.00	0.50
22	5	0.40	0.40	0.00	0.20
23	3	0.00	0.67	0.33	0.00
24	2	0.00	0.50	0.00	0.50
25	5	0.60	0.40	0.00	0.00
26	2	0.00	0.50	0.00	0.50
27	1	0.00	0.00	1.00	0.00
28	2	0.00	0.50	0.50	0.00
29	1	0.00	1.00	0.00	0.00
30	3	0.33	0.00	0.67	0.00
31-40	11	0.10	0.30	0.10	0.50
40+	17	0.06	0.28	0.22	0.44

Table 11a. Summary of estimates of Z (slope) for male canary rockfish

Stock	Years	n	N	slope	Ages
Coast	1977-1980	1342	20	-0.017	14-30
	1981-1985	589	15	-0.040	14-30
	1986,1988-1990	432	14	-0.027	14-30
	1991-1995	989	31	-0.067	14-30
	1996-1998	1239	41	-0.042	14-30
3C+3D	1977-1979	330	5	*0.006*	14-30
	1982-1985	515	11	-0.041	14-30
	1986, 1988-1990	107	5	-0.025	14-30
	1991, 1993-1995	296	8	-0.072	14-30
	1996-1998	679	24	-0.053	14-30
5A+5B	1977-1980	518	7	-0.033	14-30
	1981-1983	51	3	-0.006	14-30
	1988, 1990	185	5	-0.013	14-30
	1991-1994	470	14	-0.063	14-30
	1996-1998	238	8	-0.047	14-30
5C+5D	1978-1980	447	7	-0.013	14-30
	1990-1992	201	6	-0.065	14-30
	1994-1998	296	7	-0.021	14-30
5E	1978, 1997-1998	209	7	-0.011	14-30
	1978, 1997-1999	209	7	-0.019	14-50

Table 11b. Summary of estimates Z (slope) for female canary rockfish

Stock	Years	n	N	slope	ages
Coast	1977-1980	540	20	-0.090	14-30
	1981-1985	375	15	-0.107	14-30
	1986,1988-1990	209	14	-0.089	14-30
	1991-1995	661	31	-0.109	14-30
	1996-1998	819	41	-0.100	14-30
3C+3D	1977-1979	90	5	-0.045	14-30
	1982-1985	343	11	-0.105	14-30
	1986, 1988-1990	76	5	-0.046	14-30
	1991, 1993-1995	230	8	-0.102	14-30
	1996-1998	508	24	-0.095	14-30
5A+5B	1977-1980	168	7	-0.079	14-30
	1981-1983	25	3	-0.030	14-30
	1988, 1990	73	5	-0.064	14-30
	1991-1994	291	14	-0.092	14-30
	1996-1998	184	8	-0.092	14-30
5C+5D	1978-1980	219	7	-0.080	14-30
	1990-1992	99	6	-0.069	14-30
	1994-1998	173	7	-0.061	14-30
5E	1978, 1997-1998	95	7	-0.058	14-30
	1978, 1997-1999	95	7	-0.068	14-28

Table 12. Formulas used for estimation of life history parameters

1) Growth formula (see Case 1: Schnute 1981):

2) Length/weight formula:

$$W\ (g) = c * L\,(cm)^{d},$$

3) Maturity formula:

$$P_i = \frac{e^{\alpha + \beta x}}{1 + e^{\alpha + \beta x}},$$

4) Hoenig (1983) formula for estimation of M:

$$\ln(Z) = 1.44 - 0.982(\ln(t_{\max})).$$

Table 13. Biological parameters used for calculation of target reference points

Biological parameter	Biological parameter	Estimate	Standard error
Length-at-age for males	*a*	0.132	0.008
	b	2.108	0.203
	y_1	17.475	0.980
	y_2	53.749	0.204
	τ_1	3.000	-
	τ_2	60.000	-
Length-at-age for females	*a*	0.113	.016
	b	1.732	0.386
	y_1	20.568	1.353
	y_2	58.509	0.879
	τ_1	3.000	-
	τ_2	60.000	-
Weight-length for males[1]	*a*	0.016	-
	b	3.030	-
Weight-length for females[20]	*a*	0.015	-
	b	3.030	-
Maturity	$Age_{50\%}$	14.02	-
	a	-4.792	-
	b	0.342	-
Selectivity for females	*5*	0.000	-
	6	0.012	-
	7	0.027	-
	8	0.060	-
	9	0.123	-
	10	0.221	-
	11	0.337	-
	12	0.469	-
	13	0.590	-
	14	0.689	-
	15	0.789	-
	16	0.879	-
	17	0.885	-
	18	0.988	-
	19+	1.000	-

[20] From Crone *et al*. (1999). All data sources.

Table 14. 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)

Table 15. Biomass estimates and quota recommendations for canary rockfish from Walters and Bonfil (1999).

		Year	Region	From Walters and Bonfil (1999)					F&O	
				Biom. (t)	F_{1996}	B_{1996}/B_0^*	Most likely MSY (t)	Minimum MSY (t)	1997 Rec. (t)	1997 Quota (t)
Coastwide estimates (Table 2)*	absolute densities from CPUE	1994	Coast	4,932	0.16					
Coastwide estimates (Table 2)*	absolute densities from CPUE	1995	Coast	4,452	0.13					
Coastwide estimates (Table 2)*	absolute densities from CPUE	1996	Coast	3,246	0.14			294		
Area estimates (from Table 3)*	absolute densities from CPUE	1996	3C+3D	1,420				129	350-525	503
Area estimates (from Table 3)*	absolute densities from CPUE	1996	5A+5B	912				83	200-400	345
Area estimates (from Table 3)*	absolute densities from CPUE	1996	5C+5D	413						
Area estimates (from Table 3)*	absolute densities from CPUE	1996	5E	43						
Area estimates (from Table 3)*	absolute densities from CPUE	1996	Coast	2,788				253		
Coastwide estimates of MSY	from single-stock Bayesian analysis	1997	Coast				542	416	550-925	929
B_{1996}/B_0^*	from single-stock Bayesian analysis	1996	3C+3D			0.50				
B_{1996}/B_0^*	from single-stock Bayesian analysis	1996	5A+5B			0.53				
B_{1996}/B_0^*	from single-stock Bayesian analysis	1996	5C+5D			0.32				
B_{1996}/B_0^*	from single-stock Bayesian analysis	1996	5E			0.65				
B_{1996}/B_0^*	from single-stock Bayesian analysis	1996	Coast			0.49				

* Expanded to regional and coastwide estimates by weighting by biomass estimates

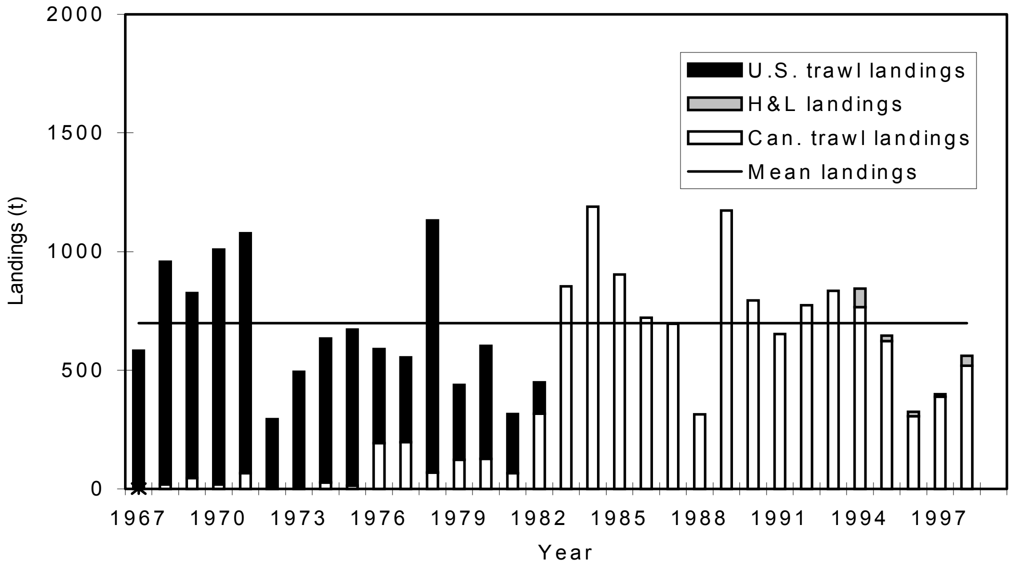

Figure 1a. Landings history for canary rockfish in Areas 3C+3D (1967-1998)

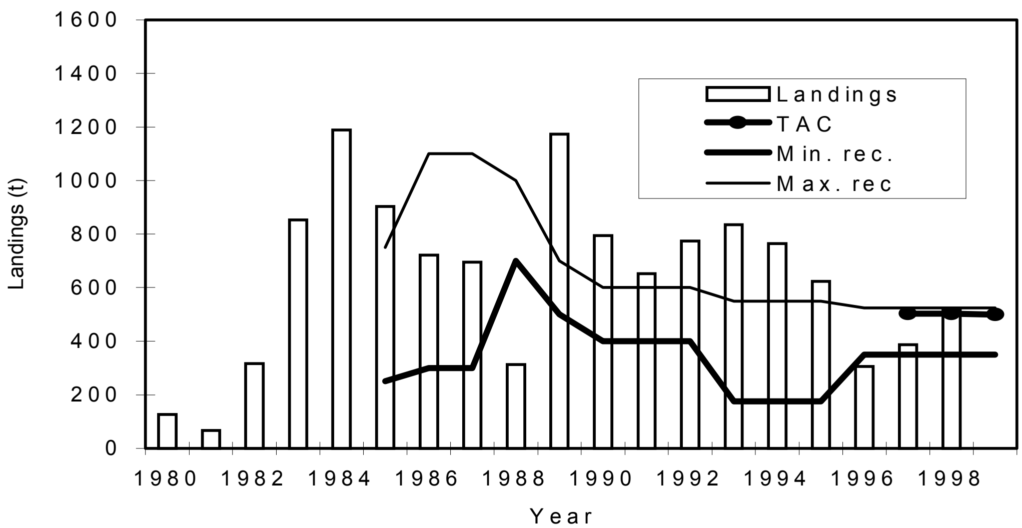

Figure 1b. Landings history and chronology of recommendations and TACs for canary rockfish in Areas 3C+3D.

