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Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2002 and Advice to Managers for 2003

La morue charbonnière (*Anoplopoma fimbria*) en Colombie-Britannique (Canada) : évaluation du stock en 2002 et avis aux gestionnaires pour 2003

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Abstract

Sablefish (*Anoplopoma fimbria*) stock status in British Columbia for 2002 was assessed and advice to managers provided for the 2003/2004 fishing year. The assessment of sablefish stock status in recent years has depended upon the interpretation of three stock abundance indices: (1) annual estimates of relative vulnerable biomass derived from a tagging model that utilizes tags recovered in the first year after release, (2) catch rates obtained from a fishery-independent trap gear survey, and (3) commercial catch rates derived from sablefish trap fishery logbooks. No stock reconstruction is available due to the absence of age data since 1996 and unresolved difficulties in the modeling of tag recovery data. Sablefish were last assessed using an age-structured population dynamics model that integrated tag recovery information in 2000.

There is general agreement among the trends in stock indices that sablefish vulnerable to trap gear experienced a decrease in abundance from (relatively) high levels in the early 1990s to low levels in the mid 1990s. The rate of decline slowed markedly in the mid 1990s for both stock areas. For the north stock area, a period of relative stability occurred in the mid 1990s until 2001 when historically low commercial CPUE and indexing survey results were observed. Index survey catch rates in the north improved in 2002, and were comparable to those observed in the mid 1990s. In contrast, the decline in commercial trap and survey indices for the south stock area was more gradual through the mid 1990s, but has continued through 2002. The pattern of monthly tagging model estimates of vulnerable biomass was generally consistent with the trends indicated by the commercial catch rate and index survey series, though it is variable through the late 1990s.

This assessment incorporated the results of the fall 2002 abundance indexing survey, a new standardized commercial catch rate index, and a new tag-recovery model that adjusts tag returns for month effects. Analysis of sablefish recruitment indicators from various sources in British Columbia and the United States suggested that future production of sablefish should improve over low levels experienced in the 1990s. A simple biomass dynamics model was used to combine the stock indices and to examine the consequences of assumed levels of future production on projected stock biomass, where production was considered to be the combined effects of recruitment, immigration, emigration, and growth. Advice to managers was cast in the form of decision tables. By necessity, frequent review of the stock indicators will be required pending the development of a satisfactory population dynamics model for examining the consequences of long-term harvest strategies for sablefish.

Résumé

L'état du stock de morue charbonnière (*Anoplopoma fimbria*) en Colombie-Britannique en 2002 a été évalué et des avis pour la saison de pêche de 2003-2004 ont été présentés aux gestionnaires. L'évaluation de l'état de ce stock dans les dernières années reposait sur l'interprétation de trois indices d'abondance, soit : (1) des estimations annuelles de la biomasse relative vulnérable à la pêche tirées d'un modèle d'étiquetage reposant sur les étiquettes récupérées au cours de la première année après la remise à l'eau, (2) les taux de capture obtenus dans le cadre de relevés aux casiers indépendant de la pêche (ou pêche repère) et (3) les taux de capture commerciale issus des journaux de bord des pêcheurs de la morue charbonnière aux casiers. Il a été impossible de faire une reconstitution du stock en l'absence de données sur les âges depuis 1996 et à cause de problèmes non résolus dans la modélisation des données d'étiquettes récupérées. La dernière évaluation de la morue charbonnière repose sur un modèle de la dynamique de la population structuré selon l'âge qui inclue des données d'étiquettes récupérées en 2000.

Les tendances des indices pour le stock semblent indiquer en général que le nombre de morue charbonnière vulnérable à la capture au casier a diminué, passant de niveaux (relativement) élevés au début des années 1990 à de bas niveaux au milieu de cette décennie. Le taux de diminution a nettement ralenti à ce moment-là dans les deux secteurs du stock, alors que le secteur nord a connu une période de stabilité relative à partir de ce moment jusqu'à 2001 quand les CPUE commerciales et les prises réalisées dans le cadre des relevés par pêche repère ont atteint le niveau le plus faible observé jusqu'à maintenant. Les taux de capture obtenus dans ce secteur lors des relevés par pêche repère ont augmenté en 2002, pour se comparer à ceux observés au milieu des années 1990. Par contre, la diminution des indices de la pêche commerciale aux casiers et des relevés pour le secteur sud a été plus graduelle jusqu'au milieu des années 1990, mais a continué jusqu'à 2002. Les tendances des estimations mensuelles de la biomasse vulnérable issues du modèle d'étiquetage concordaient généralement aux tendances révélées par les taux de capture commerciale et la série de relevés par pêche repère, bien qu'elles variaient vers la fin des années 1990.

La présente évaluation inclut les résultats du relevé de l'abondance par pêche repère réalisé à l'automne 2002, un nouvel indice normalisé des taux de capture commerciale et un nouveau modèle des étiquettes récupérées, qui corrige celles-ci des effets du mois. Une analyse des indicateurs du recrutement de la morue charbonnière provenant de diverses sources en Colombie-Britannique et aux États-Unis suggère que la production devrait s'améliorer à l'avenir par rapport aux faibles niveaux observés dans les années 1990. On a utilisé un modèle simple de la dynamique de la biomasse pour regrouper les indices du stock et établir les conséquences de niveaux supposés de production future pour la biomasse prévue du stock, où la production est considérée comme étant le résultat des effets combinés du recrutement, de l'immigration, de l'émigration et de la croissance. Les avis ont été présentés aux gestionnaires sous la forme de tableaux de décision. Par nécessité, il faudra fréquemment passer en revue les indicateurs du stock tant qu'un modèle satisfaisant de la dynamique de la population n'aura pas été mis au point pour établir les conséquences de stratégies de pêche à long terme pour la morue charbonnière.

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1 Introduction

This document provides an assessment of offshore sablefish (*Anoplopoma fimbria*) stock status in British Columbia for 2002. The assessment of sablefish stock status in recent years has depended upon the interpretation of three stock abundance indicators: (1) annual estimates of vulnerable biomass derived from a tag-recovery model that utilizes tag returns in the first year after release, (2) standardized catch rates obtained from a fishery-independent survey, and (3) commercial catch rates derived from sablefish trap fishery logbooks (Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2002). No stock reconstruction is available due to the absence of age data since 1996 and unresolved difficulties in the modeling of tag recovery data. Sablefish were last assessed using an age-structured population dynamics model that integrated tag recovery information in 2000 (Haist and Hilborn 2000). Sablefish populations at seamounts are not considered in this assessment.

Significant declines in catch rates observed during the fall 2001 abundance indexing survey prompted an unscheduled review of survey, commercial fishery, and tag-recovery model estimates in early 2002 (Kronlund et al. 2002). This review occurred after the annual stock assessment of sablefish (Haist et al. 2001), which preceded the availability of the fall 2002 indexing survey data. The results of the fall 2001 survey raised concerns that sablefish had experienced a continued decline in abundance since the mid 1990s. Consequently, an in-season reduction in yield was recommended for the 2001/2002 fishing year to be carried over into the 2002/2003 fishing year (Kronlund et al. 2002, Cass 2002).

This assessment incorporated the results of the fall 2002 survey into an updated linear model analysis of the indexing survey time series. An extension of the tag-recovery model to incorporate monthly adjustments was introduced, and the sensitivity of the monthly tag-recovery model to assumed parameters was examined. A new commercial catch rate index was derived from logbook data using generalized linear modeling. The comparison of return rates for CSA-type and B-type tags first conducted by Haist et al. (2001) was repeated with the benefit of an additional year of data. Ancillary sources of information that bear on sablefish stock status in British Columbia were considered including sablefish encountered in non-directed surveys, sablefish caught in the Hecate Strait trawl fishery, and the results of sablefish assessments conducted in Alaska and the continental United States. A new biomass dynamics model was developed to integrate the available stock indices in a simple framework. Results from this model were used to construct decision tables based on performance measures related to stock increase. Objectives for the assessment identified in a Request for Working Paper (Appendix A) include:

1. to analyse the indexing survey data and interpret derived abundance indices;
2. to analyse commercial catch and effort data for sablefish, comparing trends derived from these data to those obtained from the indexing survey data;

3. to update the tag-recovery analysis used to compute relative abundance of sablefish and consider the sensitivity of results to model assumptions;
4. to provide yield recommendations for the 2003/2004 fishery and other advice to fishery managers where appropriate.

This document consists of a main body of text with supporting appendices A to J that can be consulted for more detailed information, as required. Some appendices (Appendices B, C, D, F, I) contain details of data sources and data selection criteria. Appendix E contains indexing survey model diagnostics. Appendix G contains an update of the simple tagging analysis used in recent assessments, which is superceded by the monthly tagging model presented in this document. Appendix H contains a summary of the sablefish management history including a discussion of overage/underage rules. Appendix J describes the history of sablefish stock assessment in B.C., lists current impediments to progress in assessment, and identifies steps taken or planned to resolve these problems.

Tables and Figures referred to in the main text are sequentially numbered. Tables and Figures in appendices are labeled with the letter code of the appendix and a sequential number, e.g. Table B.2 for the second table in Appendix B. Equations presented in the main text are numbered with the section number where they occur, and a sequential equation number within the section, for example, Eq 3.1 is the first equation in Section 3.

2 Data Sources

A tabular listing of sablefish-related data used for analyses in this assessment is provided in this section. The data type, primary variables, and temporal and spatial coverage are described. A reference to the section or appendix that contains the data selection criteria is provided, and the data source is noted in the table. Some sablefish data may not be included in the list because the data are not computer accessible, or may require significant auditing before they can be considered reliable. Other data may not be relevant to the present analyses. Note that information may not be complete for all variables listed. For example, effort may be missing for some logbook records where catch is present. Or, length and age may be recorded for a given fish but no associated weight or maturity data are available. Ages are not available after 1996 although otoliths have been collected and archived.

Data Type	Response Variables	Associated Variables	Coverage	Selection Criteria	Source
Directed surveys:					
Indexing survey (sablefish trap)	Catch (wt, #) Effort (traps) Species	Survey set Lat/Lon Depth Date/Time	1990-2002 150-1,000 fm Sep-Nov	Section 4 Appendix D	GFBio
Tagging survey (sablefish trap)	Releases Recoveries	Survey set Lat/Lon Depth Date/Time Fishery type (*rec*) Fishery set (*rec*)	1990-2002 150-800 fm Sep-Nov	Section 3.5 Appendix F,G	Tag_Releases.mdb Tag_Recoveries.mdb
Survey biosamples (individual sablefish)	Length Weight Sex Maturity Age (to 1996)	Survey set Location Depth Date/Time Tag number	1990-2002 150-1,000 fm Sep-Nov	Section 5.3	GFBio
Non-directed surveys:					
Thornyhead survey (trawl)	Catch (wt) Effort (area swept) Species Lengths	Survey set Lat/Lon Date/Time Depth	2001-2002 Aug-Sep West coast Vancouver Is.	Section 5.3	GFBio
IPHC halibut survey (longline)	Catch (#) Effort Species	Survey set Lat/Lon Date/Time Depth	1993-2002 Jun-Jul IPHC area 2B	Appendix I	IPHC SSA database
Shrimp survey (trawl)	Catch (kg) Effort Species	Survey set Lat/Lon Date/Time Depth	1973-2002 < 200 m May-Jun	Section 5.2	Shellfish Data Unit

Data Type	**Response Variables**	**Associated Variables**	**Coverage**	**Selection Criteria**	**Source**
Sablefish "K" fishery:					
Logbooks (trap and longline)	Catch (*weight for trap, pieces for longline*) Effort	Set no. Lat/Lon Management area Date/Time Depth	Longline: 1987-2002 Trap: 1990-2002 Fishing year Coastwide	Section 3.2 Appendix C	PacHarvSable
Dockside validated landing	Landing by species	Trip no. Date/Time Management area	1995-2002 Fishing year Coastwide	Appendix B	PacHarvSable
Landings (Landings records and logbooks)	Landings by species	Trip no. Date/Time Management area	Longline: 1979-1986 Trap: 1979-1995 Fishing year Coastwide	Appendix B	GFCatch
Landings (landings records)	Landings by species	Date	Longline: 1987-1994	Appendix B	PacHarv 3.0
Landings (fishery reports)	Landings	Gear	1913-1981	Appendix B	McFarlane and Beamish (1983)
Fishery biosamples (Individual fish)	Length Weight Sex Age (some)	Trip no. Set Date/Time Vessel	1992-2002 Fishing year Coastwide	Not used this document.	quota biodata.mdb
Other fisheries:					
Dockside Validated Landings (trawl "T" fishery)	Landings by species	Trip no. Date/Time Management area	1996-2002 Fishing year Coastwide	Appendix B	PacHarvTrawl
Landings (trawl "T" sales slips, logbooks)	Landings by species	Trip no. Date/Time Management area	1954-1995 Fishing year Coastwide	Appendix B	GFCatch
Observer logs (trawl "T" fishery)	Catch (t) Effort Species	Set no. Lat/Lon Date/Time Depth	1996-2002 Fishing year Coastwide	Section 3.3 Appendix B	PacHarvTrawl
Fishery biosamples (trawl "T", individual fish)	Length Sex Otoliths (no ages)	Set no. Lat/Lon Date/Time Depth	1996-2002 Coastwide Fishing year	Section 3.3	GFBio

3 Fishery Dependent Catch and Effort Data

3.1 Commercial fishery catch and effort statistics

This section provides a synoptic overview of commercial fishery catch and effort data over the recorded history of sablefish exploitation. The nominal catch rate data are presented here, and no attempt is made to standardize the underlying data for ancillary effects. The commercial fishery for sablefish has been active since the late nineteenth century and was described in detail by McFarlane and Beamish (1983a). During the 1910s, total annual landings as high as 5,956 mt were realized in British Columbia. However, landings remained modest from 1920 to 1965, ranging between 209 mt and 1895 mt (Figure 1, panel A, Table 1). Since 1969, total Canadian landings have ranged from 3261 mt (2001) to 7408 mt (1975) and have averaged 4650 mt.

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 (Figure 1, panel B, Table 1). The largest annual catches of sablefish occurred during this period with a peak 7408 mt removed in 1975. Unrestricted foreign fishing ceased in 1977 when the Canadian 200-mile Economic Exclusive Zone was declared. However, some foreign fishing was allowed between 1977 and 1980 to utilise yield declared surplus to Canadian domestic fleet needs.

Domestic fishery. Canadian landings since 1951 have been reported by longline, trawl, and trap gear (Table 1). Since 1980, annual landings have averaged 4413 mt and ranged from 3261 mt in 2001 to 5402 mt in 1988. The fishery has been managed under quotas allocated to "K" licence (longline hook and trap gear) and "T" licence (trawl gear) fleets. Additional sablefish are caught as by-catch in the halibut fishery and there are small allocations to research charters and to First Nations food fisheries (Appendix H). Since 1977, the trawl components of the landings have always been the smallest, ranging from 5 to 16 percent of the total (Figure 1, panel B, Table 2). Since 1981, the trawl fishery has been allocated a fixed percentage (8.75) of the total allowable catch based on historic average trawl landings.

In the directed sablefish "K" fishery, longline was the dominant gear type in most years until 1973 when the trap fishery began to develop and the proportion of the catch taken by longline gear declined (Table 2). By 1978, trap gear clearly dominated domestic landings and the percentage of longline-caught fish in the total landings fluctuated between 6.6 percent (1980) and 28.0 percent (1990). The trap fishery landed an average of 449 mt per year over the 1973 to 1978 period. Trap landings increased significantly in 1979, and beginning in 1980 have ranged from 2,477 mt (2001) to 4,142 mt (1993) with a mean of 3,397 mt. In contrast, longline landings averaged 639 mt per year over the 1980 to 2001 period.

IVQ fishery. During the period from 1990 to 1992, the first three years of individual vessel quota (IVQ) management, the proportion of landings attributed to longline was high (0.17 to 0.28) but then dropped to below 12 percent over the 1993 to 1998 period (Table 2). The initial increase was due to large vessels that developed longline operations for other groundfish species that included their sablefish quota. In this way these vessels could fish most of the year. The subsequent decline was attributed to a move away from the multi-species longline approach in favour of dedicated trap fishing with transferable quota. The transferable quota allowed the vessels to fish sablefish most of the year and traps were chosen as the most effective gear. An increase in the proportion of the catch taken by longline from 1999 through 2002 may reflect a move back to a multiple target species approach, i.e. so-called "combination fishing" where halibut ("L" license) or rockfishes ("Zn" license) may be taken in conjunction with a sablefish "K" license to avoid discarding imposed by license regulation. The shift could also reflect reduced availability of sablefish to trap gear in the last few years (Kronlund et al. 2002).

Catch, effort, and catch per unit effort (CPUE). Sablefish catch and effort data for the "K" licensed fishery are available from logbooks and skipper interviews beginning in 1979. These data are most comprehensive for the trap fishery. Annual trap landings (mt) were determined by summing the "official catch" weight of retained sablefish in each calendar year of the fishing event. An explanation of "official catch" is included in Appendix B. Catch per unit effort, U_t, in year *t* was computed using the sum of the individual catches, C_{ti}, divided by the sum of the associated effort, E_{ti}, for all records $i = 1,\ldots,n_t$ where both catch and effort data were available

(3.1) $$U_t = \frac{\sum_{i=1}^{n_t} C_{ti}}{\sum_{i=1}^{n_t} E_{ti}} \quad .$$

The proportion of total annual landings accounted for by logbook records with both catch and effort data ranged from 62 to 100 percent (Appendix Table B.2). Since effort was not reported for all sets over the 1979 to 2002 period, total annual effort cannot be computed by direct summation. Thus, total annual effort was estimated by dividing the total annual landings by the annual catch per unit effort

(3.2) $$\hat{E}_t = \frac{\sum_{i=1}^{m_t} C_{ti}}{U_t} \quad ,$$

where m_t is the number of logbook records in year *t* with landings data.

Figure 2 shows the trap fishery landings and effort time series by calendar year and area from 1979 to 2001. The dashed line in each panel of the figure represents total annual trap landings (mt). Vertical bars show the annual effort estimated using Eq. (3.2).

Annual catch rates (kg/trap) are indicated by a solid line. The dotted vertical reference line indicates the introduction of mandatory escape rings in traps in 1999. Coast-wide catch rates were relatively stable from 1979 to 1987, but increased dramatically in 1988 and remained high for four years. Catch rates declined after 1991 to a level similar to, or lower than, those observed prior to 1988. The coast-wide CPUE trends are largely driven by the catch rates in the north stock area, which has generally accounted for a larger proportion of both trap landings and effort. The CPUE trajectory is similar in the south stock area, although with less contrast between high and low levels.

The 1979 to 2001 period witnessed considerable change in the management regime for the sablefish fishery (Appendix H) and in fishing practices. The introduction of IVQs in 1990 had a large impact on the distribution of trap effort. There was an abrupt shift in trap effort from the south (Major Statistical Areas 3 to 5) to the north (Major Statistical Areas 6 and 9) in 1991 as fishers were attracted by higher catch rates and larger fish in the north (Figure 2). The proportion of total trap catch taken from the north increased from an average of 0.56 from 1979 to 1990 to 0.87 in 1991 and 0.94 in 1992. In the late 1990s there was a shift back to the south and in 1998 landings from the south surpassed those from the north (Figure 2, Table 2). The shift can be attributed in part to declining CPUE in the north and partly to a management request to the industry to distribute effort coast-wide to avoid the complexity of implementing area-specific total allowable catches (TACs). Trap baiting practices have changed over the same period, namely a shift from squid (*Loligo* sp.) only bait to a mixture of squid and Pacific hake (*Merluccius productus*) designed to improve trap efficiency. Escape rings were introduced by regulation in 1999, although some fishers experimented with escape rings in traps in 1998.

Depth and seasonal distribution. Depth and seasonal differences in catch, effort and CPUE are shown in Figure 3. The sablefish trap fishery extends from approximately 100 to 700 fm (180 to 1300 m) although 75 percent of the fishing effort is expended between 250 to 450 fm (460 to 825 m) (Figure 3). The longline fishery generally occurs in more shallow depths, with 80 percent of the fishing effort less than 250 fm (460 m). Each panel of Figure 3 is identical in construction to those presented in Figure 2. The data were stratified by two periods (January to March, and April to December) and three depth strata (0 to 250 fm, 250 to 450 fm, or 450 fm and deeper) in addition to stock area. The period and depth stratification has been used in previous assessments (eg. Saunders et al. 1996, Haist et al. 1997, 1999). The stratification was based on two observations: (1) catch rates during the January to March period are generally higher than in other months, and (2) the January to March period has not been fished consistently over the entire data time series, e.g. the fishery was closed January 18 to March 18, 2002. Historically, the 250 to 450 fm depth interval has represented the "core" depths fished by the commercial trap fleet.

The figure panels that correspond to April to December in the 250 to 450 fm depth stratum generally reflect the trends evident in the aggregated data presented in Figure 2, albeit with slightly less variability. Inspection of the panels confirms that this component of the data has represented the majority of fishing activity over time. However, the early

1990s showed an abrupt increase in trap fishing effort in the northern area in January to March. Since the mid 1990s, the proportion of trap effort in shallow depths (0 to 250 fm) has increased markedly, with the exception of the south stock area in the January to March period where the effect is small. Note that the apparent absence of landings and effort values in some years where CPUE values are displayed is caused by small amounts of landings, and hence effort, which do not show on the scale chosen for the plots. Such instances represent minor amounts of fishing activity.

3.2 Standardization of commercial fishery catch rates

3.2.1 Trap and longline logbook data

Sablefish logbook data, which contain information from individual longline hook or trap sets, were extracted from the PacHarvSable database. Logbook data are available beginning in 1987 for the longline hook fishery and beginning in 1990 for the longline trap fishery. Collection of logbook data began earlier than 1990 for the trap fishery, but this information is not stored in the PacHarvSable database. Initially a voluntary program, the completion of logbook records when fishing under a "K" license became mandatory in 1990. The proportion of the landed catch that is captured in the logbook records has increased over the period for which these data are available. The logbook data for 2002 covers the period through to the end of July.

Estimates of sablefish catch can be derived from logbooks on a set-by-set basis. These estimates can be compared to catch validation data that record the actual landed weight of sablefish by trip. The dockside validation data for this comparison were available from 1995 onward. In general there is close agreement between the estimated retained weight computed from logbooks and the actual landed weight recorded at dockside, though there is a tendency to underestimate the sablefish landings (Figure 4). The logbook estimates of retained catch were not adjusted to the actual landings because the calibration would be possible only for the time-series beginning in 1995. Unadjusted catch data available prior 1995 would therefore be inconsistent with the calibrated series.

In addition to estimates of the retained sablefish catch, the logbook data contain estimates of the weight of sablefish that are released at sea (discards). A cursory examination of the data suggested that sablefish discard information is not consistently recorded. Of the 46 fishing masters that are represented in the trap fishery logbook database, 7 reported sablefish discards each year that they fished, 18 had no reported sablefish discards, and the remaining 21 reported discards in some but not all years that they fished (Appendix Table C.1). Because the discard data do not appear to be consistently reported, they were not included in catch estimates used in these analyses.

A data selection and grooming process was undertaken with two objectives: (1) to limit the data set to coastal offshore fishing events (i.e. remove inshore and seamount fishing records), and (2) to remove records that were likely to contain erroneous information. The criteria used in the data grooming are summarized in Appendix C. The number of fishing events (trap sets or longline strings) in the data set, both before and after the data grooming process, is shown in Appendix Table C.2.

3.2.2 Descriptive summary of logbook data

Summary statistics for catch per unit effort (CPUE) and total effort were calculated by depth, month and latitude intervals to investigate patterns or changes over the years for which data are available. Catch rates were computed as the sum of the catch (kg) divided by the sum of the effort within each interval. The effort measures were the sum of traps fished and the sum of hooks fished for the trap and longline fisheries, respectively. Latitude intervals were defined by splitting the coast into 12 nautical mile strips from 48°N to 54.5°N. Depth intervals were defined in 100 m increments from 150 m to 750 m, with a 750 m and greater interval.

For the trap fishery, the average catch rates by latitude and depth interval and by latitude and month, for the period 1990 to 2002 are shown in Figure 5. Catch rates were surprisingly consistent among the depth intervals, with little indication of higher catch rates at any part of the depth distribution. However, the shallower (<350 m) or deeper (>750 m) depth intervals have not been fished as regularly as the mid-depth intervals. Along the northern B.C. coast, the highest catch rates were observed in 1991, and appear to have declined steadily since that year. In southern B.C. catch rates were highest from 1992 to 1994. The patterns of CPUE by month show high catch rates in northern B.C. at the beginning of the year (i.e. January and February). This pattern has been previously described by fishers. In some years, the higher winter catch rates begin to develop at the end of the calendar year in November and December. There is also a tendency for higher catch rates to move in a southerly direction through the year.

The annual pattern of trap fishing effort also tends to follow the increase in catch rates that progresses from northern to southern B.C. through a year (Figure 6). Between 1991 and 1994, little trap fishing effort was expended in southern B.C. waters. More recently in 1999 to 2002 there has been considerable concentration of effort in central B.C. waters at about 51.7°N.

Unlike the trap fishery, the longline hook fishery does not show any indication of a decrease in catch rates over the time period (1987 to 2002) that data are available (Figure 7). As for the trap fishery, there appears to be a tendency for higher catch rates in northern waters at the beginning of the year progressing to higher catch rates in southern waters later in the year. This pattern is less clear than for the trap fishery, possibly because the longline fishing effort is quite patchy. In northern B.C. higher catch rates tend to occur in deeper waters than in southern B.C. Longline fishing effort is somewhat concentrated through the summer and fall period, and tends to be higher in southern waters, particularly since 1996 (Figure 6).

Although more variable during the earlier years, the average number of traps fished per set in the trap fishery has remained relatively constant over the 1990 to 2002 period (Figure 8). The median number of traps fished is 60, with an inter-quartile range of 60 to 70 traps. The mean duration of sets has decreased somewhat over the period, with the highest mean soak time (2.5 days) in 1990 and the lowest mean soak time (1.5 days) in 2002. For the longline hook fishery there was considerably greater variation in the number of hooks fished per set, and sets tended to be of much shorter duration than trap sets (Figure 8).

3.2.3 Generalized linear model standardization of CPUE

For the CPUE standardization analysis, a core set of fishing masters was selected for each of the trap fishery and the longline fishery. The selection was based on fishing master rather than fishing vessel because experience is more likely to be associated with fishing success in this fishery. For both the trap and longline hook fisheries, a selection criterion of a minimum of five years of fishing effort documented in the logbook records was adopted. Of the 46 fishing masters represented in the trap fishery logbook records, 19 were included in the CPUE standardization analysis (Appendix Table C.3). Jointly these skippers represented 84 percent of the recorded fishing effort over the 1990 to 2002 period. For the longline hook fishery, 18 of the 76 fishing masters representing 61 percent of the total fishing effort were selected for inclusion in the CPUE standardization analysis (Appendix Table C.4).

