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Sablefish stock assessment for 1997 and recommended yield options for 1998

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Abstract

This paper represents a major assessment for sablefish. Two stock assessment models are developed for the analysis of B.C. sablefish fisheries and research data. The first is a mark-recapture model that explicitly accounts for fish movement between both spatial and depth strata. The second is an integrated catch-age mark-recapture model where only movement out of the assessment region is modelled. The two analytical methods employ some different assumptions and hence allow for alternate fits to the data observations. Separate analyses are conducted for northern and southern areas of the B.C. coast due to observed differences in age and length compositions, growth and evidence from juvenile tagging that recruitment to the areas are drawn from different origins.

Estimates of the 1996 exploitation rates from the two assessment models are not substantially different but the estimated trends in abundance from 1991 to 1996 differ significantly. For the southern B.C. stock the estimated 1996 exploitation rate is 0.056 from the integrated model and 0.05 (range of 0.04 - 0.07) from the mark-recapture model. For the northern B.C. stock the estimates are 0.18 and 0.11 (range of 0.09 – 0.15) from the integrated mode and mark-recapture model, respectively. The mark-recapture model analyses suggest significant declines in stock abundance between 1991 and 1996 for both stocks. The stock reconstructions from the integrated model indicate relatively stable abundance for the southern stock and only a slight decline in abundance for the northern stock over the same period.

Potential yields are calculated based on stock projections from the integrated model analyses.
Yield calculations indicate that relatively stable stock sizes can be maintained at yields from 2310-3180 t for the south and 1150-1590 t for the north (3460-4770 t coastwide).

Résumé

Le présent document représente d'une importante évaluation de la morue charbonnière. Deux modèles d'évaluation des stocks ont été élaborés pour l'analyse des données sur la morue charbonnière de la C.-B. obtenues des pêches ou suite à des recherches. Le premier est un modèle de marquage-recapture qui fait état de façon explicite des déplacements des poissons entre les strates spatiales et de profondeur. Le second est un modèle de marquage-recapture intégrant les prises selon l'âge qui ne modélise que le déplacement à l'extérieur de la région évaluée. Les deux méthodes analytiques utilisées reposent sur des hypothèses quelque peu différentes et permettent donc plusieurs ajustements des données des observations. Des analyses distinctes ont été réalisées pour les zones nord et sud de la côte de la C.-B. étant donné les écarts observés au sein des compositions d'âges et de longueurs, de la croissance et du fait que le marquage des juvéniles a indiqué que le recrutement à ces zones avait des origines diverses.

Les estimations des taux d'exploitation de 1996 obtenues des deux modèles d'évaluation ne diffèrent pas de façon appréciable mais les tendances estimées de l'abondance entre 1991 et 1996 diffèrent de façon significative. Dans le cas du stock du sud de la C.-B., le taux d'exploitation estimé de 1996 est de 0,056 selon le modèle intégré et de 0,05 (gamme de 0,04 à 0,07) selon le modèle par marquage et recapture. Dans le cas du stock de la partie nord, les valeurs estimées sont de 0,18 et de 0,11 (gamme de 0,09 à 0,15) pour, respectivement, le modèle intégré et celui par marquage et recapture. Les analyses par modèle marquage-recapture portent à croire à des baisses significatives de l'abondance des deux stocks entre 1991 et 1996. Les reconstructions de stock à partir du modèle intégré indiquent une abondance relativement stable du stock du sud et seulement un léger déclin de celle du stock du nord au cours de la même période.

Les rendements possibles sont calculés à partir des projections des stocks par les analyses du modèle intégré.

Le calcul des rendements montre que des effectifs de stock relativement stables peuvent être maintenus à des rendements de 2 310 à 3 180 t pour le stock du sud et de 1 150 à 1 590 t pour le stock du nord (3 460 à 4 770 t pour l'ensemble de la côte).

1. INTRODUCTION

This document is a major assessment of sablefish stocks in Canadian waters for 1997. Two stock assessment models are developed for the analysis of the sablefish fisheries and research data. The first is a mark-recapture model that explicitly accounts for fish movement between both spatial and depth strata. The second is an integrated catch-age mark-recapture model where only movement out of the assessment region is modelled. The two analytical methods employ some different assumptions and hence allow for alternate fits to the data observations.

Separate analyses are conducted for north and south components of the stock in recognition of differences in age and length compositions, growth, and evidence from tagging that indicates recruitment to the two stock components are drawn from different origins.

2. LANDING STATISTICS

The commercial fishery for sablefish has been active since the late nineteenth century and was described in detail by McFarlane and Beamish (1983). Annual catches as high as 5,956 t were realised during the 1910s, however landings remained modest from 1920 to 1965, ranging between 210 t and 1,895 t (Table 1).

2.1 Foreign fishery

Exploitation increased in the late 1960s with the arrival of foreign longline fleets from Japan, the U.S., the USSR and the Republic of Korea (Table 1). The largest annual catches of sablefish occurred during this period with a peak 7408 t removed in 1975 (Table 1; Fig. 1). Unrestricted foreign fishing ceased in 1977 with declaration of the Canadian 200-nm fishery conservation zone. Some foreign fishing was allowed between 1977 and 1980 to utilise yield declared surplus to Canadian domestic fleet needs (Table 1).

2.2 Domestic Fishery

Since 1976, Canadian annual catches have averaged 4,022 t and ranged from 822 t in 1978 to 5,381 t in 1989 (Table 2). Canadian landings since 1951 have been caught with longline, trawl, and trap gear (Table 1).

2.2.1 Trawl Fishery

The trawl component of the catch has always been the smallest. Since 1977, the percentage has ranged from 5-16% (Table 1). The highest trawl landings over the period 1977 to 1995 were taken from Major area 3C, with 201 t landed on average (Table 2). In recent years, trawl landings have been limited by a quota allocation based on the historic average catch.

2.2.2 Longline Fishery

Longline was the dominant gear type in most years prior to 1973 (Table 1). In 1973, the trap fishery began to develop in earnest and the percentage of longline-caught fish in the total catch has fluctuated between 6.6% (1980) and 27.2% (1990) (Table 1). Over the period 1977-1994 longline landings averaged 575 t/y, with the majority coming from the west coast of Vancouver Island (Major areas 3C and 3D) (Table 2). The landings for longline fall under 'K' licence restriction and fishers can choose to fish hooks or traps.

During the period 1990-1993, the first three years of Individual Vessel Quota (IVQ) management, the proportion of catch attributed to longline was high (17-27%) but has dropped to 7-15 percent over the 1993-1996 period. The initial increase was due to large vessels developing longline operations for other groundfish species which included their sablefish quota. In this way the vessels could fish most of the year. The subsequent decline was due to a movement away from the multispecies longline approach in favour of dedicated trapfishing with leased quota. The leased quota allows the vessels to fish sablefish most of the year and traps were chosen as the most effective gear.

2.2.3 Trap Fishery

The trap fishery for sablefish began in 1973 and averaged 449 t over the first six years (Table 1). Since 1978, trap landings have ranged between 1,480 t (1979) and 4,168 t (1993) (Table 1). The high catches in recent years reflect the shift from longline to trap gear noted above. Landings in 1995 and 1996 have decreased as a result of lower overall quota.

The distribution of catch (Table 2) has been variable in recent years, a result of changing management strategies (Table 3). During the period 1981-1984 fishing was unrestricted until the quota was taken. The total number of days to take the quota declined from 245 days to 181 days. From 1985-1987 the fishery was split into two openings with provision for a third if quota remained. The split openings solved gear conflicts on the grounds and accommodated industry preferences for a fall vs. spring fishery. However, with increasing fleet efficiency and participation in the fishery, it was difficult for managers to predict the duration of the fishery.

In 1988 and 1989, 'K'-tab licence holders (trap and longline), were given their choice of one of five openings. They were allowed to choose an opening they felt to be optimal regarding market conditions and conflicts with other available fisheries i.e., herring, halibut, etc., It was however, difficult for DFO to determine the number of days required to take the quota, again because of variable participation and increasing fleet efficiency. As a consequence, quota overruns that had previously ranged between 2.9 and 13.8% of the quota increased to 26.4% and 17.6% in 1988 and 1989, respectively (Table 3).

In 1990 individual vessel quotas were introduced for the 'K' (longline and trap) licensed vessels, for a three-year trial period. Vessels were allocated proportional quota shares based on historical catch and overall vessel length. IVQ's remain in effect through 1997. The impact of IVQ's on the distribution of effort was considerable. Since IVQ's were implemented in 1990, the catch has been taken primarily during the 1st, 2nd and 4th quarters, to take advantage of higher prices in the Japanese market at those times. Prices generally drop at some point late in the first or early in the second quarter, which dictates the amount landed in that period. There was an abrupt shift in effort from the south (Major areas 3C, 3D, and 5A) to the north (Major areas 5B and 5E) in 1991 (Fig. 2 and Fig. 3) as fishers under the IVQ program were attracted by higher catch rates and larger fish in the north. The percentage of total catch taken from the north increased to 73% and 80% in 1991 and 1992 respectively, from an average of 51% over the period 1977-1990. In recent years there has been a shift back to the south as the percentage of catch in the north has dropped to 58% in 1995 and 64% in 1996 (Fig. 2 and Fig. 3). The shift is due in part to declining CPUE in the north and in part to a direct request to the industry to balance the effort rather than having to implement area-specific quotas.

2.2.4 Trap Fishery - CPUE

Catch data were obtained from sales slips and landing validation logs. Nominal effort data were captured from logbooks (interviewed effort), accounting for an average of 84% of the total catch between 1979-1992 (Saunders *et al.* 1994). Nominal CPUE for each stock was calculated as the sum of the catch over the sum of the effort. Total fishing effort for each stock was estimated by dividing the nominal CPUE into total catch for the stock.

The sablefish fishery extends from approximately 150-650 fm although over 85% of the fishing effort has been expended between 250-450 fm (Fig. 4), throughout the period of the foreign and domestic fisheries. Additional fishing effort was expended in deeper water (450-550 fm) from 1979-1983 in both northern and southern waters, and during 1990-1992 in the south, but this deepwater fishing averaged ~20% of the total fishing effort for those periods. Recently, additional fishing effort has been directed to the 550-650 fm stratum in northern and southern waters but still accounts for ~15% of the fishing effort.

The management history of the fishery has had a significant effect on when fishing effort is applied within a given year (Table 3) and, when combined with seasonal differences in availability (as indicated by monthly CPUE), has influenced the annual CPUE. Because CPUE during the January-March period is generally higher than other periods and this period has been fished during only a small proportion of the years in the data series, we chose the April-December period and the 250-450 fm depth range as that which would provide data most consistently reflecting stock conditions, for the calculation of nominal CPUE. We note a similar conclusion on data segregation by depth for a recent U.S. assessment of the Washington-California sablefish stock (Methot *et al.* 1994).

Nominal CPUE values have been slightly higher in northern waters over the entire time series and CPUE was relatively stable from 1979-1987 in both areas (Fig. 5 and Table 4). In 1988 and 1989, CPUE increased dramatically in both the north and south (Fig. 5). There is considerable evidence, the majority of which is difficult to quantify, which suggests that the period prior to 1988 is not comparable to the years following, specifically some combination of the following factors is likely responsible for the increase:

1. The management strategy shifted from fixed to harvester-chosen openings in 1988 (Table 3). In this management framework, some vessel masters (presumably the most efficient) fished on several different vessels for the different openings

2. We noted in Saunders et al. (1995) that hake in combination with squid began to be used as bait in the trap fishery. Preliminary observations indicate that the hake/squid results in higher catch rates than squid alone.

3. Fishers have noted that during 1988 and 1989 most were fishing to maximise yield at whatever the cost, given speculation that IVQ's would be awarded on the basis of the vessels landing history. With that in mind some reported reduced high-grading and increased bait loading. Vessel logs were modified in 1995 to capture these data, but are not available for the earlier period.

A bait loading experiment conducted during 1996 (B. Leaman, unpublished data) has confirmed that the combination of hake and squid results in higher catch rates and that CPUE increases linearly with increased weight of hake bait. Due to the concerns noted above we have not used the time series to tune the catch-at-age model.

Since the peak in 1988, CPUE has declined continuously through 1996. Although the comparability of CPUE values over the entire time series is questionable, the continuing decline since 1991 (Fig. 5), a relatively stable period in the fishery from a management perspective, is a cause for concern. The southern stock CPUE showed a rapid increase in 1989 and equally rapid declines during 1990 and 1991. A second peak occurred in 1993 and the CPUE has declined through 1995 to a level again, similar to the 1979-1987 period (Fig 5 and Table 4).

3. GENERAL BIOLOGICAL INFORMATION

3.1 Trap Surveys

3.1.1 Survey Design

Since 1984, biological samples have been collected annually during October/November, using chartered trap vessels, with the goal of sampling exploited stocks from the west coast of Vancouver Island to the Queen Charlotte Islands. Initial samples were collected during the course of normal commercial fishing. In 1986 a more structured survey design, including eight indexing sites and three depth strata was developed. The three depth strata were shallow (<300 fm), medium (301-400 fm) and deep (>400 fm). The purpose was to investigate the variation in size and age-related parameters associated with area and depth. In 1990 the number of depth strata was expanded to include 250-349 fm, 350-449 fm, 450-549 fm, and 550-649 fm, and in 1991 an additional shallow (150-249 fm) stratum was added. The index sites from south to north were Barkley Canyon, Esperanza, Solander (1994 & 95 only), Quatsino, Triangle Island, Cape St. James, Gowgaia, Buck Point and Langara (Fig. 6). It has not been possible to sample all sites each year. The five southern sites were occupied in 1988, all eight in 1989, the three southern-most sites in 1990, six sites in 1991, eight in 1992, eight in 1993, and ten in 1994, 1995 and 1996.

A standardised method of gear deployment has been used throughout the surveys and is described in Smith et al. (1996). Briefly, each set consisted of 25 Korean traps attached to a groundline at 46m intervals, baited with 1-1.5kg of frozen squid in bait bags, and soaked for 24 hours. The catch in number and weight were recorded for each trap and have been used to develop indices of abundance. Biological sub-samples of length, sex, maturity and otoliths for age determination were collected. Depth specific age compositions have been incorporated into the model reconstruction and are discussed under the stock reconstruction. Approximately 2/3 of the traps were randomly selected for tagging and the subsequent recapture data form the basis for the tagging analyses.

3.1.2 Survey Abundance Indices

Mean CPUE in number and weight (kg/trap) has declined slowly over all depth intervals in the northern area, with the exception of the 1993 survey (Fig. 7). The trend is similar in the south although the peak includes 1992 and 1993. The peak is coincidental with the 1992/93 El Niño and could represent an environmentally driven change in availability. This anomaly was also noted in longline survey's of SE Alaska (inshore) stocks (D. Carlyle ADFG pers. comm.).

4. STOCK ASSESSMENT MODELS

For last years sablefish stock assessments the analytical method for stock reconstructions was a catch-at-age analysis that was tuned to exploitation rate estimates from mark-recapture analyses (Saunders et. al 1996). There were a number of concerns with both the analytical approach and the resulting analyses including: stock reconstructions from the catch-age analysis were highly sensitive to the number of age classes modeled; neither the mark-recapture nor the catch-age models were depth stratified, thus did not consider depth related probabilities of recapture for tags and the impact of changes in the depth distribution of samples on the age-composition data; the mark-recapture analyses utilized tag release data only to 1992; and it was not possible to directly evaluate the effect of assumptions of the mark-recapture analysis on the stock reconstructions from the catch-age analysis.

The analytical methods used for the current sablefish stock assessments have been modified to deal with some of the above-noted concerns. The mark-recapture model for analyzing the tagging data is extended to a depth-stratified model that explicitly accounts for fish movement between both spatial and depth strata. The analyses use tag release data for 1991 through 1995 and recovery information to 1996. The model is described and results of analyses presented in Appendix A. The catch-at-age model is extended to integrate the tagging data and results from these analyses are presented in the following sections. These two analytical methods employ some different assumptions and hence allow for alternate fits to the data observations.

4.1 Integrated Catch-Age Mark-Recapture Model

The integrated catch-age mark-recapture model that was developed for the reconstruction of sablefish stocks is described in Appendix B. Only a brief overview of the model is presented here.