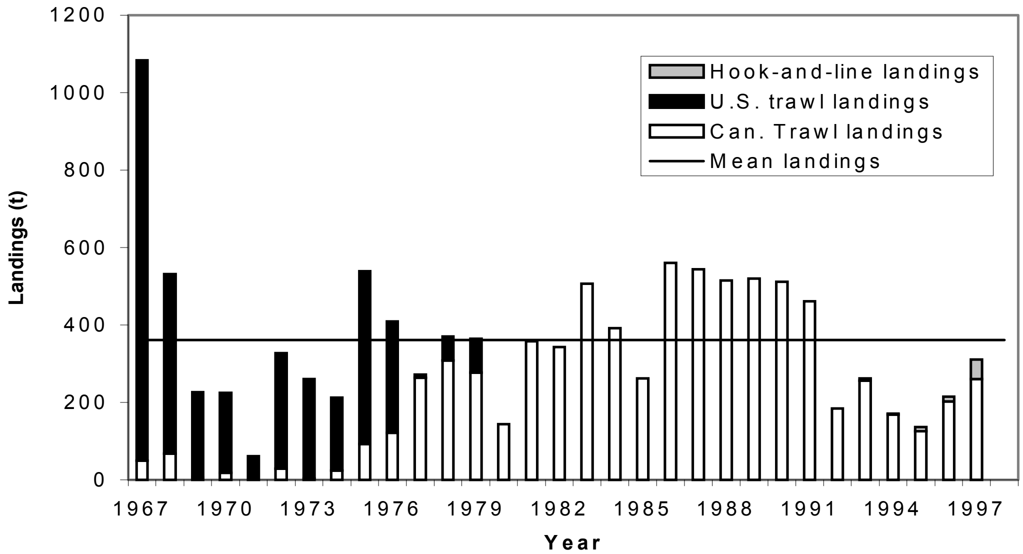

Figure 2a. Landings history for canary rockfish in Areas 5A+5B (1967-1998)

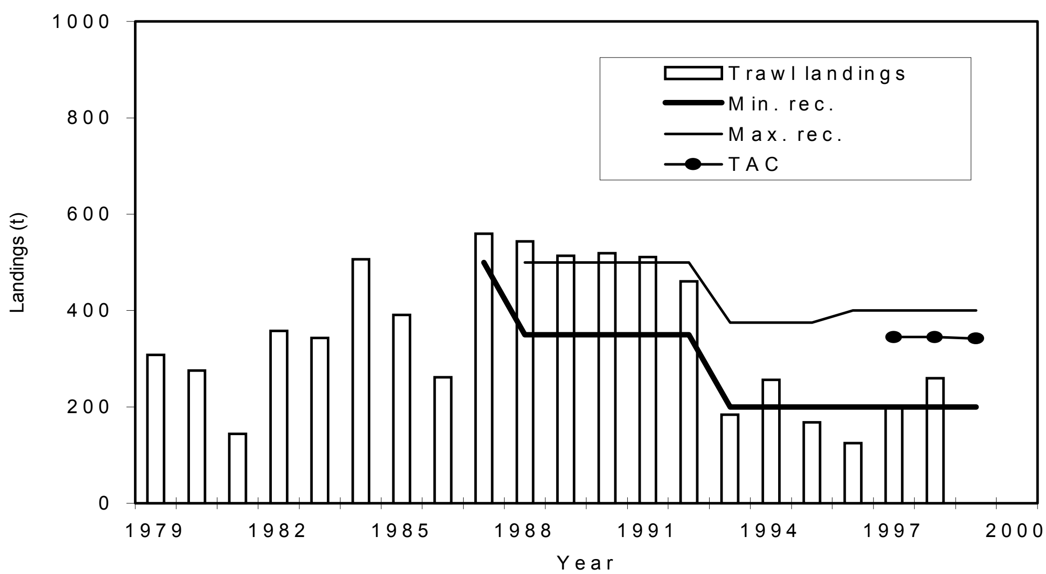

Figure 2b. Landings history and chronology of recommendations and TACs for canary rockfish in Areas 5A+5B.

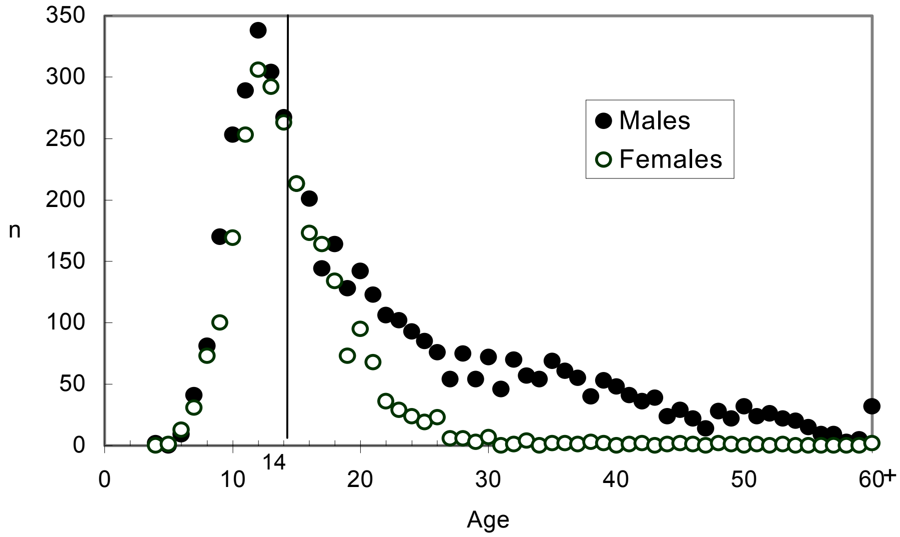

Figure 3. Numbers at age from all samples representative of commercial fishing (1977-1998) (terminal age 60+).

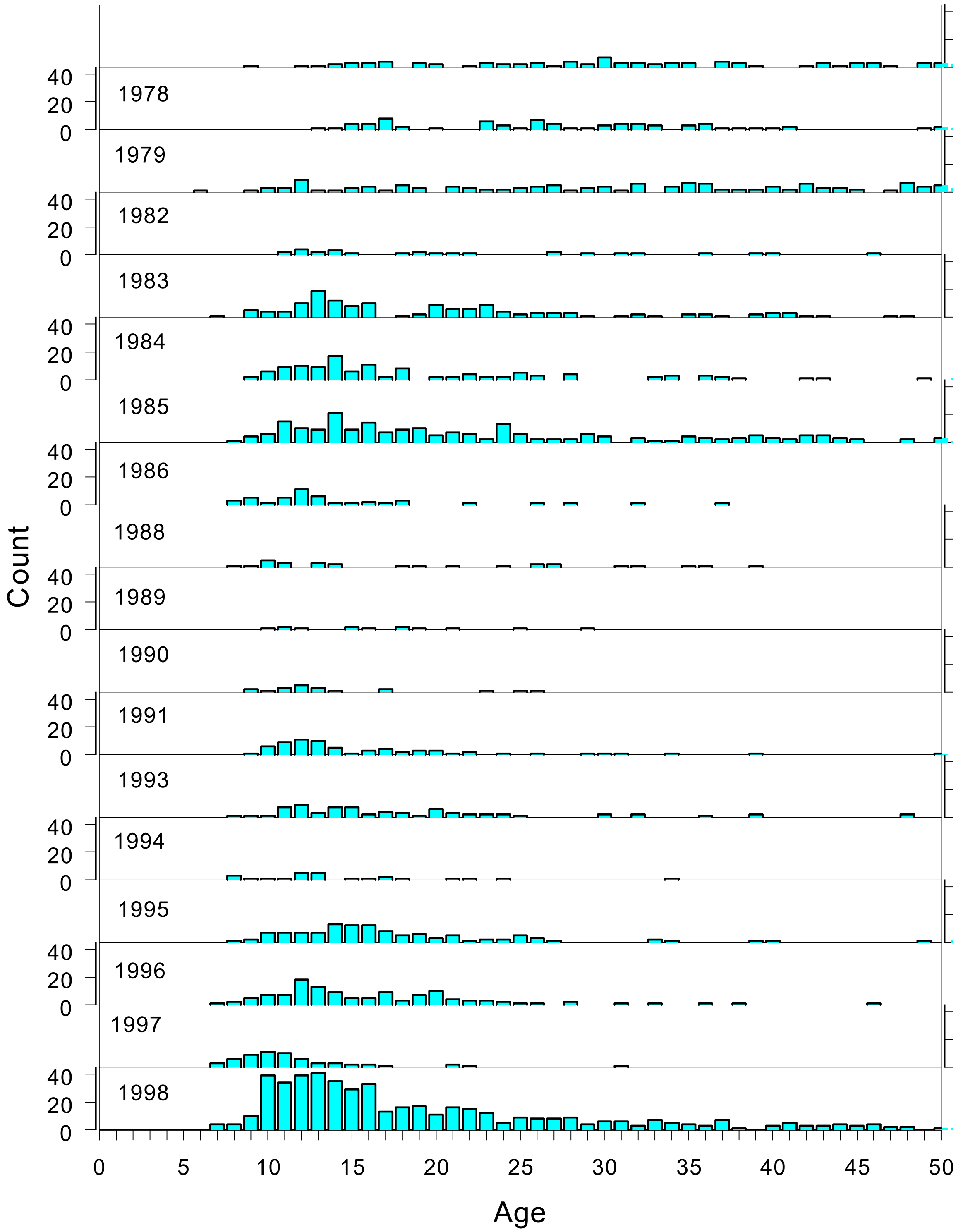

Figure 4a. Age frequency of male canary rockfish in Areas 3C+3D, all years.