Only fishing records that reported a retained sablefish catch were included in the CPUE analysis. This resulted in 0.22 percent of the trap-fishery sets and 0.52 percent of longline fishery sets being excluded from the analysis (Appendix Table C.2). These sets with no sablefish catch are such a low proportion of the total fishing effort that their removal is unlikely to bias results.

Log-normal linear models were used to estimate relative year effects in the CPUE standardization analysis (Gavaris 1980). The dependent variable for the trap fishery model was the natural logarithm of catch rate, where catch rate was measured as kilograms per trap. A different approach was adopted for the longline fishery analysis because it is possible that there is a non-linear relationship between the catch and the number of hooks in a string. That is, a greater number of hooks was generally associated with a longer string, and longer strings may extend into less ideal habitat. For the longline fishery model, the dependent variable was the logarithm of the catch and independent variables forced into the base model were the logarithm of *number of hooks* and *region*year* terms. The "*" operand in *region*year* implies the presence of the *region* and *year* main effects in addition to the *region:year* interaction.

Variables that were considered in the CPUE standardization analysis are shown in Table 3. All continuous variables were modeled as polynomials of degree 3. Catch of species other than sablefish can be recorded on the sablefish logs, however these records do not appear to be complete. The recorded by-catch was grouped into species aggregates for input to the CPUE standardization analysis. The first group included the catch of all shark and skate species. The second group included thornyheads (*Sebastolobus* sp.), scorpionfish, and all rockfishes (*Sebastes)* species. The final group was for Pacific halibut (*Hippoglossus stenolepis*). Jointly these three species groups accounted for 86 percent of the recorded by-catch (Appendix Table C.5).

A forward stepwise regression algorithm was employed to assist model selection. A model including the main effects of *region* and *year* plus the *region:year* interaction term was adopted as the initial model. The stepwise algorithm proceeds as follows. The reduction in residual deviance relative to the null deviance, denoted r^2, was calculated for each single term added to the base model. The term that resulted in the greatest decrease in the residual deviance was added to the base model if the residual deviance decreased more than 0.5 percent. The algorithm repeated this process, updating the base model, until no new terms could be added. Second-order interactions were then investigated for some of the variables in the revised base model. Interaction terms with *year* and with *fishing master* were not considered, because *year* interactions confound the objective of identifying *year* effects and because *fishing master* interactions would greatly increase the number of terms in the model. The stopping rule of a 0.5 percent decrease in the residual deviance was employed so that the resulting model would be relatively parsimonious. Although inclusion of additional terms resulted in statistically significant improvement to the model fit, these additional terms provided only minor changes in the estimated *year* effects.

For trap and longline hook fishery analyses, the *regions* that were initially selected included the southern B.C. coast (Minor Statistical Areas 23 to 27), central coast (Minor Statistical Areas 8 and 11), and northern coast (Minor Statistical Areas 31 to 35). However, for the longline hook fishery the number of observations for the central and northern regions was sparse in some years, a data shortfall that resulted in highly erratic estimates of the *year* effects. Thus, for the longline hook analysis the central and northern regions were combined.

3.2.4 Model results for the trap fishery

For the trap fishery CPUE analysis, the first variable to enter the model was *fishing master* followed by *day of year* and *minor area* (Table 4). Second order interactions involving *fishing master* were not evaluated because they would greatly increase the number of terms in the model. Inclusion of a *day of year:minor area* interaction did provide a fair improvement in the model fit, although the final model accounts for only 30 percent of the variance in the log CPUE (Table 4).

Model fit diagnostics are not particularly good for the trap fishery CPUE model. The model does not do well at fitting either the very low (<3kg/trap) or the very high (>20 kg/trap) catch rate observations (Figure 9). A quantile-normal plot indicates a skewed distribution of the residuals, with substantially more negative residuals than would be expected from a normal distribution (Figure 9). A number of alternate distributional assumptions were examined for fitting the trap fishery CPUE data; however they all exhibited worse patterns in the residuals than the lognormal, constant variance model.

The *year* effects estimated by the standardized CPUE model are shown in Figure 10 for each of the three regions. The vertical grey bars in the figures, drawn between 1998 and 1999, demarcate the introduction of mandatory escape-rings in the trap fishery. The use of escape-rings is likely to decrease catch rates relative to the period prior to their use, thus creating two time series that are not comparable.

For the northern B.C. coast, the CPUE *year* effects show a continuous decline from 1991 through 1998. Neither the central nor the southern region had as large *year* effects in the early 1990s as did the northern region, and in both regions the major decline in CPUE was between 1994 and 1995. Although it is not valid to compare *year* effects across 1998 because of the introduction of escape-rings, it is noteworthy that the *year* effects for the northern and southern region decreased substantially between 2000 and 2001, as did the sablefish indexing survey catch rates. The central B.C. coast did not show a similar decline between 2000 and 2001.

The estimated *vessel master* effects, shown in Figure 10, suggest as much as a two-fold difference in the average catch rate among the *vessel masters*, other factors being equal. The estimated *day of year* by *minor area* effects show a north-south cline in the annual patterns (Figure 11). The furthest north *minor area*, 35, has increased catch rates beginning in the late fall and continuing through winter (November through February), whereas the remaining *minor areas* off the Queen Charlotte Islands (areas 31 and 34) and the northern part of the central region (area 8) show an increase in catch rates only through January and February. The more southerly *minor areas* tend to have lower catch rates at the beginning of the year with slight increases through to year-end.

3.2.5 Model results for the longline fishery

For the longline hook fishery analysis, the first term to enter the model was *vessel master* followed by *minor area*, *day of year*, and *depth*. Interaction terms for *day of year:minor area* and *depth:minor area* improved the model fit, with the final model accounting for 43.58 percent of the variance in the log of catch (Table 5).

As for the trap fishery analysis, model diagnostics indicated a poor fit to the available data (Figure 12). The distribution of residuals was skewed, with larger negative residuals than positive residuals. Alternate assumptions about the error distribution did not improve these diagnostics.

The estimated relationship between catch rate (catch per hook) and the number of hooks in a set is non-linear, with higher catch rates occurring for sets with fewer hooks (Figure 12). Estimated *year* effects for the longline hook fishery analysis do not show the same long-term decline seen in the trap fishery analysis, though for both the central/northern region and the southern region the 2001 estimate is the lowest in the series (Figure 13). The *day of year* by *minor area* relationships indicate increased catch rates through the year for most minor areas (Figure 14). Also, for most *minor areas*, catch rates increase with fishing *depth* (Figure 15).

It is not clear why catch rates in this fishery have remained relatively constant while those in the trap fishery have declined. Fishers have suggested that gear saturation may be a partial explanation, that is, competition for bait on hooks by sablefish and other species reduces the catching potential of the longline hook gear despite the availability of actively feeding fish. However, a fisheries independent longline hook survey conducted in Alaska (Sigler 2000, Sigler et al. 2002) appears to track stock abundance changes reasonably well so that gear saturation may not be the only plausible explanation.

A factor that will likely impact the longline fisheries catch rate analysis is the recent change to combination fishing for some of the fleet. Due to management regulation changes, some of the longline trips that land sablefish and provide sablefish logbook records are also targeting and landing Pacific halibut and/or rockfishes at the same time. The change in regulation that allows this type of fishing is fairly recent, occurring in the last 3 or 4 years. Unfortunately, information on catch of species other than sablefish is not always recorded in the sablefish logbook, but may be recorded in "L" or "Zn" fishery logbooks. Also, the intended target species may not be obvious for many fishing events or trips when a vessel hails out for a halibut trip but may focus fishing on other species permitted under combination fishing. A data archiving problem occurs because dockside landing data are separated by sablefish and other species prior to delivery to the Groundfish Data Unit. The net result is that sablefish data from combination trips are uploaded to PacHarvSable, while other species landed on the trips are directed to PacHarvHL.

3.3 Observer data from the Hecate Strait trawl fishery

A coastwide trawl fishery observer program, in place since 1996, collects tow-by-tow information on the catch of all species, whether they are landed or discarded. Additionally, this program provides some biological sampling information from a subset of the observed sets. For the 2001 sablefish stock assessment, a simple CPUE index was calculated from the Hecate Strait at-sea observer data and compared to indices developed from the fisheries independent Hecate Strait Assemblage Survey and the sablefish Hecate Strait Inlets Survey (Haist et al. 2001). Treatment of the data sets for that analysis was cursory, and the document suggested further work was required to investigate the potential of those data for developing juvenile abundance indices. In particular, comparison of the length distributions from the different programs could provide information about the age-classes that were sampled. A more detailed examination of the Hecate Strait at-sea observer data is presented here.

3.3.1 Biological Information

All sablefish biological sampling data collected through the recent observer program from tows conducted in Minor Areas 4 through 8 were extracted from the GFBio database. These data includes samples collected in Hecate Strait proper (Minor Statistical Areas 4 to 6) as well as Queen Charlotte Sound (Minor Statistical Areas 7 and 8). The data extraction resulted in samples from 298 separate tows; however of these tows only 148 were coded as "random samples" or "samples of the entire catch". The remaining samples were coded as "selected" or "stratified" samples and are not included in this analysis. Most of the bio-samples are limited to information on length distribution however for some samples sex information is also available.

Comparison of the mean lengths of male and female sablefish sampled from the same tow shows similar lengths for males and females up to lengths of about 45 cm (Figure 16). At lengths above 45 cm, there is a tendency for the mean length of females to be slightly greater than the mean length of males. There is no ageing of these samples so it is not clear whether this difference is indicative of the onset of sex-specific growth, which is well documented for sablefish.

Although the trawl observer program has been in place since 1996, an adequate number of sablefish bio-samples for characterizing the catch are available only for the two-year period from mid-year 1998 through mid-year 2000 (Figure 16). The sample data indicate a strong positive relationship between mean sablefish length and fishing depth (Figure 16). In Hecate Strait (Minor Statistical Areas 4 to 6) most samples were taken from tows made at depths less than 150 m, consistent with the range of fishing depths for this area. In Queen Charlotte Sound (primarily Minor Statistical Area 8) the range in fishing depths, and resulting sablefish samples, is broader.

The sablefish length distribution data was summarized by year and quarter (three month periods) for Hecate Strait and Queen Charlotte Sound samples to investigate whether year-class modes could be distinguished (Figure 17). The samples from Hecate Strait show clearer patterns than those from Queen Charlotte Sound, with an apparent year-class showing up in the samples in the fourth quarter of 1998 at a modal length of 24 cm. Given the timing of sample collection, fish of this size are consistent with age 0+ or the 1998 year-class (see for example McFarlane and Beamish 1983, Rutecki and Varosi 1997). This year-class can be followed through the sampling data to the third quarter of 2000 where the modal length is 45 cm (age 2+). Over the period for which there are data, the Hecate Strait samples appear to be dominated by 3 age classes (age 0+, age 1+, and age 2+). Sablefish caught in Queen Charlotte Sound tend to be larger than those caught in Hecate Strait, which may be related to the deeper fishing depths in that area.

Figure 18 compares the length distributions of sablefish caught and sampled during the Hecate Strait Assemblage Survey Program (e.g. Choromanski et al. 2001) to those sampled through the at-sea observer program. Note that for both data series, the length distributions are based on the total fish sampled across all tows. Ideally, samples from each tow would be scaled by the catch weight, so that the length distributions were representative of the entire catch. Sample weight data are not collected, but could be estimated from a length-weight relationship.

The Hecate Strait Assemblage Survey appears to consistently sample age 1+ sablefish, and there appears to be little inter-annual variation in the length-distribution of this age class (Figure 18). For most years the Hecate Strait assemblage survey samples show two very distinct size modes but there is greater variation in the size distribution related to the larger mode. It is not clear whether the larger modes evident in 1987, 1989, 1991, and 1998 represent year-classes that are 2-years older, or if they represent faster-growing year-classes that are 1-year older, than the fish represented by the smaller modes. The two length modes in the 2000 sample data clearly represent consecutive year-classes because they are consistent with the two length modes seen in the Hecate Strait at-sea observer data, which can be tracked through a year by modal progression.

Unlike the Hecate Strait Assemblage Survey, samples obtained from the Hecate Strait at-sea observer program do not appear to consistently sample age 1+ sablefish (Figure 18). The commercial trawl gear used in Hecate Strait has considerably larger cod-end mesh size than the research gear used in the Hecate Strait Assemblage Survey so smaller sablefish are likely less vulnerable to the commercial gear.

Continued and increased sampling through the Hecate Strait at-sea observer program would provide valuable growth information for juvenile sablefish. Because the trawl fishery operates throughout the year, it provides on opportunity to obtain samples where year-classes can be tracked through modal progression of size distributions. This would allow inter-annual variability in juvenile sablefish growth to be examined, and potentially to identify year-classes that are sampled by the Hecate Strait survey. A possible limitation here is that the Hecate Strait trawl fishery does not appear to regularly sample the 1+ year-class.

3.3.2 Catch Rates

Over the 1996 to 2002 period, 66 percent of the observed Hecate Strait trawl tows did not catch sablefish. The distributions of locations where sablefish were caught and locations where they were not caught are quite similar (Figure 19). Two covariates that appear to influence the probability of catching sablefish are the depth of the tow and the time-of-year. The probability of catching sablefish increases with depth and is highest during summer and early fall months (Figure 20). Although the probabilities of catching sablefish are generally low at tow depths less than 100m, they were substantially higher in late summer and early fall of 1999.

Hecate Strait trawl fishery CPUE was calculated on both an annual and a quarterly basis. For both cases the CPUE measure was the sum of catch (kg) divided by the sum of effort (hours towed). Both CPUE measures were highest in 1998 and 1999 (Figure 21). Inter-annual differences in the CPUE estimates are greater when third quarter (July-September) estimates, which are generally the highest over a year, are compared. The 1998 and 1999 third-quarter CPUE estimates are more than double those of other years. While the 1998 sampling data is too limited to identify dominant year-classes in the commercial catch, the 1999 sampling data is dominated by the 1997 year-class.

A more useful CPUE index might be developed from the Hecate Strait trawl fishery data using a compound function that integrates a model for predicting the proportion of zero observations with a GLIM that models positive observations. A possible limitation of the observer data for indexing juvenile sablefish abundance is that the 1+ year-class does not appear to be consistently sampled in the fishery. Further analyses of both Hecate Strait observer and survey data is warranted to determine their utility in developing juvenile abundance indices.

4 Fishery independent catch and effort data

Annual surveys for indexing sablefish abundance have been conducted since 1990. Details of the survey protocol, gear, and data selection for analysis are described in Appendix D. Data observed from the standardized indexing sets were used in this analysis; data observed from tagging sets were excluded as described in Appendix D.

4.1 2002 Indexing Survey

The nine localities surveyed since 1994 were included in the 2002 indexing survey and are shown in Figure 22 to Figure 24. Locality bounds include the majority of survey sets from 1990 to 2002 (Figure 22 to Figure 24). The configuration of the bounding boxes has changed from that presented in Kronlund et al. (2002) to accommodate two deep depth strata added in 2002, however the surveyed locations remain similar to historical practice. The timing of the 2002 survey (October) was very similar to that achieved in 2000 and 2001 (Appendix D). Unlike previous years, a second charter vessel conducted the tagging component of the annual stock assessment surveys, except during the inlets portion of the survey where the charter vessel that conducted indexing sets also tagged and released sablefish. For the indexing survey, the fishing master was instructed to place sets within each specified depth stratum, as has been the protocol throughout the indexing time series. For most years in the indexing series, a single set was conducted within each locality and depth stratum (Appendix D). In 2002, three replicate sets were conducted in each depth stratum at Hippa Island, Gowgaia Bay, and Esperanza Inlet to examine variability due to small-scale spatial and temporal effects. The fishing master was instructed to spread the sets out over time as much as possible, and was directed to avoid repeating the same set locations.

4.2 Exploratory data analysis for the indexing survey time series

Each standardized set of survey gear consisted of a string of 25 traps. Catch was recorded in numbers of sablefish per trap and aggregate sablefish weight (kg) per trap. The survey gear was inspected upon retrieval to determine if each trap was actually fishing ("effective") and not fouled or holed. The catch rate for each set was computed by summing the number (or weight) of sablefish in each effective trap, C_{tijk}, and dividing by the number of effective traps

$$(4.1) \qquad U_{tijk} = \frac{\sum_{l=1}^{n_{tijk}} C_{tijkl}}{n_{tijk}} \quad ,$$

where U_{tijk} is the catch rate for set k in depth stratum j of survey locality i for year t. The value U_{tijk} is the mean catch rate per trap for the set, but is hereafter referred to as the catch per unit effort (CPUE) for the set. Note that the number of effective traps may differ from 25 traps due to miscounting of traps on deployment, or to detection of fouled or holed gear upon retrieval.

Protocols for indexing surveys prior to 2002 specified that the deepest depth stratum include depths greater than 1006 m (550 fm). In 2002, strata bounds at 1189 m (650 fm) and 1372 m (750 fm) were specified to ensure sampling of deep habitat (Table D.3). By design, the addition of the deep strata in 2002 resulted in sets distributed deeper than those achieved in the 1990 to 2001 period. Figure 25 and Figure 26 characterize the catch rates (number of fish per trap) for each indexing set by mean bottom depth of set for the localities in the north and south stock areas, respectively. Each figure shows a multi-panel display of the catch rate (number of fish per trap) plotted against mean bottom depth (m) of the set for a given locality. Open circles represent catch rates for the 1990 to 2001 period and filled circles indicate 2002 catch rates. Vertical dotted lines in each panel represent depth stratum boundaries. Three replicate sets conducted in each depth stratum at Hippa Inlet, Gowgaia Bay, and Esperanza Inlet in 2002 account for the greater number of observations by depth stratum at these locations. In most cases the sets in 2002 achieved the target depth stratum or, if outside the target depth stratum, are very close to a boundary. Catch rates in depth strata 6 and 7 are among the lowest observed, reflecting either lower sablefish densities at these depths and/or decreased efficiency of trap gear at depth. Observations targeted at depth stratum 6 and 7 in 2002 were excluded from the examination of time trends to make the data series as comparable as possible.

Exploratory analysis of time trends in the observed catch rate data was conducted separately for the north and south stock areas. Boxplots arrayed by year and stock area were used to summarize the distribution of CPUE values (mean number of fish per trap) achieved for each set (Figure 27). The lower bound of the box indicates the first quartile (25^{th} percentile) of the data and the upper bound of the box is the third quartile (75^{th}

percentile). The horizontal line the divides the box is the median (50^{th} percentile). The upper and lower whiskers of each boxplot are positioned at 1.5 times the inter-quartile range. Open circles indicate data values that fall outside the whiskers, or outliers. A filled circle represents the mean value of the data summarized in the boxplot. The lightly shaded rectangle positioned in each box represents an approximate 95 percent confidence interval for the sample median.

The time trends of survey catch rates in both stock areas show a decline from high CPUE values in the early 1990s to a period of relative stability beginning in the mid-1990s. The 2001 survey produced the lowest mean and median catch rates observed in the times series, with marked compression of the variance for the north stock area. Catch rates for the north stock area improved in 2002 relative to 2001, and were comparable to those observed in the mid-1990s, but with higher variability. In contrast, catch rates observed in 2002 for the south were similar to those observed from the 2001 survey. The time trends suggest constant catch rates from the mid-1990s to 2002, with a very low point in 2001, for the north and a continued decline from the mid-1990s to 2002 in the south.

Spatial variability in the density of sablefish results in different catch rate characteristics among the nine indexing localities. Multi-panel displays of CPUE by year for each locality are shown in Figure 28. Note that the catch rate scales differ among the panels to allow details of the time trends within each locality to be visible. Open circles represent the catch rate (number of fish per trap) achieved on each set. Filled circles are the arithmetic mean of the catch rates for each year. Two loess (Cleveland 1985) trend lines are superposed on each panel to illustrate the impact of the most recent survey; the solid line is the trend over the entire time series while the dashed line excludes the most recent survey point. The loess trend lines are fit using the observed catch rates rather than the annual means.

In general, time trends at all survey localities show a similar decline in catch rates from highs in the early 1990s. Beginning in the mid-1990s the rate of decline generally decreased or there was no trend through to 2002, depending on the locality. However, notable increases in trap CPUEs were recorded for the north stock area (Figure 28) at the Langara Island-North Frederick and Hippa Island survey localities. Catch rates at Buck Point and Gowgaia Bay were comparable to those observed in the mid 1990s. The markedly reduced variance among sets observed for northern survey localities in 2001 was not evident in 2002. Catch rates at Cape St. James have been highly variable over time with little signal evident. Time trends in trap CPUE for the south stock area do not show evidence of improvement from values observed in 2001, although four of the 21 Esperanza Inlet sets yielded improved catch rates.

4.3 Linear model standardization of indexing survey data

A general linear model (GLM) was used to standardize CPUE data over the survey time series and to separate effects due to locality and depth. The observations can be described by the linear statistical model

$$U_{tijk} = \mu + \alpha_t + \beta_i + \gamma_j + \varepsilon_{tijk} \quad , \tag{4.2}$$

where μ is the overall mean effect, α_t is the effect of the *t*th level of the year factor, β_i is the effect of the *i*th level of the depth factor, γ_j is the *j*th of the locality factor, and ε_{tijk} is a random error component. Random errors were assumed to be normally distributed with mean 0 and variance σ^2. This main effects model does not include interaction terms of the form $(\beta\gamma)_{ij}$ since there are very few replicates by depth and locality (Table D.4). The factors are assumed to be fixed effects. The model is over-parameterized, so that constraints must be imposed to obtain parameter estimates. The so-called corner point constraints are applied here, so that the first level of each factor is set to 0, i.e. $(\alpha_1 = 0, \beta_1 = 0, \gamma_1 = 0)$, and the remaining levels of each factor represent the additive effects of each level relative to the first “reference” level. The overall mean, μ, is then the model estimate of the catch rate for the first year in the time series, the first level of the locality factor, and the shallow depth stratum.

The model was applied to the north and south stock areas independently, and to all data to obtain combined results for the coast. For the north area, the reference CPUE was selected as year 1991, depth stratum 1, and locality Langara Island-North Frederick. Similarly, the reference level for the south was defined as year 1990, depth stratum 1, and locality Triangle Island. Initial trials of the model suggested that the catch rate observations should be square root transformed to satisfy the assumptions of homogeneity and normally distributed errors. Experimentation with a natural logarithm transform of catch rates and with Poisson distributed errors failed to produce superior model diagnostics (not shown here).

The Analysis of Variance (ANOVA) tables and related statistics are shown in Table 6 for the north, south, and coast areas. The tables show the sequential (Type I) sums of squares. For the south and coast-wide model fits, the locality factor is significant; differences among localities are not significant for the north model fit. The locality factor could be removed from the north model, however it was retained for consistency with other model fits and in practice there is no real penalty for leaving it in the simple additive model. Graphical representations of the contribution of each factor to the predicted values are shown in Figure 29 to Figure 31 for the north, south, and coast data, respectively. Each figure panel represents the fitted effects for a factor in the main effects model. Factor effects have been centered about zero. The broken line for each effect indicates two standard errors. The rugplot at the base of each plot indicates the locations of observed values of the response variable, randomly jittered to expose the density of observations. Within each figure, the y-axis has been set to the same vertical scale on each panel to allow visual judgments of the relative importance of each factor to the fit. All models explain between 59 (north) and 65 (south) percent of the observed variation.

The time trend of estimated year effects for the north and south stock areas, and the coast-wide fit (upper panels of Figure 29 to Figure 31), is in general agreement with the boxplots of observed CPUE values presented in Figure 27. The highest catch rates in the north area are achieved for sets conducted in depth stratum 2. The lack of dependence on locality for the north stock area is clearly evident. For the south stock area, the year effect is greatest and the locality effect appears to contribute more to the fit than the depth effect. Detailed model diagnostics are described in Appendix E for each model. The fit appears better for the north and coast-wide models than for the south stock area model.

Table 7 summarizes the year effects for each of the model fits. The estimated coefficients for each model and associated standard errors are listed, along with the coefficients adjusted for the reference levels of depth and locality by adding the model intercept as the first year effect. Both are provided on the square root CPUE scale. The marginal means adjusted for depth and locality are also listed with associated standard errors on the square root CPUE scale. Figure 32 shows a plot of the back-transformed marginal means for the north, south, and coast-wide model fits on the CPUE (numbers/trap) scale. The vertical line segments indicate plus or minus two standard errors obtained by back-transforming endpoints obtained on the square root CPUE scale. Trends by all areas are consistent with those indicated by the exploratory analysis.

The design of the indexing survey lacks the replication within each combination of locality and depth stratum required to assess interactions among years, localities, and depth. These interactions might alter the trajectory of the index, or may give insight into different behavior in the time series among locations and by depth. Nevertheless, the main effects model explained at least 59 percent of the observed variability and the model fits were adequate. Placement of survey sets within depth strata at the discretion of the fishing master has likely produced a positive bias in observed catch rates over what would have been achieved by random set positions. This issue is not important to the purpose of developing a relative abundance index if bias introduced by fishing masters has been similar over time. The strengths of the survey are the relative consistency in the conduct of standardized fishing over time and the broad geographic and depth coverage. The credibility of survey catch rates as an abundance index is reinforced by similarities in the pattern of decline in catch rates from 1990 to 2002 among most localities and within most depth strata.

5 Sablefish in non-directed surveys

5.1 Sablefish catch in the IPHC set line survey

The International Pacific Halibut Commission has conducted a fixed-station survey to assess Pacific halibut in regulatory area 2B (Canadian zone) from 1993 to the present. Longline gear designed to capture Pacific halibut is used but also catches sablefish as a bycatch species. In this section the spatial and temporal distribution of the survey catch rates for sablefish in the Hecate Strait area are considered, since this region has the most extensive data series. The IPHC survey is described in Appendix I, where estimators of catch rate (numbers/skate) used in the analysis are developed.

For a survey with (approximately) consistent spatial coverage, the depth effects should in part reflect the prevailing bathymetry rather than changes in the distribution of fishing effort, as might be the case for fishery dependent data. Figure 33 shows catch rates in units of pieces per effective skate as sized circles, where the area of the circle is proportional to the catch rate. Each circle corresponds to one set. Sets where the catch for the species was zero are indicated by plus signs. Each figure panel shows a year of data for the Hecate Strait/Queen Charlotte Sound region of regulatory area 2B. A scale is provided in the lower left corner of each panel using a circle sized proportionally to the indicated catch rate. All figure panels are drawn on a common scale.

Sablefish catch rates (Figure 33) were higher in association with Moresby, Reed, and Sea Otter Troughs located in Hecate Strait, with the exception of high catch rates at deep stations north of the Queen Charlotte Islands. This feature becomes particularly striking in 1998 through 2002, but the visual impact is partly a function of the uniform survey grid adopted for those years. The spacing of the stations prior to 1998 meant that distances between station groupings were larger, thus, the continuity of catch rate patterns appears somewhat interrupted compared to that observed in recent years. The figure suggests higher catch rates in 1998 and 1999 compared to other years, with sablefish catch observed at a higher proportion of stations distributed over a wider area in association with the troughs (Table 8).