Biological data indicate that sablefish are stratified by both age and sex such that younger fish and females are relatively more abundant at shallower depths. The integrated sablefish model includes age and sex segregation of the population by depth strata. Movement between strata is not explicitly modeled, instead, model parameters estimate the probability of each age and sex class occurring in a depth stratum. The model structure assumes partial recruitment of younger age classes and that all recruited fish are vulnerable to the fisheries. Natural mortality has been estimated at 0.08 for B.C. sablefish stocks (Saunders et al. 1996) and that value is used for the average natural mortality rate in the integrated model. However, sex specific deviations from the average level are estimated to allow the model to fit the higher proportion of female fish observed in all depth zones in northern B.C. Sablefish survey data is included in the model. However, because there appear to be environmentally induced anomalies in these data for some years, the model is fit to the average abundance in each depth stratum rather than the time-series of observations.

The mark-recapture component of the model tracks tag cohorts, that is, all the fish tagged in a year. The age and sex of tag cohorts is estimated based on the numbers of tags applied in each depth stratum and the age and sex composition estimated for the stratum. Tag cohorts are assumed to have the same fishing and natural mortality rates as the population. A parameter to account for the immediate loss of tagged fish resulting from tag shedding and tag-induced mortality is fixed at 0.15 for most analyses. An additional tag loss parameter is estimated to account for the on-going loss of tagged fish from the tag cohorts. Two parameters related to migration are estimated – a migration rate parameter for the population and a separate migration rate parameter for the tag cohorts. The population migration parameter can account for net migration from the population (i.e. immigration plus emigration) whereas the migration parameter for tag cohorts will account only for emigration. The fishing mortality rates on fish that have migrated out of the population are estimated with two parameters. These are the migrants fishing mortality rates in 1980 and in 1996, and we assume a linear trend between the two estimates. Additionally, a tag reporting rate parameter is estimated.

The model, as described, can also be implemented as a model without migration if the value of the migration parameters and the migrant fishing mortality rate parameters are fixed at 0. This implementation of the model will be termed the "non-migration" model, as opposed to the "migration" model where all the mark-recapture related parameters are estimated. For the non-migration implementation, the parameters in addition to those estimated for the catch-age component of the model are the tag loss and reporting rate parameters.

4.1.1 Data Sources

Analyses using the integrated catch-age mark-recapture model were conducted for the northern B.C. and the southern B.C. sablefish stocks with the data segregated into three depth strata (<500m, 500-800m, >800m). Most analyses used data for the 1980 to 1996 period. Additional sets of runs were conducted using catch data back to 1960 to investigate the long-term stock trajectories. The annual catch data, by stock and depth strata are shown in Table 5. The age and sex composition data were obtained primarily from research surveys using trap gear because few age-composition samples have been collected from commercial catches (Fig. 8, Table 6).

Annual relative abundance indices were calculated from survey CPUE (catch in numbers/trap) data for each depth strata. The mean annual CPUE's are assumed to be indices of fish density and these estimates were weighted by the relative size of the depth strata (Saunders and McFarlane, 1993, Table 5.6) to generate relative abundance estimates for each stratum (Table 7). The depth strata area measurements were based on slightly different geographical units than those used for the current analyses, so the abundance indices may not provide accurate information on the relative abundance by depth.

Sablefish were tagged in B.C. during the late 1970s through early 1980s and from 1991 to the present. Only tag release data since 1980 and recovery data from these taggings are used. Summaries of tag and recapture data are presented in Tables 8 and 9, and in Fig. 10. Of the tags applied to fish in the southern B.C. stock assessment region, approximately 84% were recovered in the southern region, with the remainder of the recoveries primarily in the northern B.C. assessment region and in Alaska. For the northern B.C. assessment region, 79% of recoveries were in northern B.C. and 12% were in Alaska.

4.1.2 Stock Reconstructions

A series of stock reconstructions were conducted using both the migration and the non-migration implementations of the sablefish model. For the migration version of the model all recoveries of tags which occurred outside of the assessment (and tagging) region were treated as a single migrant pool. For the non-migration version of the model, tags that were recovered in areas outside the assessment area were treated as if they had been recovered within the assessment area. This treatment of the data would be consistent with the stock dynamics if there were no net stock migration (i.e. immigration is equal to emigration) and if the fishing mortality rates on the tagged migrant population were the same as the rates on the tagged non-migrant population. The first series of results, which are presented, are from analyses using the migration model.

Initial runs using the migration implementation of the model indicated that values for the migrant fishing mortality parameters were unrealistically high so a series of runs were conducted where the value of these parameters were constrained to maximum levels ranging from 0.08 to 0.45. Estimates of the mark-recapture model parameters for this series of analyses are shown in Table 10. For the southern stock the 1980 fishing mortality parameter is at the upper limit for all runs, while for the northern stock the 1996 estimates are consistently at the upper limit. Results from these runs show a high correlation between the fishing mortality parameters and the tag migration rate parameter, although estimates of 1997 exploitable biomass are relatively insensitive to these parameters. The value of the population migration parameter was 0 for most runs, indicating that the best fit to the observed catch and age composition data is obtained with no net migration from the population.

The residuals (standard normal deviates) of the predicted versus observed proportion of tag recoveries by recovery stratum are shown in Fig. 11, for the runs with the maximum fishing mortality parameters fixed at 0.15. For the migrant tag recoveries, the pattern of residuals follow a strong non-random pattern with primarily negative residuals for 0 and 1 year-at-large followed by positive residuals for 2 and greater years-at-large. That is, the model is unable to fit the observed decline in the number of tag recoveries for the migrant fish that occurs over time. The analyses with high F's on migrant fish and low migration rates provide a somewhat better fit to the data observations because under this scenario the migrant pool of tagged fish decreases at a faster rate. With higher migration rates and lower F's the on-going emigration of tagged fish maintains the numbers in the migrant pool. However, the non-random pattern of residuals holds even for the runs where the maximum value for the migrant fishing mortality parameter was fixed at 0.45. Clearly, the pattern in the residuals suggests that the model formulation for the migration implementation is inconsistent with the data observations. Therefore we reject the migration implementation of the integrated model for the current stock assessments and focus on analyses using the non-migration implementation.

A series of runs were conducted with the non-migration implementation of the integrated model to evaluate the sensitivity of parameter estimates to the penalty weights for the tag data and the survey abundance data. The weightings for the tag data are 1.0, 0.5, and 0.1, and for the survey data they are 500, 50 and 5. Results from this series of runs are shown in Table 11. For the runs with a high weight on the survey data, the model estimates of the proportions of the population in each depth stratum fit the observations almost exactly. With lower weighting on the fit to the survey data the model estimates a higher proportion of the population in the middle depth stratum for the northern population and a higher proportion in the shallow stratum for the southern population. The tag loss, reporting rate and 1997 exploitable biomass estimates are relatively insensitive to the weightings, with the exception of analyses for the northern stock with low weight on the fit to the tagging data. For further analyses the penalty weights used are 0.5 for the fit to the tagging data and 50 for the fit to the survey relative abundance data. The non-migration model implementation using these penalty weights will be referred to as the base case runs.

The estimated values for the tag loss parameter are quite high relative to expected values if this parameter accounts primarily for tag shedding. A series of runs were conducted with the tag loss parameter fixed at values ranging from 0.05 to 0.35 (Table 12). The model fits to the data observations, as measured by the objective function value, deteriorates significantly when the tag loss parameter value is less than 0.20. For the southern stock the estimated 1997 exploitable biomass is relatively insensitive to the value of the tag loss parameter whereas for the northern stock the 1997 biomass estimates decrease substantially with the low tag loss values.

For the analyses described so far, the value of the initial tag loss parameter was fixed at 0.15. This parameter is intended to account for the immediate loss of tags from the tag cohort resulting from tag shedding and tag-induced mortality. Table 13 shows the results of model runs where the value of this parameter was fixed at levels ranging from 0.05 to 0.35. As the results for the northern stock show, this parameter is completely confounded with the reporting rate parameter. That is, as the value of this parameter is changed, the values for the tag loss parameter, the 1997 exploitable biomass, and the function value remain the same and only the value of the reporting rate parameter changes. For the southern stock, the estimate for the reporting rate parameter is at its upper bound (1.0) so the correlation with the initial tag loss parameter is not apparent. Because it is not possible to separate the effect of initial tag loss and reporting rates the initial tag loss parameter is fixed at 0.15 for all analyses.

The estimated 1980 to 1996 stock trajectories resulting from the base case runs are shown in Fig. 12. The stock reconstructions suggest that the exploitable biomass for the southern B.C. stock has changed little over this time period whereas the northern stock shows a 40% decrease from 22,400 t. in 1988 to 13,600 t. in 1997. These results are inconsistent with both the commercial and survey CPUE abundance indices (Table 4; Figs. 5 and 7a) which suggest significant decreases in relative abundance for both stocks. To investigate the possibility that sablefish stock abundance has decreased more significantly than suggested by the base model runs, the model objective function was modified to include terms for the predicted versus observed fit to each of the sablefish survey abundance data points (Table 7). Penalty weights for this component of the objective function ranged from 5 to 50 and the resulting stock trajectories are shown in Fig. 12. For the southern stock, the inclusion of the fit to individual survey data points in the objective function had only a small effect on the stock trajectory. For the runs with the high survey penalty weight the estimated decline in exploitable biomass from 1988 to 1997 was 12% for the southern stock and 62% for the northern stock.

Because of concerns that the proportion of recovered tags that were returned has changed over time, an additional set of analyses was conducted where the reporting rate parameter was allowed to vary over time. The changes in the reporting rate were modeled as a random walk. That is, parameters were estimated for the change in reporting rate each year from that estimated for the previous year. The time series of estimated reporting rates is shown in Fig. 13. The estimated reporting rates are similar for the northern and southern B.C. stocks for the 1986 to 1996 period, but are higher for the southern stock in the earlier years. There is no reason to believe the reporting rates should be different for the two stock assessment regions. Under the variable reporting rate scenario, the estimated stock trajectories change somewhat with a lower 1997 exploitable biomass estimate for the southern stock and a higher terminal biomass estimate for the northern stock. The combined 1997 exploitable biomass estimates (northern stock plus southern stock) are 39,900 t. and 37,900 t. for the constant and variable reporting rate analyses, respectively.

Estimated tag report rates (#tags/tonne) for individual vessels in the sablefish trap-fishery provide some support for the model estimate of time-trend in reporting rates (Fig. 9). In 1993 there are a number of vessels, representing a substantial proportion of the catch, that have unreasonably low tag recovery rates. By 1996 all vessels are returning tags.

At this time, the base case model stock reconstructions are considered to be the most appropriate for stock assessment purposes. The residuals of the predicted versus observed tag recoveries by tag cohort and recovery stratum are presented in Fig 14. The distribution of residuals appears to be somewhat non-random. In particular, the residuals for the northern deep stratum are mostly positive, indicating the predicted tag recoveries for this stratum are consistently higher than observed. The likelihood profile estimates of the probability density functions for the tag loss and tag reporting rate parameters (Fig. 15) suggest that given the base model structure and the data observations the value for these two parameters are well determined.

The base model runs provide reasonable fits to the observed age and sex composition data by depth stratum (Table 6) For the southern stock the model estimates that there is no difference in the natural mortality rate (M) for males and females. For the northern stock the estimates of M are 0.106 for males and 0.054 for females. The estimated age and sex-specific partial recruitment parameters and average fishery selectivities are shown in Fig. 16. Calculation of the average selectivities includes both partial recruitment and depth-specific fishing mortality parameters and hence represents the relative selectivity of the entire population. Estimates of depth-specific fishing mortality rates and total annual exploitation rates (catch summed over depth divided by exploitable population size) are plotted in Fig. 17.

An additional set of runs with the base case formulation were conducted with the catch time series extended to 1960. The numbers-at-age in the initial population (i.e. 1960) were calculated assuming a stable age distribution based on the average age and sex specific fishing mortality rates for the first three years (i.e. 1960-62) and an estimated constant recruitment level. For the southern stock the recruitment level estimated was 1.1 times the mean for the historic time series while for the northern stock the estimate was 0.7 times the mean. The stock trajectories are plotted in Fig. 18 and the estimated recruitment time series shown in Fig. 19.

4.1.3 Discussion of Integrated Model Analyses

There are a number of areas where results from the integrated model analyses are either inconsistent with other information on sablefish stock dynamics or inconsistent with the data observations. A brief description of some of these inconsistencies follows.

The values estimated for the tag loss parameters are much too high if the primary source of tag loss is through tag shedding. Two studies based on experimental double tagging of sablefish estimated tag shedding rates in the range of 0.02 to 0.08 (Beamish and McFarlane 1988, Lenarz and Shaw 1997), significantly lower than the 0.26 tag loss rate estimated here. Another study (McFarlane and Beamish, 1990) showed that the growth of tagged juvenile sablefish was slower than the growth of untagged fish, and suggested that the slower growing tagged fish had higher mortality rates than untagged fish. However, the tagging data used in the current analyses are from adult sablefish only, and it is not known if growth of adult sablefish is also effected by tagging.

The estimate of a higher natural mortality rate for males than for females in northern B.C. appears inconsistent in that there is no reason to believe that there are differences in the natural mortality schedules between the northern and southern B.C. stocks. The model estimates a higher M for males in the northern stock to account for the higher proportion of females in the age-composition samples at all ages and depth zones. The greater number of females may result from higher selectivity for female fish rather then greater numbers in the population. Alternately, the differential in the sex ratio may result from sex-specific migration rates.

The residual pattern for tag recoveries in the northern deep stratum indicate a persistent lack of fit to the tag recovery data. The model may be underestimating the size of the population in the deep stratum, thereby overestimating the F levels and the predicted number of tag recoveries.

The estimate of the tag reporting rate of 1.0 for the southern stock is improbable. There is no reason to believe that this rate should be different between the two stocks, and it is unlikely that all tag recoveries are reported.

4.2 *Comparison of Mark-Recapture Model and Integrated Model Results*

There are some major differences in both model assumptions and results from the mark-recapture model (Appendix A) and the integrated model. For the southern B.C. stock the estimates of the 1996 exploitation rate are 0.05 from the mark-recapture analysis and 0.056 from the integrated analysis. While terminal abundance estimates are similar, the stock trajectories are not. The mark-recapture analysis estimates an 80% decline in stock abundance from 1991 to 1996 and the integrated analysis estimates a 17% increase for the same period. For the northern B.C. stock, the 1996 exploitation rate estimates are 0.11 and 0.18 for the mark-recapture model and integrated model analyses, respectively. Results from the mark-recapture analysis indicate a 55% decrease in stock biomass between 1991 and 1996 while the integrated model analysis suggests a 34% decrease. The estimated declines in stock abundance obtained with the mark-recapture model analyses are more consistent with the observed declines in both the commercial CPUE and the survey CPUE data.

The mark-recapture model explicitly accounts for movement between depth strata and estimates the proportion of the population moving from the southern shallow and middle depth strata to the deep stratum and from the northern deep stratum to the southern deep stratum seem unrealistically high. This movement allows the model to fit the observed decline in tag recoveries because the exploitation rate in the southern deep stratum is extremely low, therefore the probability of recovering tags from this stratum is small. For the integrated model the tag loss parameter accounts for the rapid decline in tag recoveries, but we can not rationalize the high value for this parameter. Neither model provides a satisfactory explanation for the observed decline in tag recoveries with years-at-large.

5. STOCK PROJECTIONS AND YIELD OPTIONS

A series of analyses were conducted for the 1996 sablefish stock assessment to determine appropriate fisheries harvest reference points for the B.C. sablefish stocks (Saunders et. al. 1996). The analyses were based on spawning stock biomass per recruit (SSBR) calculations, and the appropriate target fishing mortality rates (F) were considered to be those which reduced the SSBR to 40-45% of the unfished level. The analyses resulted in target fishing mortality rates of 0.11 to 0.13.

The estimation of SSBR is based on estimates of the population maturation ogive, the fecundity schedule, natural mortality estimates, and the fisheries age-selectivity parameters. Because we do not feel that the current integrated model provides an adequate description of the sablefish population dynamics, we do not re-estimate the fisheries harvest reference points at this time. Rather, we calculate potential yields for a slightly broader range of target F levels, namely, 0.10, 0.12, and 0.14. Stock projections are based on the population estimates from the base case runs of the integrated model.

The stocks are projected forward for 1998 through 2000 assuming that the 1997 catch will be 2,896 t. for the northern stock and 1,629 t. for the southern stock. Projections are conducted for three levels of recruitment based on the historic mean level ($0.5 \cdot$mean, mean, and $1.5 \cdot$mean). Estimates of the potential yield and exploitable biomass for 1998 through 2000 for the three levels of recruitment and for the three F reference points are shown in Table 14.