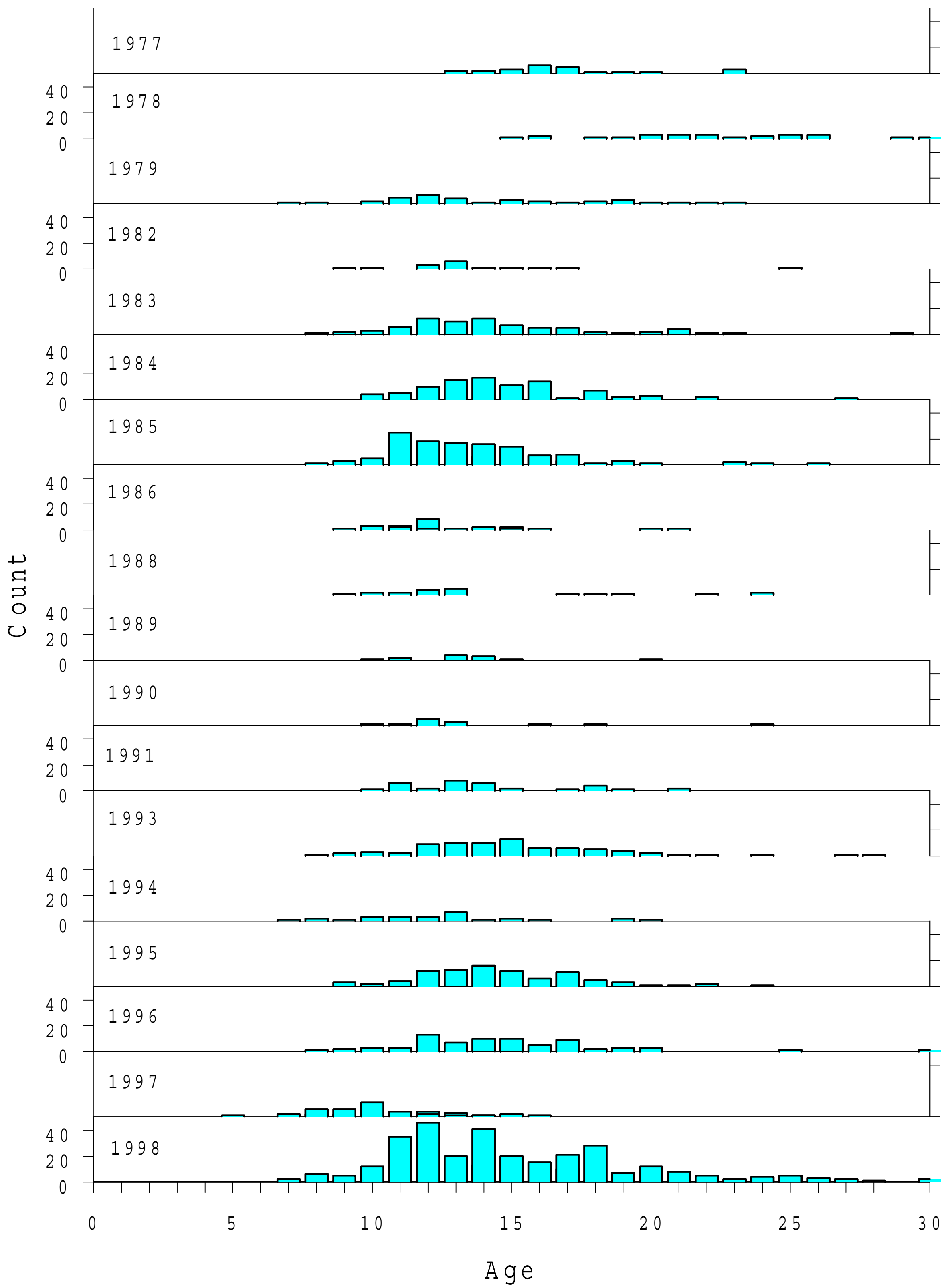

Figure 4b. Age frequency of female canary rockfish in Areas 3C+3D, all years

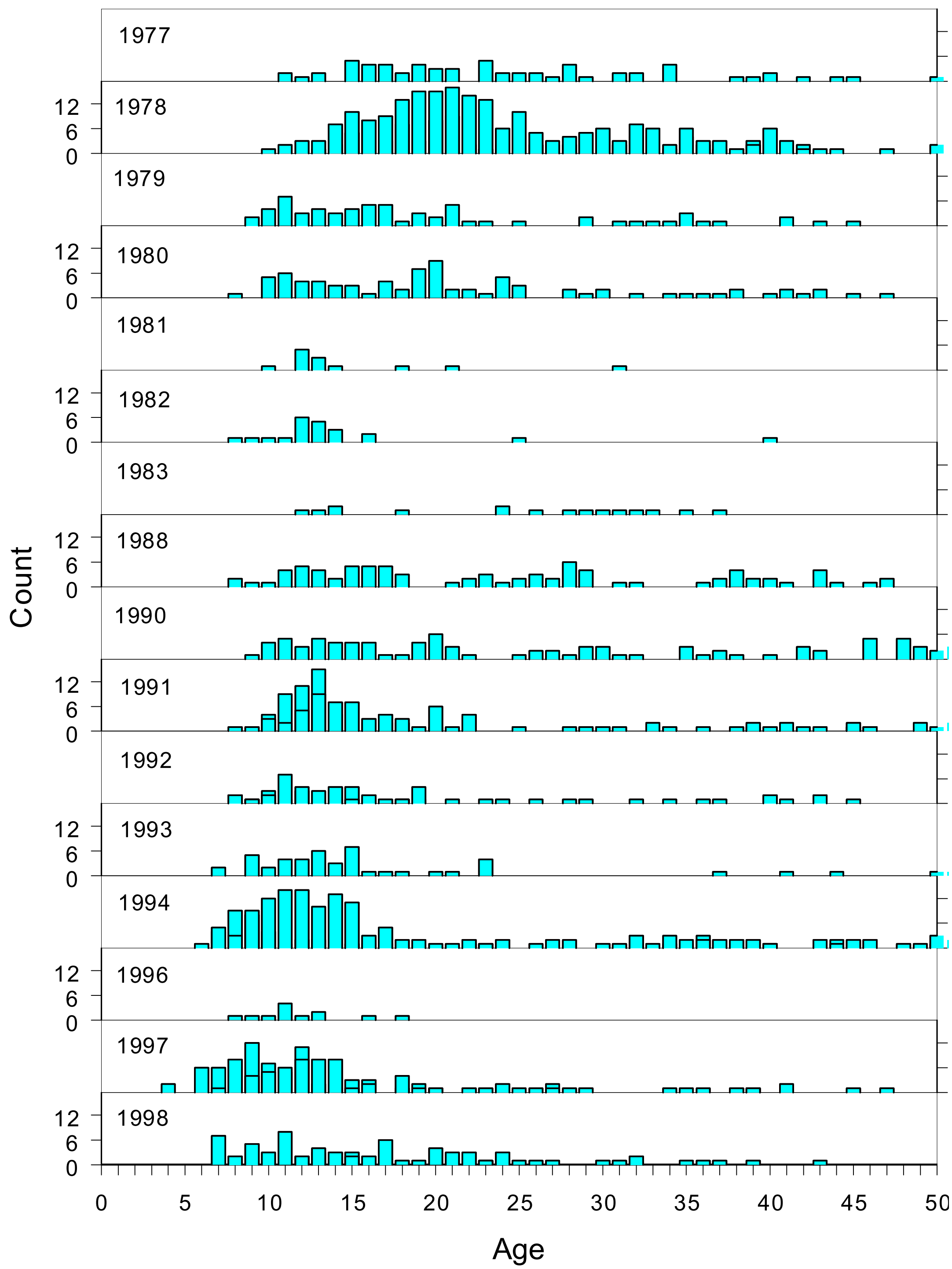

Figure 5a. Age frequency of male canary rockfish in Areas 5A+5B, all years

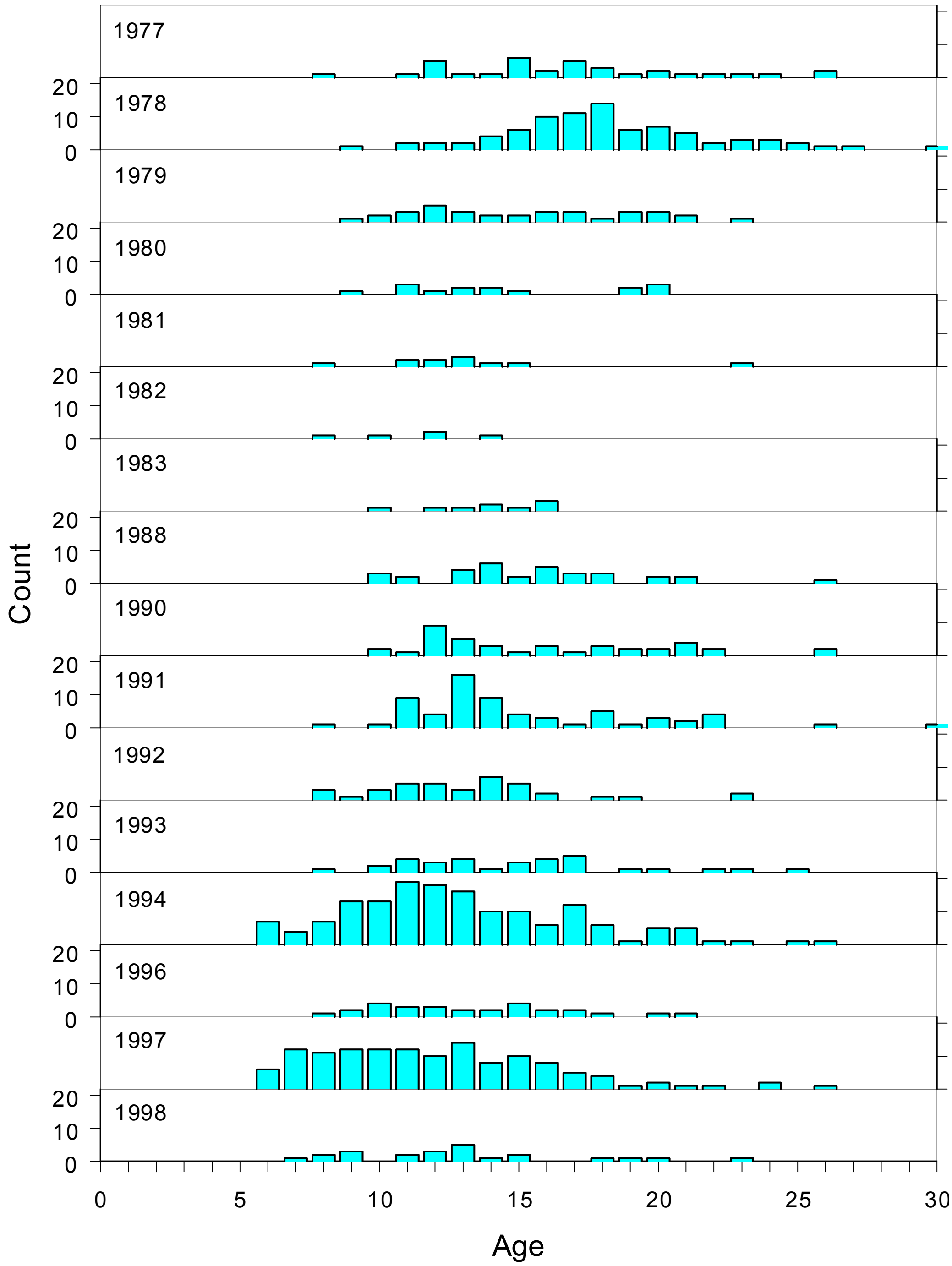