A trellis plot of the catch rate trend over time is included as Figure 34. The plot panels are ordered by increasing depth interval across the columns from left to right, and increasing latitude along the rows from bottom to top. There is 10 percent overlap of points among panels. Open circles represent the catch rate (number/skate), while the solid line is a loess smooth (Cleveland 1985) through all the points in a panel and the dashed line is a loess smooth through the positive values only. The trend lines indicate that catch rates increase with depth, and there is a decline in catch rates over time for middle latitudes in Hecate Strait that becomes more pronounced at the deepest depths surveyed.

A generalized additive model was fit to the data, treating year as a factor and fitting the additive effects of depth and latitude as loess smoother terms

$$(5.1) \quad \log(y_{ij}) = m + a_i + lo(avgdep) + lo(lat) + e_{ij} \quad ,$$

where a_i is the effect of the i^{th} year, *lo(avgdep)* is the smoothed average depth term, *lo(lat)* is the smoothed latitude term, and e_{ij} are Poisson distributed errors. Inspection of Figure 34 indicated a high proportion of zero catches in the data (Table 8), most of which are at shallow depths less than 70 fm (the incidence of zeros is greater than 70 percent of the sets at depths less than 70 fm). Thus, the data were selected to include sets greater than 80 fm only. Results of the model fit are shown in Figure 35, where clearly the depth effect dominates the fit. Components of the fit due to year indicate a decline in catch rates from 1998 to 2002. The year effect was determined to be statistically significant. A quantile-normal plot of the residuals shows the typical effects of zero observations in the lower tail of the distribution.

Results of this analysis warrant more detailed comparative analysis and perhaps coordination of survey effort with the IPHC to work towards an index of sablefish abundance in the region. Biological sampling is required to examine the characteristics of sablefish selected by the IPHC longline survey gear (sablefish selected by the survey gear were approximately 5 to 8 lbs, Tracee Geernaert, IPHC, *pers. comm.*). Support for the use of longline surveys to index sablefish abundance can be found in the work of Sigler and Fujioka (1988) and Sigler (2000) for Alaskan stocks. One caveat is that sablefish in the shallow waters of Hecate Strait and Queen Charlotte Sound are likely to include a large juvenile component, so care should be taken in verifying that interactions of adult sablefish with the longline gear in Alaska are comparable for sablefish in B.C. waters.

5.2 Sablefish catch in the West Coast Vancouver Island shrimp survey

Systematic shrimp trawl surveys have been conducted in selected Pacific Fisheries Management Areas (PFMA) off the west coast of Vancouver Island beginning in 1973 (see Sinclair et al. 2001 for a more complete description). Sablefish occur as a bycatch species during these surveys. Spatial coverage varied among years with annual surveys in PFMA 124 except for 1974, 1984, and 1986, and in PFMA 125 except for 1974, 1984, 1986, 1989, and 1991. The time series for PFMA 123 extends from 1996 to 2001. Survey stations are positioned along Loran lines (e.g. Y lines, 20 microseconds part and Z lines, 10 microseconds apart). The inshore and offshore extensions of the survey were determined annually by occupying stations until shrimp catches became negligible or the bottom prohibited trawling. The Fisheries Research Vessels G.B. Reed (1973-1985) and W.E. Ricker (1987-present) were used for most surveys in areas 123, 124, and 125. Charter vessels were used in 1977, 1978, and 1989 but no attempt to adjust for vessel effects have been attempted in the data presented in this document.

The gear used from 1973 to 1976 consisted of a semi-balloon trawl fitted with a bobbin and roller groundline, and with wood flat doors. The gear was changed in 1976, when comparative trials were conducted, to a NMFS high-rising shrimp sampling trawl fished with steel Vee Doors (Boutillier et al. 1976). The change in efficiency due to adoption of the high-rising shrimp trawl has not been estimated for fin fish species so no attempt has been made here to calibrate the historical data. Tows were generally of 30 minutes duration unless curtailed due to hostile bottom or snags, etc. Fishing was conducted during daylight hours. The aggregate weight of sablefish caught per tow was recorded and counts of sablefish per tow have been noted in recent years. No length data are available. The catch density of sablefish (kg) per square meter was determined by dividing the catch by area swept (net width by distance traveled). Mean depth (m) for each tow was computed as the arithmetic mean of the minimum and maximum depths observed during the tow. Fishing generally occurred from 50 to 175 m depth.

Catch weight of sablefish per tow over the time series has generally been very low, with the equivalent of a few animals captured on each set (Table 9). Occasional catches greater than 50 kg occur throughout the series. However, mean catch rates in 2001 and 2002 increased more than tenfold over catch rates since 1979. Also, the proportion of tows with zero sablefish catch dropped substantially in 2001 and 2002 (Table 9). Mean weights of the sablefish encountered were 420 grams (n=5768) in 2001 and 801 grams (n=1239) in 2002. Figure 36 shows the log density (kg/m2) of sablefish per tow plotted against year for area 124 and 125. The large increase in sablefish density is evident for 2001 and 2002, but the plots also suggest an increase in density in 1978 and 1979, which would coincide with the 1977 year class (Table 9). The results in 2001 and 2002 are consistent with observations from the continental U.S. Pacific coast where the 1999 and 2000 year classes were thought to be relatively strong (Schirripa 2002).

5.3 Sablefish catch in the longspine thornyhead survey

In 2001, a 3-year bottom trawl survey, funded by the Canadian Groundfish Research and Conservation Society, was implemented on the continental slope of the west coast of Vancouver Island (Starr et al. 2002). The survey used a random stratified design with three depth strata (501-800 m, 801-1200 m, 1201-1600 m) and, in 2001, six areal strata (Figure 37). For the 2002 survey, an additional areal stratum was added to extend the northern range of the survey. Although the design of the survey is targeted at the longspine thornyhead (*Sebastolobus altivelis*) resource, the survey may provide informative abundance indices for other species such as sablefish. The objective of the analyses described here is to examine the utility of the thornyhead survey for indexing sablefish abundance on the west coast of Vancouver Island.

The first thornyhead survey was conducted between September 15 and October 2, 2001, using the F/V Viking Storm skippered by Chris Roberts and Kelly Anderson. The second survey was conducted by the F/V Ocean Selector with skipper Dave Clattenberg from September 7 to 23, 2002. The survey was conducted approximately 4 weeks earlier than the sablefish trap index survey. Detailed descriptions of the thornyhead survey design, trawl gear specifications, and results from the 2001 survey are presented in Starr et al. 2002. Data from the 2002 survey are preliminary. Data quality control editing has not been completed, so final results may differ from those presented here.

5.3.1 Biomass Estimates

Sablefish was the most abundant species caught in the 2001 thornyhead survey, and only 2 of the 58 useable tows did not catch sablefish (Figure 38). In 2002, the sablefish catch was slightly lower than that of roughscale rattail (*Coryphaenoides acrolepis*) and longspine thornhead, and there were no sablefish in 5 of the 67 useable tows. Tows with no sablefish were generally in the deepest (1201 – 1600 m) stratum.

Sablefish biomass estimates were derived using a standard survey design-based methodology that is described in Starr et al. (2002; their Appendix D). This approach scales the total catch in the area swept during tows in a stratum to the total area of that stratum. Calculations were based on the trawlable area, rather than total area, of the stratum. Starr et al. (2002) present biomass estimates based on both the total distance traveled during a tow and the total distance with bottom contact during the tow. The bottom contact data is not yet available for 2002, so sablefish biomass estimates were only calculated using the total distance approach. Also, in their analysis of the 2001 survey data, Starr et al. (2002) combined tow data from regions “E” and “F” because of small sample sizes in region “F”. We also combined these two regions in analyzing the 2002 survey data. Note that while estimates are presented as absolute biomass, they should be viewed as a relative index due to unknown survey catchability.

The estimated west coast Vancouver Island sablefish biomass was lower in 2002 than in 2001 (2,594 mt versus 3,823 mt). The relative errors of the biomass estimates (standard error divided by estimate) are quite small, 0.13 and 0.16 in 2001 and 2002, respectively. Although not designed to index sablefish abundance, the thornyhead survey achieves a high degree of precision on the biomass estimates for this species. Note that the sablefish biomass estimate does not include fish surveyed in region “G”, because stratum areas are not yet available. This region was not surveyed in 2001, so the 2001 and 2002 biomass estimates are based on comparable areas.

Sablefish catch rates (kg /km) are generally highest in the shallow (501–800 m) depth strata, decreasing to very low catch rates in the deepest strata (1201–1600 m; Table 10). During the 2001 survey the highest sablefish catch rates occurred in the most southern region, “A”. In 2002 the highest sablefish catch rates occurred in the new and most northerly region, “G” (Table 10).

5.3.2 Comparison of thornyhead survey with sablefish indexing survey

Biological characteristics of sablefish caught in the thornyhead survey can be compared to those of sablefish caught in the sablefish trap indexing survey during the

2001 surveys. Biological data from the 2002 sablefish trap index survey has not yet been processed, so the comparison is limited to one years' data. For these comparisons, the sablefish trap index survey data have been summarized using the same depth strata as used in the thornyhead surveys, and includes data from the Barkley Canyon, Esperanza, and Quatsino sablefish survey localities (Figure 38).

Selected quantiles of the length distributions, summarized by sex and depth stratum, are shown in Figure 39. The size distributions of the sablefish captured by trawl gear in the thornyhead survey are very similar to those of sablefish captured by trap gear in the sablefish survey. Where differences occur, these may result from small sample sizes (eg. males caught in 1201–1600 m stratum) or, possibly, differences in sampling localities (Figure 38).

The sex ratios of the sablefish caught in the thornyhead survey are markedly different from those of sablefish caught in the sablefish survey (Table 11). The thornyhead survey captures a higher proportion of male sablefish in all depth strata, with particularly high male proportions in the shallow stratum (86% in 2001 and 82% in 2002). It would be interesting to investigate whether these differences in sex ratios result from differences in the timing of the two surveys (approximately 4 weeks) or differences in sablefish vulnerability to the gear.

Sablefish catch rates observed in the 2001 and 2002 thornyhead and sablefish surveys were compared, with data summarized using the thornyhead survey stratification scheme. Samples from the three sablefish survey localities, Barkley Canyon, Esperanza, and Quatsino, were compared with samples from the thornyhead regions, "A", "D", and "F", respectively. Catch rates, summarized by stratum and year are shown in Figure 40. In this figure, the two CPUE axes (kg/trap for the sablefish survey and kg/km for the thornyhead survey) have been scaled so that mean catch rates for each survey are plotted at equivalent levels. There is some, albeit slight, indication in the data that catch rates in the thornyhead survey are relatively higher in the shallow strata and relatively lower in the deep strata, than catch rates in the sablefish survey. Sample sizes for comparing the survey specific catch rates are small, so further data will be required to determine if depth related differences are real.

5.3.3 Potential of thornyhead survey for sablefish abundance index

The thornyhead survey appears to have very good potential for the development of a sablefish abundance index. Sablefish catch rates are relatively high, there are few tows with no sablefish catch, and the relative error of abundance estimates is small. A potential limitation of the survey for indexing sablefish abundance is that it does not cover the full sablefish distribution in shallower depths. Also, fishers have suggested that higher towing speeds would increase sablefish catch, but this may not limit the utility of the survey for developing relative abundance indices. Further investigations to explore the differences in sex ratios and possible depth-related differences in catch rates between trawl and trap gear, would be useful toward understanding the vulnerability of sablefish to different gear types. A sablefish trap survey, conducted at the same time as the thornyhead survey, would be one way to examine gear vulnerability differences.

6 Tag-recovery Analysis

The sablefish tag-recovery program began in 1977 and has been described in previous assessments (Haist et al. 1999, 2000, 2001). Beginning in 1991, a tagging component was integrated into the fall sablefish surveys to release tagged fish at each survey locality and at depths where most commercial fishing effort occurs (Haist et al. 2001). Sets designated for tag releases were distinct from those used as abundance indexing sets. In general, tagging sets have included more than 25 traps and have been baited with hake in addition to squid to maximize the number of tags released per set. Tags are recovered through voluntary returns from the sablefish directed fishery (trap and longline), groundfish trawl fishery, halibut longline fishery, and the "Zn" license rockfish (*Sebastes*) hook and line fishery. A reward system is offered through the Canadian Sablefish Association as incentive to return tags.

Appendix Table F.1 lists tag releases by year and area. Table F.2 through Table F.7 summarize the annual number of tags recovered by all gear types by release year. The sablefish trap fishery accounts for the majority of tag returns (Table F.3). Some tags are returned without associated capture information (Table F.6), while for a few tag returns the capture gear is known but the year of recovery is unknown (Table F.7).

6.1 Analysis of tag reporting rates

The percentage of tags on captured fish that are detected, recovered and returned to the database is an important parameter in analysis of tagging data. In 1999, Pascual and Hilborn (*in* Haist et al. 1999) estimated the tag return percentage for trap gear by comparing the tags recovered per ton of landed fish among vessels. This section contains an update of that analysis.

The basic assumption of this method was that between vessel differences in tags returned per ton of fish landed were due to the diligence of the crews in looking for, and returning, tags. A group of vessels with consistently high tag return rates were assumed to have returned 100 percent of tags captured. Each other vessel's tags per ton were compared to these "100 percent" vessels to calculate the vessel by vessel tag return rate. The return rate for each vessel was weighted by its total catch to determine the total proportion of tags returned.

The data available were the total tons landed, and the total tags returned by vessel, month, year and area (north or south). The raw data for trends in tags per ton in the north are shown in Figure 41. There are two key results: (1) the number of tags returned per ton has increased considerably since 1990, and (2) the difference between vessels has declined. As subsequent analysis will show, the general increase in tags per ton landed is due primarily to there being more tags at large, while the decrease in between vessel differences appears to be due to more vessels returning the majority of tags encountered.

A generalized linear model (GLM) was used to standardize for vessel, month, year and area (north or south). A log link and Poisson distributed errors were assumed. The effects of the GLM are summarized in Table 12. All the effects tested were statistically significant, but the large number of observations meant that some terms explained little additional variation and their inclusion did not influence the overall trends. A parsimonious subset of model terms was adopted, calculating only *year*, *area*, and *year:vessel* effects, to obtain the *year:vessel* interactions shown in Table 13. The average *vessel* effect, and the number of years that the vessel was in the fishery, was identified to determine which vessels consistently returned the most tags per ton (Table 14). Vessels 1, 2, 7, 10, 14 and 23 stand out as having fished consistently and returned higher than average tags per ton. These vessels were selected as the "100 percent" group. For each other vessel and year the "reporting rate" for that vessel was calculated

(6.1) $$r^*_{v,y} = \frac{E_{v,y}}{\overline{E}_{100\%,y}} \quad ,$$

where

$r^*_{v,y}$	is the estimated tag return rate for vessel v in year y;
$E_{v,y}$	is the estimated *year:vessel* interaction from the GLM (Table 13);
$\overline{E}_{100\%,y}$	is the average *year:vessel* interaction from the GLM for the 100% vessels.

The tag reporting rate of the 100 percent vessels was assumed to be 100 percent. The percentage of tags returned was calculated as

(6.2) $$r_y = \frac{\sum_v r^*_{v,y} C_{v,y}}{\sum_v C_{v,y}} \quad ,$$

where $C_{v,y}$ is the catch of vessel v in year y. Table 15 lists the results by year from this analysis. The pattern from 1992 to 1996 is roughly similar to what was found by Pascual and Hilborn (*In* Haist et al. 1999), but the tag return rate is estimated to drop off in 1997 and 1998, followed by an increase. The 2002 data show particularly high reporting rates.

6.2 A monthly tag-recovery model

In this section an extension of the simple Petersen-type tag-recovery model (Haist et al. 2000, Haist et al. 2001, updated in Appendix G) used in the last two stock assessments is presented. The model incorporates an effect for month to attempt to adjust for unequal seasonal patterns in tag recoveries per ton of fish landed. A list of data and model notation is provided in Table 16.

Model equations. The dynamics of the population biomass available for harvest are

$$(6.3) \quad B_{y,m+1} = B_{y,m} s\left(1-u_{y,m}\right) \quad \text{for months} > 1 \quad ,$$

where

$B_{y,m}$	is the biomass alive at the start of month m year y;
s	is the monthly net survival, recruitment and somatic growth rate;
$u_{y,m}$	is the monthly fishing mortality rate year y month m.

The monthly fishing exploitation rate is the total removals divided by the population size

$$(6.4) \quad u_{y,m} = \frac{C_{y,m}}{B_{y,m}} \quad ,$$

where $C_{y,m}$ is the total removals in year y month m. The dynamics of the number of tags released the previous year available to be caught is

$$(6.5) \quad \begin{aligned} T_{y,m+1} &= T_{y,m}(1-v)\left(1-u_{y,m}\right) \quad \text{for months} > 1 \\ T_{y,m} &= R_{y-1} l \quad \text{for months} = 1 \end{aligned} \quad ,$$

where

$T_{y,m}$	is the number of tags released year y-1 alive month m,
v	is the survival rate from natural mortality and emigration,
l	is the loss rate of tags between tagging and the beginning of the following year due to tag shedding, tag mortality, natural and fishing mortality,
R_{y-1}	is the number of qualified tags released year y-1.

The predicted tag recoveries are obtained by the equation

$$(6.6) \quad P_{y,m} = T_{y,m} \tilde{u}_{y,m} r_y c_y d_m \quad ,$$

where

$P_{y,m}$	is the predicted number of tags returned year y, month m
$\tilde{u}_{y,m}$	is the exploitation rate from trap vessels year y, month m.
r_y	is the tag reporting rate for year y
c_y	is the ratio of the sorted catch to the landed catch year y

d_m is a month effect, scaled so that October has a value of 1.

The likelihood of the observed recoveries, given the predicted recoveries, is assumed to be lognormal

$$(6.7) \quad L\left(O_{y,m} \mid P_{y,m}\right)=\frac{\ln\left[O_{y,m} / P_{y,m}\right]^{2}}{2 s^{2}} \quad ,$$

where

$O_{y,m}$ is the number of tags returned month m year y,
s is the coeffcient of variation (cv) of the lognormal distribution.

Assumptions and parameters to estimate. The parameters estimated by the model are the vulnerable population alive in the first month each year ($B_{y,1}$), and the month effects (d_m). Values for fixed parameters were drawn from sources external to the model:

1. *Tag reporting rates* by year were assumed known from the independent analysis of tag reporting rates (Table 17);

5. The amount of *sorting* relative to the landings for each year (Table 17) was taken from a previous analysis by Haist and Hilborn (2000, their Appendix C);

6. *Tag loss rate* was set at 20 percent loss of tags prior to the start of the year, and consisted of 10 percent tagging mortality, 5 percent tag loss, and 5 percent combined natural and fishing mortality between time of tagging in October and January 1. The tagging mortality and tag loss rates are consistent with those used in previous analyses (Haist et al. 2000, Haist et al. 2001);

7. The *monthly emigration and natural mortality rate* of tags was assumed to be 0.3/12=0.025. This was calculated as follows. Previous tag analysis shows a total annual instantaneous loss rate over the first 5 years after release of Z=0.5, which corresponds to a discrete rate of about 40 percent loss per year, i.e. 1-exp(-0.5). If there is about 10 percent loss for exploitation, accounted for in Eq. (6.3) explicitly, then there is 30 percent per year loss from natural mortality and emigration;

8. The *cv* of the lognormal likelihood distribution was assumed to be 0.3.

Model results. The month effect (d_m) was highly significant and produced monthly estimates shown in Figure 42. Monthly fits to the predicted number of tags were generally very good as shown in Figure 43. The predicted trend in abundance is shown in Figure 44 (panel A) and the corresponding estimates in Table 18.

Sensitivity analysis. Sensitivity of the model estimates to the fixed input parameters was examined by running the model with various trial values of the parameters:

1. *Tag disappearance rate*. Annual tag disappearance rates of 0.15, 0.3, and 0.45 were tried. The best fit population trajectories are shown in Figure 45, and the overall predications of population trend seem insensitive to this parameter;

2. *Tag loss rate*. Values of the pre-season tag loss of 0.1, 0.25, and 0.4 were input to the model. The best fit population trajectories are shown in Figure 46. This parameter is simply a scaling factor, and has no impact if the annual estimates of biomass are regarded as a relative trend. If the biomass estimates are regarded as absolute values then the more pre-season tag loss, the smaller the population size.

3. *Tag reporting rate*. The tag reporting rate estimates were based on using six vessels as the 100 percent tag return standard. Two sensitivities were explored. First, the four vessels with the highest average tag return rates were chosen rather than the six best. These four vessels accounted for 33 percent of the total trap landings. There were some differences in the tags reporting rates between the estimated tag return rates in the four vessel versus six vessel comparison (Figure 47). The overall trend is similar, but there are differences among years. A case was also explored where a straight line was fit through the six vessel trend in reporting rates to smooth out among year differences (Figure 47). The best-fit population trajectories are shown in Figure 48, and again there is little sensitivity to the choice of values on the trend or in the absolute values of the estimated biomass. A fit with reporting rates set at the 1999 estimates with the reporting rate set to 0.75 after 1996 was conducted for comparison with previous assessments (Figure 44, panel B).

4. *Lognormal cv.* Results were insensitive to the choice of this parameter.

Discussion. This analysis suggests the sablefish stock has generally declined during the period the tagging data are available, a result consistent with the indexing survey data and trends in the standardized commercial trap CPUE data. Perhaps the most difficult observation to explain is the month effect in the tag returns. It is very clear that at the beginning of the year in January, February and March, there are fewer tags being captured per ton of fish landed. This strongly suggests that the tags are not uniformly distributed over the population as a whole, and that there is an influx of untagged fish early in the year that disappears by April. Fishers believe that there is an influx of fish from Alaska early in the year and the CPUE in the north is particularly high during this period. Given the magnitude of the effect, this would suggest that an input of untagged fish on the order of the same size as the tagged population takes place for three months or so and then disappears, so these fish do not remain available to B.C. fishers.

6.3 Reporting rates for “CSA” type and “B” type tags

The majority of tags released during the 2000 sablefish tagging program contained different information than tags released in earlier years (Appendix F). In particular, these tags did not provide an address for returning the tags. When these tags (CSA-type tags) were purchased, a concern was raised that their rate of return by fishermen would be lower, biasing subsequent tag-return analyses. At the time it was agreed that analyses of return-rates for the CSA-type tag and the previously used B-type tag would be conducted, and if rates were lower for the CSA-type tags they would not be used in subsequent tagging analyses.

An analysis of tag returns from the 2000 sablefish tag releases suggested that there was no evidence to support rejecting a null hypothesis of no difference in tag-return rates between CSA-type and B-type sablefish tags (Haist et al. 2001). However, because there were only seven releases of B-type tags in 2000, and these were all in southern B.C. waters, it was not possible to investigate potential differences in tag-return rates by American fishermen. During the 2001 sablefish tagging program, both CSA-type and B-type tags were used and this has substantially increased the number of tag-returns that can be used in analyzing return rates. The analysis presented here includes all tag returns that had been entered in the database through August 2002.

For the tag return analysis, the data included only tag releases from sets where both CSA-type and B-type tags were applied. This subset of the 2000 and 2001 tag release data resulted in a collection of 11,203 B-type tags and 11,637 CSA-type tags that had been released from 59 tagging sets. For most tagging sets the number of CSA-type tags and B-type tags released were similar (Appendix Table F.8). The following table summarizes the tag releases and subsequent recoveries by Canadian and American fishermen.

	Number		Proportion Returned		
	B	C	B $\left(p^B\right)$	C $\left(p^C\right)$	$p^B - p^C$
Releases	11203	11637			
Recoveries					
Canadian	659	683	0.0588	0.0587	0.00013
American	18	30	0.0016	0.0026	-0.00097

The null hypothesis for testing for differences between tag return rates for the two tag types is:

H_0: The tag return rate of B-type tags is the same as the tag return rate of CSA tags;
H_a: The tag return rate of B-type tags is greater than the tag return rate of CSA tags.

The test statistic used to test the null hypothesis is the difference between the two tag-type return rates $\left(p^B - p^C\right)$. The hypothesis was evaluated using re-randomization methods (Lunneborg 2000). The 59 tagging sets were randomly sampled with replacement. Then for each set, the treatment (i.e. CSA or B tag-type) was randomly assigned to the two tag release groups, consistent with the null hypothesis. This procedure was repeated 5000 times to generate the re-randomization distribution of the test statistic under the null hypothesis.

For tags returned by Canadian fishermen, the estimated *p*-value of the test statistic is 0.398, therefore the null hypothesis is not rejected (Figure 49). For tags returned by American fishermen, the estimated *p*-value is 0.981, therefore the null hypotheis is not rejected for this group. Note, however, that for a 2-sided test the null hypothesis would be rejected as the observations suggest higher return rates of CSA-type tags by American fishermen.

This analysis suggests that there is no basis for excluding CSA-type tag releases from tagging-based analyses because of lower return rates. On the contrary, tag returns by American fishermen appear to be higher for CSA-type tags, though the number of recoveries is still very low. The tag return rates by American fishermen should be re-evaluated when there is an additional year of tag recoveries to determine if the CSA-type tags have a higher return rate.

7 Status of sablefish in U.S. waters

7.1 Gulf of Alaska sablefish

Data sources: Catch (1960-2001) was available from Japanese longline, Japanese trawl, U.S. longline, and U.S. trawl fisheries. Effort (1964-1981) and fish lengths (1963-1980) were available from the Japanese longline fishery with lengths only (1964-1971) from the Japanese trawl fishery. The U.S. longline fishery data yielded effort, lengths, and discards (1990-2001) and ages (1999-2001). The U.S. trawl fishery provided lengths (1990,1991,1999) and discards (1990-2001). The Japanese-U.S. longline survey produced measurements of catch, effort and lengths (1979-1994). The domestic longline survey provided catch, effort, lengths (1990-2002) and ages (1996-2001).

Assessment methodology: The model is an age-structured sequential population reconstruction tuned to catch rate indices derived from longline surveys and fishery. Age classes 2 to 31 (plus group) are included in the model with an ageing error matrix based on known-age otoliths (Heifetz et al. 1999). Model structure includes gear-specific selectivity's for the longline survey (asymptotic), longline fishery (asymptotic), and trawl fishery (dome-shaped). Separate estimates of catchability for the Japanese longline fishery, domestic longline fishery, U.S. longline fishery, and cooperative longline survey are included. Natural mortality was estimated in the model at $\hat{M} = 0.106$. Growth and maturity parameters were estimated independently of the assessment model and enter the model as fixed parameters.