The potential yields are relatively insensitive to the assumed level of recruitment because of the low selectivity for young fish. The projections suggest the exploitable biomass for the southern stock will decrease slightly over the next three years independent, of the target F level. The biomass for the northern stock is projected to increase under most of the recruitment/F level scenarios. Assuming average recruitment, the potential yield estimates range from 2,131 t. to 3,176 t. for the southern stock and from 1,155 t. to 1,585 t. for the northern stock.

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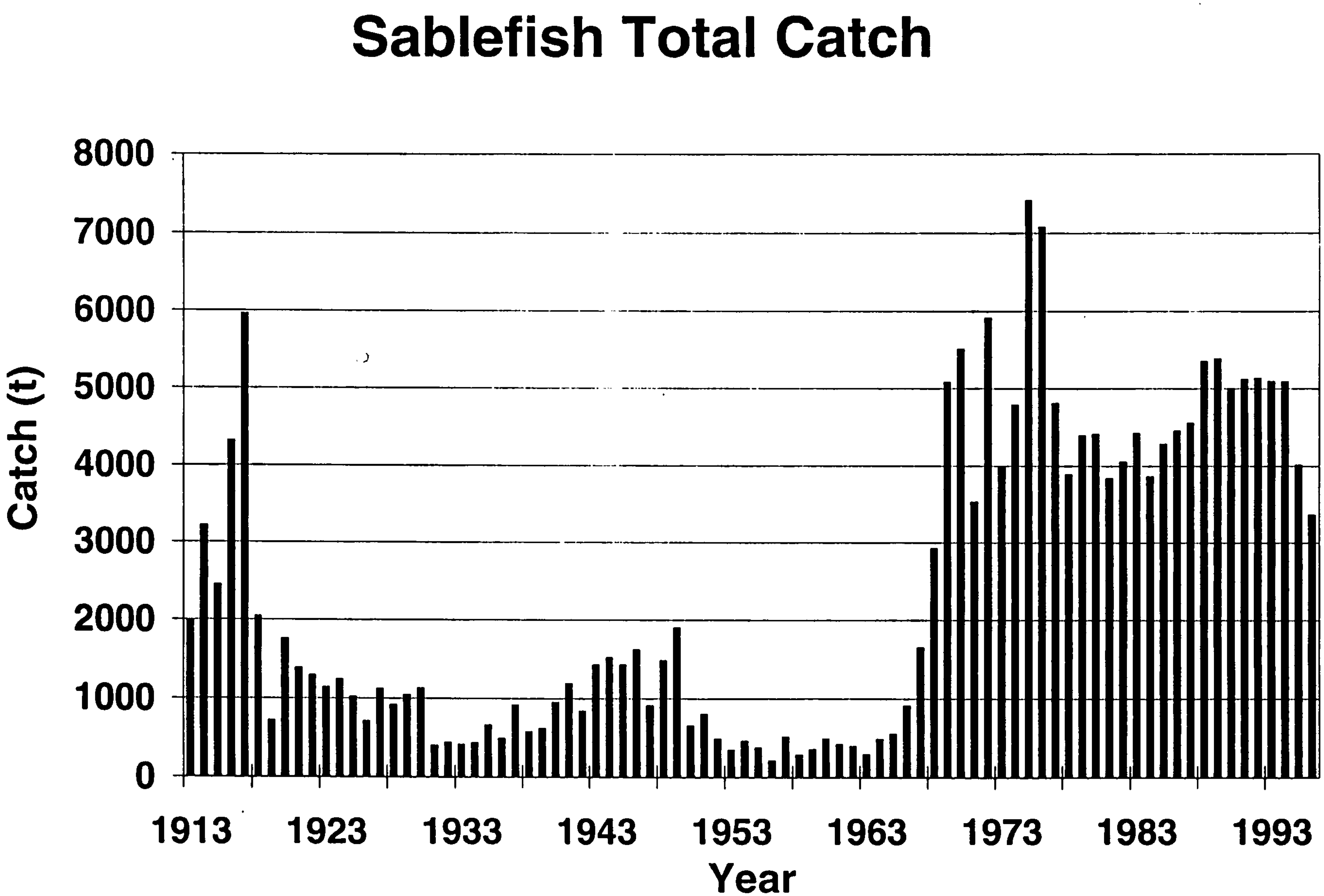


Figure 1. All-nation catch of sablefish in the Canadian zone by gear, by year, from 1913 to 1996.

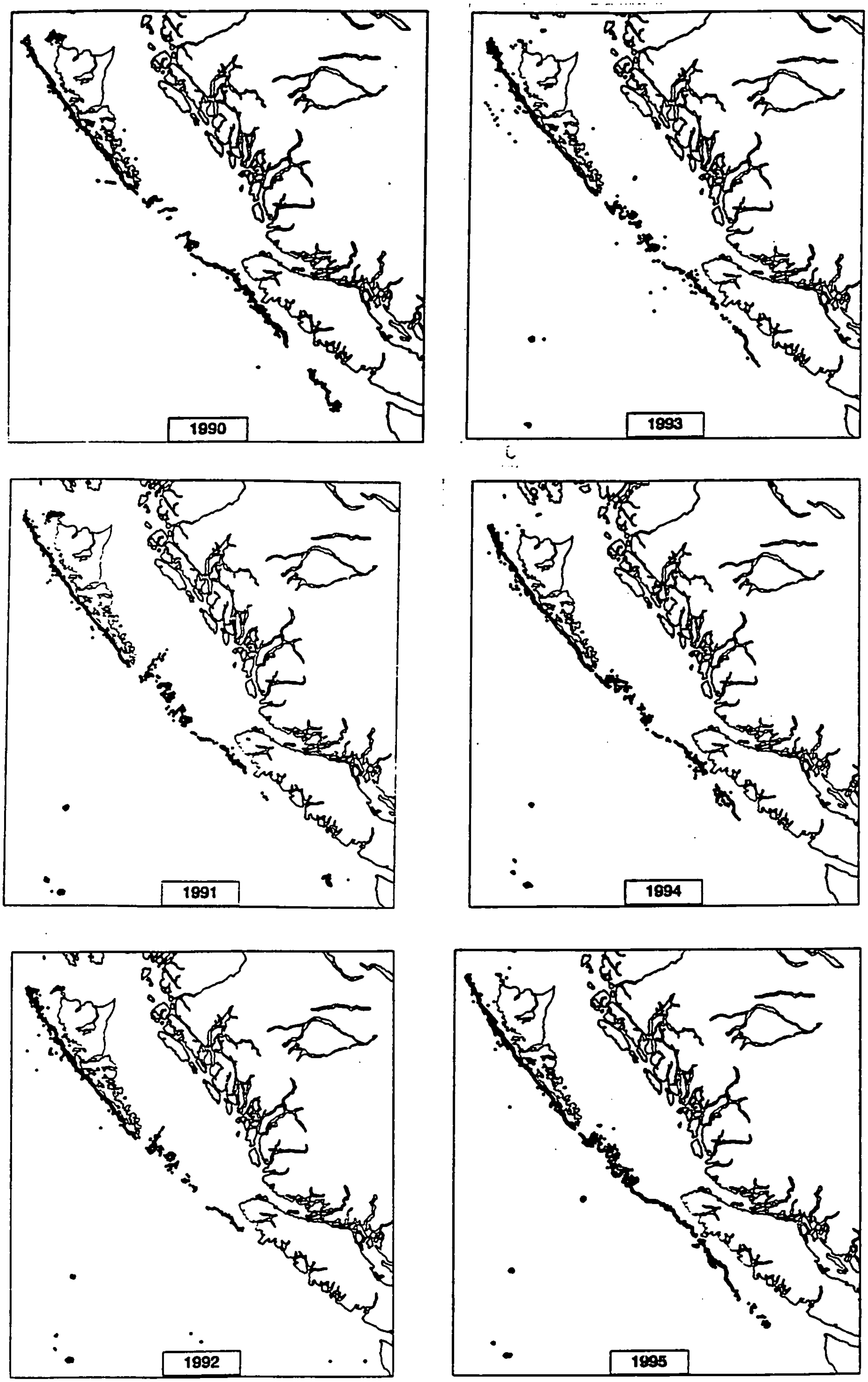
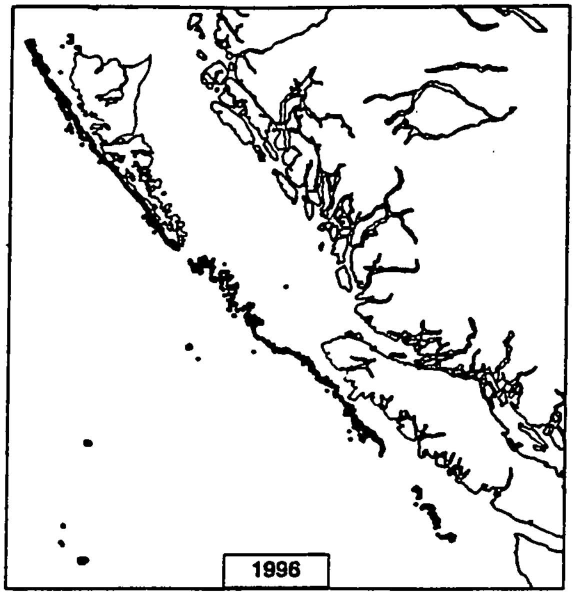


Figure 2. Distribution of trap fishing effort by the Canadian sablefish fleet from 1990-1996.



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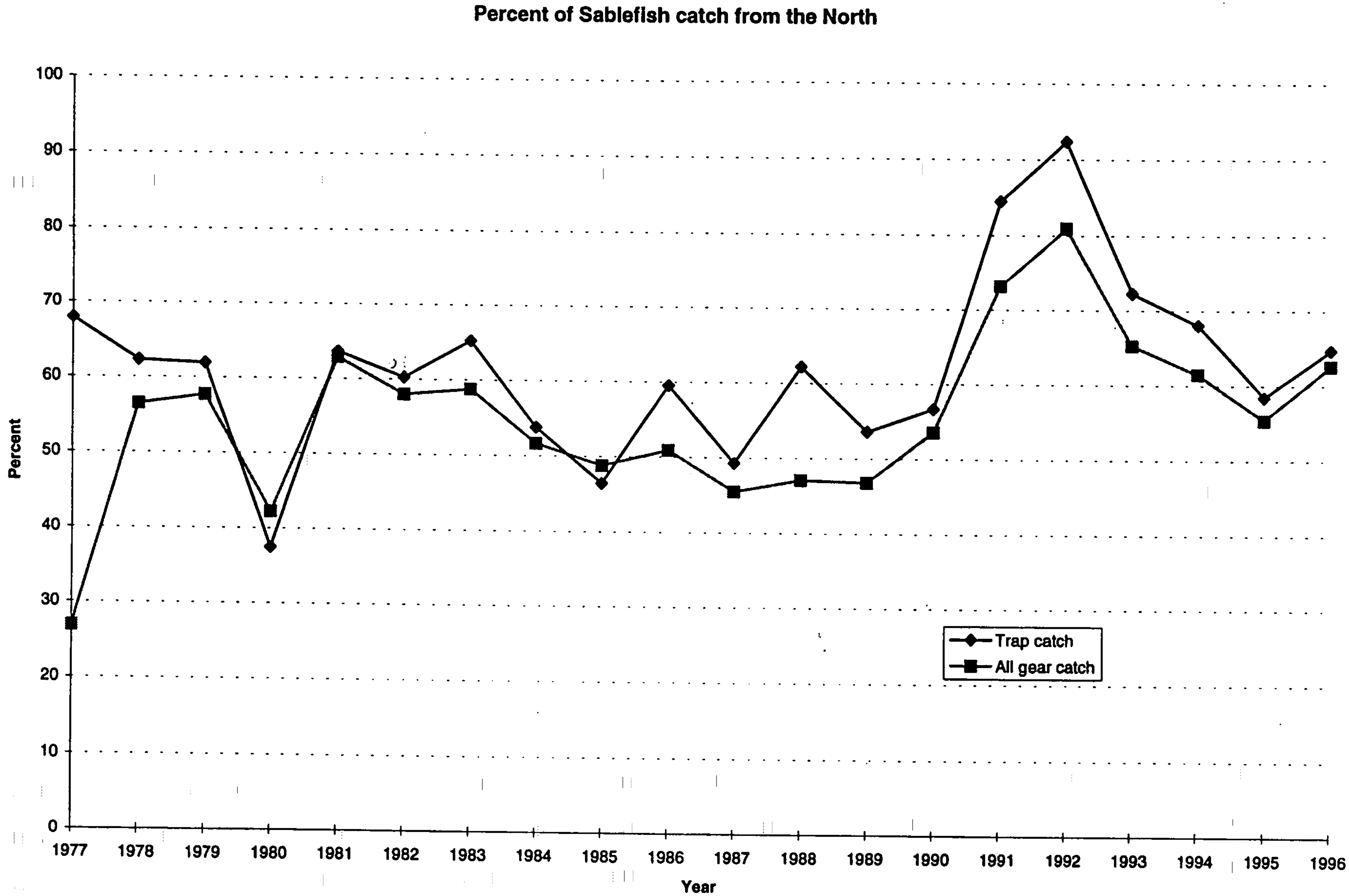
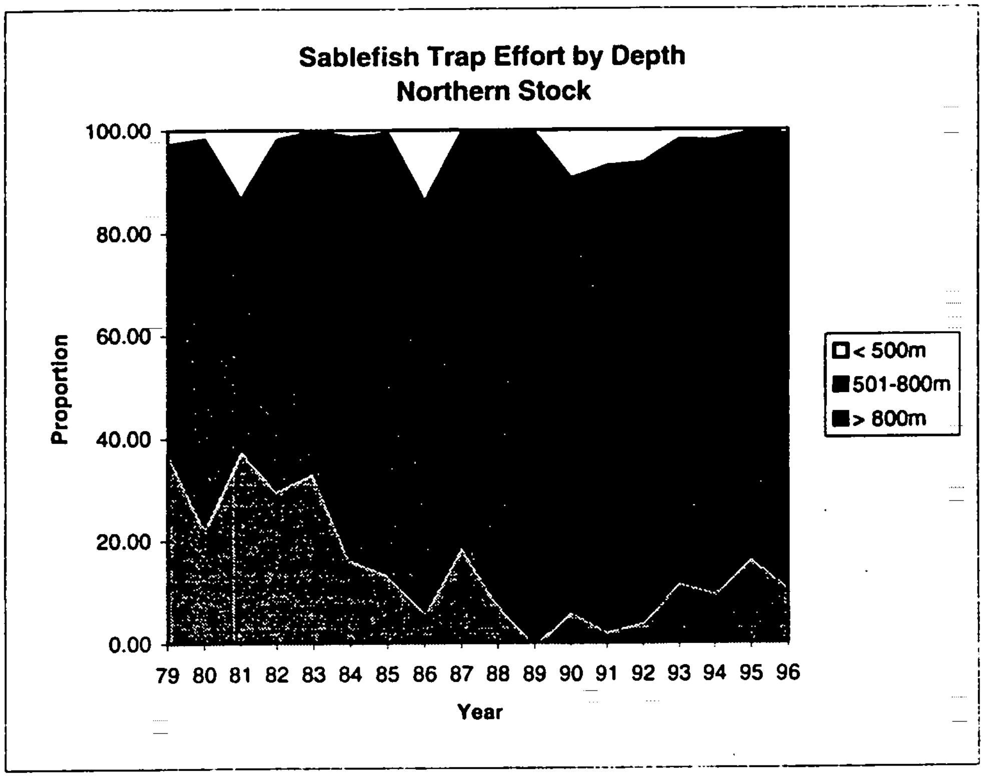


Figure 3. Percent of sablefish total and trap catch from the northern area, by year.