Figure 5b. Age frequency of female canary rockfish in Areas 5A+5B, all years

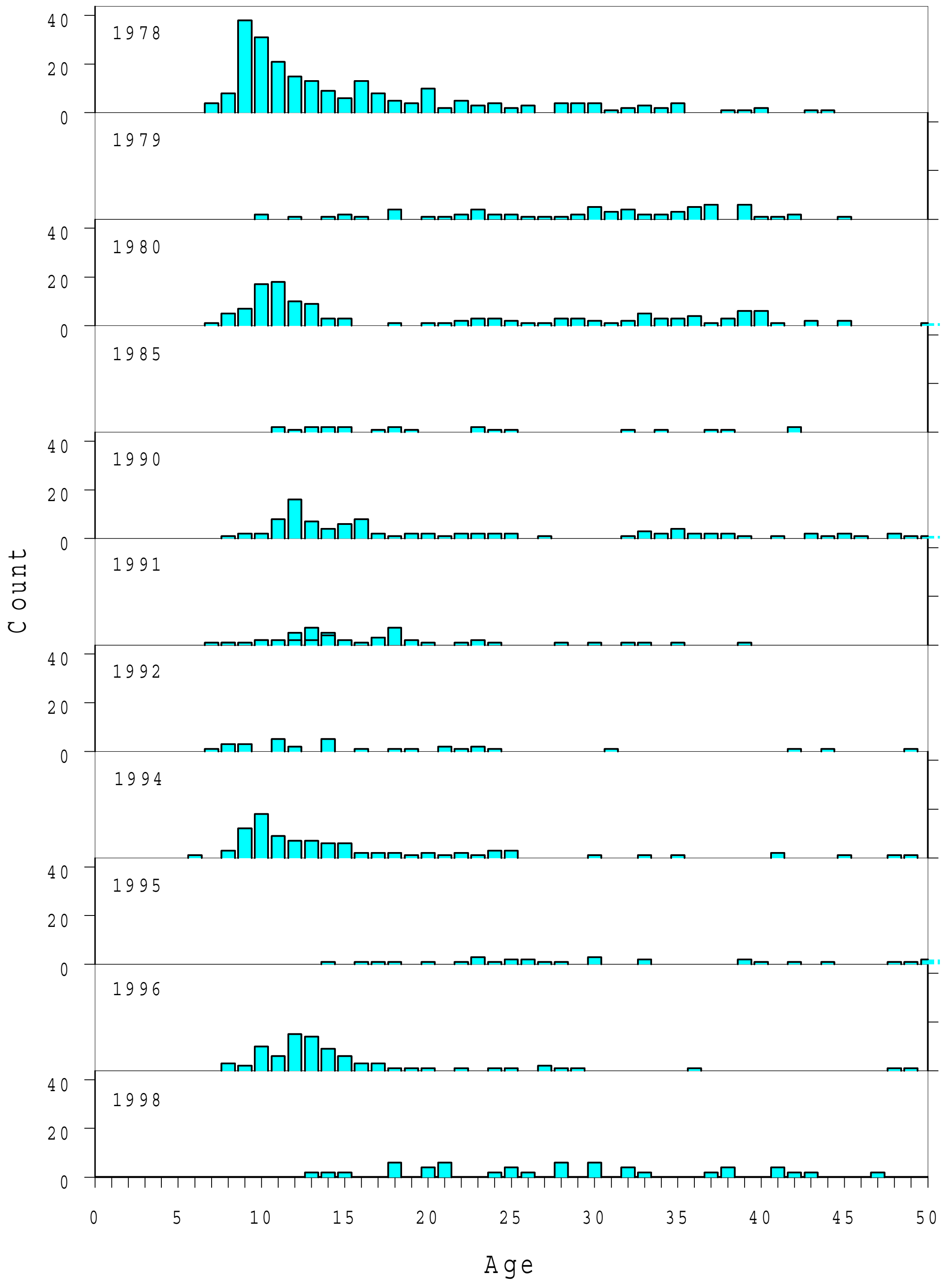

Figure 6a. Age frequency of male canary rockfish in Areas 5C+5D, all years

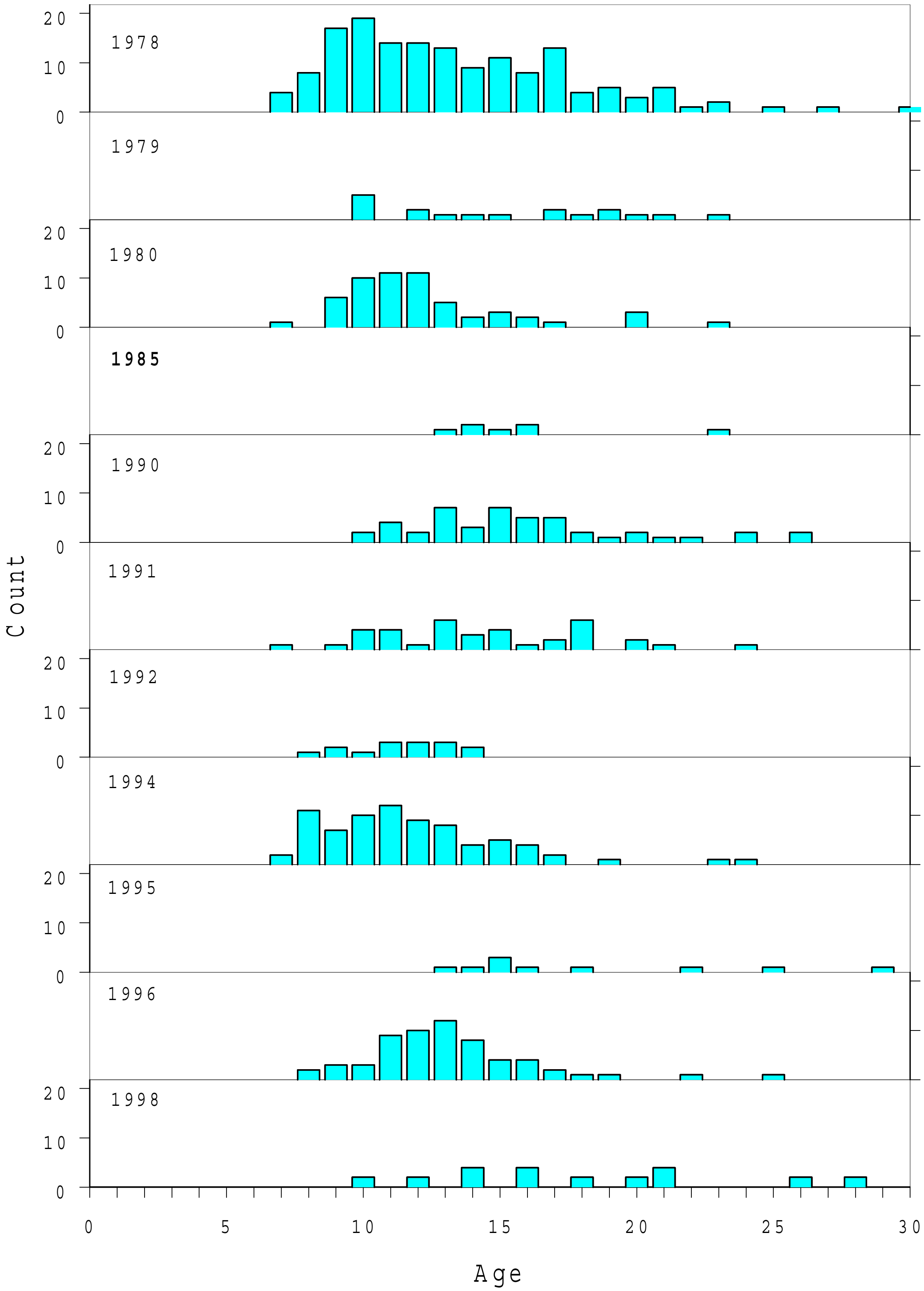

Figure 6b. Age frequency of female canary rockfish in Areas 5C+5D, all years