Stock Status. Gulf of Alaska sablefish spawning abundance declined during the 1970s due to fishing mortality, but recovered due to contributions from exceptional year classes in the late 1970s and reached a peak in 1987 (Sigler et al. 2002, Figure 50). The population declined over the course of the late 1980s and 1990s until 2000 when a modest increase was observed from 2000 to 2001. The longline survey abundance index conducted in Alaska increased 5 percent by number and 7 percent by weight from 2001 to 2002 (Sigler et al. 2002). Projections from an age-structured population analysis indicate the exploitable and spawning biomass should increase 6 and 3 percent in 2003, respectively. Spawning biomass for 2003 is projected to be 39 percent of unfished spawning biomass, up from recent lows of 35 percent in the 1998 to 2000 period. This result is consistent with the 2001 assessment that indicated an above average 1997 year class (Figure 51) would contribute to increased biomass. This year class is projected to constitute 24 percent of the 2003 spawning biomass.

Status of the Gulf of Alaska sablefish spawning abundance was revised from "low and slowly increasing overall" to "moderate and increased from recent lows". Exploitable biomass for the combined Aleutian Islands, eastern Bering Sea, and Gulf of Alaska areas increased 4.6 percent from 2001 to 2002, while spawning biomass increased 3.2 percent. Projected 2003 exploitable biomass is estimated to be 221,000 mt (5.5 percent increase) and estimated spawning biomass for 2003 is 210,000 mt (2.5 percent increase). Fishery reference point estimates for the projections were estimated to be $F_{40\%}$=0.133 and M=0.106.

Fishery decision rule. The decision rules for the 2002 Alaskan sablefish assessment were changed relative to the approach used in 2001. The 2001 "abundance trend" decision analysis was framed in terms of estimating the probability of a decrease in spawning biomass given future catches. When updated for 2002, an annual catch of 7,400 mt was identified as the catch where the probability was 0.5 that 2003 and 2007 abundance was the same. This relatively low catch was required to avoid a decrease in biomass by 2007 because the assessment model projected abundance to decrease as the contribution of the 1997 year class diminishes over time. This projected decrease depends also on the fate of the 1998 year class which may also be of above average strength. For the 2002 assessment, the decision rule was changed to adapt to the improved characterization of the Alaskan stock from "low and steady" to "moderate and increased from recent lows". The new "abundance status" decision rule is based on estimating the probability that the projected abundance will reach the historic low observed in 1979.

Yield recommendation. Application of the new rule showed that an annual catch of 18,400 mt corresponded to a 0.2 probability of driving the 2007 spawning biomass below the historic low. An $F_{40\%}$ harvest strategy corresponding to an annual catch of 25,400 mt had a 0.6 probability of being less than the 1979 spawning biomass by 2007. The annual catch for 2003 recommended in the Alaskan stock assessment (Sigler et al. 2002) was 18,400 mt, corresponding to a fishing mortality of 0.092 and 18 percent higher than the recent 5-year average fishing mortality of 0.078. A quota of 20,900 mt was approved on the basis that abundance had improved from 36 to 39 percent of unfished spawning biomass.

Although the abundance of Alaskan sablefish is increasing overall, the recommended catch in the East Yakutat/Southeast region adjacent to northern B.C. has been decreased by 2 percent. The decrease arises because coast wide yield recommendations in Alaska are split by region based on a weighted combination of the abundance survey and commercial fishery catch rates. Although the abundance survey increased in 2002 relative to 2001, the commercial fishery catch rates have steadily decreased over the 1997 to 2001 period, and the 2002 fishery data is not complete. The pattern of abundance index decline over time in the eastern Gulf of Alaska is similar to that observed for the B.C. survey index (Sigler et al. 2002, their Figure 5.6, Figure 50). Alaskan tag movement studies indicated small fish move north and west from their release sites, and return eastward as a function of age. Thus, biomass in the southeast region is expected to lag behind more westward regions as strong year classes recruit.

7.2 Continental U.S. Pacific coast sablefish

Data Sources. Landings (1956-2001) by major gear type (longline, trap, trawl) were available along with commercial fisher logbook data (1978-1988). Fishery independent abundance indices were available from shelf trawl (1980-2001) and slope trawl (1988-2001) surveys. Trap surveys were conducted by NMFS (1979-1981, 1983, 1985, 1987, 1989) in the northern Vancouver and Columbia INPFC areas, while Eureka, Monterey and Conception were surveyed in the south(1984, 1986, 1988, 1991). The trap surveys provided abundance indices and size-stratified abundance indices. A fishery-dependent abundance index was obtained from trawl fishery logbooks. Size and age distributions were obtained from the longline, trawl, and trap fisheries (1986-2001), and from the shelf and slope trawl surveys. Age-distributions were constructed using age-length keys. Size distribution data were obtained from the longline and trawl fisheries.

Assessment methodology. The assessment model is based on stock synthesis (Methot 1989) population reconstruction with age-structured and length-structured components, tuned to five abundance indices: (1) the AFSC shelf survey biomass estimates (1980-1998), (2) the AFSC and NWFSC slope survey biomass estimates (1988-2000), (3) the NMFS northern trap survey for “medium” and “large” size sablefish (1971-1989), (4) the NMFS south trap survey for “medium” and “large” size sablefish (1984-1991), and (5) the logbook CPUE as estimated via a GLM procedure (1978-1988). Dome-shaped selectivity was adopted for fishery and trawl survey indices and some selectivity parameters were time-varying. Ageing error was modeled as a function of among reader agreement. A Beverton-Holt stock-recruitment function was utilized for generating annual recruitment. Natural mortality was fixed at M=0.07. Various model configurations were examined.

Stock Status. The 2001 assessment of sablefish stocks of Washington, Oregon, and California north of Point Conception indicated that poor recruitment over the last ten years contributed to a significantly decreased spawning biomass (Schirripa and Methot 2001). In all the model configurations examined, the ratio of the current estimate of spawning stock biomass to the virgin state was at 25 percent, below which the stock is considered overfished under U.S. federal legislation. Spawning stock biomass was estimated to have declined from a high of 122,000 mt in 1980 to a low of about 60,000 mt in 2000. An update of the continental U.S. sablefish assessment for 2002 (Schirripa 2002), which added data from 2001 fishery and survey sources, produced an increase in the absolute biomass estimate to 72,000 mt but there was little change in the ratio of current spawning stock biomass to virgin biomass. Results from the shelf and slope trawl surveys indicate two relatively strong incoming cohorts corresponding to the 1999 and 2000 year classes. The 2001 shelf survey biomass estimates are the highest in the 1980 to 2001 time series.

Fishery decision rule. A target fishing mortality of $F_{45\%}$ with a $F_{40\text{-}10}$ adjustment (a proxy for maximum sustained yield) was applied to current biomass estimates in order to project future stock status under constant harvest and various recruitment assumptions.

Yield recommendation. The Scientific and Statistical Committee of the Pacific Fishery Management Council (PFMC 2001) recommended an optimum yield of 3,200 mt for the 2002 fishing season, a reduction of 54 percent from the 2001 harvest. The Groundfish Management Team of the PFMC suggested a three-year strategy that required a reduction in harvest to 4,000 mt in 2002. The PFMC adopted a yield of 4,500 mt (a 36 percent reduction from the 2001 harvest) citing evidence from the 2001 National Marine Fishery Service (NMFS) shelf survey of a strong 2000 year class. In 2003, the yield was increased from 4,500 mt to about 7,000 mt as a result of a change in the estimate of the catchability parameter for the slope trawl survey (a shift from q=0.6 to q=0.4). One reason for the change was that young fish seen in the 2001 shelf survey were not subsequently seen in the 2002 slope survey.

8 A simple biomass dynamics model

Integration of the fishery data and abundance indicators within an age-structured population dynamics model is unlikely to have much utility given recent age data are not available and there is no satisfactory rationalization of the patterns in tag-recoveries that led to the discontinuation of complex tagging models (Haist et al. 1999, Haist and Hilborn 2000). A simple biomass dynamics model is proposed here as one means of integrating the abundance indices to provide a pragmatic tool for projecting relative abundance and identifying rationale choices of annual total allowable catch (TAC). The model provides a vehicle for quantifying the consequences of assumptions in a simple framework and is not intended to capture all the complexities of sablefish population dynamics. In this section the model structure is defined and the interpretation of the resulting decision tables is described. Sensitivity analyses are presented graphically to illustrate the consequences of varying the model assumptions.

8.1 Model description

The model simulates changes in vulnerable biomass as a function of the catch removed each year and a productivity term. Here production encompasses the net effect of changes to the *vulnerable* biomass due to recruitment, growth, immigration, and emigration. In addition to catch, the data inputs include the three abundance indices derived from the standardized trap fishery catch rates, indexing survey, and the monthly tag-recovery model. The time series of abundance indices are short, and although consistent in their general trend through the 1990s, they suggest somewhat different patterns in the inter-annual changes in abundance. Thus, there is no attempt to estimate a stock production term for each year, but rather a term for the average stock production in recent years. The analysis is restricted to recent years starting in 1996 because this is a period where average production is thought to have been low. If the model fits were started earlier, say 1992 or 1993, the model would need to allow for negative production. A single stock model was fit to the data because the tag-recovery index of trap vulnerable biomass is not separated into north and south area components, although this may be feasible for future analyses.

The following equations are used to model the dynamics of the vulnerable stock:

(8.1)
$$\tilde{C}_i = \frac{F_i}{F_i + M} \exp\left(-F_i - M\right) B_i \qquad i \geq start\_yr$$
$$B_{i+1} = \exp\left(-F_i - M\right) B_i + \bar{P} \qquad i \geq start\_yr$$

All model parameters and data are defined in Table 19. The predicted relative abundance indices are estimated as:

(8.2)
$$\hat{I}_i^j = \begin{cases} q^j \exp\left(t^j\left(-F_i - M\right)\right) B_i & j = 1,2;\ i \geq start\_yr \\ q^j \exp\left(t^j\left(-F_i - M\right)\right) B_i & j = 3; \quad i = start\_yr, 1998 \\ q_e q^j \exp\left(t^j\left(-F_i - M\right)\right) B_i & j = 3; \quad i \geq 1999 \end{cases}$$

Note that an additional proportionality constant, q_e, is included in the calculation of the post-1998 predicted commercial trap fishery-based relative abundance indices (j=3) to allow for escape-ring effects.

A Bayesian approach was used to estimate model parameters (Gelman et al. 1995). Bayesian estimation allows the absolute estimates of vulnerable biomass from the tagging-based analysis to be used, while recognizing the considerable uncertainty in these estimates. The objective function is defined as a negative log-posterior

(8.3)
$$\text{Objective}\,(\mathbf{p}) = -\sum_j \sum_i \log\left[L\left(\mathbf{p} \mid \tilde{I}_i^j\right)\right] - \log\left[p\left(\mathbf{p}\right)\right] \ ,$$

where p is the joint prior density of the parameter vector **p**. A normal distribution was assumed for the logarithm of the abundance indices. The negative log-likelihood for the abundance index data is then

$$(8.4)\quad -\log\left[L\left(\mathbf{p}\mid\tilde{I}_i^j\right)\right]=\sum\nolimits_{j=1}^{3}\sum\nolimits_{i=start\_yr}^{2003}\log\left(s_I\right)+0.5\left(\frac{\log\left(\tilde{I}_i^j/\hat{I}_i^j\right)}{s_I}\right)^2 \quad .$$

Uninformative priors (ie. unrestricted uniform distributions) were assumed for most model parameters (see Table 19 for details). The exceptions were:

1. a uniform prior for the average production parameter, $\overline{P}$, that allows only positive values;
2. a uniform prior for the natural mortality parameter, M, over the range 0.06 to 0.1;
3. a normal prior for the tagging-based proportionality constant, q^1, with mean 1 and variance $s_{q^1}^2$.

The joint prior density of the model parameters is give by

$$(8.5)\quad -\log\left(p\ (\mathbf{p})\right)=0.5\left(\frac{q^1-1}{s_{q^1}}\right)^2 \quad .$$

The model was implemented using the AD Model Builder software package (Otter Research 1999). This software package uses a Markov Chain Monte Carlo (MCMC) method based on the Metropolis-Hastings algorithm (Gelman et al 1995) to obtain samples from the full posterior distribution. Ten million MCMC draws were done separately for each the model runs. A sample (n=2000) from the multivariate posterior distribution from each was stored and used in the projection simulations.

A model reference case was defined to have a starting year of 1996, with the standard deviation of the tagging index proportionality constant, $s_{q^1}^2$, set to 0.5. The vulnerable biomass index was derived from the monthly tagging model with reporting rates estimated from the GLM analysis. The back transformed year coefficients from the indexing survey coast model were used as the second index. The back-transformed year coefficients from the north, central and south commercial trap GLM were averaged to obtain a coast wide proxy for the third index. The 1996 starting year was selected because it coincides with the transition from steep decline to markedly slower decline in stock indicators. This choice also corresponds to the period from the mid 1990s to the present where production was thought to be low. The $s_{q^1}^2=0.5$ assumption was *ad hoc*, and sensitivity analyses were conducted to examine the effect of this assumption. Other sensitivity analyses were conducted for the starting year and for the tag reporting rate assumption. A final sensitivity was conducted to evaluate the influence of the 2001 survey index on model results. Table 20 provides a list of the sensitivity runs that were examined.

8.2 Model results

Figure 52 shows the chain of 2003 biomass estimates from the MCMC algorithm for the *reference* case. The chains for all estimated parameter are well mixed and the autocorrelations in the parameter estimates are low (maximum approx. 0.25), indicating reasonable convergence to the posterior distribution. Distributions of the estimated vulnerable biomass over the time-series are shown as quantile plots in Figure 52.

The joint posterior distribution of initial biomass (vulnerable biomass in 1996) and the production parameter, $\bar{P}$, show a strong negative correlation (Figure 53), a feature common to biomass dynamics models. The posterior distributions of the natural mortality parameter, *M*, and tagging proportionality parameter, q^1, are very similar to their prior distributions indicating there is little information in the data about these quantities.

8.3 Model projections, performance indicators, and decision tables

The simple biomass dynamics model was used to project vulnerable stock biomass trends over the 2003 to 2008 period. Stock projections were conducted for a range of potential future catch levels. Each simulated projection held the catch fixed over the projection period. Projections for the reference case run were conducted with production set at the estimated value. This choice reflects the average level of production over the 1996 to 2002 period. Based on an assumption that production will be higher over the next five years, two alternative cases were examined with production set to multiples of the estimated value, $1.25\bar{P}$ and $1.5\bar{P}$. The alternative that production will decrease was not investigated because all indicators suggest an increase in recruitment over the projection period. Projections were also conducted for all sensitivity runs listed in Table 20.

In general, stock indices are at, or near, the lowest levels observed in the available time series, which are short relative to the generation time of sablefish. It is not known whether further decrease in abundance will risk future production. Thus, the choice of performance indicators produced by the simple biomass dynamics model relate to stock increase. Two performance measures were selected to facilitate comparison of stock performance at different future catch levels:

1. the *probability* that vulnerable stock biomass increases over the projection period, $P\left(B_{2008} > B_{2003}\right)$; and
2. the *magnitude* of the expected change in vulnerable stock biomass over the projection period, $E\left(B_{2008} / B_{2003}\right)$.

Performance measures are presented in decision tables that allow comparison of stock status at different future catch levels. The model constructs a distribution of B_{2003} over the sample from the MCMC chain. Thus, the full distribution of B_{2003} values can be used in decision tables to summarize results relative to current stock condition, i.e. the impacts of the B_{2003} being lower (or higher) than estimated can be assessed. This was achieved by dividing the marginal posterior distribution of 2003 vulnerable biomass estimates into three ranked groups (0^{th}-25^{th}, 25^{th}-75^{th}, and 75^{th}-100^{th} percentiles). Performance indicators are presented for each of these groups, representing expected outcomes given poor, medium, or good levels of biomass in 2003. Note that the group differences are relative.

Alternative performance measures are possible if the biomass estimates from the tag-recovery program were considered to be absolute estimates, thereby eliminating the need to estimate a catchability parameter for those data. One reviewer suggested that this alternative should lead the initial biomass estimate (B_{1996}) to be nearly independent of production and also produce a better defined posterior distribution. The net result might be slightly more optimistic projections because the probability of high biomass and low production combinations would be reduced, i.e. less negative correlation structure in Figure 53. Given the uncertainties in the analysis, it was decided to retain the view that the tag-recovery model estimates were relative rather than absolute measures of trap vulnerable biomass.

8.4 Sensitivity analyses

Sensitivity of model results was examined for the cases listed in Table 20. For example, B1994+ refers to setting the start year of the model run to 1994 rather than 1996. The name “Qsd0.7” corresponds to a value of 0.7 for standard deviation of the proportionality constant for the tagging-based index, q^1. The name “AltRepRate” indicates a case where the tag reporting rate was set to 0.7, approximately the mean of the GLM estimated tag-reporting rates over the 1995 to 2002 period. Finally, the name “Surv2001” refers to a case where the 2001 survey point was removed from the trap survey index.

Figure 54 is a trellis dotplot of the probability that vulnerable stock biomass increases over the projection period, $P(B_{2008} > B_{2003})$, for given levels of the total annual catch. The reference case is shown for comparison. In general, higher assumed levels of production give higher probabilities of stock increase for all catch levels. Removal of the 2001 trap index survey point always results in higher probabilities of stock increase, and the assuming a fixed reporting rate results in lower values of $P(B_{2008} > B_{2003})$ for all catch levels except 3,500 mt. The results are relatively insensitive to the choice of standard deviation for q^1. Setting the start year to 1994 or 1995 typically results in a lower $P(B_{2008} > B_{2003})$ at intermediate levels of catch.

8.5 Interpretation of decision tables

Model results are summarized in the following table for three assumed levels of future production and over catches ranging from 0 to 3,500 mt. These results were drawn from Table 21, by focusing on the expectation over the joint posterior, integrating the results at poor, medium and good categorizations of 2003 biomass estimates. The projection results mostly depended on the assumption regarding future production.

	$P(B_{2008} > B_{2003})$		
	Productivity Assumption		
Total Annual Catch 2003-2008	$1\bar{P}$	$1.25\bar{P}$	$1.5\bar{P}$
0	0.91	0.92	0.93
2000	0.70	0.83	0.88
2500	0.54	0.78	0.85
3000	0.30	0.68	0.81
3500	0.07	0.53	0.75

For the reference case, TACs of 2,500 and 3,000 mt correspond to $P(B_{2008} > B_{2003})$=0.54 and 0.30, respectively. Thus, a TAC of 2,500 mt is approximately the level where stock abundance is expected to remain at the 2003 level through to 2008, the replacement level. The probability of maintaining at least the 2003 biomass is lower (0.3) for a TAC of 3,000 mt, and very low (0.07) at 3,500 mt. The reference case makes the conservative assumption that no improvement in production will occur over the 2003 to 2007 projection period relative to the 1996 to 2002 period.

Assumptions about future production that acknowledge positive signals in various indicators are represented by the $1.25\bar{P}$ and $1.5\bar{P}$ cases. For example, a 25 percent increase in production relative to the 1996 to 2002 period results in $P(B_{2008} > B_{2003})$=0.78 for a TAC of 2,500 mt. Under a five year TAC of 3,000 mt the probability of increasing biomass is 0.68. The replacement harvest would be approximately 3,500 mt.

Complete decision tables can be found in Table 21 for $P(B_{2008} > B_{2003})$ and $E(B_{2008} / B_{2003})$. Consider the reference case $1\bar{P}$ in the first five rows of Table 21. If the 2003 biomass is actually located in the upper quartile of the distribution, then a TAC of 2,500 mt corresponds to $P(B_{2008} > B_{2003})$=0.31. In contrast, if the 2003 biomass is actually in the lower quartile of the 2003 biomass distribution, a TAC of 2,500 mt leads to $P(B_{2008} > B_{2003})$=0.72. Similar consequences of model assumptions can be derived from Table 21 for other values of future production and 2003 biomass levels. In general, the value of $P(B_{2008} > B_{2003})$ decreases as the B_{2003} level increases, and increases as production increases. This effect is likely due to the negative correlation between initial biomass and the mean production parameter noted previously and shown in Figure 53.

Table 21 also presents an alternative performance measure, $E(B_{2008}/B_{2003})$. Again focusing on the expectation over the joint posterior for the reference case, a TAC of 2,500 mt is expected to result in the 2008 biomass at 0.97 of the 2003 biomass or approximately the replacement level. A TAC of 3,000 mt is expected to result in a 14 percent decline in the 2008 biomass relative to the 2003 biomass. For the 1.25 $\bar{P}$ case, a 2,500 mt TAC is expected to result in the 2008 biomass at 1.20 times that of the 2003 biomass. A TAC of 3,000 mt is expected to result in an 8 percent increase in 2008 biomass relative to 2003 biomass, and a 3,500 mt TAC somewhat exceeds the replacement level, leading to a 4 percent decline relative to B_{2003}.

The reference case was selected to represent the view that future production will remain at recent low levels. Other cases with higher production were selected to represent the view that production will improve due to the impacts of stronger year classes or immigration of fish from outside the Canadian zone.

The expectation of exceeding B_{2003} can be examined for time horizons other than 2008. Figure 55 shows the expectation of vulnerable stock biomass in years 2004 through 2008, relative to B_{2003} for catch levels from 0 through 4,000 mt and two levels of assumed future production. The left panels of the figure show lines with slopes that become more negative with increasing TAC and time horizon. A value of 1.0 on the y-axis of the panels represents the replacement level. At assumed 1.5 $\bar{P}$ the expected increase in biomass declines with increasing TAC, but all time horizons remain above the replacement level. The quantile plots in the right four panels of Figure 55 show the expected downside risk of falling below the current level of vulnerable biomass with increasing TAC and time horizon. Uncertainty increases with time from 2003, and higher assumed production increases the probability of stock increase, $P(B_{2008} > B_{2003})$. These figures can be used to compare potential outcomes on the time scale that sablefish assessments and TAC adjustments are made. For example, a one year time horizon shows that the difference in potential outcomes between a 2,500 and 3,000 mt TAC are small compared to the effect of an increase in production from 1 $\bar{P}$ to 1.5 $\bar{P}$.

Alternatives to the decision tables presented here are possible if uncertainties in the tag-recovery analysis can be resolved to the point where absolute estimates of abundance can be assumed. A reviewer pointed out that catch options could be specified based on fractions, *f*, of production. If *f*=1, then all production is caught, and a decline in biomass proportional to *M* can be expected. Trade-offs between allocating some production to catch, *f*<1, and the balance 1-*f* to rebuilding could be examined in a decision table.

9 Discussion

9.1 Synopsis of sablefish stock status indicators

This assessment relies on the interpretation of time trends derived from three primary indicators of the vulnerable biomass: commercial trap fishery catch rates, indexing survey catch rates, and relative estimates of vulnerable biomass computed from the monthly tag-recovery data. General agreement among the time series of indices indicates that sablefish vulnerable to trap gear experienced a decrease in abundance from (relatively) high levels in the early 1990s to low levels in the mid 1990s. The rate of decline slowed markedly in the mid-1990s for both stock areas. For the north stock area, a period of relative stability occurred in the mid 1990s until 2001 when historically low commercial CPUE and indexing survey results were observed. Index survey catch rates in the north improved in 2002, and were comparable to those observed in the mid 1990s. In contrast, the decline in commercial trap and survey indices for the south stock area was more gradual through the mid 1990s, but has continued through 2002. The pattern of monthly tagging model estimates of vulnerable biomass was generally consistent with the trends indicated by the commercial catch rate and index survey series, though it is variable through the late 1990s.

The three primary stock indicators analyzed in the assessment share two common features: (1) the time series are short compared to the longevity (70+ years) and hence long generation time of sablefish, and (2) they all relate to sablefish that are vulnerable to trap gear. Each series is limited to about 10 to 15 years of data that must be judged relative to the long history of sablefish exploitation. At least two of the primary stock indicators do not provide an absolute estimate of sablefish abundance, and each should be viewed as providing a relative index for the component of the sablefish population measured. If reporting rates and other scaling factors are considered accurate, then the tagging model estimates of vulnerable biomass could be considered absolute. The three indices relate to the offshore biomass (excluding seamounts) vulnerable to trap gear and do not, for example, index juvenile sablefish or sablefish in inside waters or coastal inlets. It is not known what factors motivate sablefish to enter traps, and hence it is not clear what component of the stock is selected. Also, the relative proportion of the total sablefish stock indexed by the trap-related indices is unknown.

A synopsis of the stock indicators for vulnerable biomass is provided in the following list:

- *Standardized commercial trap CPUE* (North). Trap fishery catch rates for the north coastal area declined from 1991 to 1998 prior to the mandatory adoption of escape rings in the trap fishery. Subsequent to 1998 the four-year trend indicates a decline, with a historic low in 2001 and improvement in 2002 in agreement with the indexing survey trajectory.

- *Standardized commercial trap CPUE* (Central). Catch rates in the central coastal area increased in the early 1990s, and then experienced a large decrease from 1994 to 1996. The trend subsequent to 1998 indicates a decline. The central B.C. coast did not decline between 2000 and 2001.
- *Standardized commercial trap CPUE* (South). The south coastal area catch rates initially increased and then declined from 1992 through 1998. Subsequent to 1998, the four-year trend indicates a decline. Like the north area, it is noteworthy that the index for the southern region decreased substantially between 2000 and 2001, as occurred in the indexing survey.
- *Standardized commercial longline CPUE*. Longline catch rates show no long-term trend over the period 1987 to 2002.
- *Indexing survey* (North). Results for the north stock area in 2002 indicated improvement in catch rates to a level comparable to the mid 1990s. This change was largely driven by the two most northern indexing localities. The compression of catch rate variance observed in 2001 was not evident in 2002.
- *Indexing survey* (South). Results for the south stock area in 2002 show no improvement from levels in the mid 1990s.
- *Tag-recovery estimates of vulnerable biomass*. Assuming the estimated tag reporting rates, the vulnerable biomass indicated a decline in abundance from 1993 through 1998, an increase from 1998 to 1999, followed by a decline through 2002.
- *Nominal trap CPUE in British Columbia 1979-2001.* Recent catch rate levels are at, or slightly below, levels experienced in the early 1980s. This time series is not standardized and coincides with a period of change in the fishery management regime and fishing practices. The timing of the peak of nominal trap CPUE during the early 1990s is consistent with a similar pattern observed for the Gulf of Alaska stock.
- *Gulf of Alaska stock status.* The U.S. stock assessment concluded that abundance is moderate and increased from recent lows, in large part due to the influence of the 1997 year class.
- *Thornyhead survey.* Estimated sablefish biomass in 2002 was lower than in 2001, however, only two surveys have been conducted.