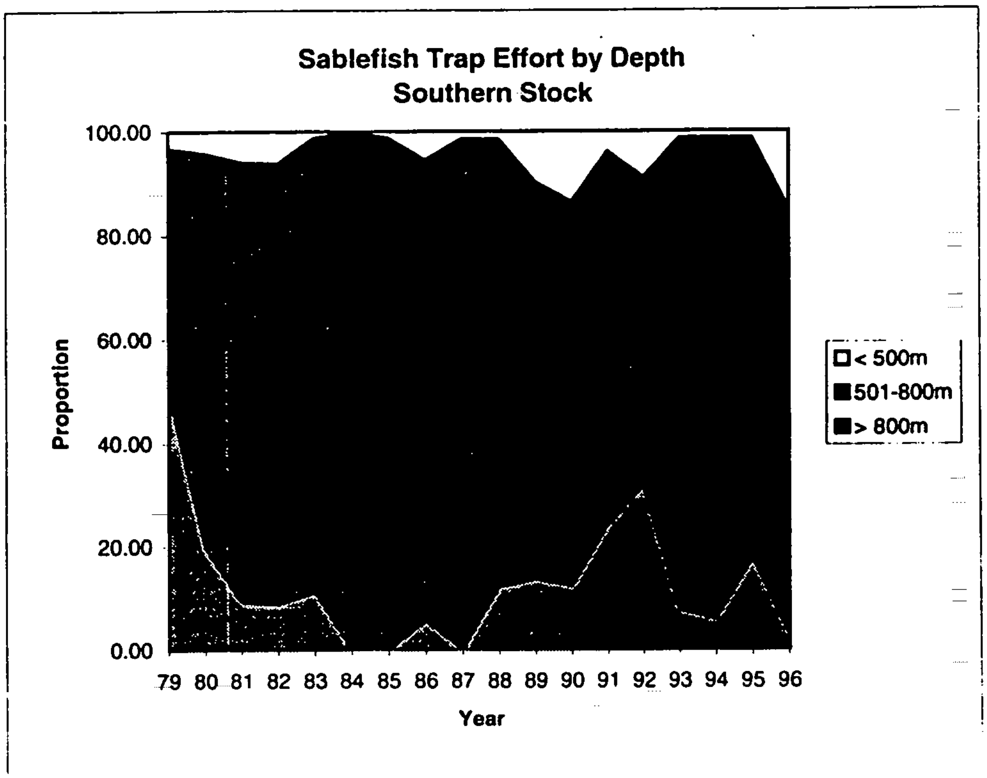
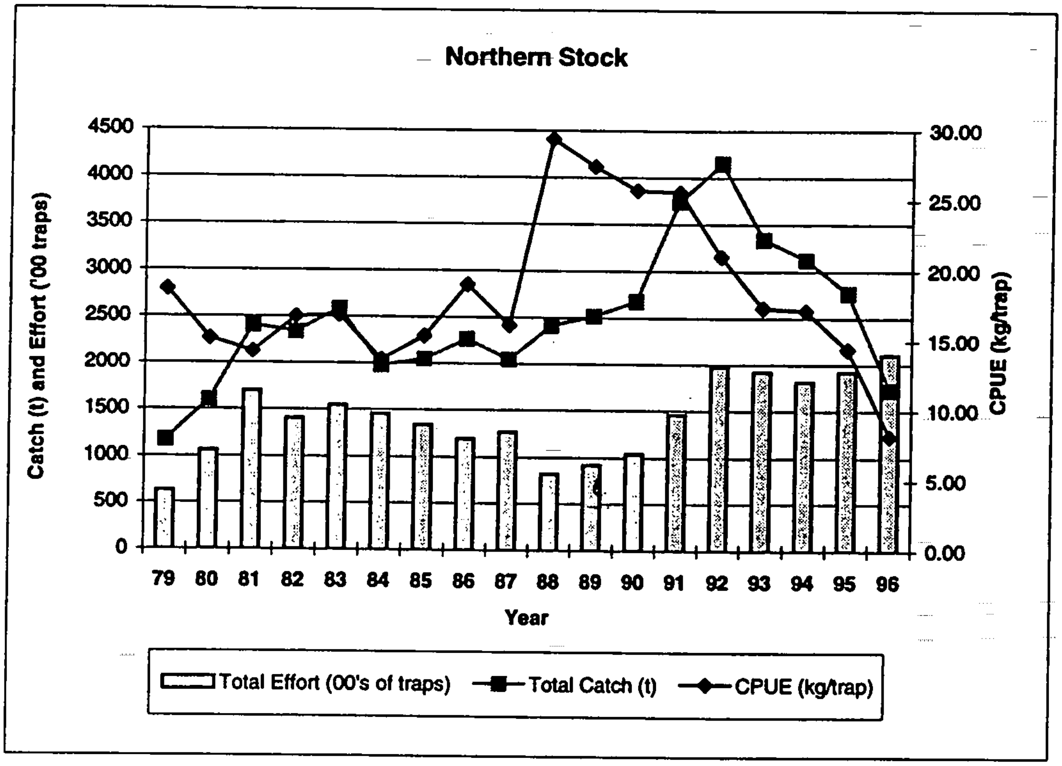


Figure 4. Distribution of sablefish trap effort (traps) by depth interval, 1979-1996, by stock.



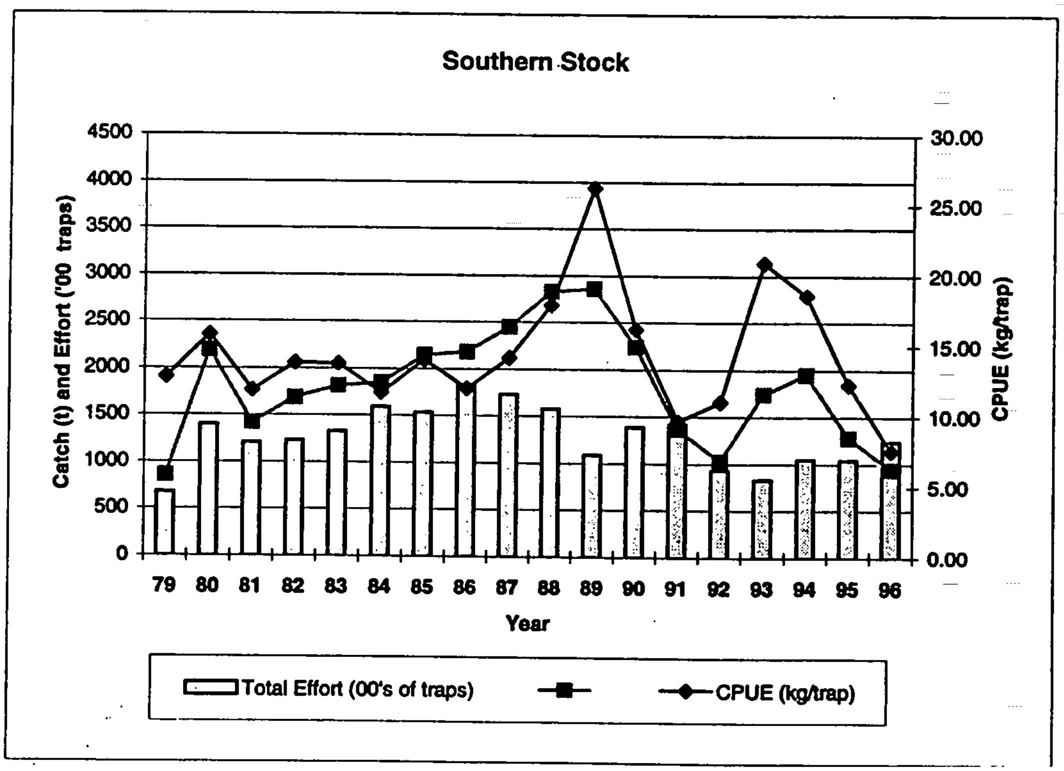


Figure 5. Sablefish trap fishery CPUE, effort and catch, by stock and year.

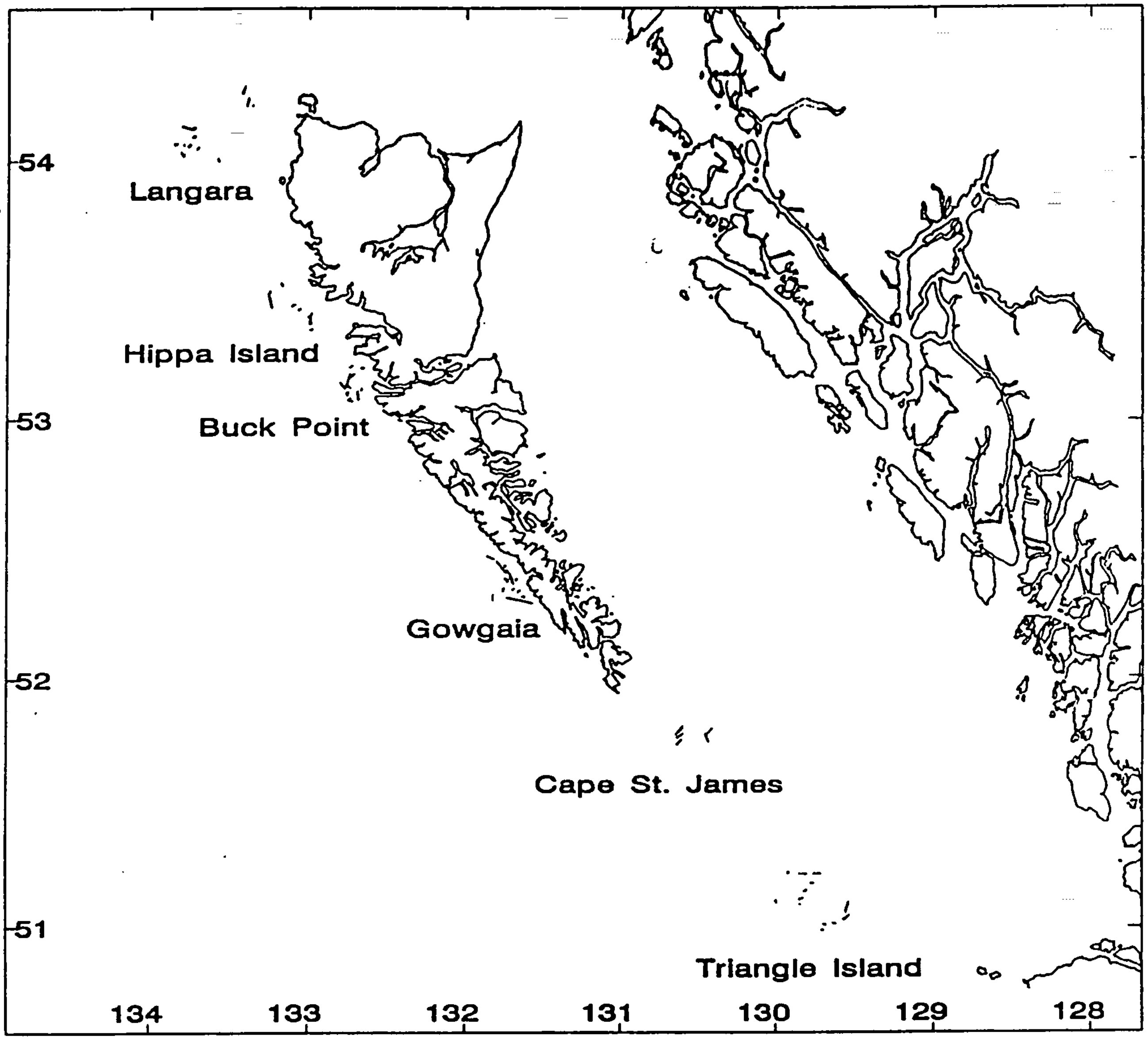
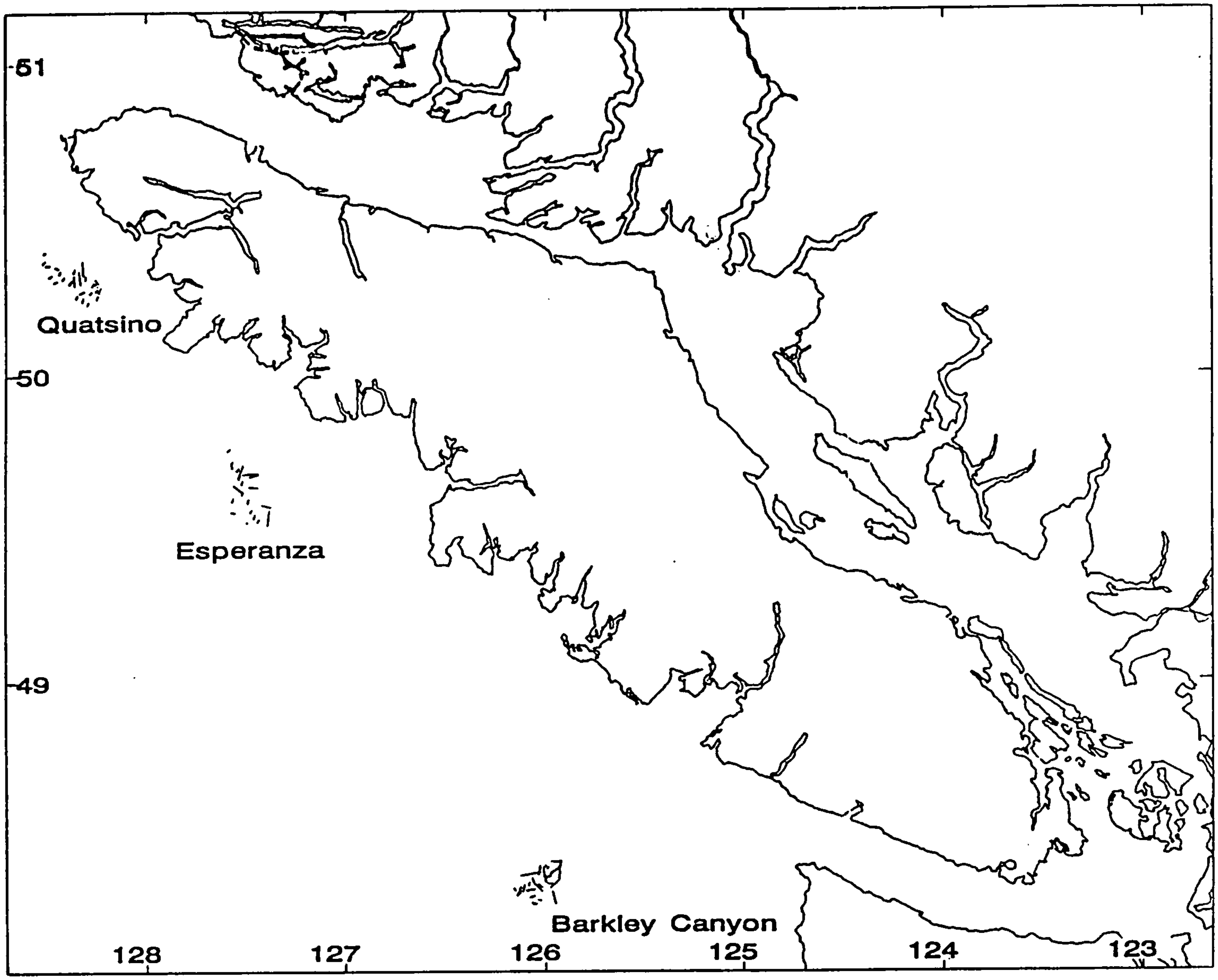


Figure 6. Sablefish survey sites off: (a). The west coast of Vancouver Island and (b) the west coast of the Queen Charlotte Islands and Queen Charlotte Sound.