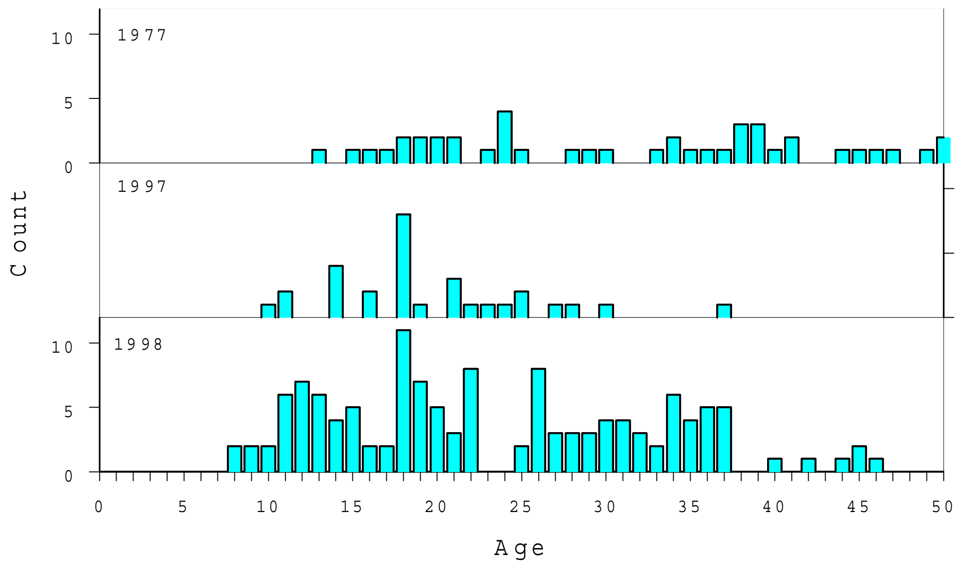

Figure 7a. Age frequency of male canary rockfish in Areas 5E, all years

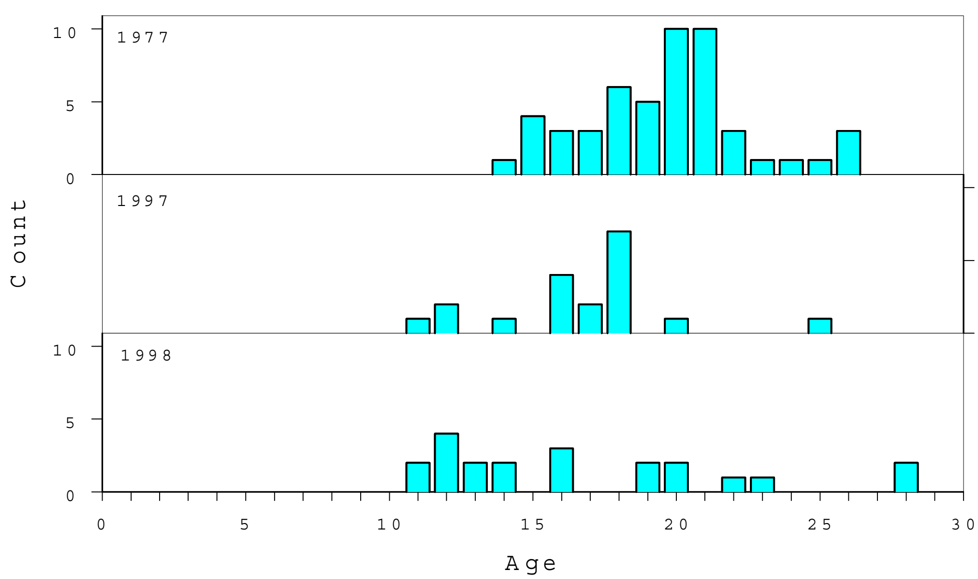

Figure 7b. Age frequency of female canary rockfish in Areas 5E, all years

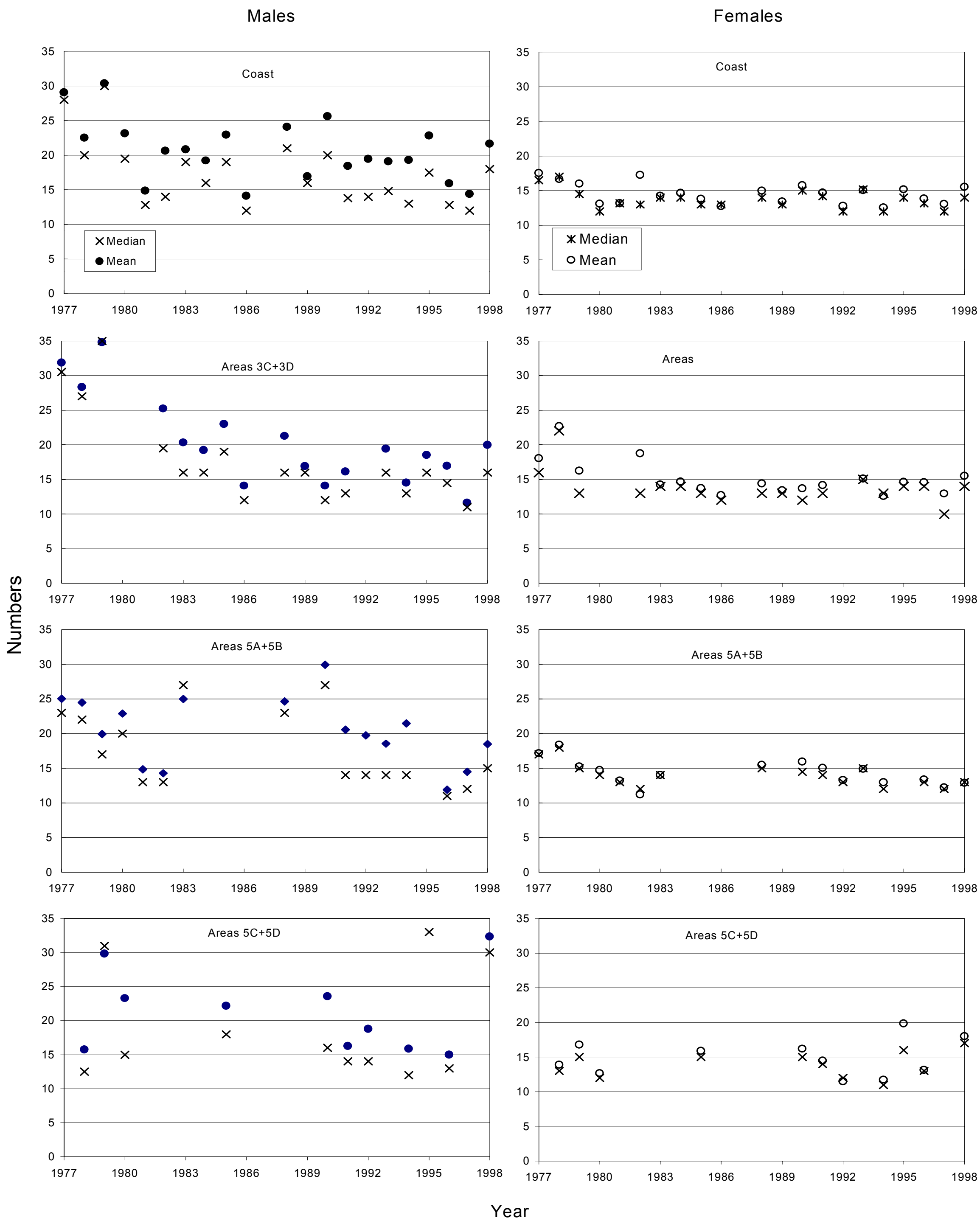