The following list of indicators relate to expected increases in sablefish production through recruitment and/or immigration to the Canadian zone:

- *Gulf of Alaska stock status*. Exploitable biomass is expected to increase 6 percent from 2002 to 2003 due to the above average 1997 year class, which now accounts for 24 percent of the 2003 spawning biomass. The 1998 year class may also emerge as being above average with the accumulation of one or two more years of data.
- *Continental U.S. indicators*. Relatively strong 1999 and 2000 year classes were observed by the triennial shelf survey, and the 2001 shelf survey results are the highest in the 1980 to 2001 series. This optimism that the 2001 year class might be very good follows poor recruitment through the 1990s (King et al. 2001) and a consequent decline in sablefish spawning stock biomass in the continental States.
- *Shrimp survey.* WCVI shrimp survey shows marked increase in sablefish catch rates in 2001 and 2002, in agreement with results from the continental U.S. shelf and slope

surveys and Pacific hake fishery bycatch, which suggest above average 1999 and 2000 year classes.
- *Hecate Strait Observer Data.* Analyses of these data suggested an increase in the abundance of juvenile sablefish in 1998 and 1999 attributed to the 1997 year class.
- *IPHC Survey.* Mean catch rates and proportion of sablefish encounters at survey sites peaked in 1998 and 1999 in Hecate Strait, which may indicate passage of sablefish through the region to outside waters.

These indicators suggest that production of sablefish due to recruitment to the vulnerable biomass over the next five years may be greater than the low levels experienced in the 1990s.

9.2 Yield recommendations for the 2003/2004 fishing year

This assessment follows an interim review of the primary stock status indicators precipitated by the historically low indexing survey result observed in fall 2001. In response to concern that the stock had experienced continued decline since the mid-1990s, a yield of 2,800 mt was identified by PSARC as guidance to fishery managers (Cass 2002). An in-season reduction was implemented in the 2001/2002 fishing year that reduced the TAC from 4,000 mt to 2,800 mt. A further precautionary reduction of the TAC to 2,450 mt was applied to the fishery in 2002/2003.

Positive results from the 2002 indexing survey have alleviated our immediate concerns regarding decline of the northern stock from levels observed in the mid 1990s. With the exception of the improved indexing survey catch rates for northern localities in 2002, the primary sablefish stock indicators available for analysis do not show evidence of increased vulnerable biomass. We view the revised trend in relative vulnerable biomass from the monthly tagging model as now being consistent with the general trends reflected by the commercial catch rate data and indexing survey data. Based on the monthly tagging analysis results, the current low level of the B.C. stock is about 30 percent of the peak level of vulnerable biomass and 57 percent of the mean level, so the stock is unlikely to have fallen to levels of spawning stock biomass that would be cause for a conservation concern.

Fishery objectives for the B.C. sablefish resource have not been specified. We suggest there is a need to define an “interim fishery objective”. Our recommendation is to pursue fishery objectives that will increase abundance from current levels. The decision-making procedure based on output from the simple biomass dynamics model depends explicitly on two considerations external to available data:

1. the degree of optimism regarding future production, e.g. $1\bar{P}$ to $1.5\bar{P}$;
2. the desired trade-off between fishery yield and the objective to increase stock abundance, e.g. $P\left(B_{2008} > B_{2003}\right)$ and $E\left(B_{2008}/B_{2003}\right)$.

Based on the decision analysis, the assumption that future production will not increase from that experienced in the recent past implies that a TAC of 2,500 mt will maintain 2003 biomass. In our view, this level of harvest represents a conservative choice that poses little risk to the stock, particularly when TACs are set on a short-term basis. Given the positive recruitment indicators described above, we believe an increase in future production over the 2003 to 2008 projection period relative to the 1996 to 2002 period is likely. If future production of 1.25 times the 1996 to 2002 estimate is considered, then TACs of 2,500 or 3,000 mt imply $P\left(B_{2008} > B_{2003}\right)$ values of 0.78 and 0.68, respectively. Over the 2003 to 2008 period, these two choices of TAC correspond to projected increases in biomass, $E\left(B_{2008}/B_{2003}\right)$, of 20 and 8 percent. As yields increase from 3,000 to 3,500 mt the probability of stock increase is reduced to 0.53 with a projected reduction in biomass of four percent.

One approach to selecting performance criteria in anticipation of increased production is to maintain a reasonably high prospect of stock increase, say, $P\left(B_{2008} > B_{2003}\right) \geq 0.75$ and $E\left(B_{2008}/B_{2003}\right) \geq 1.1$. For the 1.25 $\overline{P}$ case, these criteria suggest yields of about 2,700-2,900 mt. This choice of performance criteria is a pragmatic one; different criteria will translate into alternative yield choices. We note again that the decision procedure used here is not intended to set harvest levels over the duration of the projection period. By necessity, frequent review of the stock indicators will be required pending the development of a satisfactory population dynamics model for examining the consequences of a long-term harvest strategy. Fishery managers and industry should anticipate that re-assessment of stock indices and recruitment will allow the opportunity to revise yield recommendations in response to changing trends.

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Table 1 Annual sablefish landings (mt) in Canadian waters by gear type, excluding sablefish landed from seamounts. Preliminary data for 2002 reported to Dec 3, 2002.

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total
1913					1,988		1,988
1914					3,209		3,209
1915					2,441		2,441
1916					4,312		4,312
1917					5,956		5,956
1918					2,039		2,039
1919					716		716
1920					1,754		1,754
1921					1,383		1,383
1922					1,293		1,293
1923					1,135		1,135
1924					1,238		1,238
1925					1,017		1,017
1926					705		705
1927					1,118		1,118
1928					911		911
1929					1,042		1,042
1930					1,124		1,124
1931					397		397
1932					436		436
1933					413		413
1934					435		435
1935					659		659
1936					490		490
1937					912		912
1938					576		576
1939					617		617
1940					948		948
1941					1,188		1,188
1942					835		835
1943					1,426		1,426
1944					1,519		1519
1945					1,428		1,428
1946					1,619		1,619
1947					905		905
1948					1,483		1,483
1949					1,895		1,895
1950					648		648
1951	23.1		772.8	0.5	796.4		796.4
1952	34.0		453.2	0.6	487.8		487.8
1953	8.0		335.6	1.1	344.7		344.7
1954	26.4	0.3	432.3		459.0		459
1955	15.2		359.0		374.2		374.2
1956	36.5		172.8		209.3		209.3
1957	51.0	0.3	465.6		516.9		516.9

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total
1958	117.6	0.6	167.1		285.3		285.3
1959	88.2		298.3		386.5		386.5
1960	65.5		423.3		488.8		488.8
1961	97.9		321.3		419.2		419.2
1962	113.7		277.7	1.1	392.5		392.5
1963	64.8		222.3	0.2	287.3		287.3
1964	125.2		274.5	0.1	399.8	83	482.8
1965	261.9		193.2	0.3	455.4	92	547.4
1966	311.9		325.7	0.2	637.8	269	906.8
1967	138.6		252.9	0.1	391.6	1,254	1,645.6
1968	167.0		292.3	15.1	474.4	2,455	2,929.4
1969	148.3		162.3	0.6	311.2	4,763	5,074.2
1970	165.9		142.1	0.5	308.5	5,246	5,554.5
1971	189.3		123.0		312.3	3,211	3,523.3
1972	688.3		399.7		1,088.0	4,818	5,906.0
1973	82.8	745.8	119.8		948.4	3,038	3,986.4
1974	121.8	327.1	41.3	1.8	492.0	4,287	4,779.0
1975	279.8	469.4	152.2	0.9	902.3	6,506	7,408.3
1976	382.0	303.4	89.4	0.1	774.9	6,302	7,076.9
1977	786.5	214.6	77.1	6.8	1,085.0	3,718	4,803.0
1978	130.5	634.6	57.2	7.8	830.1	3,051	3,881.1
1979	276.1	1,480.1	276.8	6.0	2,039.0	2,348	4,387.0
1980	335.3	3,210.8	248.6		3,794.7		3,794.7
1981	228.8	3,275.3	326.1		3,830.2		3,830.2
1982	245.9	3,437.8	343.6		4,027.4		4,027.4
1983	274.1	3,610.5	451.4		4,336.0		4,336.0
1984	187.0	3,275.4	365.1		3,827.4		3,827.4
1985	233.1	3,501.3	458.3		4,192.7		4,192.7
1986	551.8	3,277.1	619.2		4,448.1		4,448.1
1987	406.9	2,954.3	1,268.6	0.7	4,630.5		4,630.5
1988	637.3	3,488.5	1,273.6	3.2	5,402.6		5,402.6
1989	623.4	3,772.0	928.6	0.0	5,324.0		5,324.0
1990	460.7	3,072.4	1,371.8		4,904.9		4,904.9
1991	438.8	3,494.4	1,179.2		5,112.4		5,112.4
1992	448.7	3,710.2	847.5	1.1	5,007.5		5,007.5
1993	543.1	4,142.4	424.2	0.1	5,109.8		5,109.8
1994	483.1	4,050.7	467.7		5,001.5		5,001.5
1995	427.4	3,272.3	474.3		4,174.1		4,174.1
1996	190.8	2,999.5	278.7		3,469.0		3,469.0
1997	157.3	3,555.3	430.6		4,143.2		4,143.2
1998	376.6	3,772.1	443.7		4,592.4		4,592.4
1999	403.1	3,665.7	628.1		4,696.8		4,696.8
2000	326.3	2,727.5	750.3		3,804.1		3,804.1
2001	298.0	2,476.6	486.0		3,260.6		3,260.6
2002	*124.2*	*1,307.1*	*483.1*		*1,914.3*		*1,914.3*

Table 2 Proportion of annual sablefish landings (mt) by gear type, excluding sablefish landed from seamounts. Preliminary data for 2002 reported to Dec 3, 2002.

Year	Foreign	Trawl	Trap	Longline	Other	Canadian	Landings
1951		2.9		97.0	0.1	100.0	796.4
1952		7.0		92.9	0.1	100.0	487.8
1953		2.3		97.4	0.3	100.0	344.7
1954		5.8	0.1	94.2		100.0	459.0
1955		4.1		95.9		100.0	374.2
1956		17.4		82.6		100.0	209.3
1957		9.9	0.1	90.1		100.0	516.9
1958		41.2	0.2	58.6		100.0	285.3
1959		22.8		77.2		100.0	386.5
1960		13.4		86.6		100.0	488.8
1961		23.4		76.6		100.0	419.2
1962		29.0		70.7	0.3	100.0	392.5
1963		22.6		77.4	0.1	100.0	287.3
1964	17.2	25.9		56.9	0.0	82.8	482.8
1965	16.8	47.8		35.3	0.1	83.2	547.4
1966	29.7	34.4		35.9	0.0	70.3	906.8
1967	76.2	8.4		15.4	0.0	23.8	1,645.6
1968	83.8	5.7		10.0	0.5	16.2	2,929.4
1969	93.9	2.9		3.2	0.0	6.1	5,074.2
1970	94.4	3.0		2.6	0.0	5.6	5,554.5
1971	91.1	5.4		3.5		8.9	3,523.3
1972	81.6	11.7		6.8		18.4	5,906.0
1973	76.2	2.1	18.7	3.0		23.	3,986.4
1974	89.7	2.5	6.8	0.9	0.0	10.3	4,779.0
1975	87.8	3.8	6.3	2.1	0.0	12.2	7,408.3
1976	89.0	5.4	4.3	1.3	0.0	11.0	7,076.9
1977	77.4	16.4	4.5	1.6	0.1	22.6	4,803.0
1978	78.6	3.4	16.4	1.5	0.2	21.4	3,881.1
1979	53.5	6.3	33.7	6.3	0.1	46.5	4,387.0
1980		8.8	84.6	6.6		100.0	3,794.7
1981		6.0	85.5	8.5		100.0	3,830.2
1982		6.1	85.4	8.5		100.0	4,027.4
1983		6.3	83.3	10.4		100.0	4,336.0
1984		4.9	85.6	9.5		100.0	3,827.4
1985		5.6	83.5	10.9		100.0	4,192.7
1986		12.4	73.7	13.9		100.0	4,448.1
1987		8.8	63.8	27.4	0.0	100.0	4,630.5
1988		11.8	64.6	23.6	0.1	100.0	5,402.6
1989		11.7	70.8	17.4	0.0	100.0	5,324.0
1990		9.4	62.6	28.0		100.0	4,904.9
1991		8.6	68.4	23.1		100.0	5,112.4

Year	Foreign	Trawl	Trap	Longline	Other	Canadian	Landings
1992		9.0	74.1	16.9	0.0	100.0	5,007.5
1993		10.6	81.1	8.3	0.0	100.0	5,109.8
1994		9.7	81.0	9.4		100.0	5,001.5
1995		10.2	78.4	11.4		100.0	4,174.1
1996		5.5	86.5	8.0		100.0	3,469.0
1997		3.8	85.8	10.4		100.0	4,143.2
1998		8.2	82.1	9.7		100.0	4,592.4
1999		8.6	78.0	13.4		100.0	4,696.8
2000		8.6	71.7	19.7		100.0	3,804.1
2001		9.1	76.0	14.9		100.0	3,260.6
2002		*6.5*	*68.3*	*25.2*		*100.0*	*1,914.3*

Table 3 Variables that were considered in the CPUE analysis of the trap fishery (T), the longline fishery (L), or both (B) fisheries.

Variable	Type	Fishery	Description
fishing master	Categorical	B	Unique fishing master identification number
vessel CFV	Categorical	L	Unique fishing vessel identification number
year	Categorical	B	Calendar year
month	Categorical	B	Month code
day of year	Discrete	B	Number of days since the start of the calendar year
minor area	Categorical	B	Minor statistical area
region	Categorical	B	Code for geographical region of B.C. coast
mean depth	Continuous	B	Average of depth (m) at start and end of fishing
duration	Continuous	B	Time (minutes) between start and end of fishing
halibut catch	Continuous	B	Recorded catch of halibut
Sebastes spp. catch	Continuous	B	Recorded catch of catch of Sebastes spp. plus Scorpionfish and Thorneyheads
skates plus sharks catch	Continuous	B	Recorded catch of all skate and shark spp.
latitude	Continuous	B	Latitude (decimal degrees) at start of tow
hook type	Categorical	L	Code for type of hook
hook spacing	Categorical	L	Code for hook spacing distance
gangion length	Continuous	L	Length of gangion
escape-ring size	Categorical	T	Code for escape-ring diameter

Table 4 Variables selected, by order of selection, for the sablefish trap fishery standardized CPUE model.

Order	Variable	Cumulative proportion of deviance explained (r^2)	Number of parameters
1	*year*region*	0.1879	39
2	*fishing master*	0.2476	57
3	*day of year*	0.2736	60
4	*minor area*	0.2784	67
5	*day of year:minor area*	0.3005	87

Table 5 Variables selected, by order of selection, for the sablefish longline hook fishery standardized CPUE model.

Order	Variable	Cumulative proportion of deviance explained (r^2)	Number of parameters
1	*ln(Hooks), year*region*	0.3398	35
2	*fishing master*	0.3794	52
3	*minor area*	0.3911	60
4	*day of year*	0.3985	63
5	*depth*	0.4072	66
6	*day of year:minor area*	0.4236	85
7	*depth:minor area*	0.4358	112

Table 6 Indexing survey model ANOVA tables by area.

Main effects normal-theory model for North

Term	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	11	74.70694	6.791540	26.77822	0.0000000
depthFact	4	19.55960	4.889900	19.28029	0.0000000
locality	4	0.34197	0.085493	0.33709	0.8528362
Residuals	263	66.70252	0.253622		

Residual standard error: 0.5036 on 263 degrees of freedom
Multiple R-Squared: 0.5865
F-statistic: 19.63 on 19 and 263 degrees of freedom, the p-value is 0

Main effects normal-theory model for South

Term	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	12	133.3917	11.11598	26.77197	0.00000000
depthFact	4	5.3228	1.33070	3.20490	0.01365891
locality	3	53.6675	17.88917	43.08468	0.00000000
Residuals	255	105.8784	41521		

Residual standard error: 0.6444 on 255 degrees of freedom
Multiple R-Squared: 0.645
F-statistic: 24.39 on 19 and 255 degrees of freedom, the p-value is 0

Main effects normal-theory model for Coast

Term	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	12	213.8199	17.81832	46.56903	0.00000000000
depthFact	4	10.7309	2.68272	7.01141	0.00001662582
locality	8	84.0695	10.50869	27.46495	0.00000000000
Residuals	533	203.9374	0.38262		

Residual standard error: 0.6186 on 533 degrees of freedom
Multiple R-Squared: 0.6021
F-statistic: 33.61 on 24 and 533 degrees of freedom, the p-value is 0

Table 7 Year index estimates for the survey model fits of north, south, and coastal areas.

Years	Model Coefficients	Std. Err.	Coef+Intercept (sqrt scale)	Coef+Intercept (numbers/trap)	Marginal Mean (sqrt scale)	Std. Err.
North						
1991	0.000	0.173	2.293	5.256	2.421	0.145
1992	-0.106	0.189	2.186	4.780	2.315	0.116
1993	0.337	0.187	2.630	6.915	2.758	0.113
1994	-0.583	0.187	1.709	2.922	1.838	0.109
1995	-0.861	0.180	1.431	2.049	1.559	0.098
1996	-0.761	0.180	1.532	2.347	1.660	0.096
1997	-1.100	0.187	1.193	1.423	1.321	0.110
1998	-0.589	0.181	1.704	2.903	1.832	0.099
1999	-1.118	0.180	1.174	1.379	1.303	0.096
2000	-1.069	0.179	1.224	1.498	1.352	0.096
2001	-1.782	0.181	0.511	0.261	0.639	0.099
2002	-0.818	0.167	1.475	2.175	1.603	0.069
South						
1990	0.000	0.192	2.051	4.206	2.701	0.131
1991	-0.159	0.200	1.891	3.577	2.542	0.142
1992	0.643	0.199	2.694	7.255	3.344	0.139
1993	0.867	0.192	2.917	8.511	3.568	0.129
1994	-0.148	0.202	1.903	3.621	2.554	0.143
1995	-0.252	0.199	1.799	3.236	2.450	0.139
1996	-0.775	0.199	1.276	1.628	1.927	0.139
1997	-0.935	0.200	1.116	1.245	1.767	0.139
1998	-0.784	0.202	1.266	1.604	1.917	0.143
1999	-0.923	0.199	1.128	1.273	1.779	0.139
2000	-0.486	0.200	1.565	2.449	2.216	0.140
2001	-1.364	0.199	0.686	0.471	1.337	0.139
2002	-1.211	0.180	0.840	0.705	1.490	0.111
Coast						
1990	0.000	0.172	2.059	4.241	2.462	0.131
1991	-0.034	0.173	2.026	4.104	2.428	0.109
1992	0.374	0.167	2.434	5.923	2.836	0.097
1993	0.714	0.164	2.773	7.690	3.175	0.092
1994	-0.267	0.167	1.792	3.211	2.194	0.096
1995	-0.479	0.164	1.581	2.498	1.983	0.090
1996	-0.649	0.163	1.411	1.990	1.813	0.089
1997	-0.930	0.167	1.129	1.275	1.532	0.095
1998	-0.572	0.165	1.488	2.213	1.890	0.091
1999	-0.916	0.163	1.143	1.307	1.545	0.089
2000	-0.691	0.164	1.369	1.873	1.771	0.089
2001	-1.486	0.164	0.574	0.329	0.976	0.090
2002	-0.870	0.153	1.189	1.415	1.592	0.067

Table 8 Catch rate (number/effective skate) for sablefish captured during the IPHC set line survey. Zeros is the proportion of stations with zero catch of sablefish.

Year	N	Min.	1st.Quart.	Median	Mean	3rd.Quart.	Max.	Zeros
1993	96	0.00	0.00	0.66	4.25	7.46	21.73	0.43
1995	110	0.00	0.00	0.20	4.78	8.56	25.55	0.46
1996	115	0.00	0.00	0.22	4.70	6.17	31.69	0.47
1997	117	0.00	0.00	0.00	4.11	7.41	29.64	0.53
1998	128	0.00	0.00	2.81	6.10	10.17	29.52	0.36
1999	131	0.00	0.00	1.21	4.73	8.02	29.70	0.37
2000	127	0.00	0.00	0.71	3.62	5.52	27.98	0.43
2001	132	0.00	0.00	0.00	3.86	4.27	34.18	0.55
2002	131	0.00	0.00	0.92	3.20	4.42	22.99	0.49
ALL	1087	0.00	0.00	0.67	4.36	6.39	34.18	0.45

Table 9 Sample statistics for sablefish catch rates (kg/hour) during the West Coast shrimp survey. The column "pZero" is the proportion of tows with no catch of sablefish.

			Area 124										Area 125					
Year	**n**	**Min**	**25th Per.**	**Median**	**Mean**	**75th Per.**	**Max**	**pZero**		**Year**	**n**	**Min**	**25th Per.**	**Median**	**Mean**	**75th Per**	**Max**	**pZero**
1973	57	0	0.0	0.0	1.1	0.5	14.0	0.68		1973	26	0	0.0	0.0	0.4	0.0	10.0	0.88
1975	64	0	0.0	0.5	1.6	0.5	18.0	0.47		1975	24	0	0.0	0.0	0.2	0.5	0.5	0.58
1976	70	0	0.0	0.0	0.1	0.0	4.0	0.91		1976	19	0	0.0	0.0	0.0	0.0	0.0	1.00
1977	62	0	0.0	0.0	1.7	0.0	46.0	0.81		1977	26	0	0.0	0.0	2.3	0.0	58.0	0.92
1978	85	0	0.5	4.0	14.8	16.0	144.0	0.20		1978	16	0	0.0	5.0	10.3	18.0	34.0	0.44
1979	52	0	1.6	7.0	9.5	12.0	54.0	0.23		1979	25	0	0.0	4.0	7.5	16.0	30.0	0.28
1980	59	0	0.0	0.0	1.3	2.0	18.0	0.61		1980	26	0	0.0	3.0	7.0	12.0	32.0	0.42
1981	58	0	0.5	2.0	3.8	4.3	30.0	0.24		1981	30	0	0.5	6.0	8.1	8.0	68.0	0.27
1982	57	0	0.0	0.0	0.7	0.5	4.0	0.65		1982	25	0	0.0	0.0	0.8	2.0	6.0	0.56
1983	51	0	0.0	0.0	1.7	0.5	20.0	0.71		1983	26	0	0.0	0.0	0.9	0.0	8.0	0.81
1985	59	0	0.0	0.0	0.1	0.0	2.0	0.81		1985	22	0	0.0	0.0	0.3	0.5	2.0	0.64
1987	55	0	0.0	2.0	5.2	5.0	36.0	0.36		1987	13	0	0.0	0.0	1.0	0.5	8.0	0.69
1988	71	0	0.0	0.0	2.4	2.0	53.3	0.58		1988	10	0	0.0	0.2	1.1	1.6	4.0	0.50
1990	72	0	0.0	0.0	1.6	2.0	10.0	0.54		1990	10	0	0.0	0.0	0.3	0.0	2.0	0.80
1991	87	0	0.0	0.0	3.7	2.0	38.0	0.69		1991								
1992	77	0	0.0	0.0	5.3	2.0	96.0	0.61		1992	6	0	0.0	0.0	0.3	0.0	2.0	0.83
1993	70	0	0.0	0.0	2.8	2.0	57.0	0.61		1993	33	0	0.0	0.0	1.1	2.0	6.0	0.61
1994	67	0	0.0	0.0	2.1	3.0	18.0	0.52		1994	30	0	0.0	0.0	1.6	2.0	10.3	0.63
1995	63	0	0.0	0.0	3.8	2.0	112.0	0.68		1995	25	0	0.0	0.0	0.4	0.0	6.0	0.84
1996	57	0	0.0	2.0	4.0	6.0	27.1	0.30		1996	17	0	0.0	0.0	0.9	2.0	4.0	0.65
1997	63	0	0.0	1.4	2.8	5.0	13.0	0.37		1997	21	0	0.0	0.0	1.7	3.2	10.6	0.62
1998	46	0	0.0	0.0	1.5	0.8	16.4	0.61		1998	22	0	0.0	0.0	0.6	0.0	6.8	0.77
1999	52	0	0.0	1.8	3.2	4.8	28.0	0.29		1999	31	0	0.0	0.0	0.6	0.5	6.4	0.71
2000	45	0	0.0	2.7	5.8	8.6	39.6	0.27		2000	30	0	0.0	0.5	3.3	2.6	28.0	0.50
2001	51	0	8.8	22.2	64.7	38.6	1781.6	0.04		2001	22	0	3.2	12.2	16.7	30.3	44.4	0.09
2002	51	0	8.6	23.0	91.5	56.1	1890.6	0.14		2002	26	0	16.4	29.0	36.0	51.3	139.4	0.08
All	1601	0	0.0	0.0	8.2	4.0	1890.6	0.51		All	561	0	0.0	0.0	4.5	2.0	139.4	0.59

Table 10 Summary of sablefish catch in the thornyhead survey by stratum for 2001 and 2002.

Region	Depth stratum	2001 Survey CPUE Mean	S.D.	N	2002 Survey CPUE Mean	S.D.	N	Stratum Area Total	Trawlable	Biomass Estimate 2001	2002
A	501-800	43.96	43.13	4	15.35	8.82	4	487	384	844.0	294.7
A	801-1200	14.45	5.99	4	5.04	2.74	4	702	637	460.4	160.4
A	1201-1600	3.77	4.10	2	0.55	0.78	2	577	577	108.7	15.9
B	501-800	34.06	25.93	4	12.08	2.75	4	330	233	396.8	140.7
B	801-1200	15.13	7.79	4	7.23	3.47	4	373	336	254.2	121.5
B	1201-1600	2.42	1.23	2	1.54	0.17	2	694	694	84.0	53.6
C	501-800	13.11	9.13	4	17.94	9.27	4	265	238	156.0	213.5
C	801-1200	9.65	3.34	4	4.42	2.85	4	380	380	183.4	84.0
C	1201-1600	1.27	0.13	2	0.15	0.21	2	462	462	29.4	3.5
D	501-800	37.86	30.49	4	9.66	5.11	4	274	154	291.5	74.4
D	801-1200	16.42	8.44	4	7.78	3.10	5	386	221	181.4	86.0
D	1201-1600	0.62	0.88	2	2.68	0.95	2	448	427	13.3	57.2
E+F	501-800	17.30	16.68	8	35.94	52.26	8	628	403	348.6	724.2
E+F	801-1200	11.65	6.33	8	16.58	11.33	8	895	657	382.7	544.6
E+F	1201-1600	2.30	0.14	2	0.51	1.01	4	830	775	89.1	19.6
G	501-800				39.79	23.05	2				
G	801-1200				20.69	5.32	2				
G	1201-1600				1.32	0.91	2				
Total				58			67	7731	6578	3823.3	2593.9
Rel. Error										0.13	0.16

Table 11 Comparison of sablefish sex ratio (proportion males) by survey, depth stratum and year.