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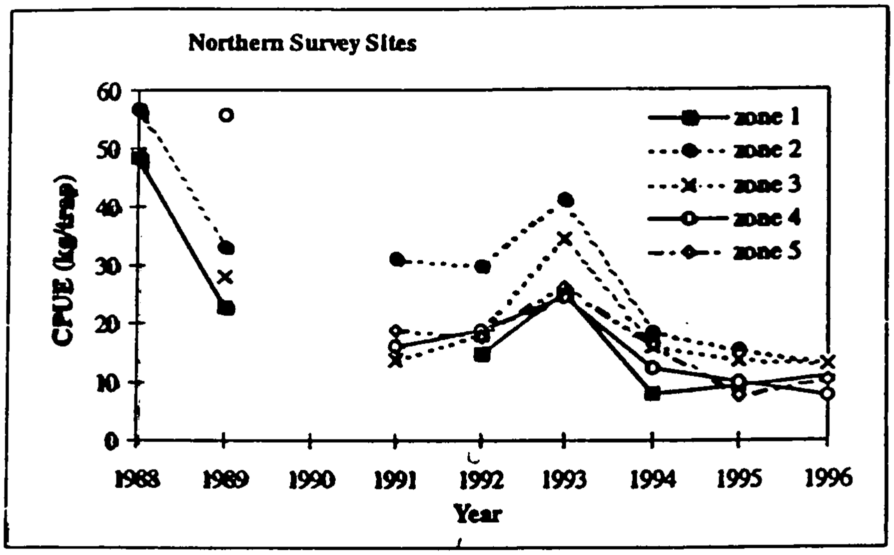

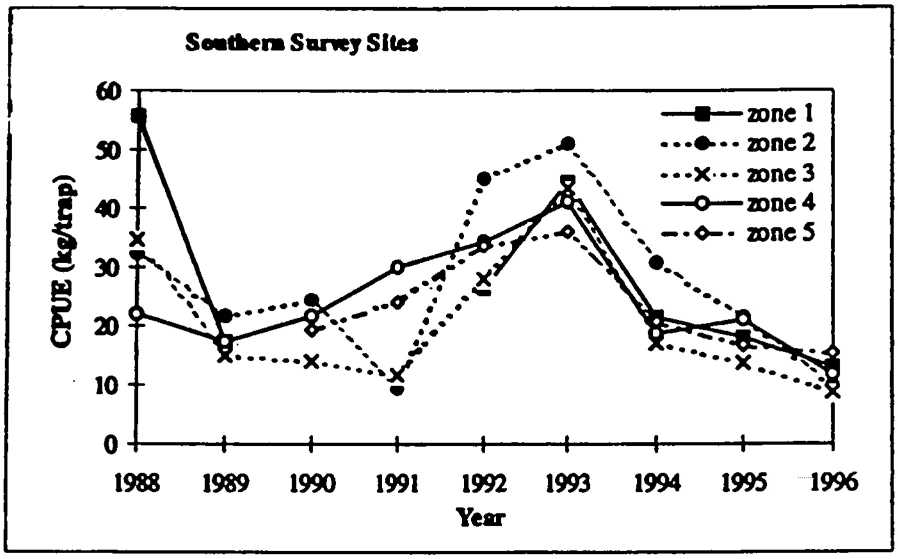

Figure 7. Sablefish trap survey annual CPUE in weight (kg/trap) and number by stock and by 100 fm depth intervals from 150-650 fm (eg. zone 1 = 151-250fm).

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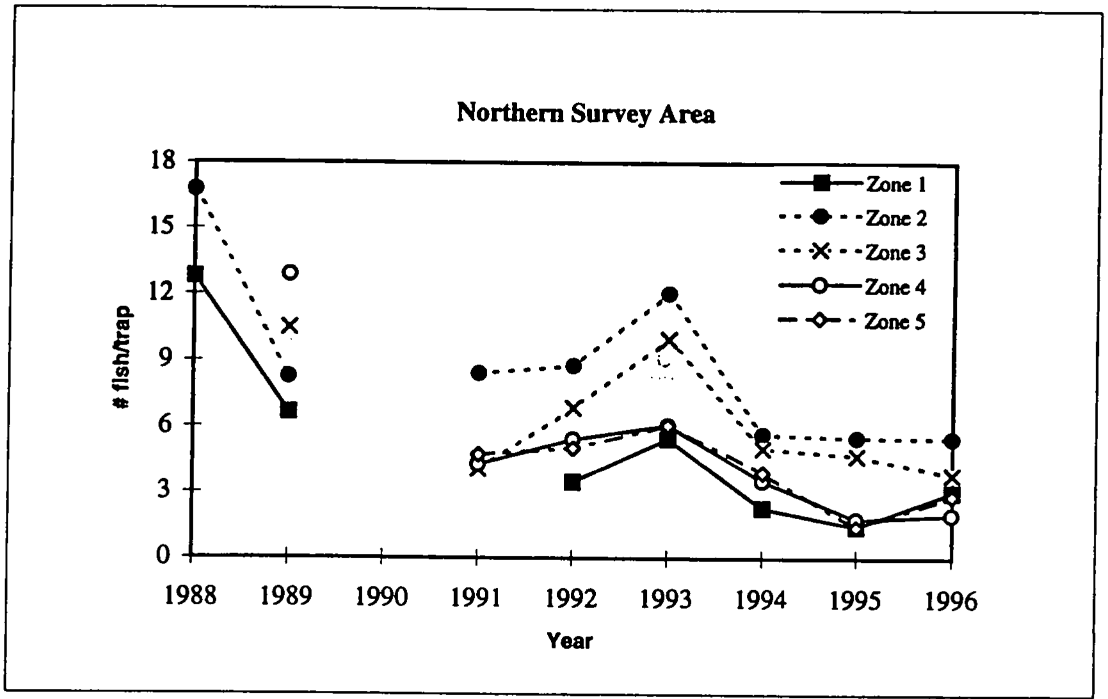

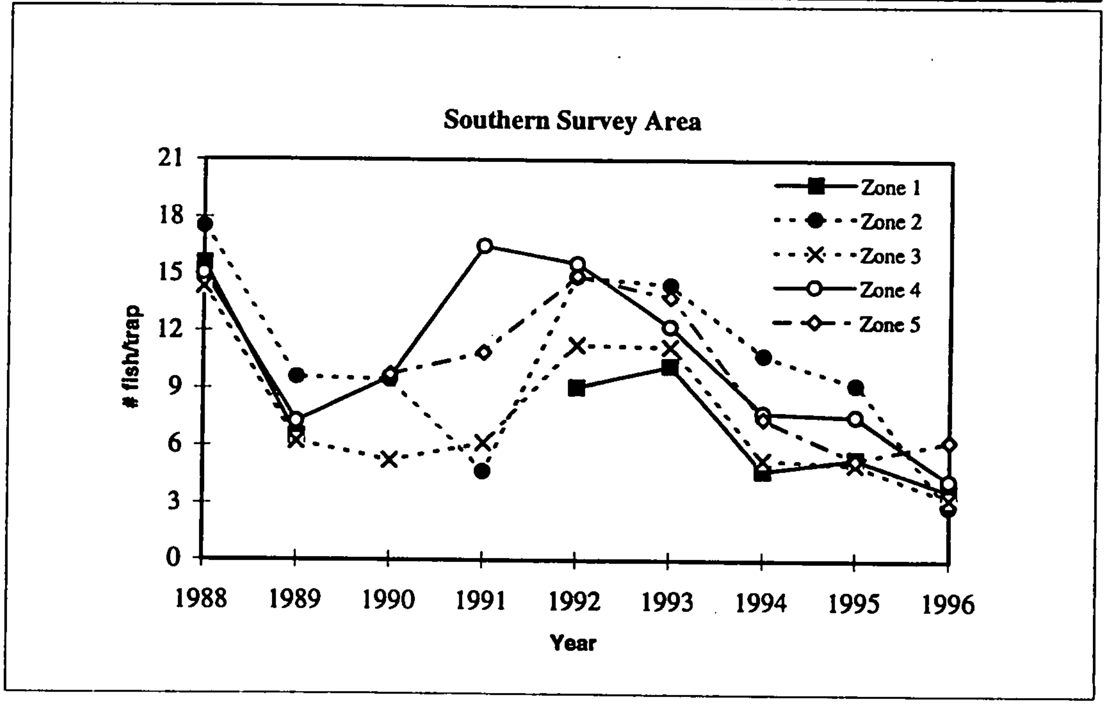

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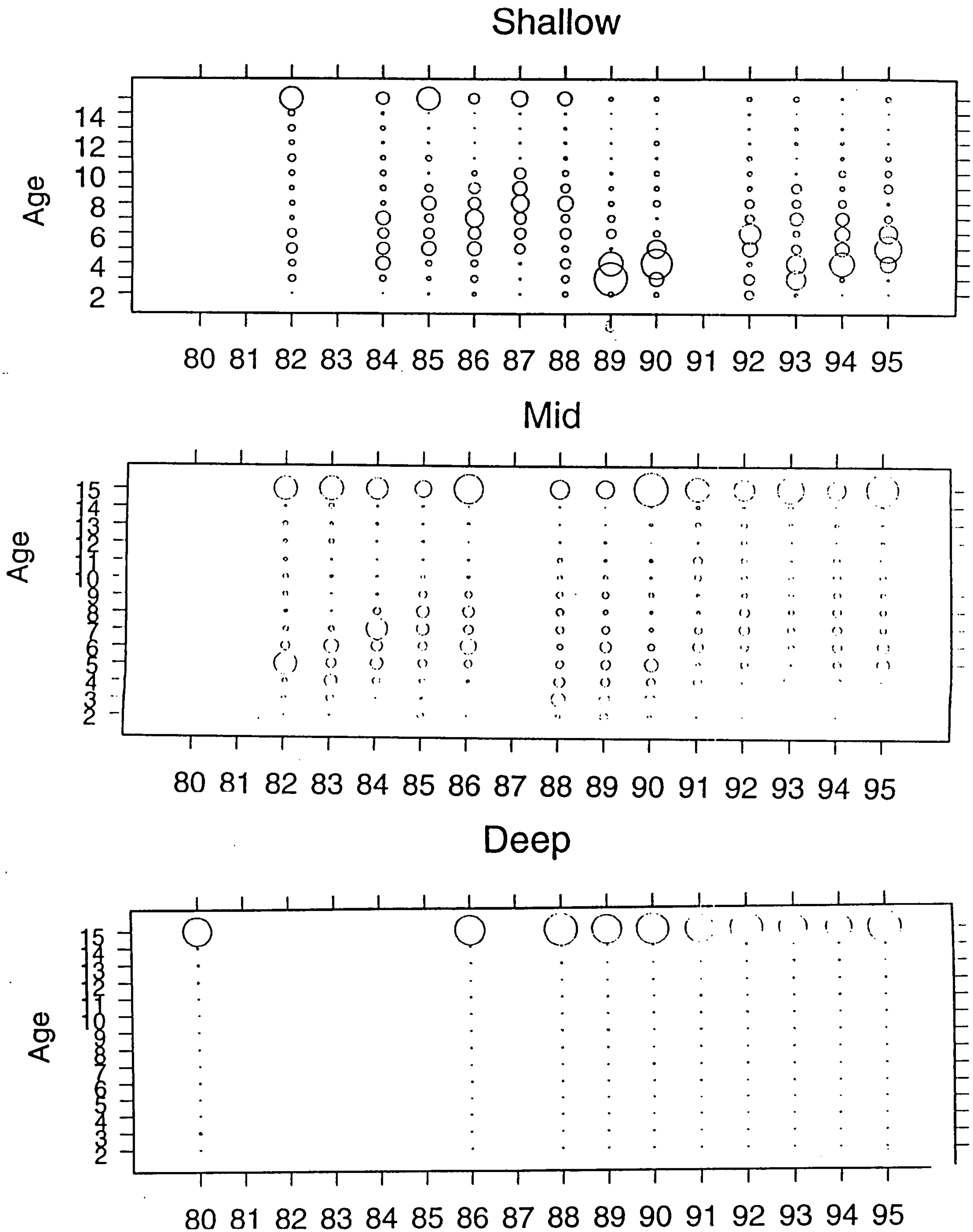
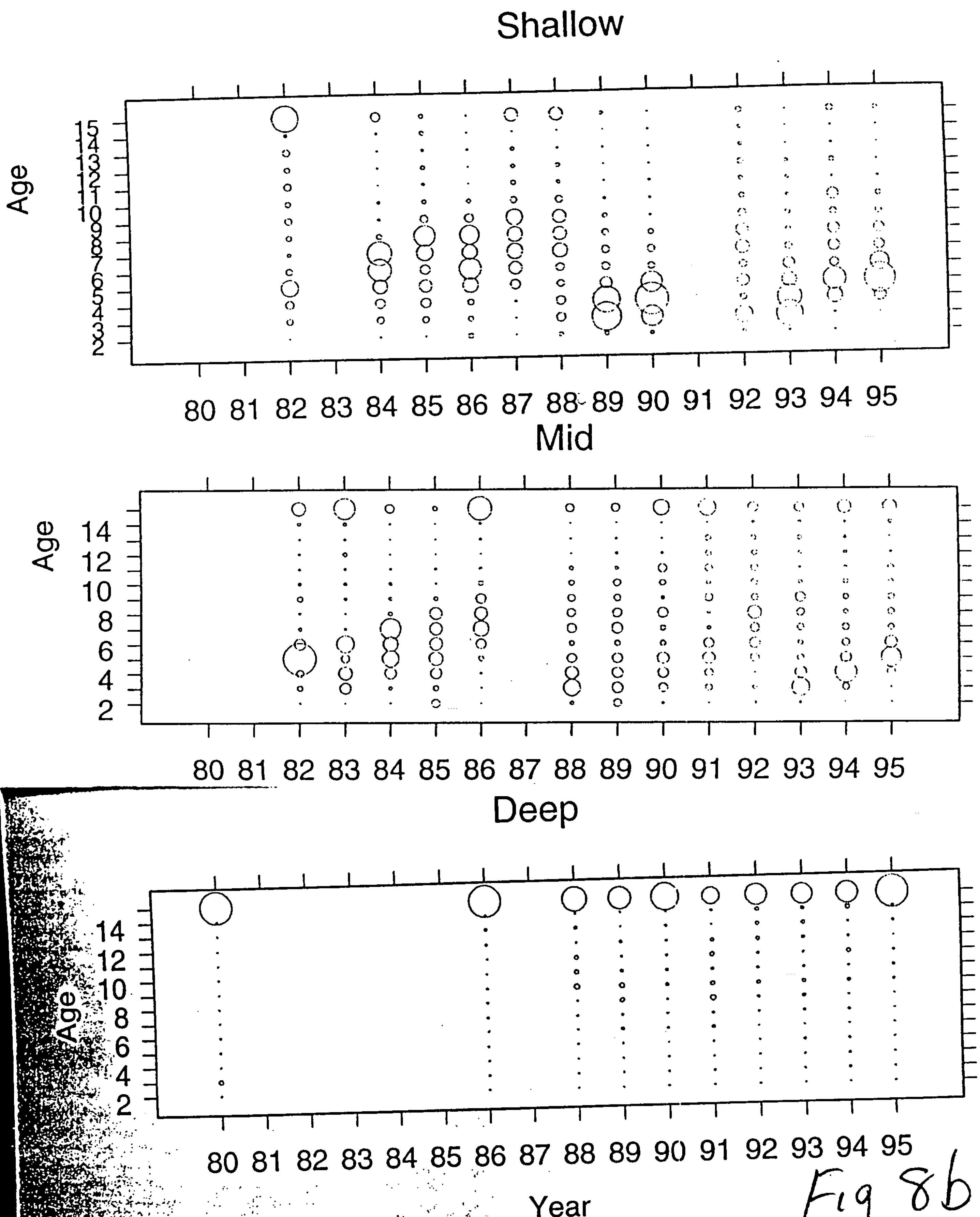


Figure 8. Sablefish age compositions for 1980-95 by, stock and sex. The diameter of a circle is proportional to the measured age proportions where data are scaled to sum to 1 down each column. Age 15 is an accumulator age. (a) South Males (b) South Females (c) North Males (d) North Females.