Figure 8. Mean and median size of canary rockfish by region, 1977-1998

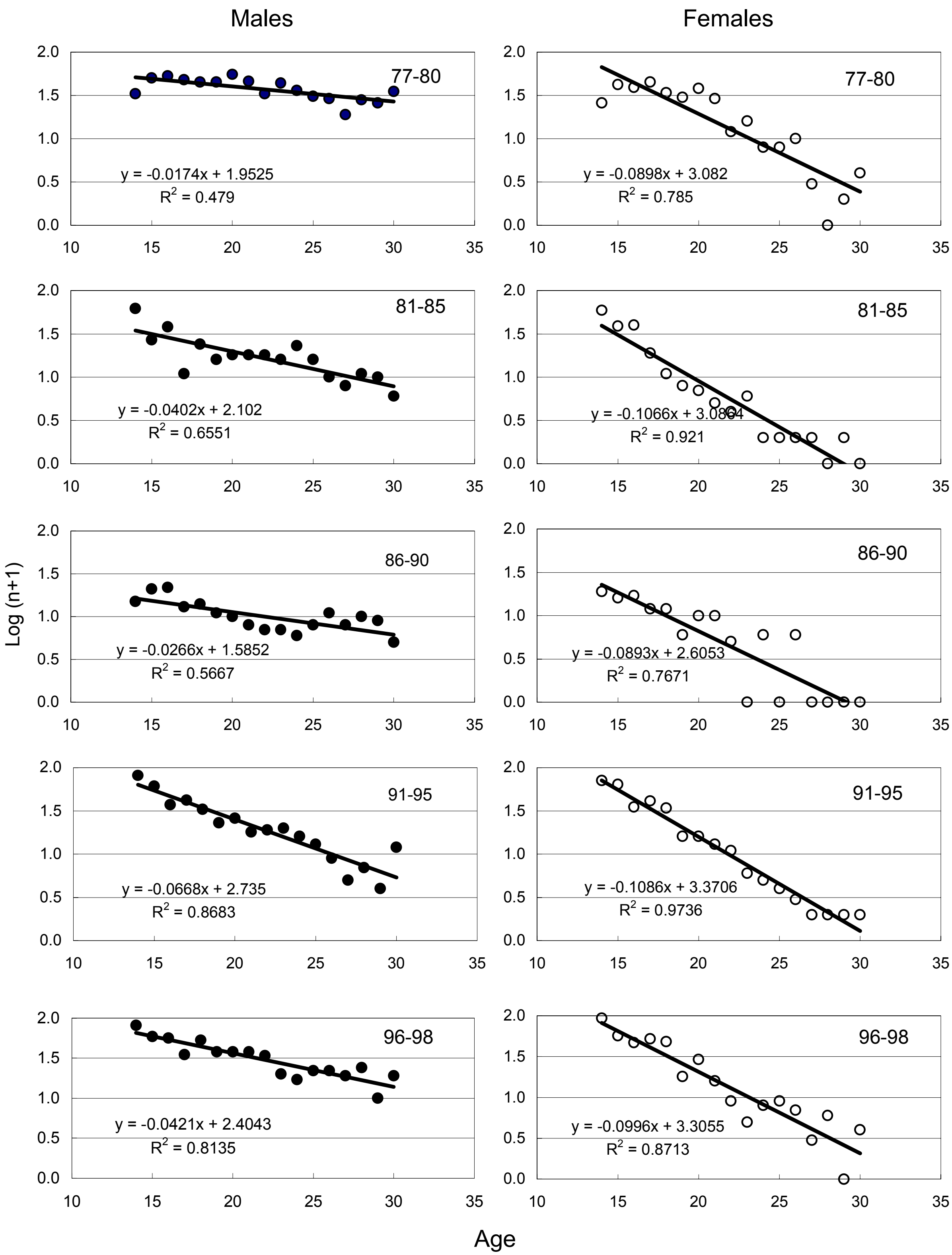

Figure 9. Catch curve analysis for canary rockfish, all samples.

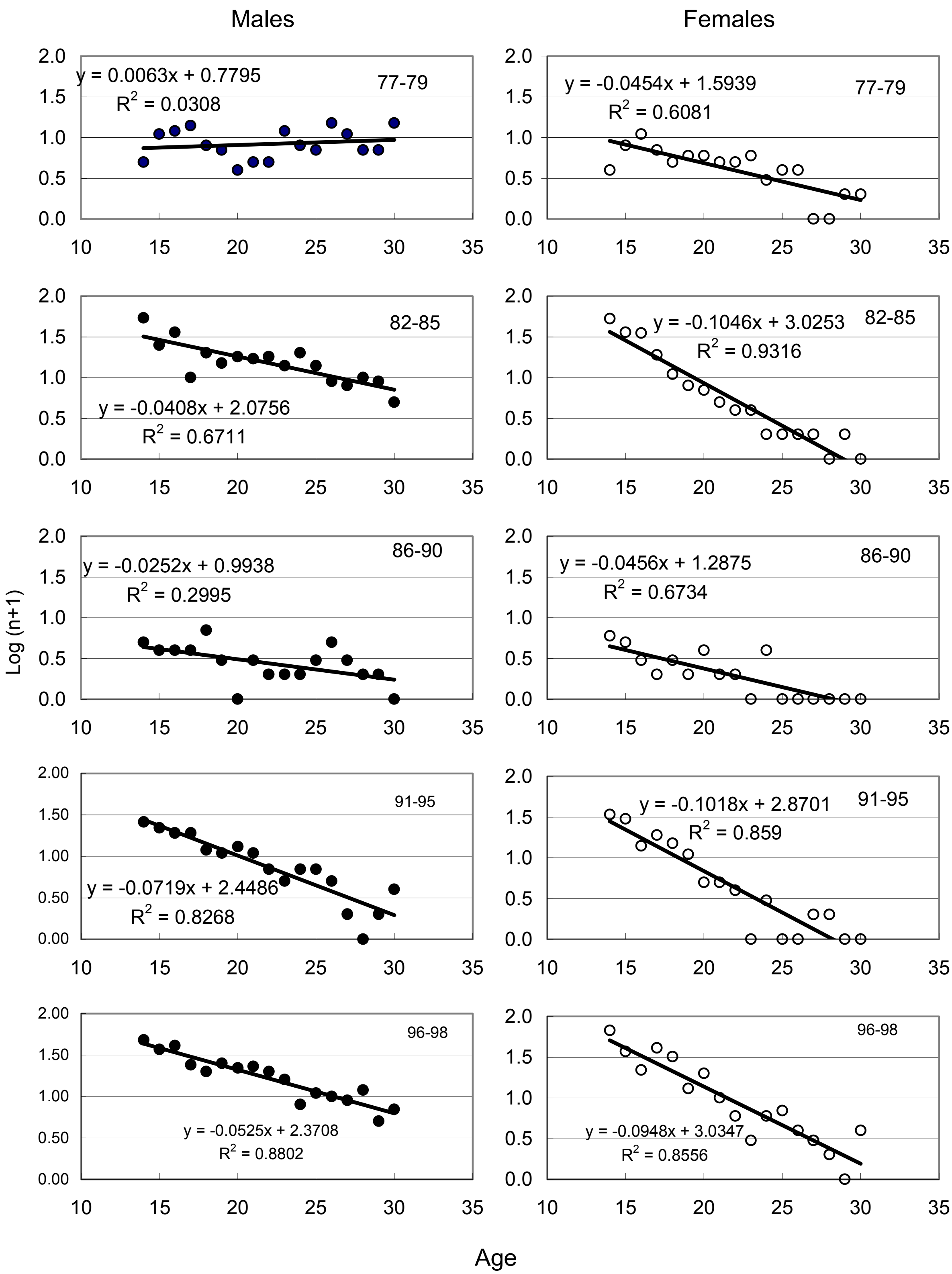

Figure 10. Catch curve analysis for canary rockfish, Areas 3C+3D.