Year	Depth stratum	Thornyhead survey No. sexed	Prop. male	Sablefish survey No. sexed	Prop. male
2001	<500			153	0.46
2001	501-800	1419	0.86	194	0.69
2002	501-800	848	0.82		
2001	801-1200	672	0.61	315	0.53
2002	801-1200	573	0.65		
2001	1201-1600	26	0.23	190	0.03
2002	1201-1600	14	0.07		

Table 12 Analysis of deviance table for tag reporting rate analysis.

Term	df	Deviance	df left	Deviance left	Deviance explained	F	p
Null	1	0	1004	1234	0%	0.0	0.00
year	12	769	991	465	62%	95.2	0.00
area	1	17	990	449	64%	30.0	0.00
vessel	28	86	962	363	71%	6.7	0.00
month	11	10	951	353	71%	2.1	0.02
year:area	12	12	939	341	72%	2.3	0.01
year:vessel	126	92	813	249	80%	2.2	0.00
area:vessel	21	18	792	231	81%	2.7	0.00
vessel:month	196	84	596	147	88%	1.8	0.00

Table 13 Vessel by year interaction coefficients (exponentiated) for the tag reporting rate model.

Vessel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1						0.94	1.51	4.42	1.70	1.19	0.92	1.09	0.74
2		0.96		2.01			4.03	2.73	1.84	1.76	0.62	0.95	
3				0.19	0.90	0.93	0.78	0.76	0.71	0.95	0.45	1.03	1.13
4			2.46	1.00	4.67								
5	0.78	0.87							0.96	2.04			
6			4.73										
7							5.14	2.73	1.91	1.06	0.77	0.85	0.59
8	1.01	1.12					3.56	0.56	0.90	1.27	0.60	1.02	0.47
9	0.78	0.89											
10			16.29	5.30	10.31	1.15	7.22	2.74	1.93	0.99	0.67	2.05	0.97
11			11.36										
12								0.98	0.37				
13		0.90		0.43	4.64	0.09							
14	1.14	1.12	13.05	3.87	4.51	1.17	4.13	3.03	2.24	1.39	0.60	1.65	0.45
15							1.68	1.01	0.64	0.55			
16							0.45						
17												0.99	0.72
18	1.02				0.28	0.49							
19	1.00	1.12	1.64	0.34	0.44	0.20	4.02	1.25		0.30	0.29	1.07	0.44
20			0.36										
21			5.31										
22												1.20	0.34
23			0.96	0.17	2.96	0.27	2.78	5.85	4.40	1.30	0.87		
24					2.84			4.55	1.27		0.38	0.72	0.30

Table 14 Average vessel effect and number of years that the vessel was in the fishery.

Vessel	Average effect	Number of years
1	1.56	8
2	1.86	8
3	0.78	10
4	2.71	3
5	1.16	4
6	4.73	1
7	1.86	7
8	1.17	9
9	0.83	2
10	4.51	11
11	11.36	1
12	0.67	2
13	1.51	4
14	2.95	13
15	0.97	4
16	0.45	1
17	0.86	2
18	0.60	3
19	1.01	12
20	0.36	1
21	5.31	1
22	0.77	2
23	2.17	9
24	1.68	6

Table 15 Estimated annual tag reporting rates.

Year	This analysis	1999 Analysis
1992	0.42	0.39
1993	0.40	0.37
1994	0.47	0.53
1995	0.70	0.76
1996	0.66	0.74
1997	0.54	
1998	0.53	
1999	0.74	
2000	0.63	
2001	0.73	
2002	0.92	

Table 16 Data and parameters for monthly tag-recovery model.

Symbol	Description
	Indices and Index Ranges
m	month index $(m = 1,\ldots,12)$
y	year index $(y = 1,\ldots,Y)$
Y	number of years of tag releases and recoveries
	Data
C_{ym}	total removals in year y and month m
D_{ym}	catch landed from all fisheries in year y and month m
O_{ym}	number of tags returned by the trap fishery in year y and month m that were released in year y-1
R_y	number of selected tags released in year y
	Fixed Parameters
c_y	ratio of the sorted catch to the landed catch in year y
l	loss rate of tags between tag application and start of the following year due to tag shedding, tag mortality, natural mortality, and fishing mortality
r_y	proportion of tags examined (reporting rate) that are returned in year t
s	monthly net survival, recruitment, and somatic growth rate
s_y	ratio of the number of fish sorted to the number of fish landed by the trap fishery in year y
u_t	proportion of tagged population examined for tags in trap fishery in year t
v	survival rate from natural mortality and emigration
w_y	ratio of the mean weight of fish in the vulnerable population to the mean weight of fish landed by the trap fishery in year y
s	coefficient of variation of the log-normal distribution in the likelihood
	Estimated Parameters
B_{y1}	biomass of fish alive at the start of month m=1 in year y
d_y	month effect, scaled so that October (m=10) has a value of 1
	Derived Parameters
B_{ym}	biomass of the population tagged in year y and the start of month m
P_{ym}	predicted number of tags recovered in year y and month m
T_{ym}	number of tagged fish alive in year y at the start of month m, released in year y-1
u_{ym}	fishing exploitation rate in year y and month m
$\tilde{u}_{ym}$	fishing exploitation rate from trap vessels in year y and month m

Table 17 Annual tag reporting rate estimates and corresponding sorting factors.

Year	Tag Return Rate	Sorting factor
1992	0.42	1.24
1993	0.40	1.30
1994	0.47	1.31
1995	0.70	1.32
1996	0.66	1.31
1997	0.54	1.33
1998	0.53	1.33
1999	0.74	1.00
2000	0.63	1.00
2001	0.73	1.00
2002	0.92	1.00

Table 18 Annual estimates of relative vulnerable biomass from monthly tagging model.

Year	Relative biomass
1992	34,073
1993	68,536
1994	39,766
1995	44,860
1996	34,792
1997	25,978
1998	19,388
1999	41,350
2000	20,893
2001	27,518
2002	19,354

Table 19 Description of model parameters, prior assumptions, and data for the simple biomass dynamics model.

Fundamental Model Parameters (estimated through minimization):

Parameter	Description	Prior
B_k	Vulnerable biomass in the first year, k, of the analysis	$\ln(B_k) \sim U[-\infty,\infty]$
$\overline{P}$	Average stock production over the reconstruction period, k to 2002	$\ln(\overline{P}) \sim U[-\infty,\infty]$
M	Instantaneous natural mortality rate	$M \sim U[0.06,0.1]$
q^1	Proportionality constant for the tagging-based abundance index	$q^1 \sim N[1, s^2_{q^1}]$
q^2, q^3	Proportionality constants for the survey-based and commercial fishery-based abundance indices	$q^2, q^3 \sim U[0,\infty]$
q_e	Proportionality constant for escape-ring effects on the commercial CPUE index	$q_e \sim U[0.5,1]$

Fixed model parameters:

Parameter	Description
$t^1 = 0.0$	Fraction of calendar year that occurs prior to tagging-based index observation
$t^2 = 0.792$	Fraction of calendar year that occurs prior to survey index observation
$t^1 = 0.5$	Fraction of calendar year that occurs prior to commercial fishery index observation
$start\_yr$	The first year in the model for which abundance index data are fitted
$s_{q^1} = 0.5$	Standard deviation of the tagging-based index proportionality constant. Note: alternate values examined in sensitivities
$s_I = 0.35$	Standard deviation of the random error in the abundance indices (0.35 values based on the among-index variance of annual estimates)

Model Parameters estimated as functions of fundamental parameters:

Parameter	Description
F_i	Instantaneous fishing mortality rate for year i. The F_i's are estimated using an iterative Newton-Raphson algorithm to solve the catch equations assuming the observed catch in year i, $(\tilde{C}_i)$, is measured without error
B_i	Vulnerable stock biomass in year i
$\hat{I}_i^j$	Predicted abundance index for index j in year i

Model data:

Data	Description
$\tilde{C}_i$	Observed catch (tonnes), in year i
$\tilde{I}_i^j$	Observed abundance index for index j in year i

Table 20 List of assumptions for the reference case and sensitivity cases examined with the simple biomass dynamics model.

Name	Start year	Tag Reporting Rate	s_{q^1}	Include 2001 survey in fit?	Productivity 2003-2008
Reference	1996	GLM	0.5	yes	$1\cdot\bar{P}$
B1994+	1994	GLM	0.5	yes	$1\cdot\bar{P}$
B1995+	1995	GLM	0.5	yes	$1\cdot\bar{P}$
B1997+	1997	GLM	0.5	yes	$1\cdot\bar{P}$
Qsd0.7	1996	GLM	0.7	yes	$1\cdot\bar{P}$
Qsd0.3	1996	GLM	0.3	yes	$1\cdot\bar{P}$
AltRepRate	1996	fixed, 1995-2002	0.5	yes	$1\cdot\bar{P}$
Surv2001	1996	GLM	0.5	no	$1\cdot\bar{P}$
P*1.25	1996	GLM	0.5	yes	$1.25\cdot\bar{P}$
P*1.50	1996	GLM	0.5	yes	$1.5\cdot\bar{P}$

Table 21 Decision table showing the expected outcome of the performance indicators, $P\left(B_{2008} > B_{2003}\right)$ and $E\left(B_{2008} / B_{2003}\right)$ at 2003 to 2008 catch levels from 0 to 3500 mt for three levels of future stock production.

		Biomass in 2003			
		Poor	Medium	Good	Exp.
	Mean B_{2003}	11.9	18.2	36.4	21.2
Productivity Assumption	2003–2008 Annual catch	$P\left(B_{2008} > B_{2003}\right)$			
$1\times\bar{P}$	0	0.99	0.96	0.71	0.91
$1\times\bar{P}$	2000	0.89	0.74	0.43	0.70
$1\times\bar{P}$	2500	0.72	0.56	0.31	0.54
$1\times\bar{P}$	3000	0.36	0.32	0.19	0.30
$1\times\bar{P}$	3500	0.05	0.09	0.07	0.07
$1.25\times\bar{P}$	0	0.99	0.97	0.76	0.92
$1.25\times\bar{P}$	2000	0.95	0.89	0.59	0.83
$1.25\times\bar{P}$	2500	0.92	0.83	0.52	0.78
$1.25\times\bar{P}$	3000	0.84	0.72	0.45	0.68
$1.25\times\bar{P}$	3500	0.66	0.56	0.35	0.53
$1.5\times\bar{P}$	0	0.99	0.98	0.78	0.93
$1.5\times\bar{P}$	2000	0.97	0.94	0.66	0.88
$1.5\times\bar{P}$	2500	0.95	0.90	0.63	0.85
$1.5\times\bar{P}$	3000	0.93	0.86	0.59	0.81
$1.5\times\bar{P}$	3500	0.89	0.79	0.52	0.75
Productivity Assumption	2003–2008 Annual catch:	$E\left(B_{2008} / B_{2003}\right)$			
$1\times\bar{P}$	0	1.95	1.57	1.16	1.56
$1\times\bar{P}$	2000	1.25	1.11	0.90	1.09
$1\times\bar{P}$	2500	1.07	0.99	0.84	0.97
$1\times\bar{P}$	3000	0.90	0.88	0.78	0.86
$1\times\bar{P}$	3500	0.73	0.76	0.71	0.74
$1.25\times\bar{P}$	0	2.27	1.79	1.28	1.78
$1.25\times\bar{P}$	2000	1.57	1.33	1.03	1.31
$1.25\times\bar{P}$	2500	1.39	1.21	0.96	1.20
$1.25\times\bar{P}$	3000	1.22	1.10	0.90	1.08
$1.25\times\bar{P}$	3500	1.05	0.99	0.83	0.96
$1.5\times\bar{P}$	0	2.59	2.02	1.40	2.01
$1.5\times\bar{P}$	2000	1.89	1.55	1.15	1.54
$1.5\times\bar{P}$	2500	1.71	1.44	1.08	1.42
$1.5\times\bar{P}$	3000	1.54	1.32	1.02	1.30
$1.5\times\bar{P}$	3500	1.37	1.21	0.96	1.18

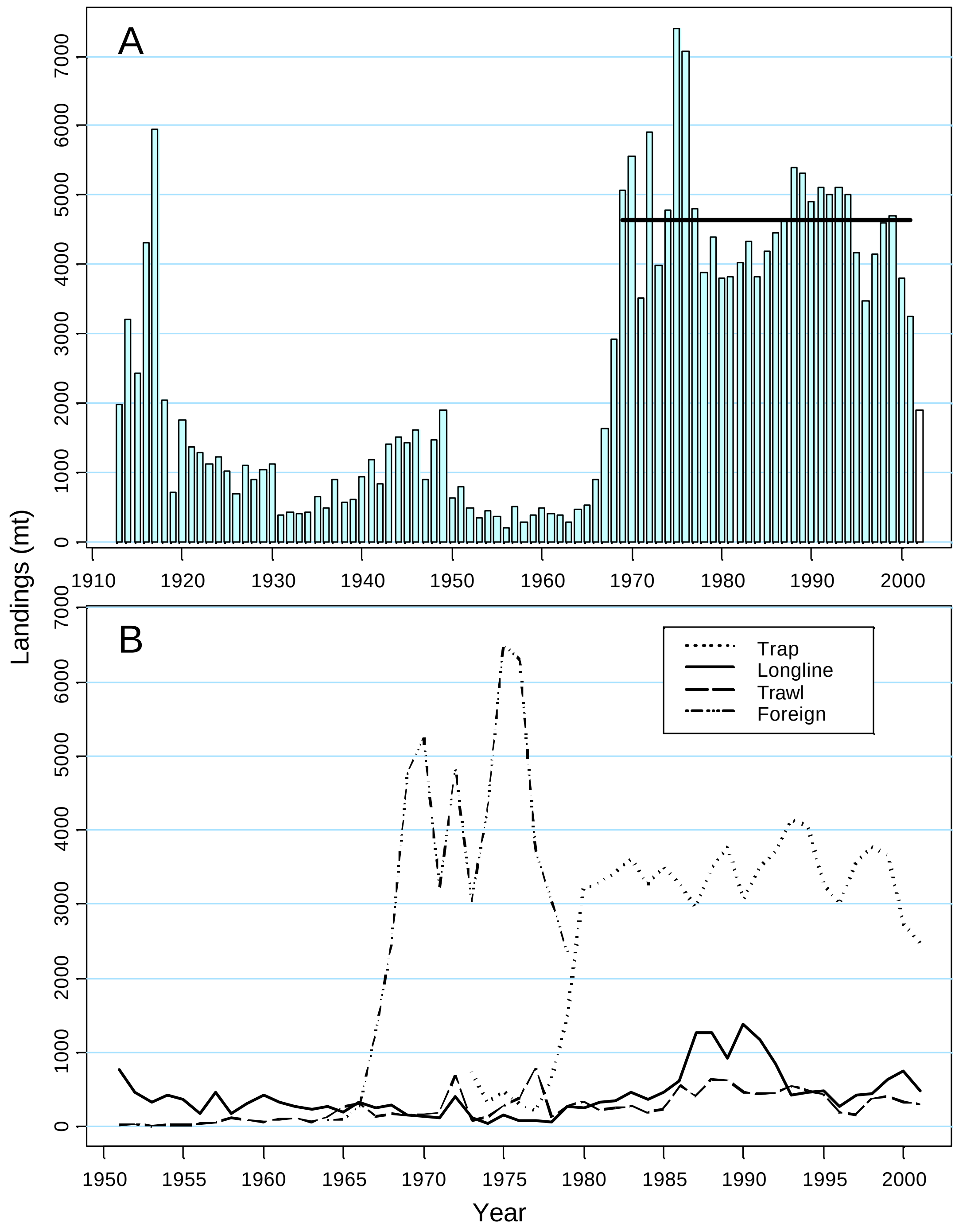


Figure 1 Annual sablefish landings (mt) from all sources 1913 to 2001 (Panel A). The thick line segment is the mean of landings from 1969 to 2001. Panel B shows annual landings by gear type for the period 1951 to 2001.

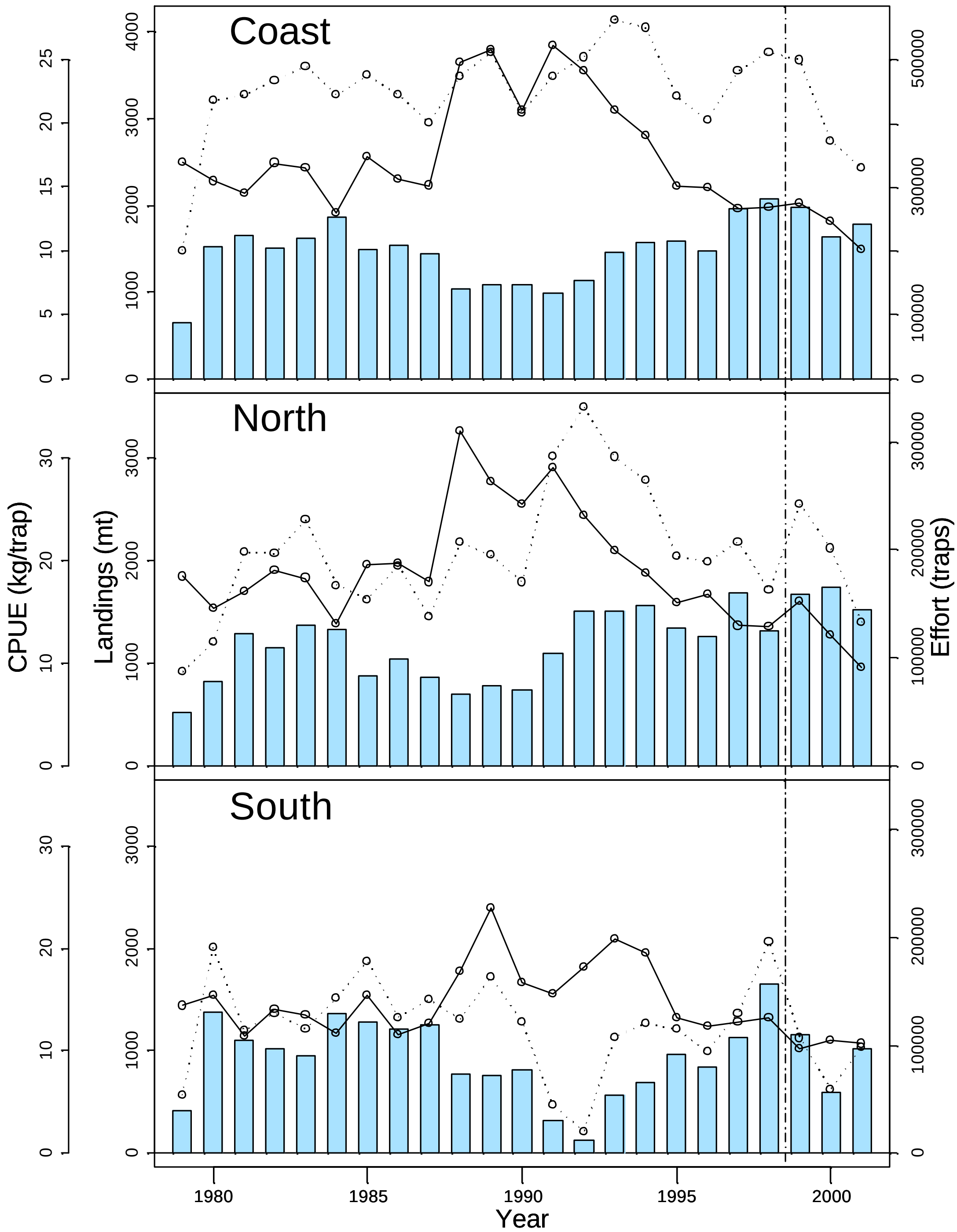


Figure 2 Annual trap fishery landings (mt, dotted line), CPUE (kg/trap, solid line), and estimated effort (traps, vertical bars) by coast-wide, north, and south stock areas. The vertical dot-dash line indicates the inception of mandatory escape rings on trap gear.

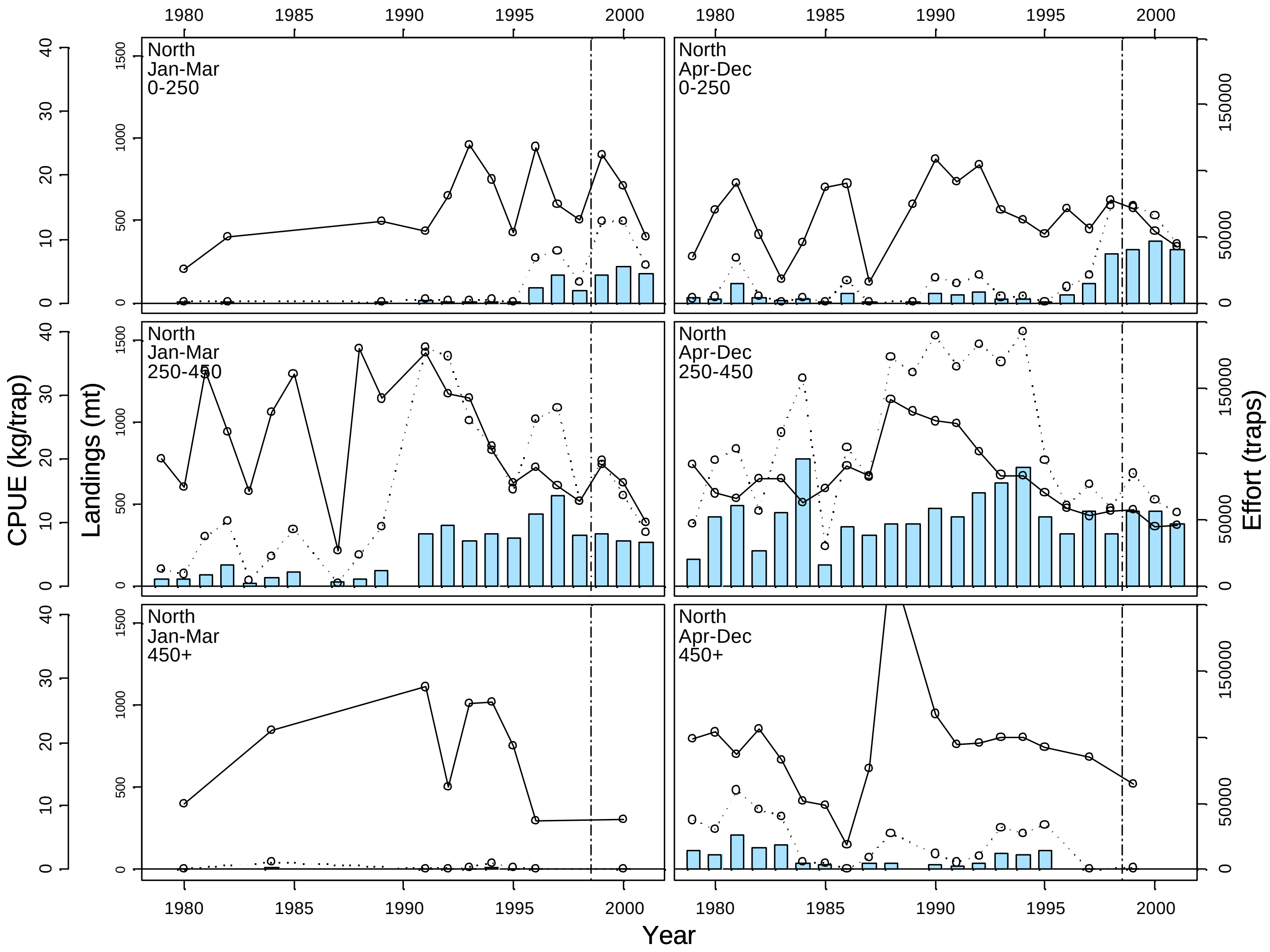


Figure 3 Annual trap fishery landings (mt, dotted line), CPUE (kg/trap, solid line), and estimated effort (traps, vertical bars) by area, season, and depth stratum (fm).

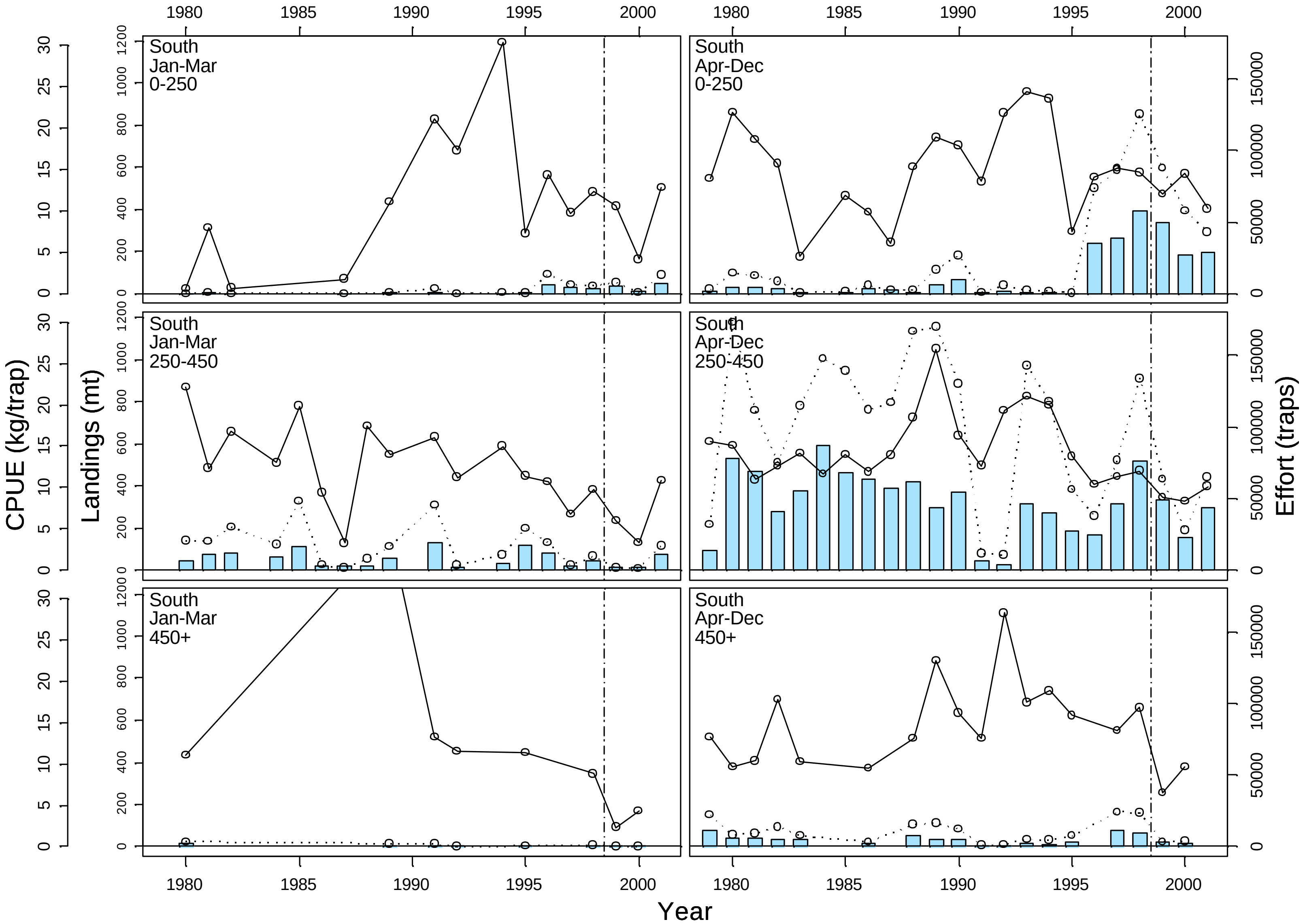


Figure 3 Continued

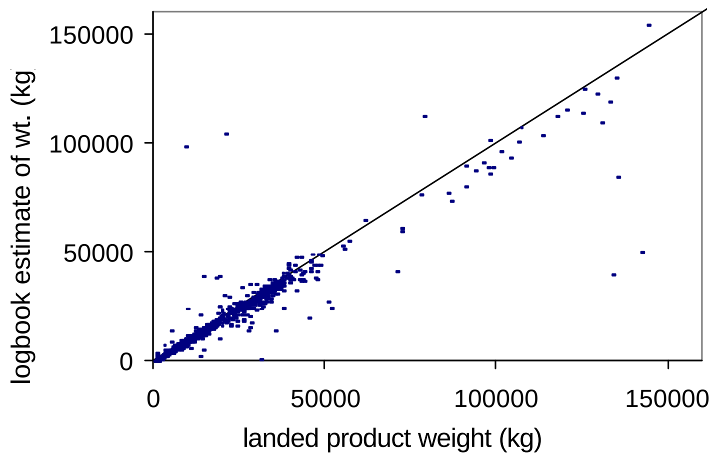


Figure 4 Comparison of validation estimates of landed sablefish product weight (kg) versus logbook estimates of retained sablefish catch (kg) for fishing trips conducted between 1995 and 2002. The line shows the 1:1 relationship.