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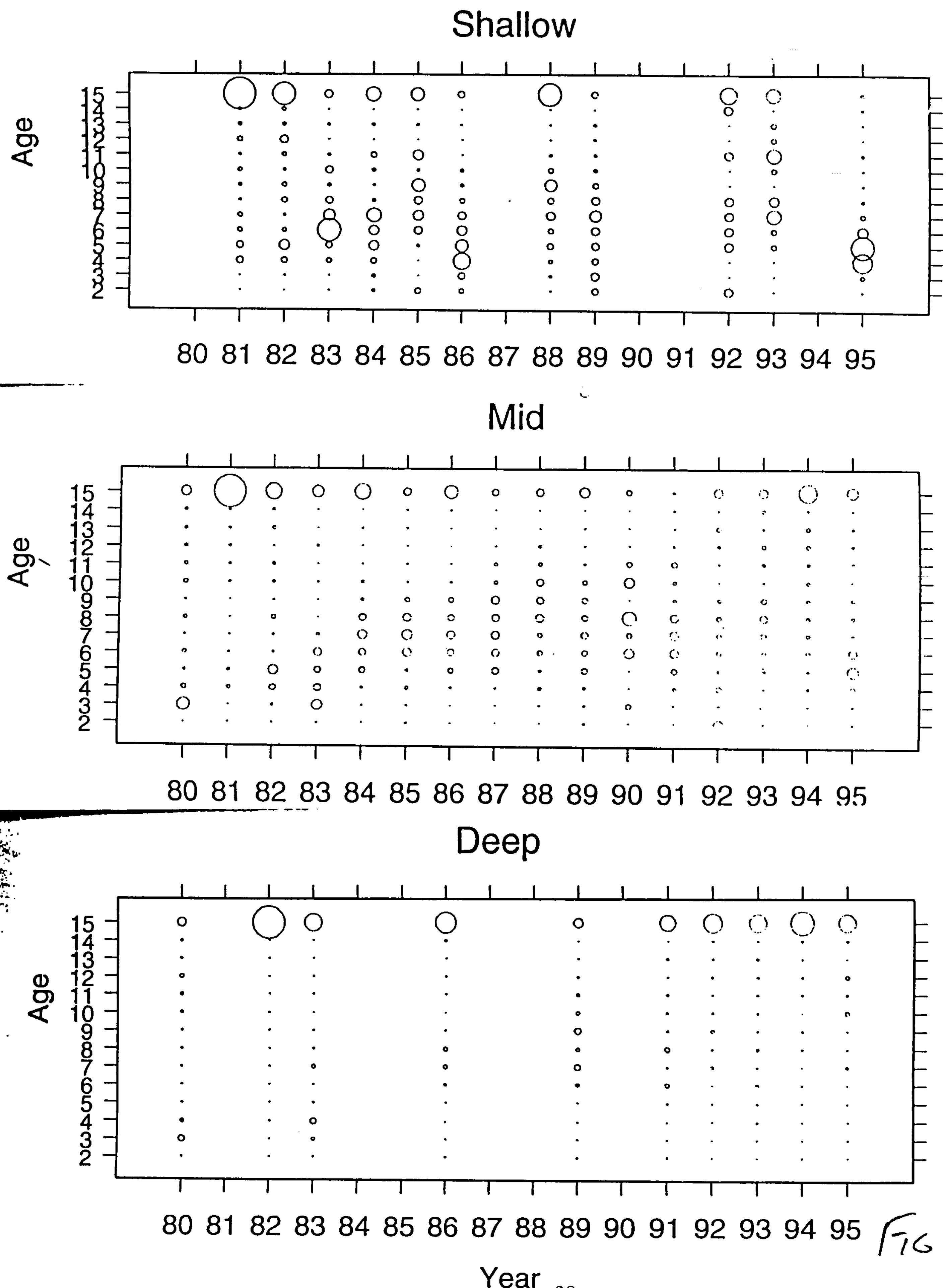
Shallow
Age
2 3 4 5 6 7 8 9 10 11 12 13 14 15
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Mid
Age
2 3 4 5 6 7 8 9 10 11 12 13 14 15
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Deep
Age
2 3 4 5 6 7 8 9 10 11 12 13 14 15
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Year

FIG 8C

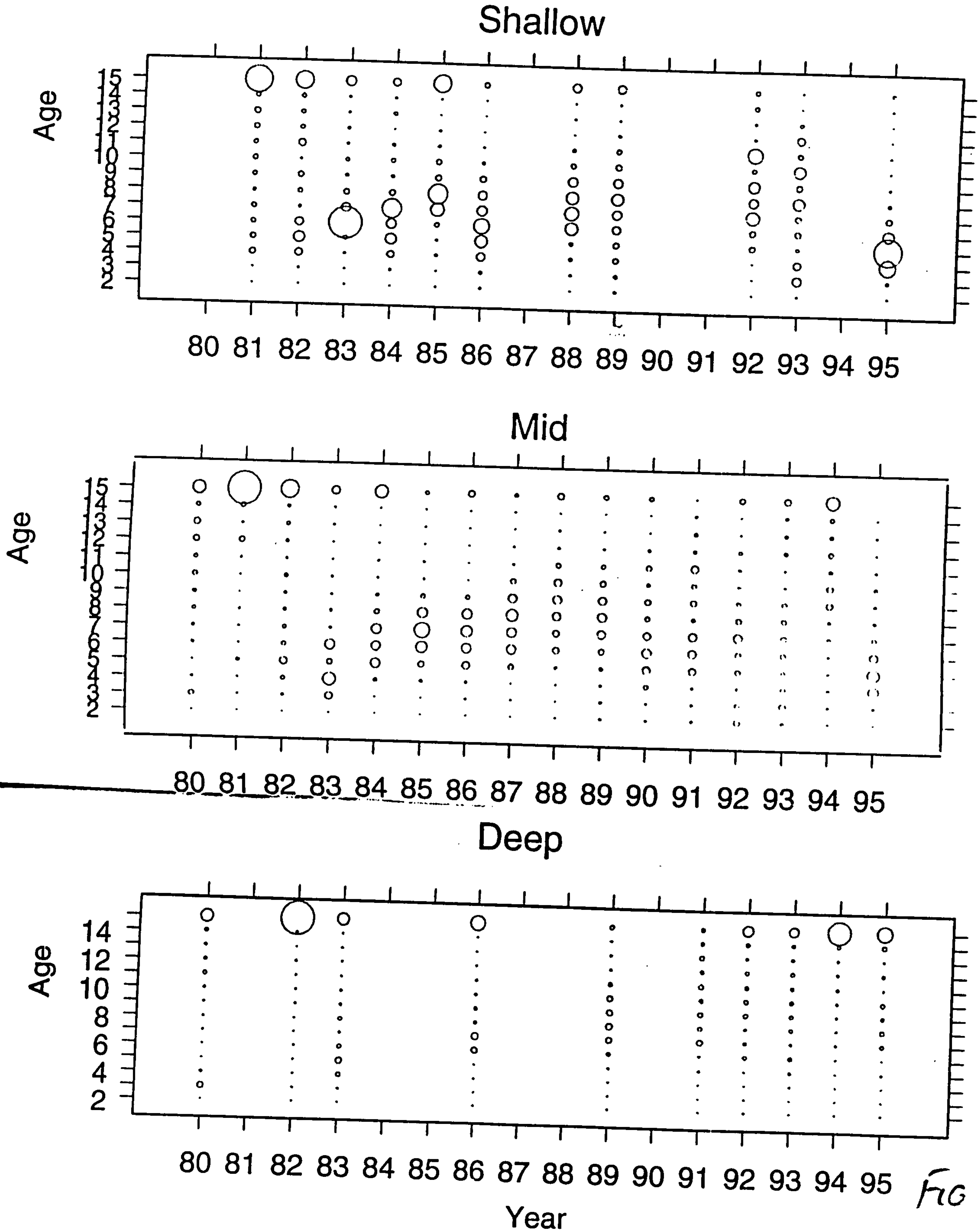

FIG 8d

NORTH FEMALES

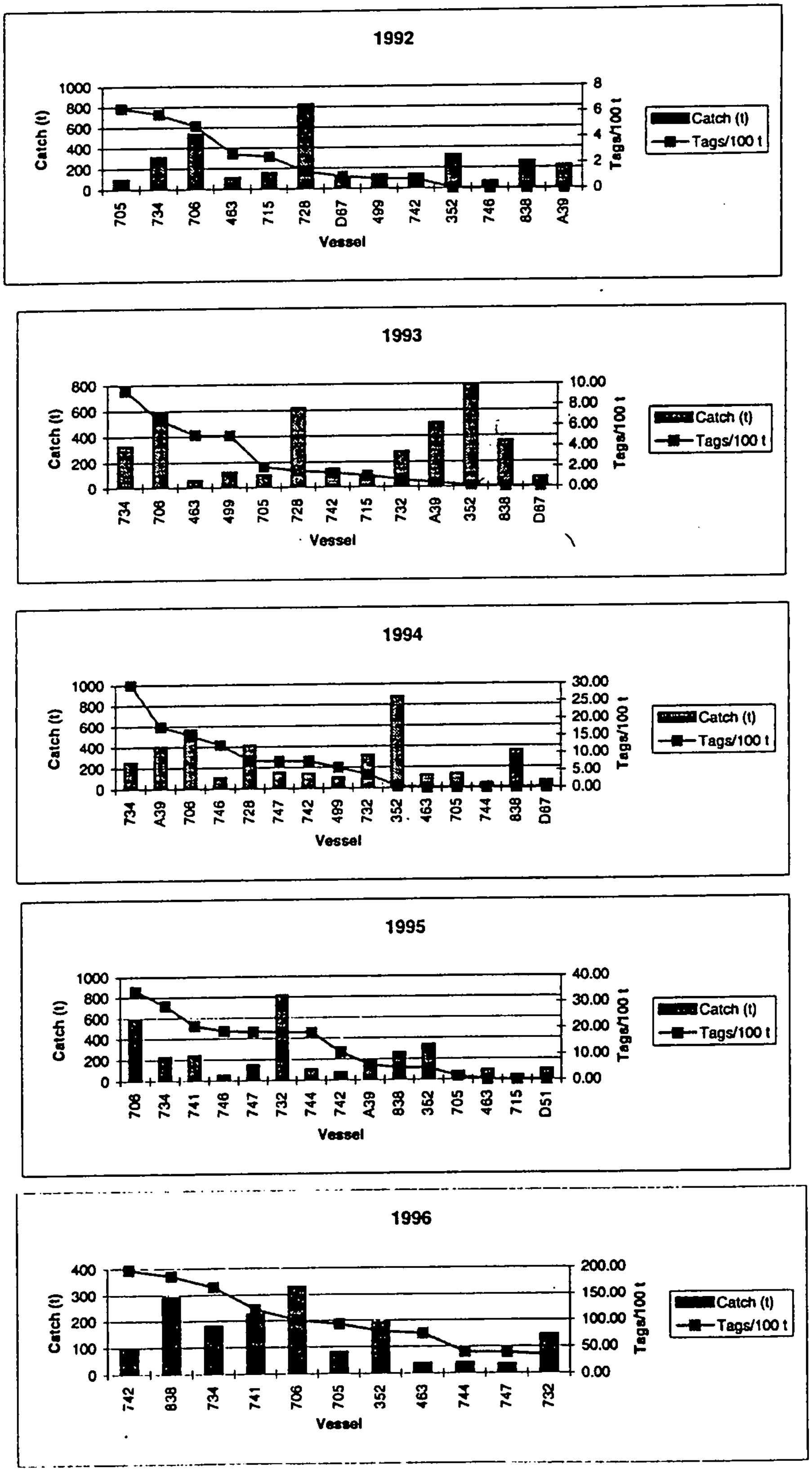

Figure 9. Individual trap vessel sablefish tag reporting rate (tags/100t) and catch, by year.

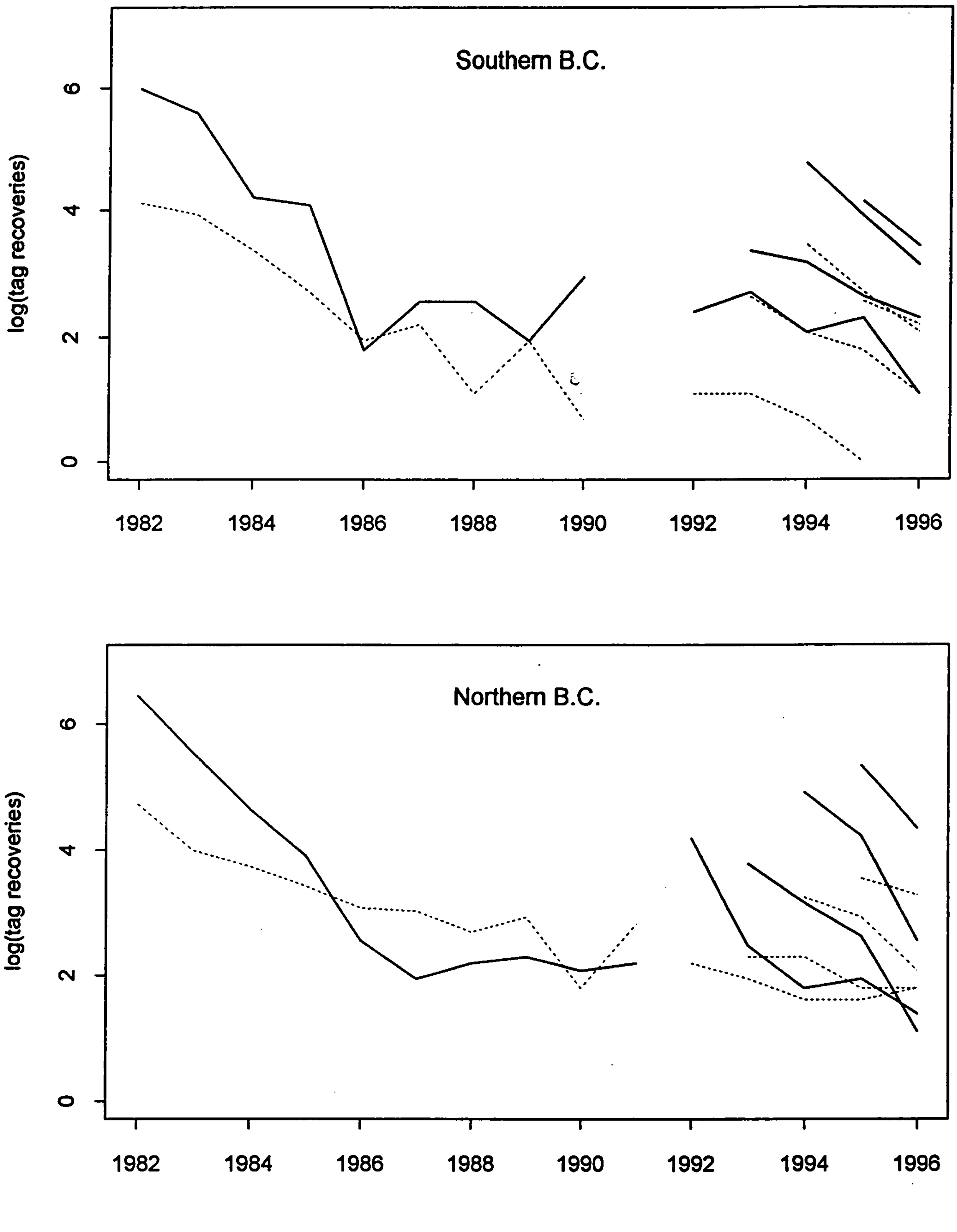

Fig. 10. The log of number of tags recovered against recovery year for tags recovered in area tagged (solid lines) and tags recovered outside the tagging area (dashed lines), plotted by tag group. Tag recovery data for 1980 through 1982 is adjusted and plotted as if tags were released in 1981.

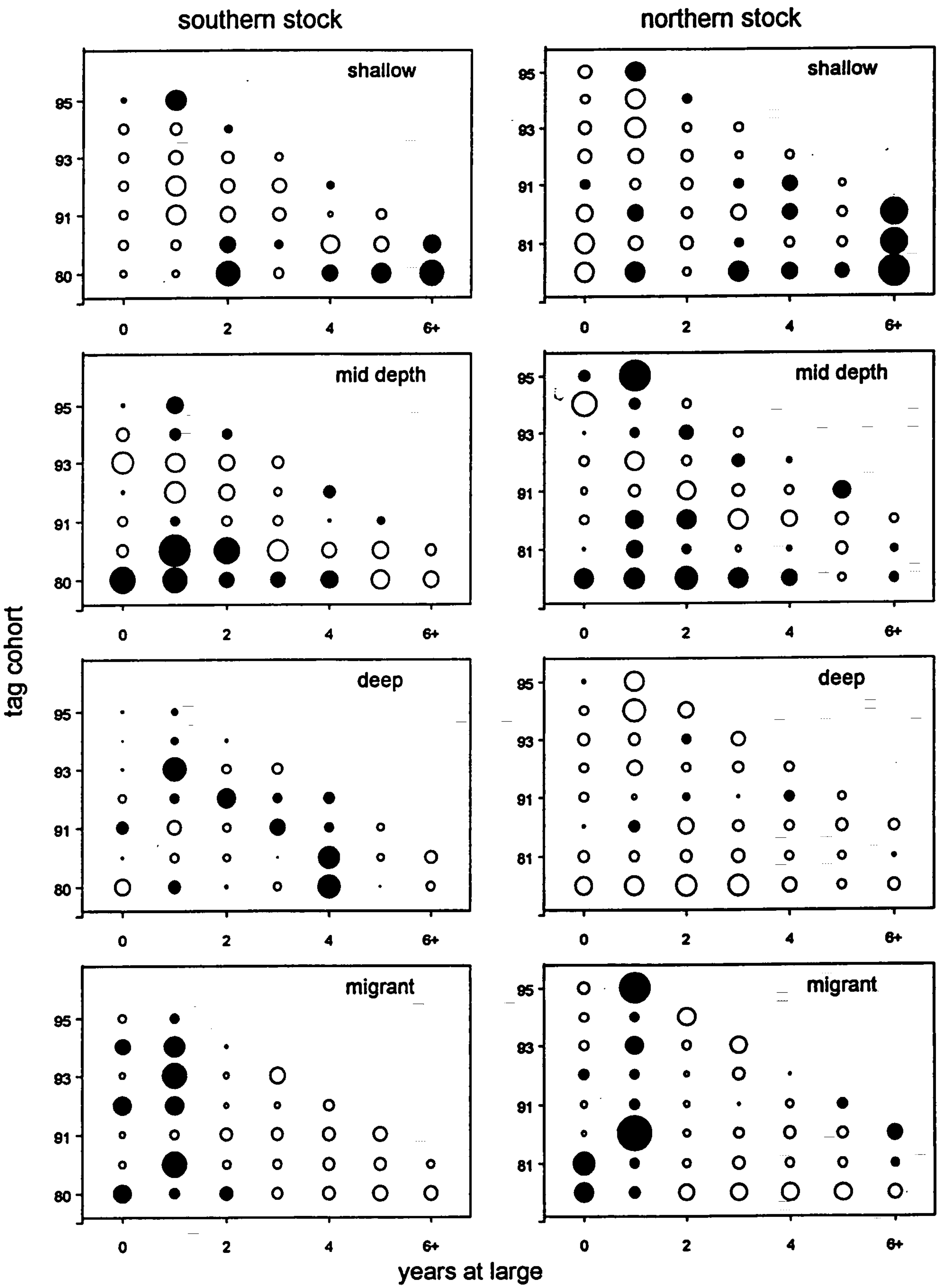

Fig. 11. Tag recovery residuals by tag cohort and years-at-large for the migration model. Positive residuals are represented by open circles and negative residuals by closed circles. The circle area is proportional to the absolute value of the residual.