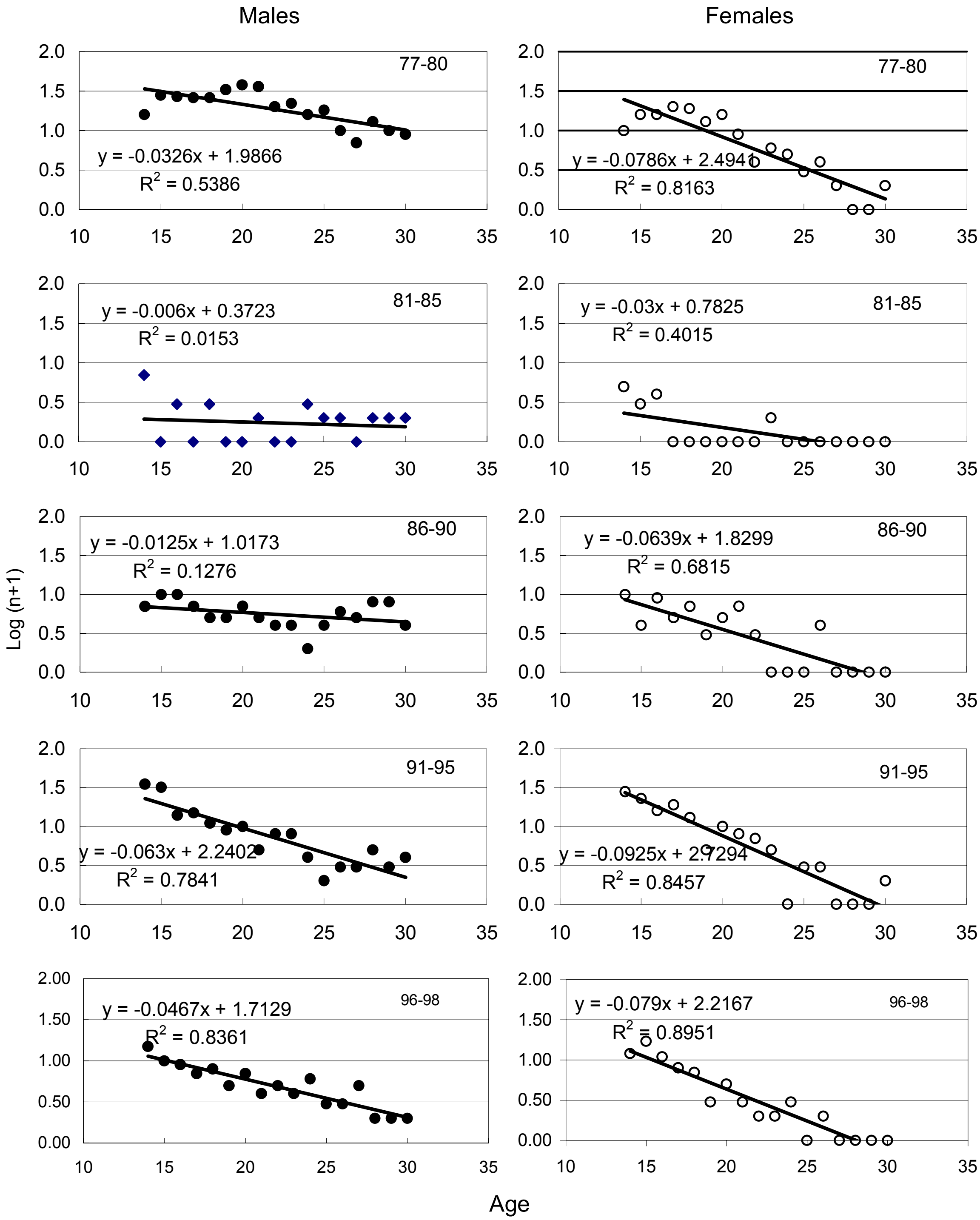

Figure 11. Catch curve analysis for canary rockfish, Areas 5A+5B

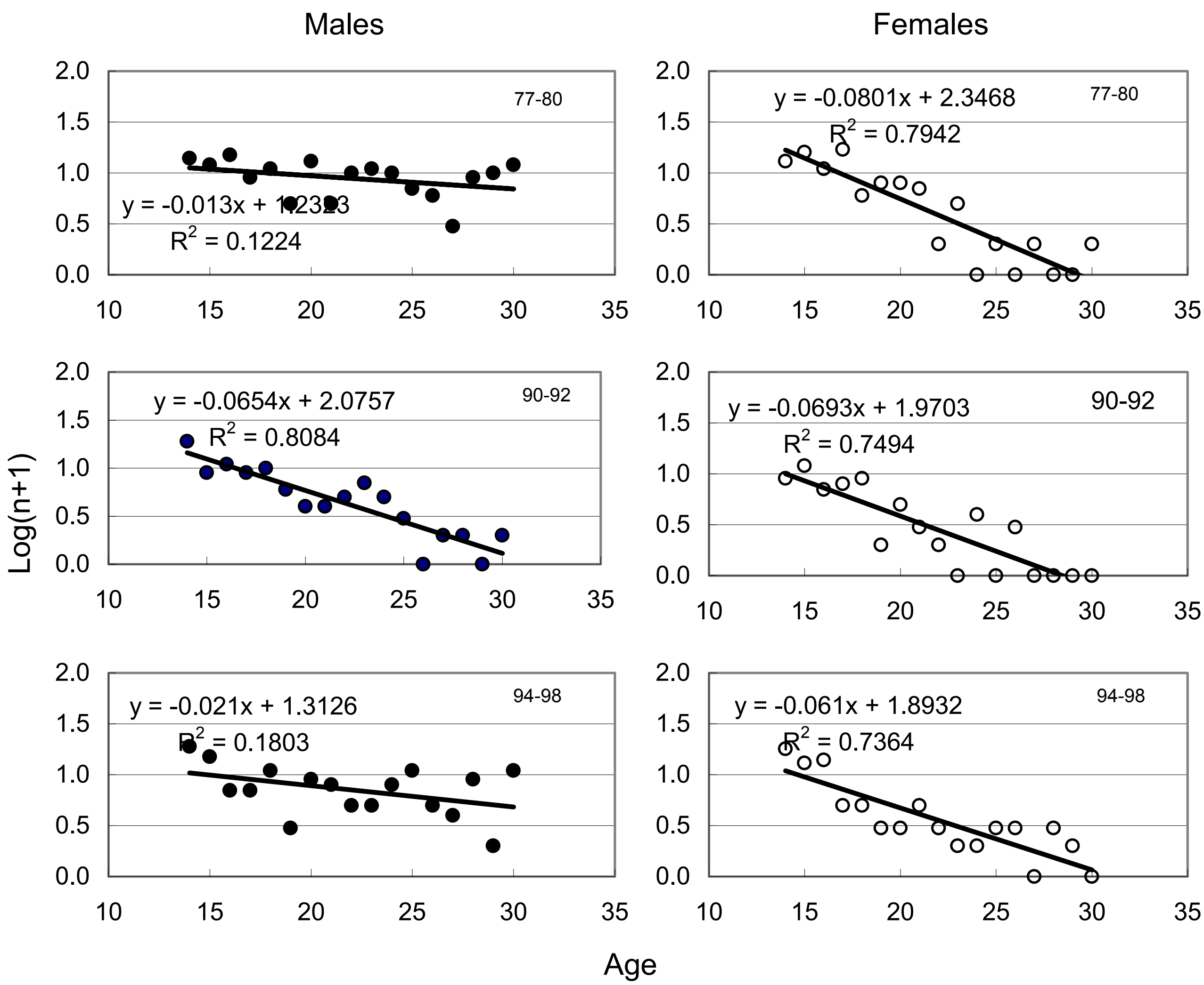

Figure 12. Catch curve analysis for canary rockfish, Areas 5C+5D

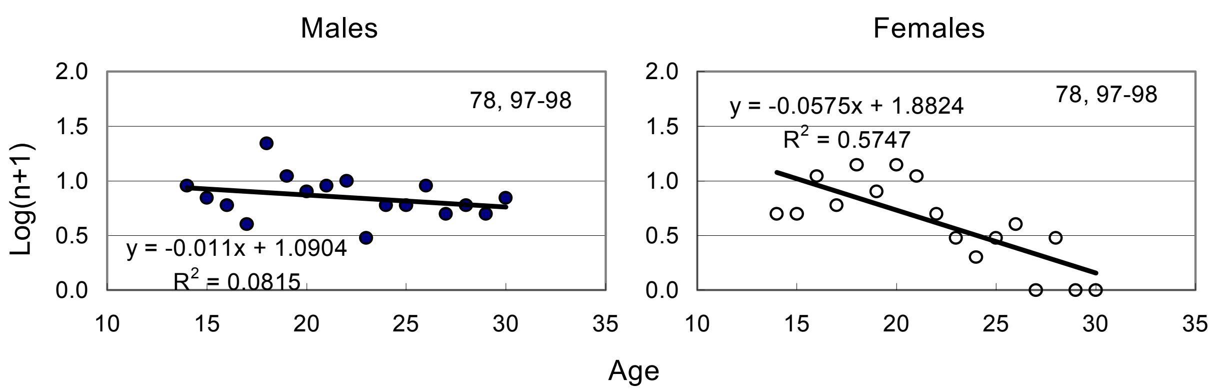

Figure 13. Catch curve analysis for canary rockfish, Area 5E

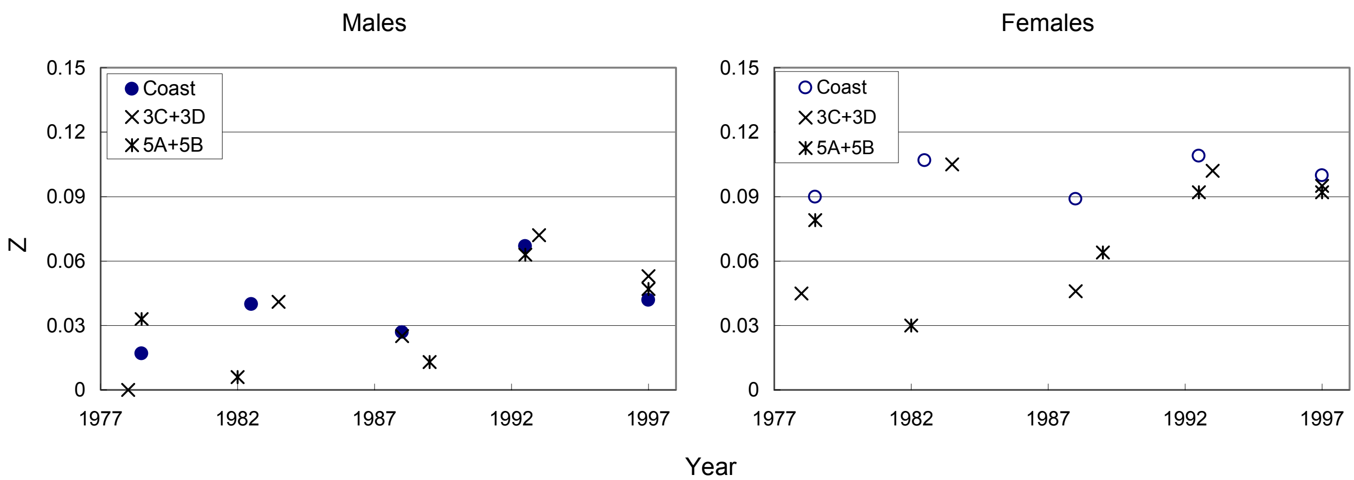

Figure 14. Plot of estimates of Z from canary rockfish against mid-point of year group