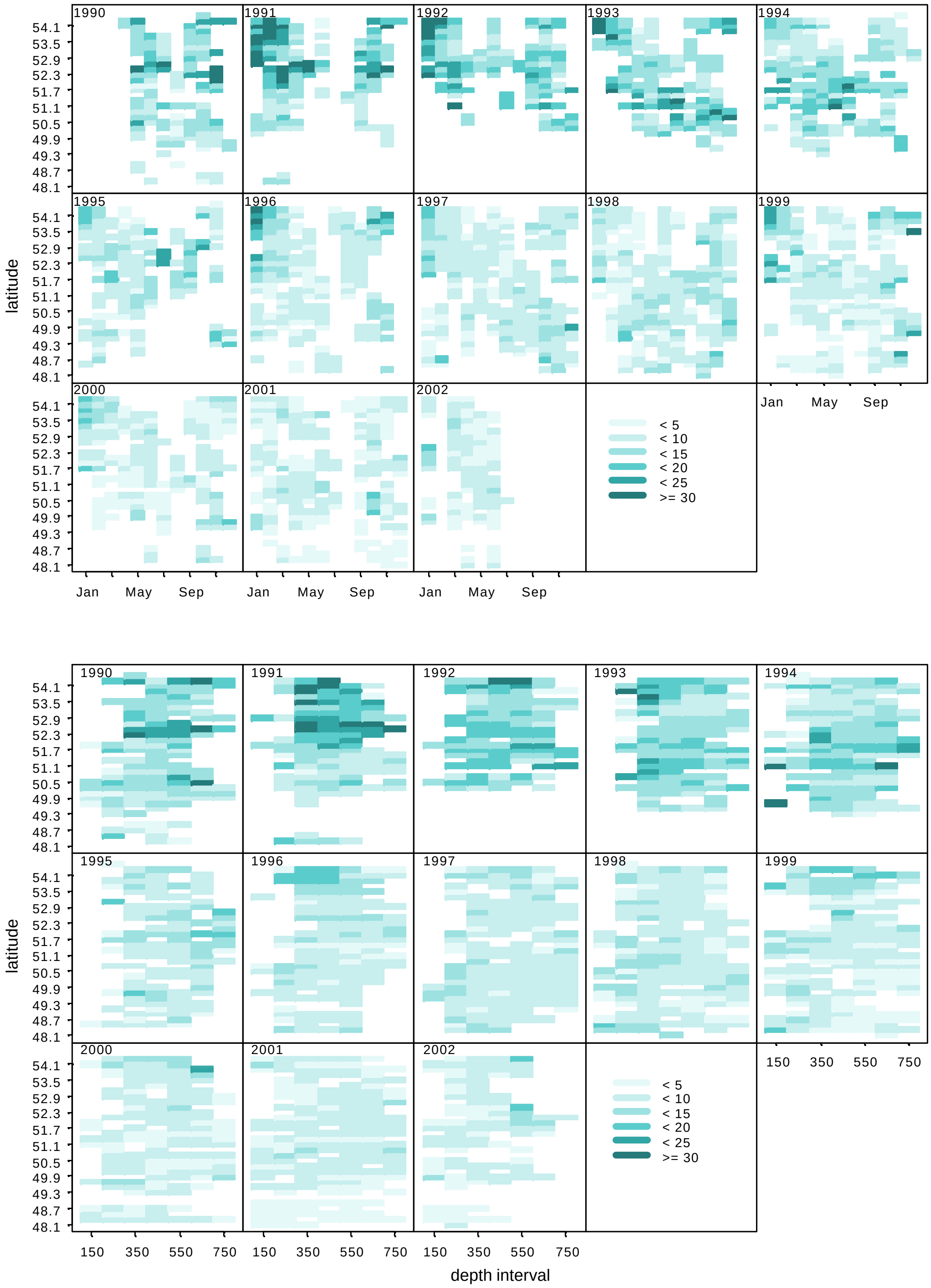


Figure 5 Sablefish CPUE (kg/trap) by latitude and month (upper panel) and by latitude and depth (m) (lower panel) for the trap fishery, 1990 to 2002. The colour intensity reflects the CPUE for the grid block with stronger intensity indicating higher catch rates.

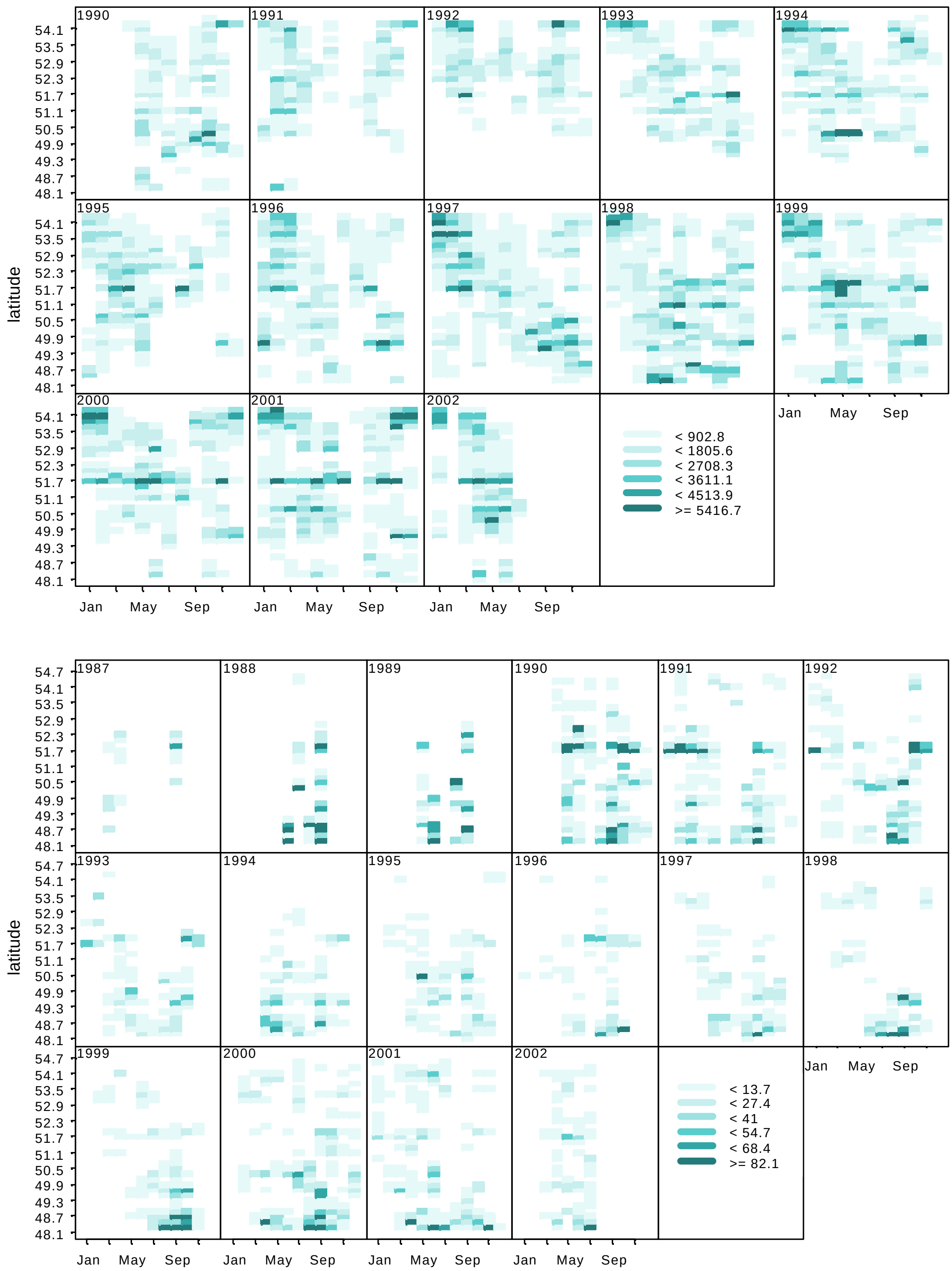
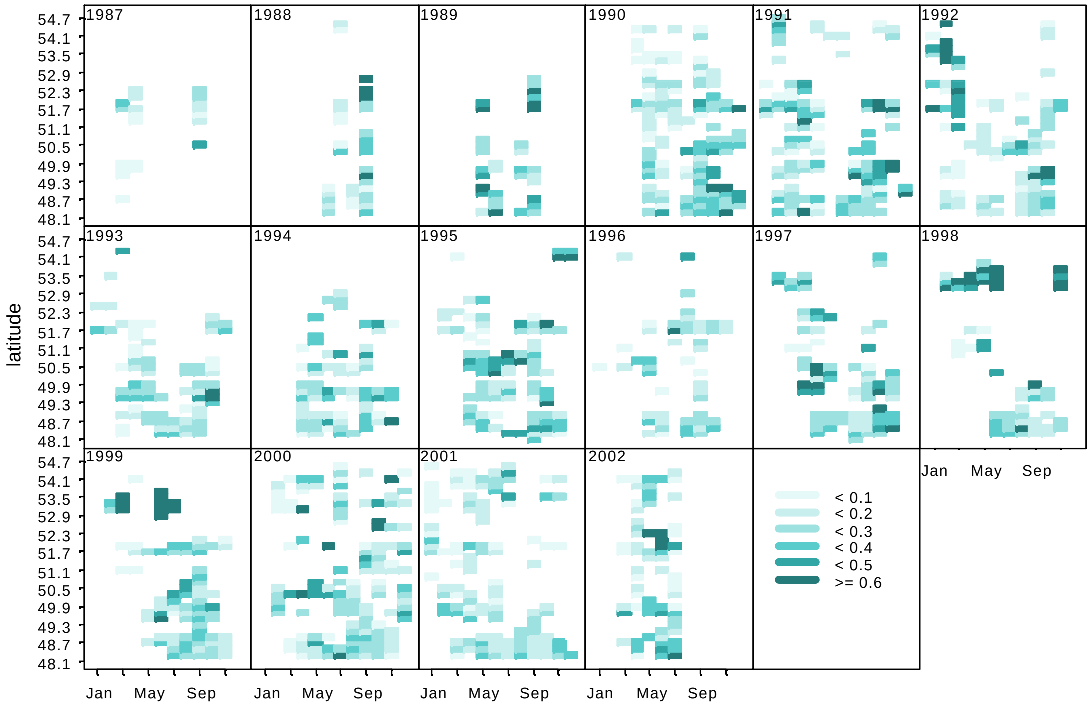


Figure 6 Sablefish fishing effort (traps fished) by latitude and month for the trap fishery, 1990 to 2002 (upper panel) and for the longline fishery (lower panel), 1987 to 2002. The colour intensity reflects the effort for the grid block with stronger intensity indicating higher catch rates.



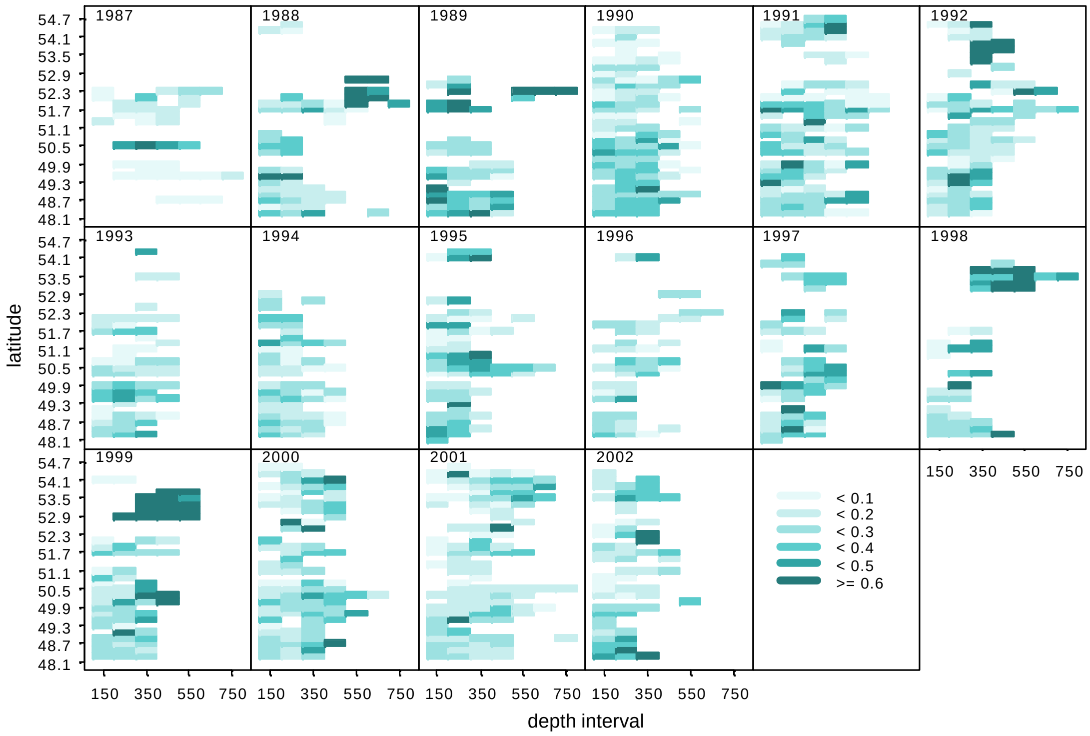


Figure 7 Sablefish CPUE (kg/hook) by latitude and month (upper panel) and by latitude and depth (lower panel) for the longline fishery, 1987 to 2002. The colour intensity reflects the CPUE for the grid block with stronger intensity indicating higher catch rates.

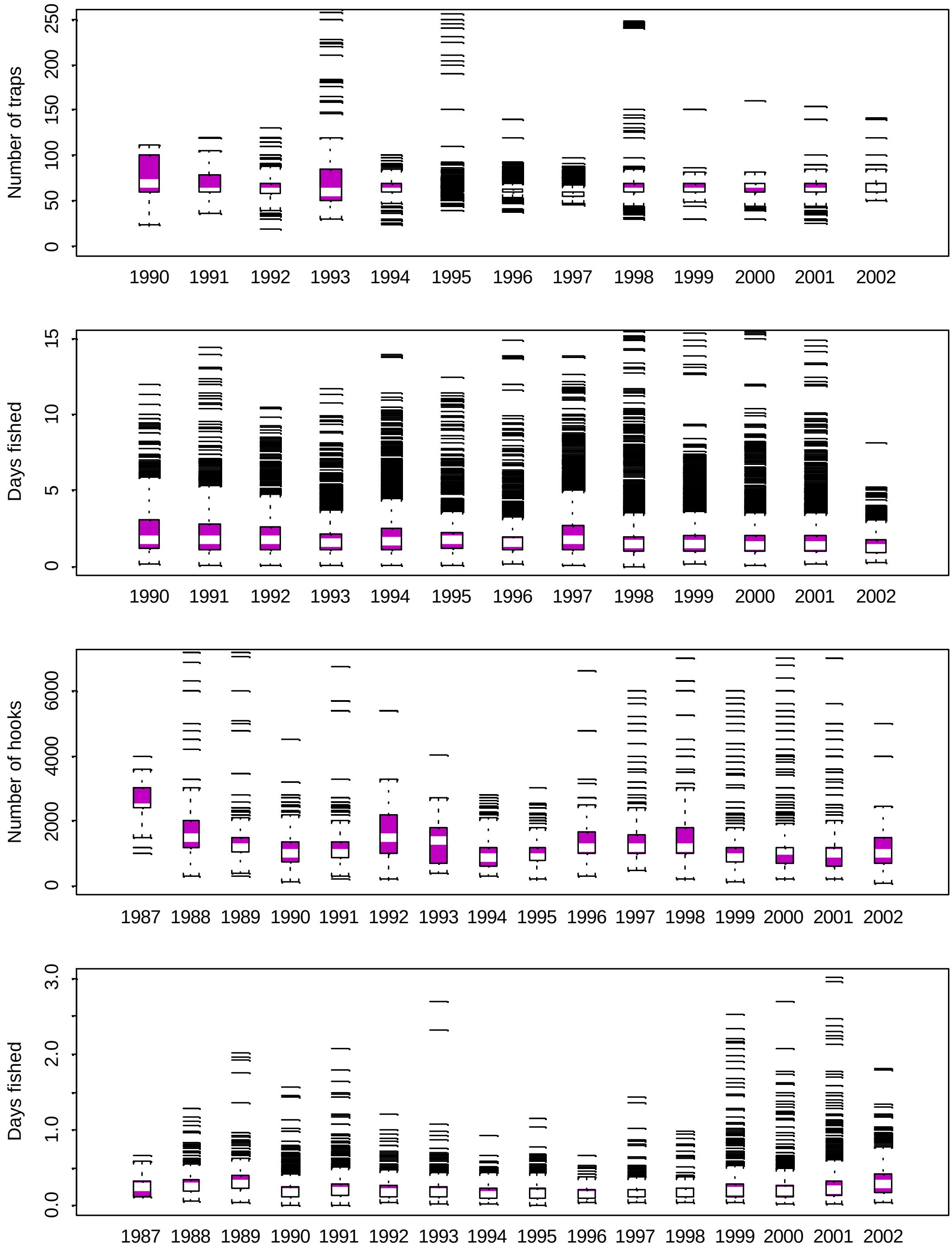


Figure 8 Boxplot distributions of the number of traps fished per set and duration (days) of sets (trap fishery, upper two panels), and the number of hooks per string and average duration of sets (longline fishery, lower two panels), by year. Note that the y-axes do not encompass the full range of the observations.

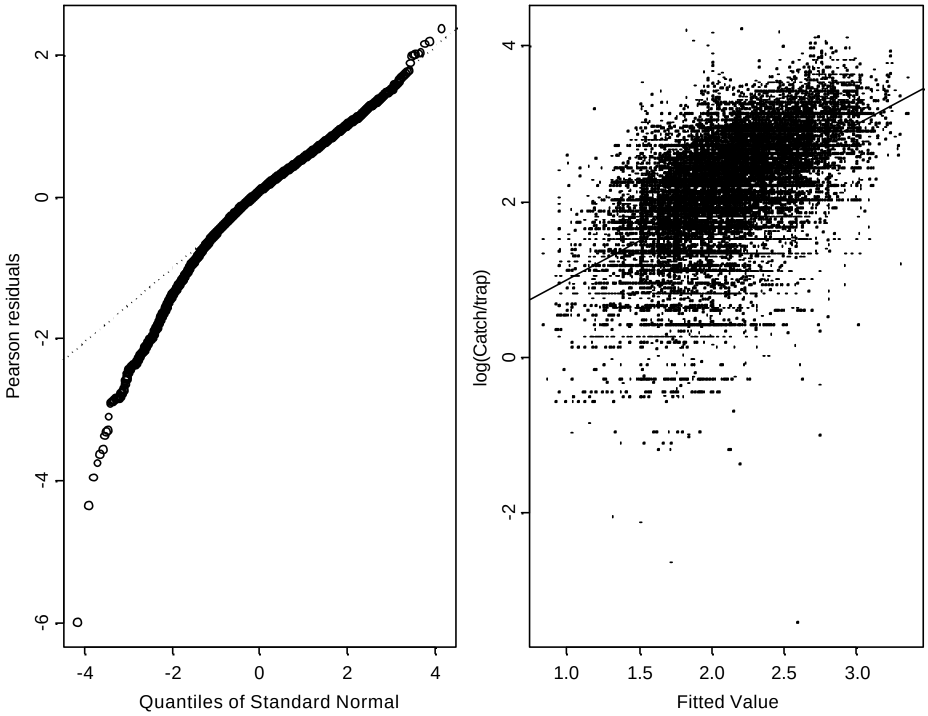


Figure 9 Quantile-normal plot of residuals and observed versus fitted values for the trap fishery CPUE model.

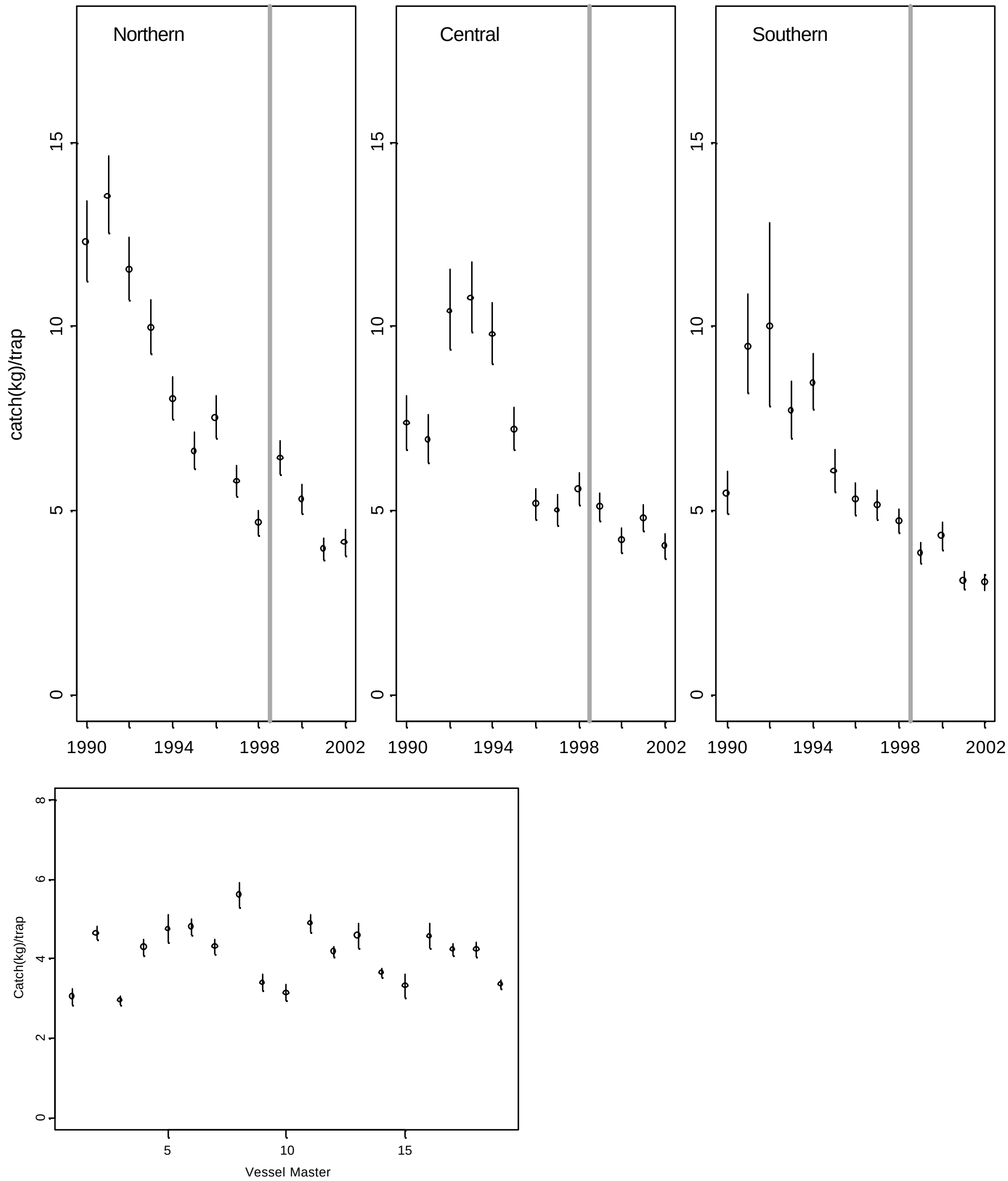


Figure 10 Estimated *year* and *region* effects (vertical lines indicate plus/minus two standard errors) for the trap fishery CPUE model (upper panel). The aspect ratio has been set to expose relative differences among the *year* effects. Estimated *vessel master* effects are shown in the lower panel.