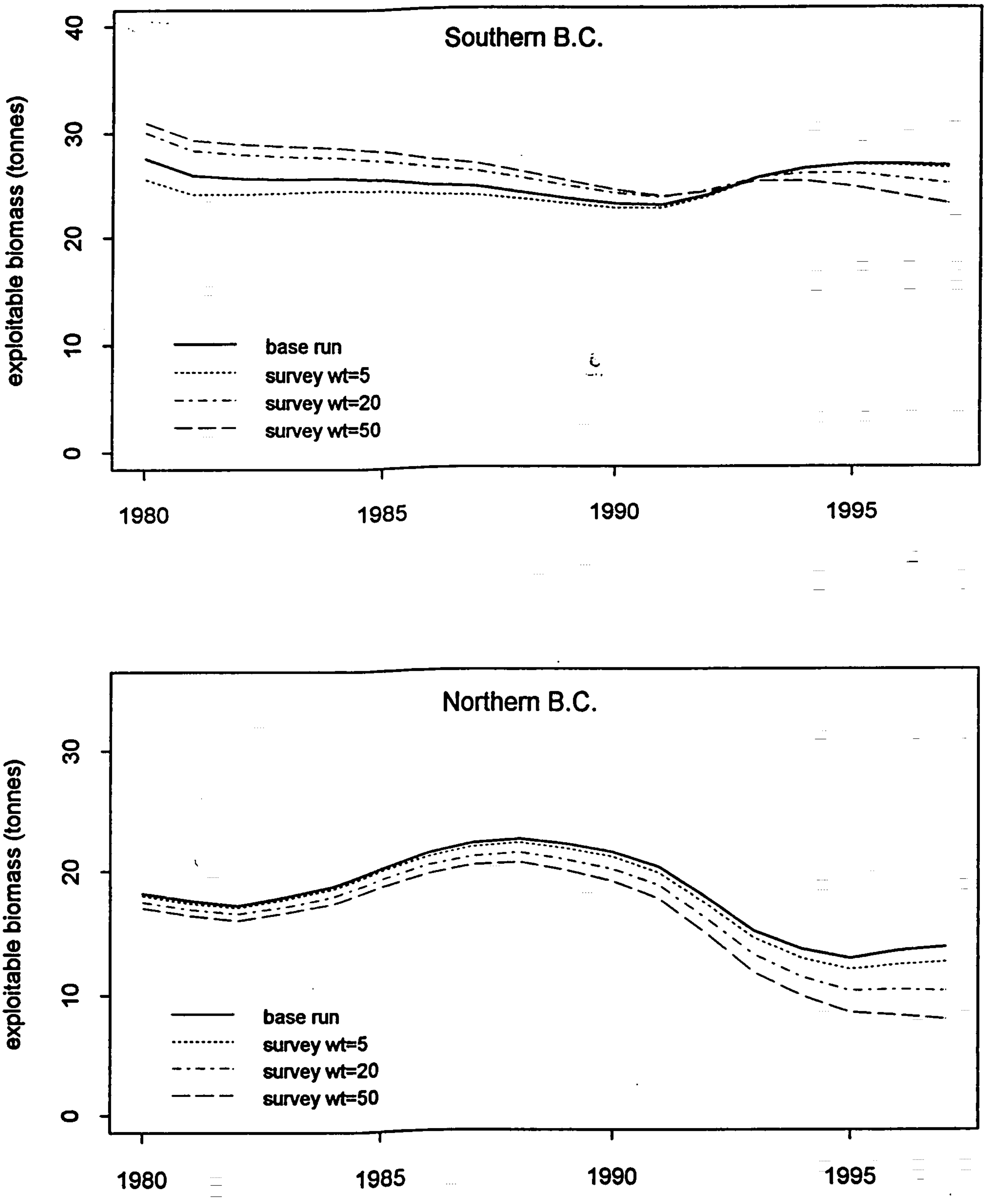

Fig. 12. Estimates of exploitable biomass for runs with various penalty weights on the fit to individual survey abundance data points.

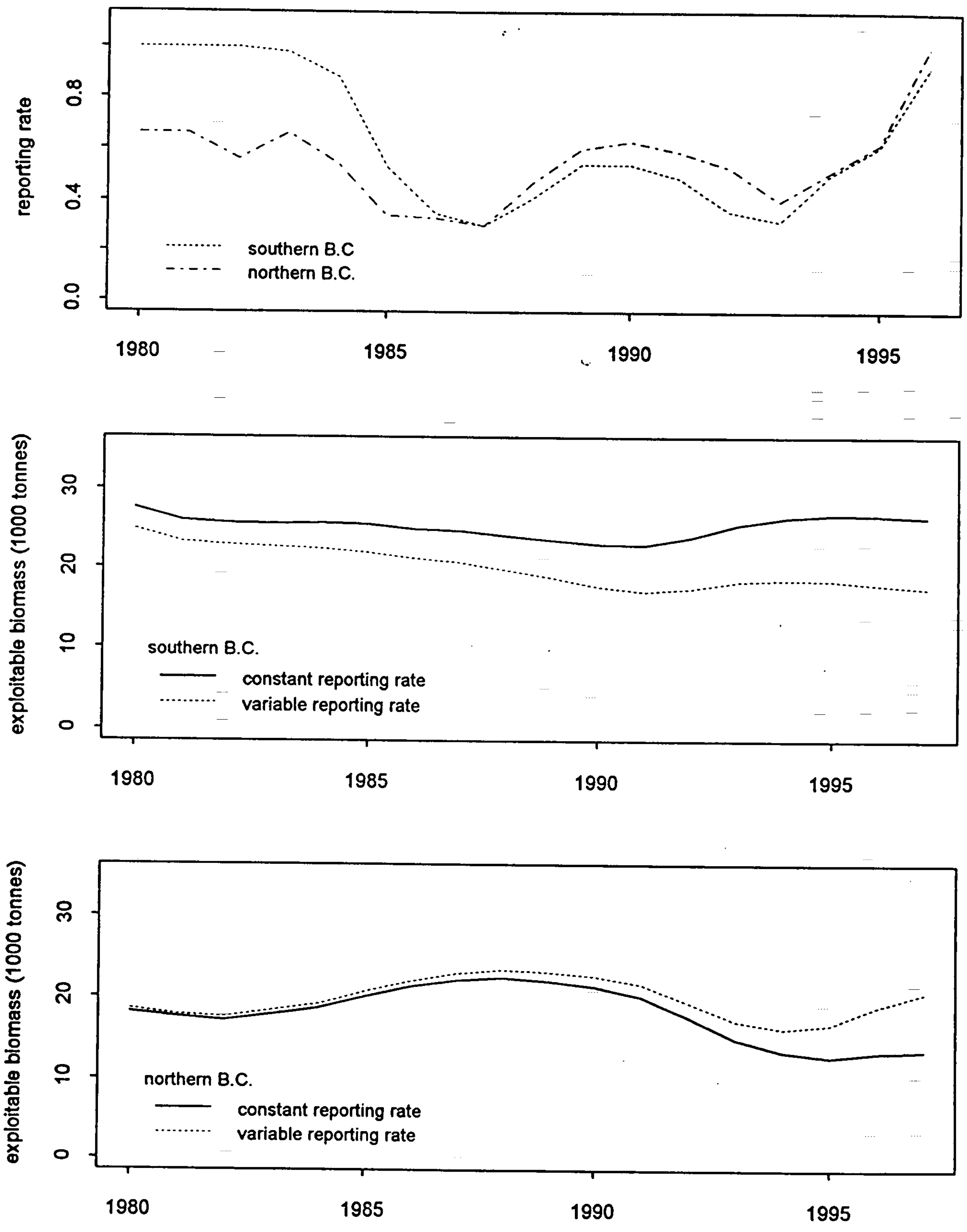

Fig. 13. Estimates of time-varying reporting rates and resulting exploitable biomass estimates for northern and southern B.C. stocks.

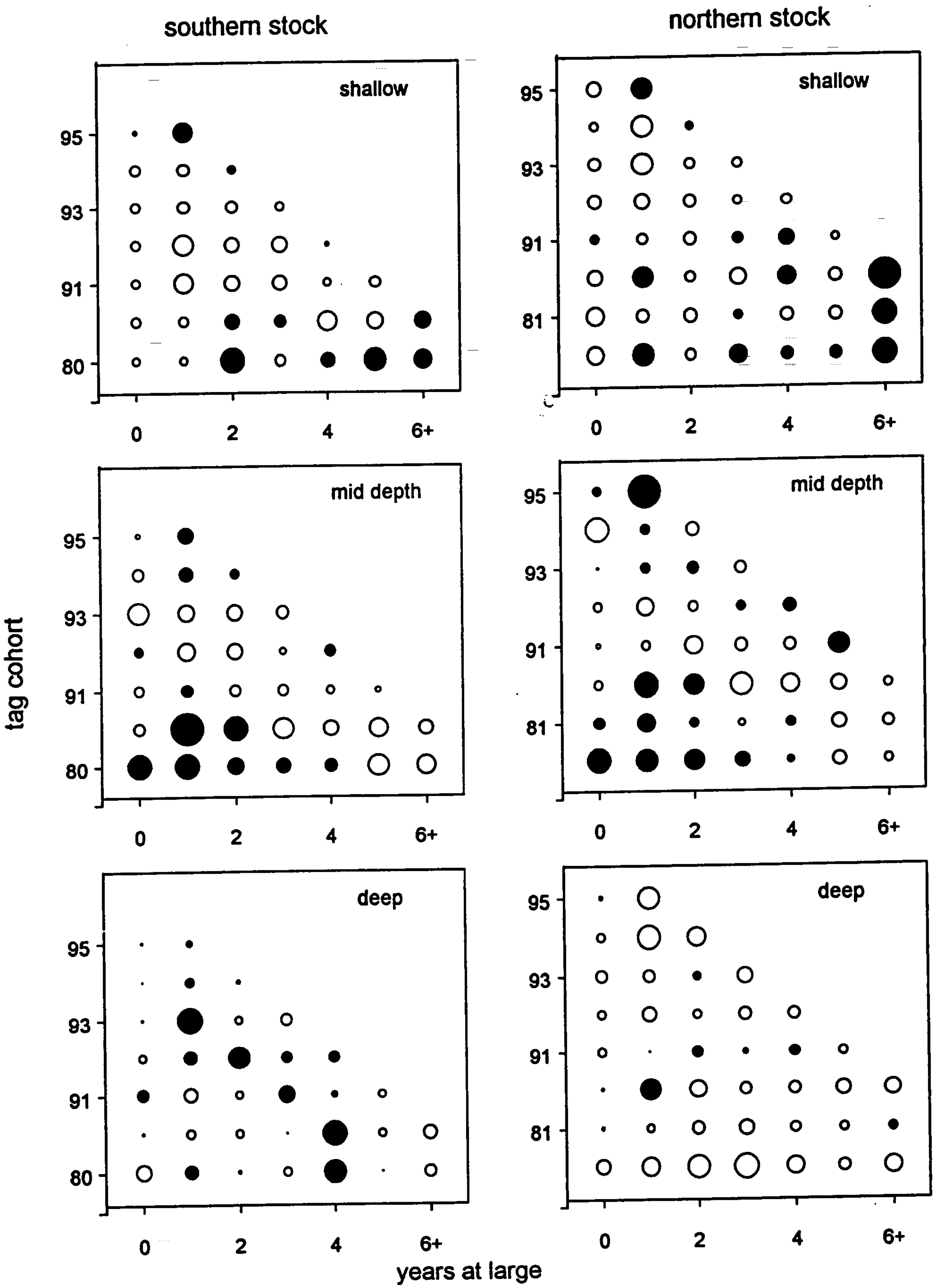

Fig. 14. Tag recovery residuals by tag cohort and years-at-large for the non-migration model. Positive residuals are represented by open circles and negative residuals by filled circles. The circle area is proportional to the absolute value of the residual.

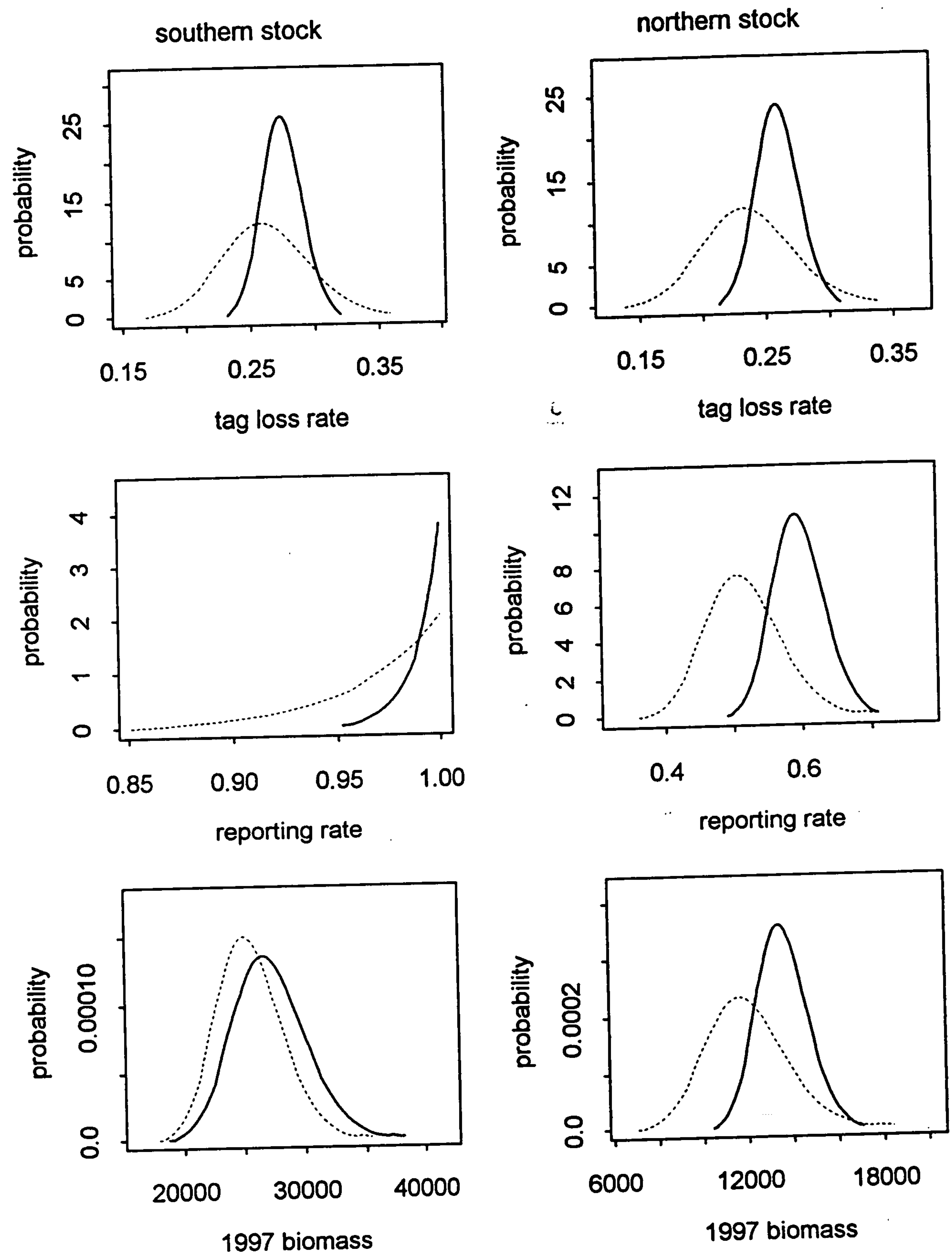

Fig. 15. Likelihood profiles for tag loss rates, tag reporting rates, and 1997 biomass estimates. The solid lines are from the base case runs and the dashed lines are from runs with penalty weights of 0.1 on the tag data and 50 on the relative survey data.