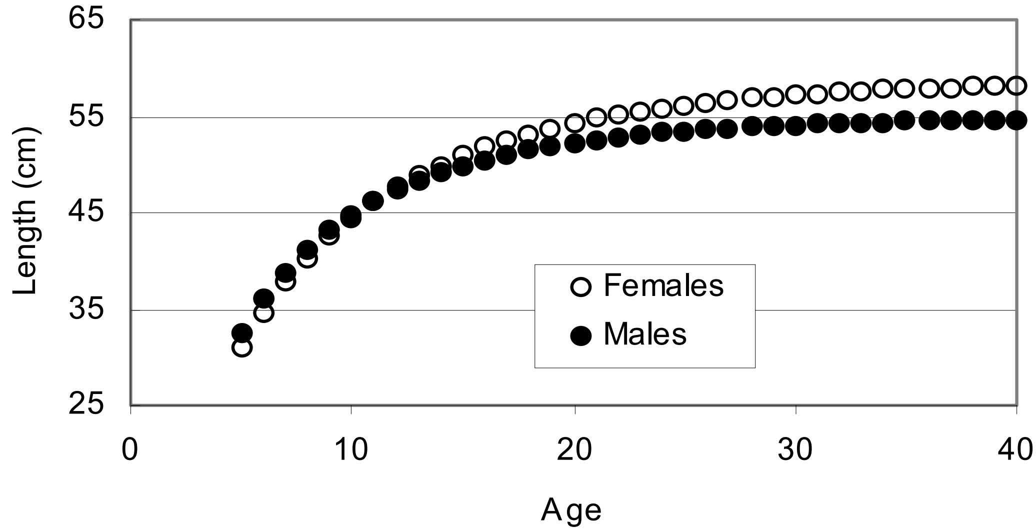

Figure 15. Length at age for canary rockfish (1998 samples)

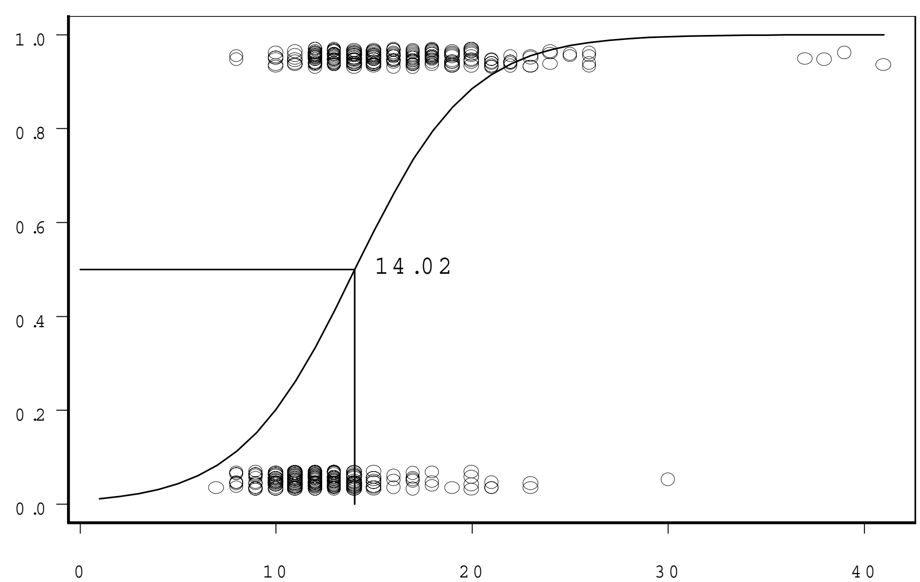

Figure 16. Maturity at age for canary rockfish females

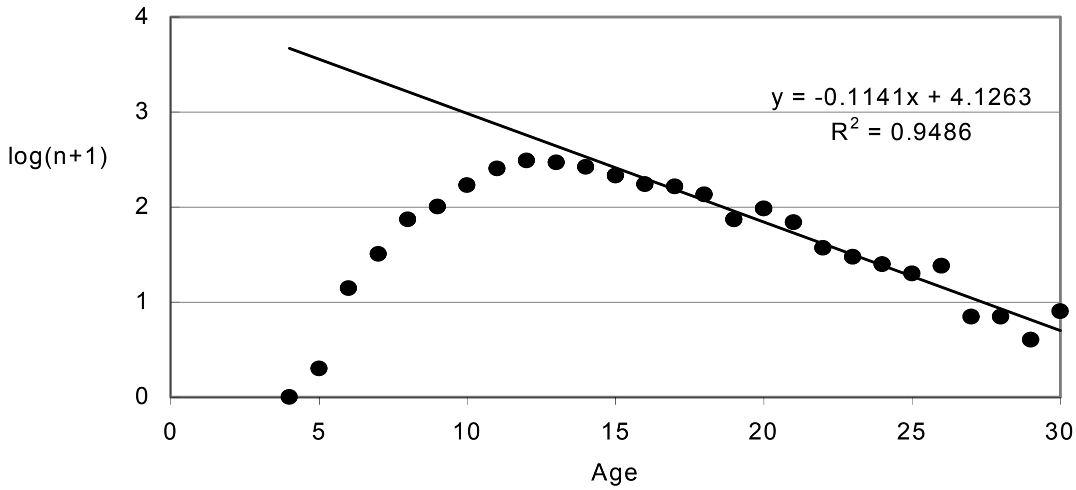

Figure 17. Age specific selectivity for female canary rockfish

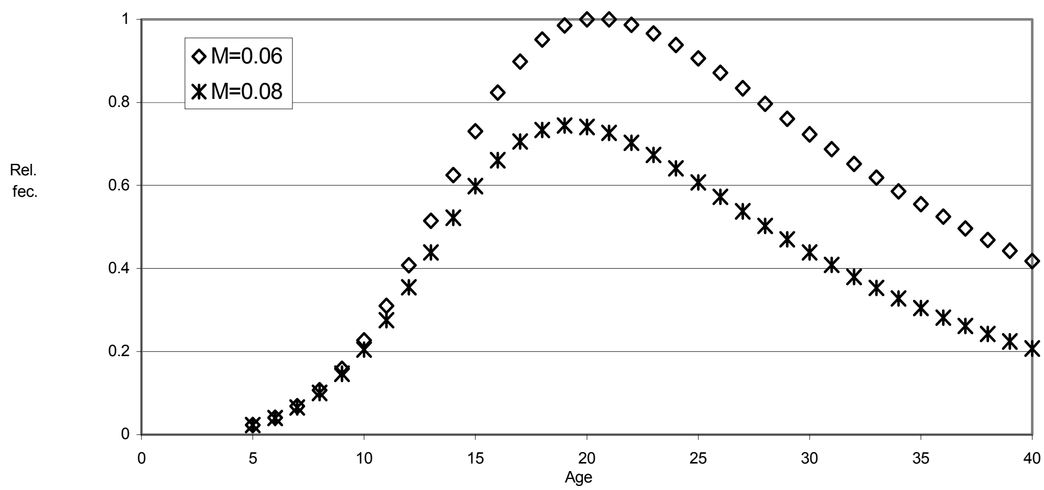

Figure 18. Age specific relative fecundity of female canary rockfish

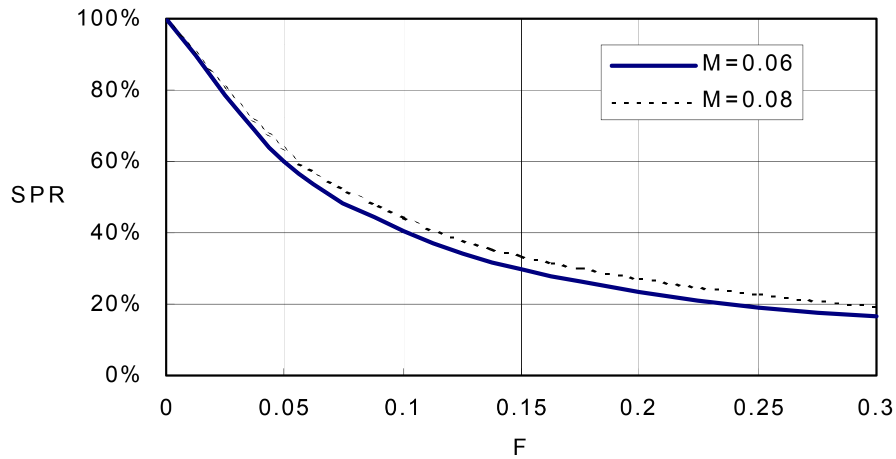

Figure 19. Spawning population per recruit for canary rockfish