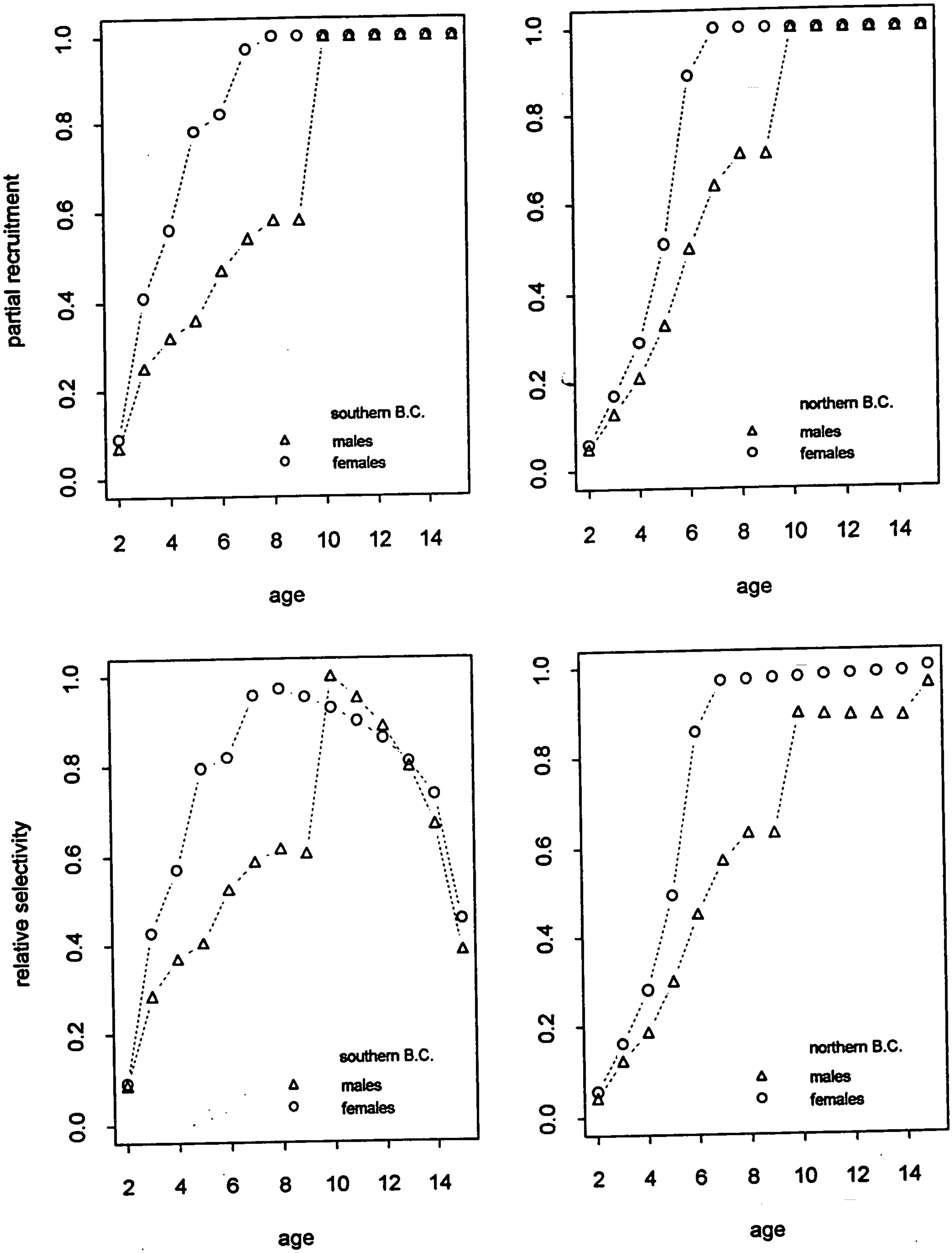

Fig. 16. Estimates of age and sex specific partial recruitment and relative selectivity.

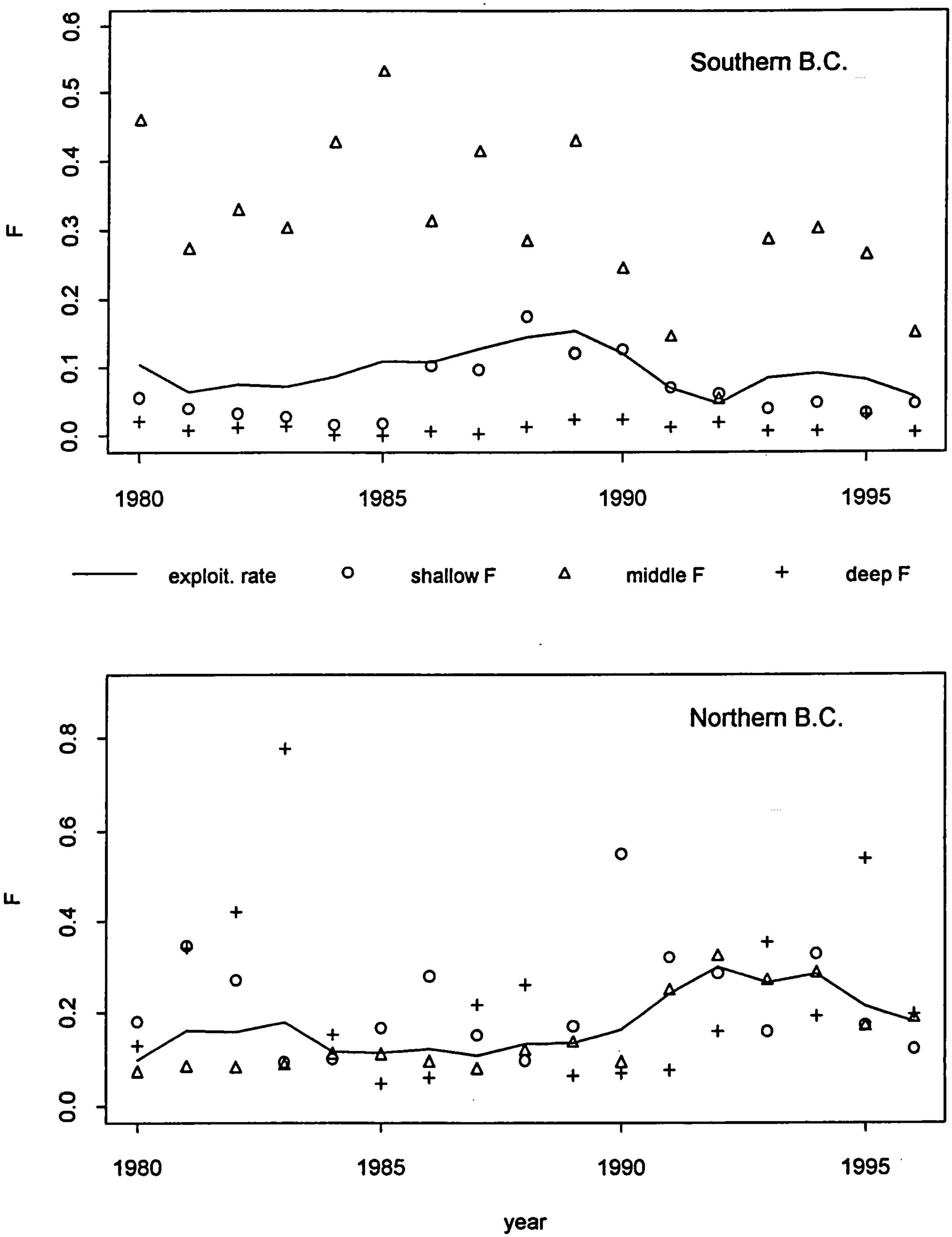

Fig. 17. Estimates of total exploitation rates and fishing mortality rates (F) for shallow, middle, and deep strata, 1980-1996.

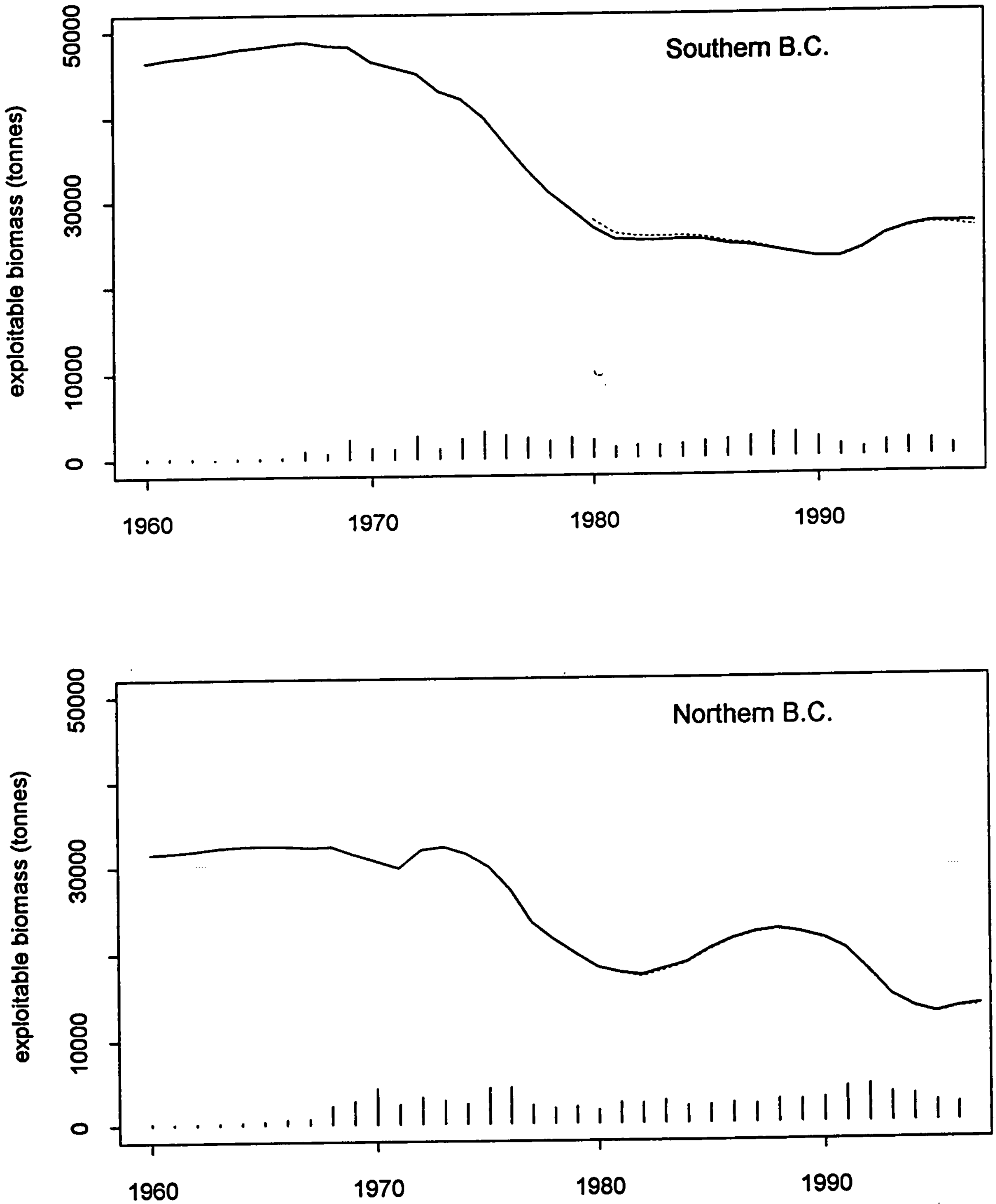

Fig. 18. Estimates of exploitable biomass from runs using catch data for 1960-1997 (solid lines) and catch data for 1980-1997 (dashed line). Annual catches are shown with vertical bars.

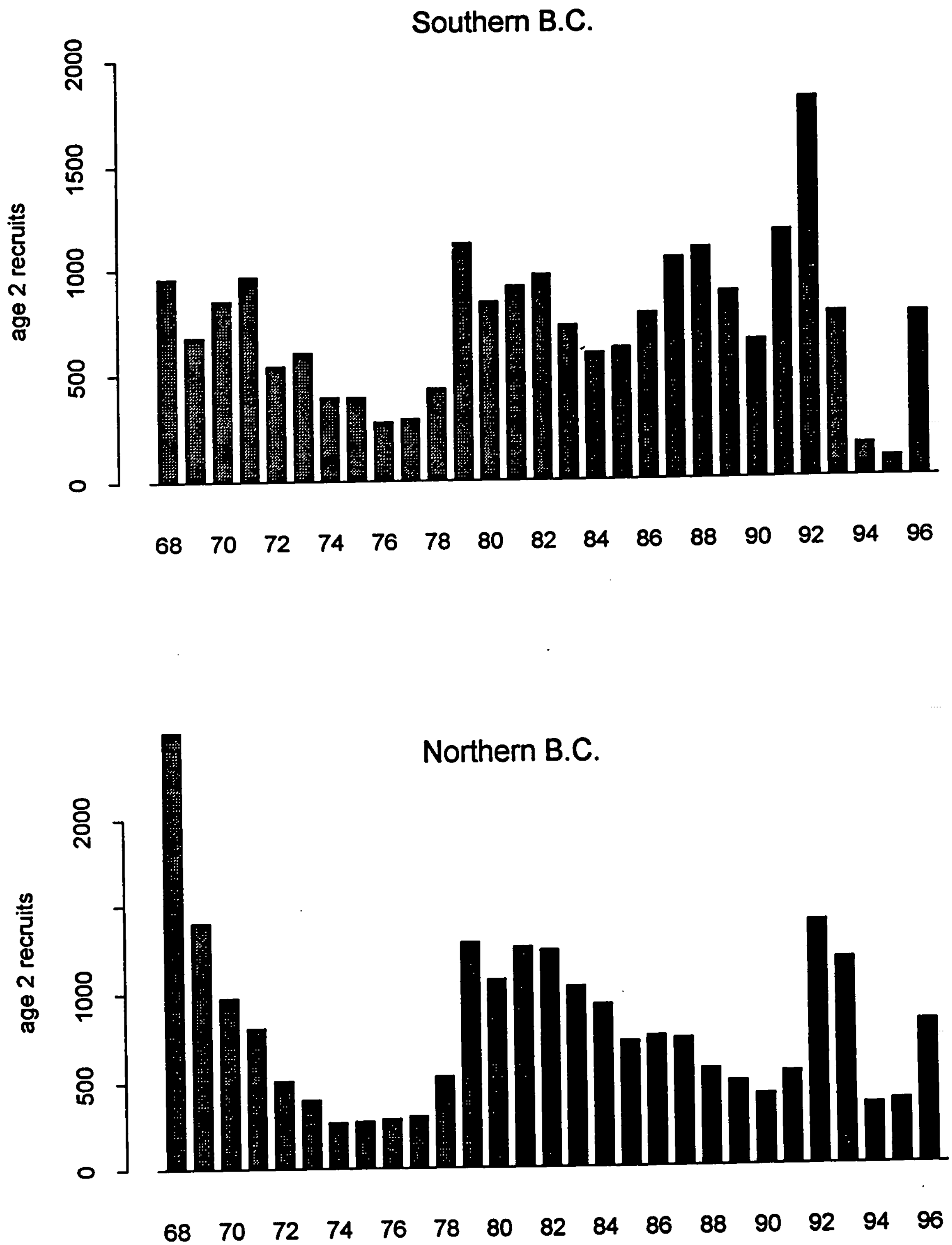

Fig. 19. Time series of relative recruitment estimates for the northern and southern B.C. sablefish stocks.