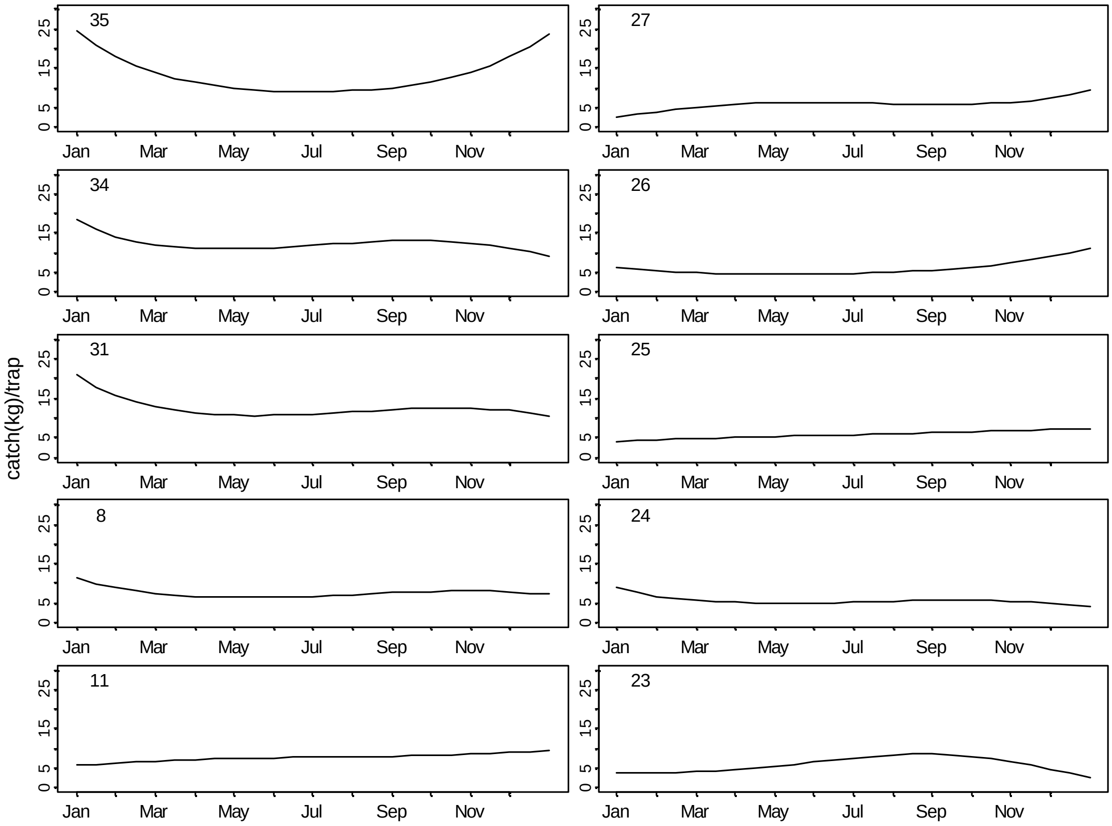


Figure 11 Estimated *day of year* effects by *minor area* from the trap fishery CPUE analysis.

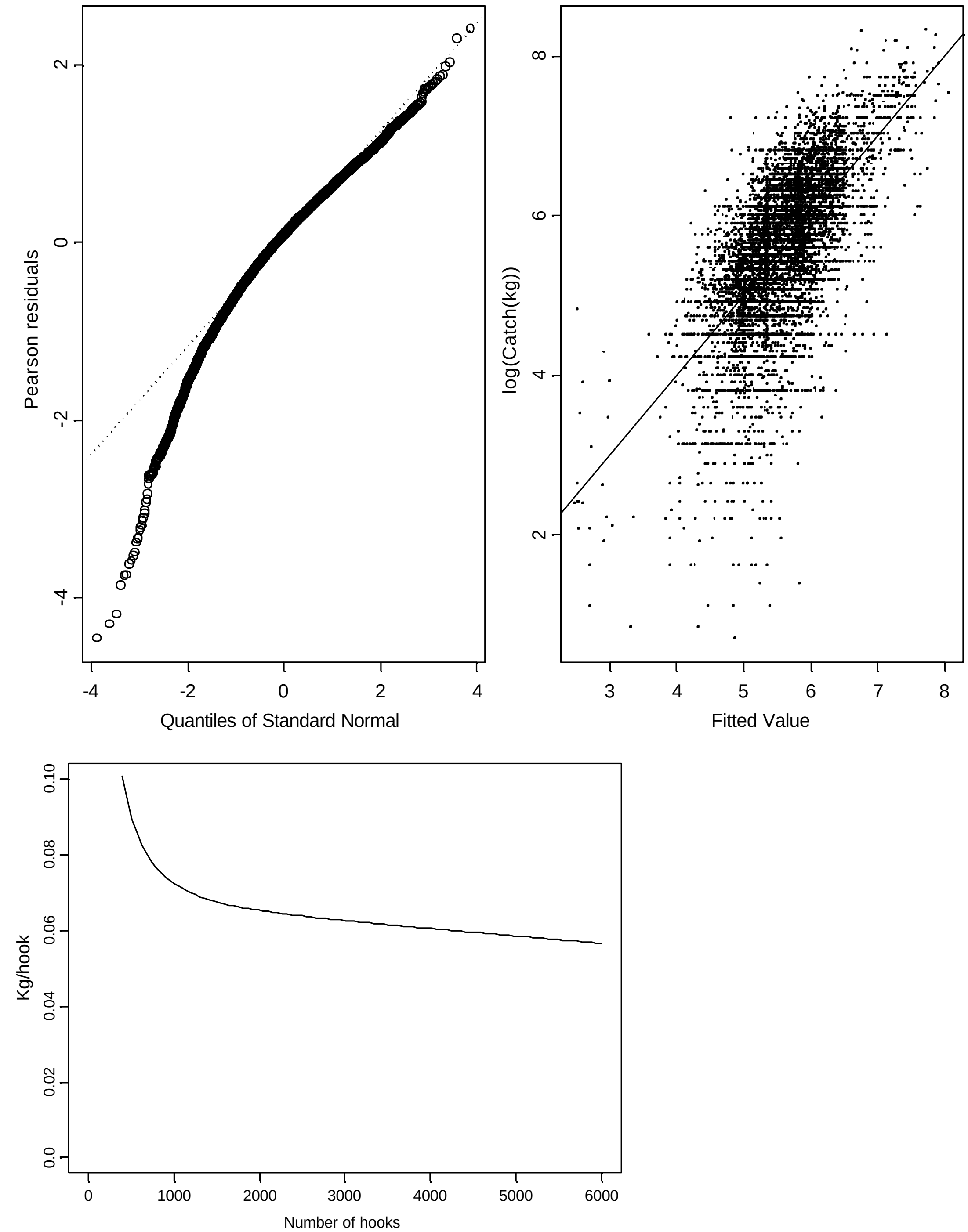


Figure 12 Quantile-normal plot of residuals and observed versus fitted values for the longline fishery CPUE model (upper panel). The estimated relationship between catch rate (kg/hook) and the number of hooks set is shown in the lower panels.

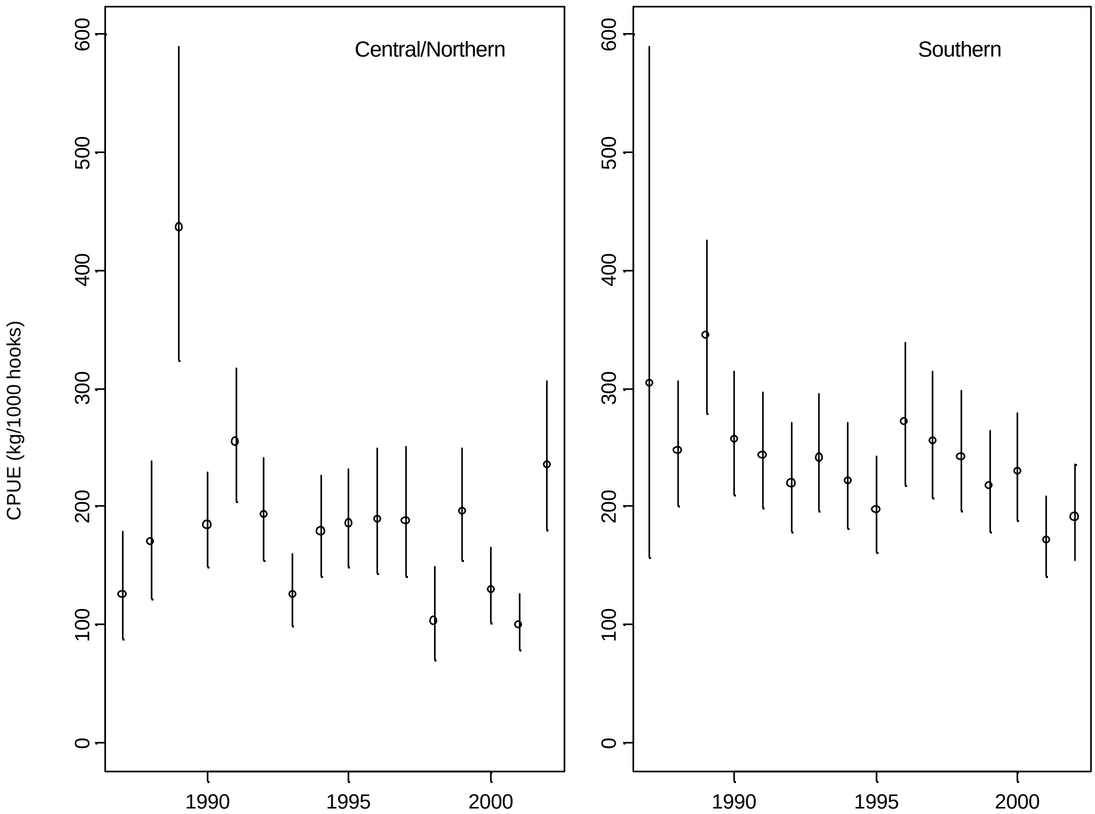


Figure 13 Estimated *year* and *region* effects (vertical lines indicate plus/minus two standard errors) for the longline fishery CPUE model, 1987 to 2002.

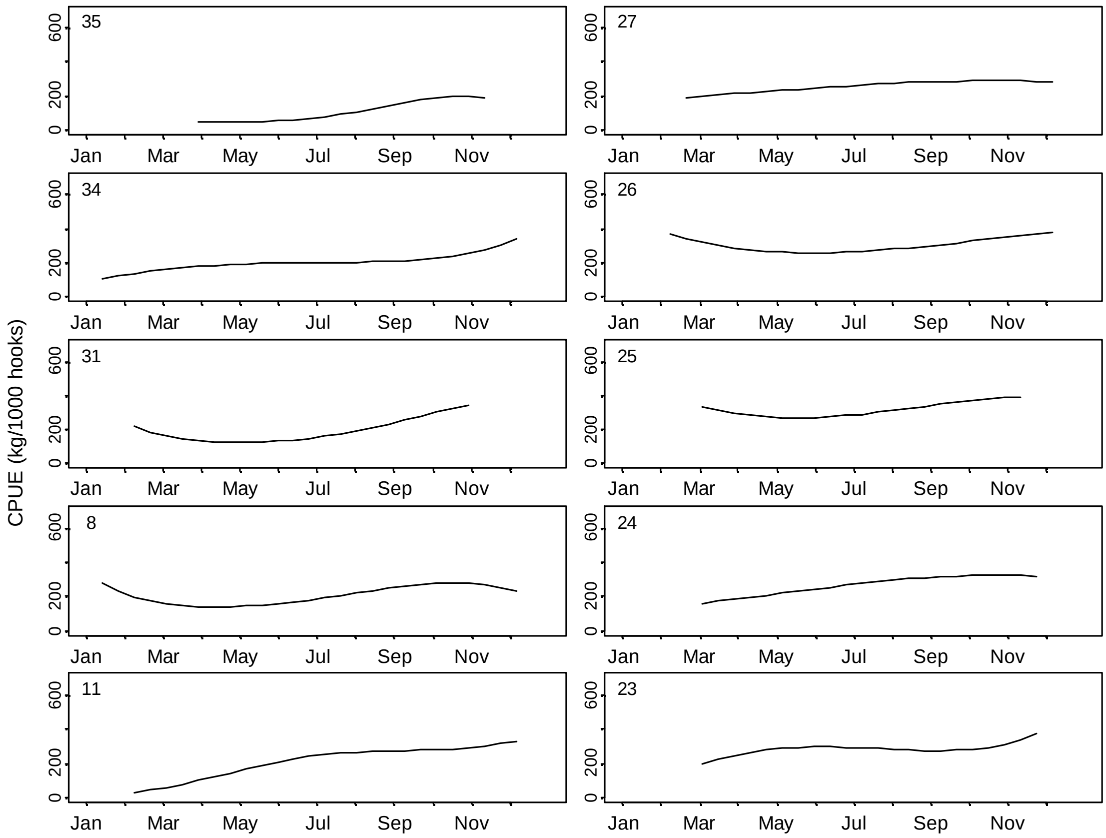


Figure 14 Estimated *day of year* effects by *minor area* from the longline hook fishery CPUE analysis. Note that the *day of the year* effects are only shown over the time interval for which there are data observations.

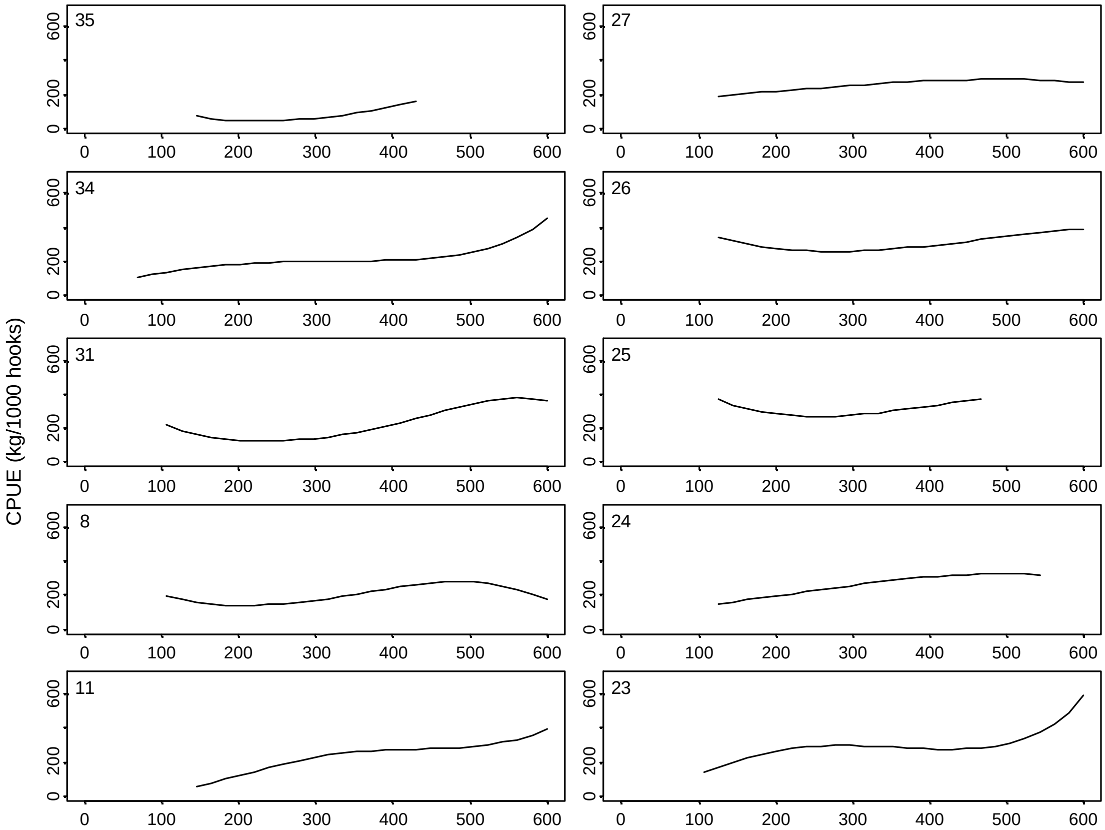


Figure 15 Estimated depth effects by minor area from the longline fishery CPUE analysis. Note that the depth effects are only shown over the time interval for which there are data observations.

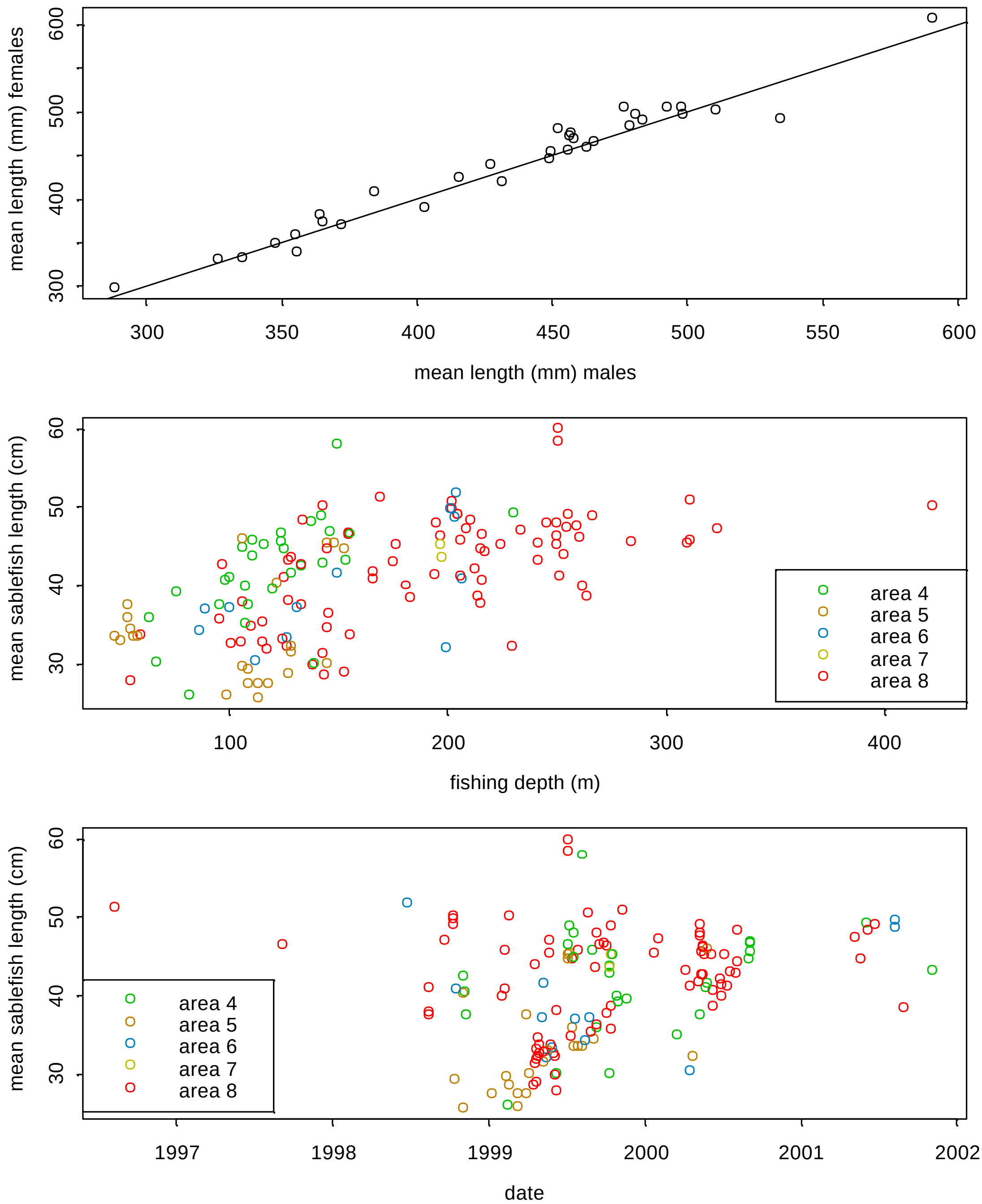


Figure 16 Comparison of the mean length (mm) of male and female sablefish by trawl tow (upper panel); mean sablefish length (cm) versus fishing depth (m) (middle panel); and mean sablefish length (cm) by fishing date (lower panel). In the lower two panels the colour of the circles indicate the Minor Area where the tows were conducted.

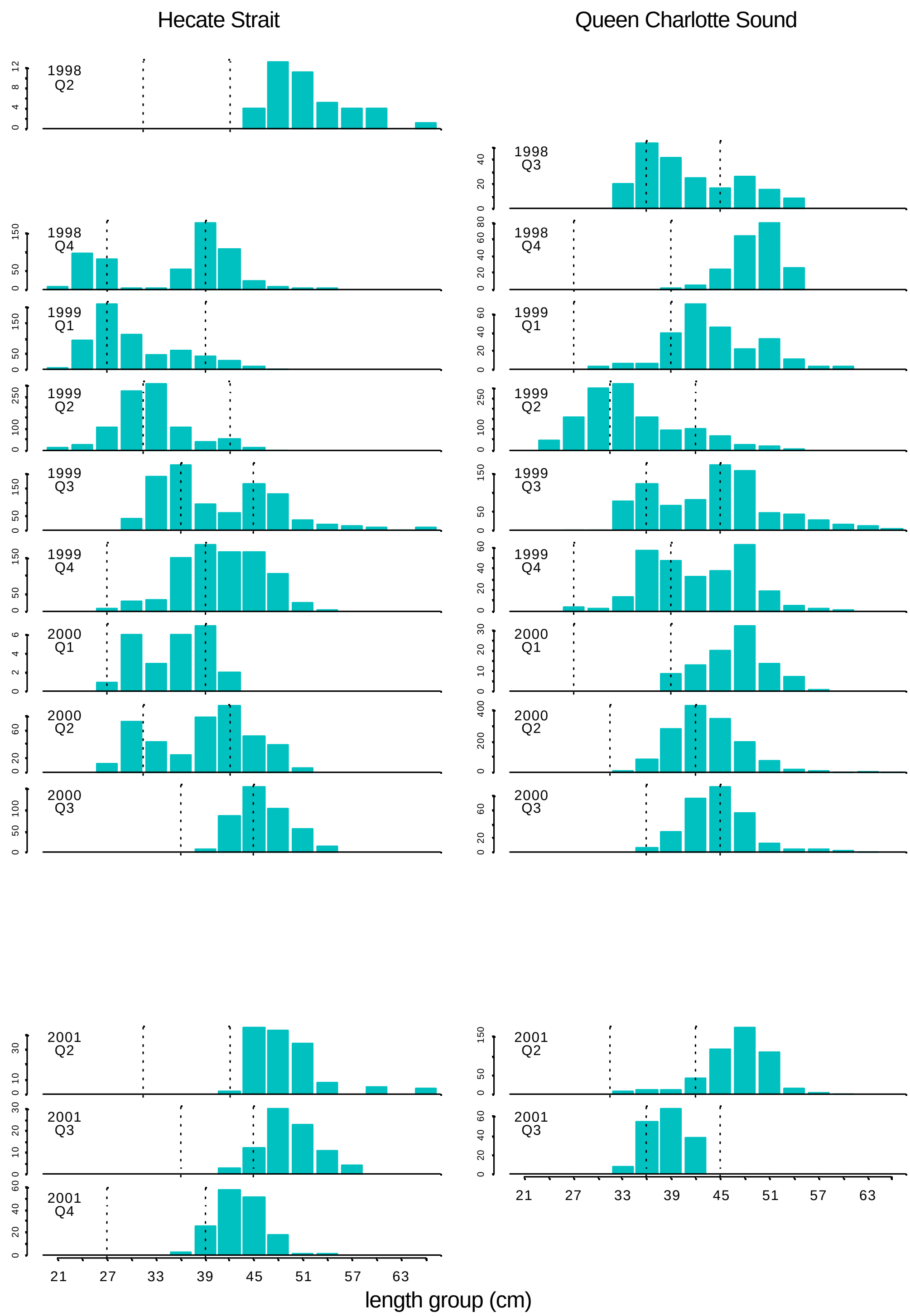


Figure 17 Length frequency distribution of sablefish sampled from observed trawl tows in Hecate Strait and Queen Charlotte Sound by year and quarter, 1998–2001. The horizontal lines are drawn to show modal progression, beginning with the smaller mode in the 1998 Q2 samples through to the 2002 Q3 samples.

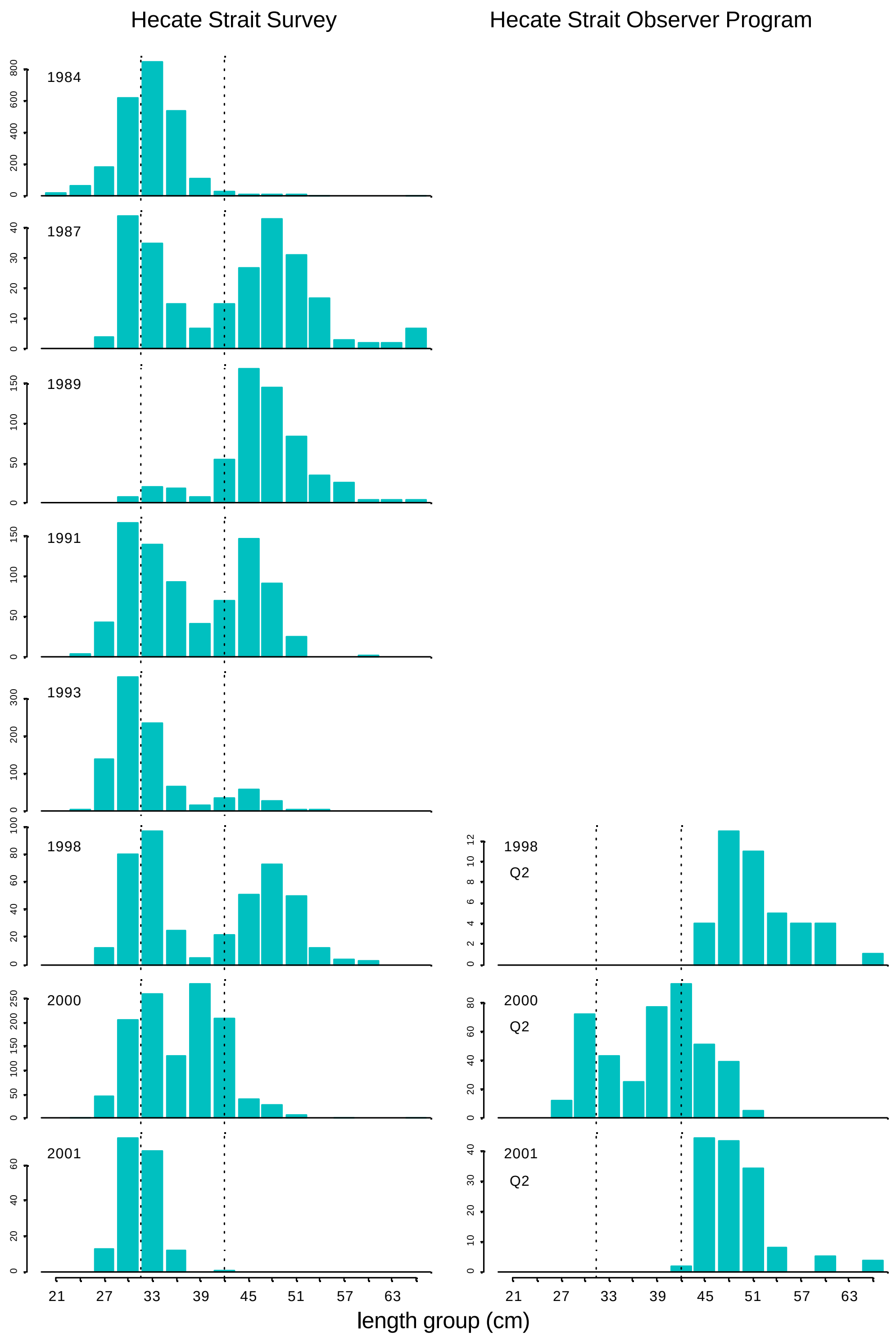


Figure 18 Comparison of length frequencies from Hecate Strait Survey Program and Hecate Strait Observer Program taken at similar times of the year. The horizontal lines are drawn at the same locations as those in the previous figure.

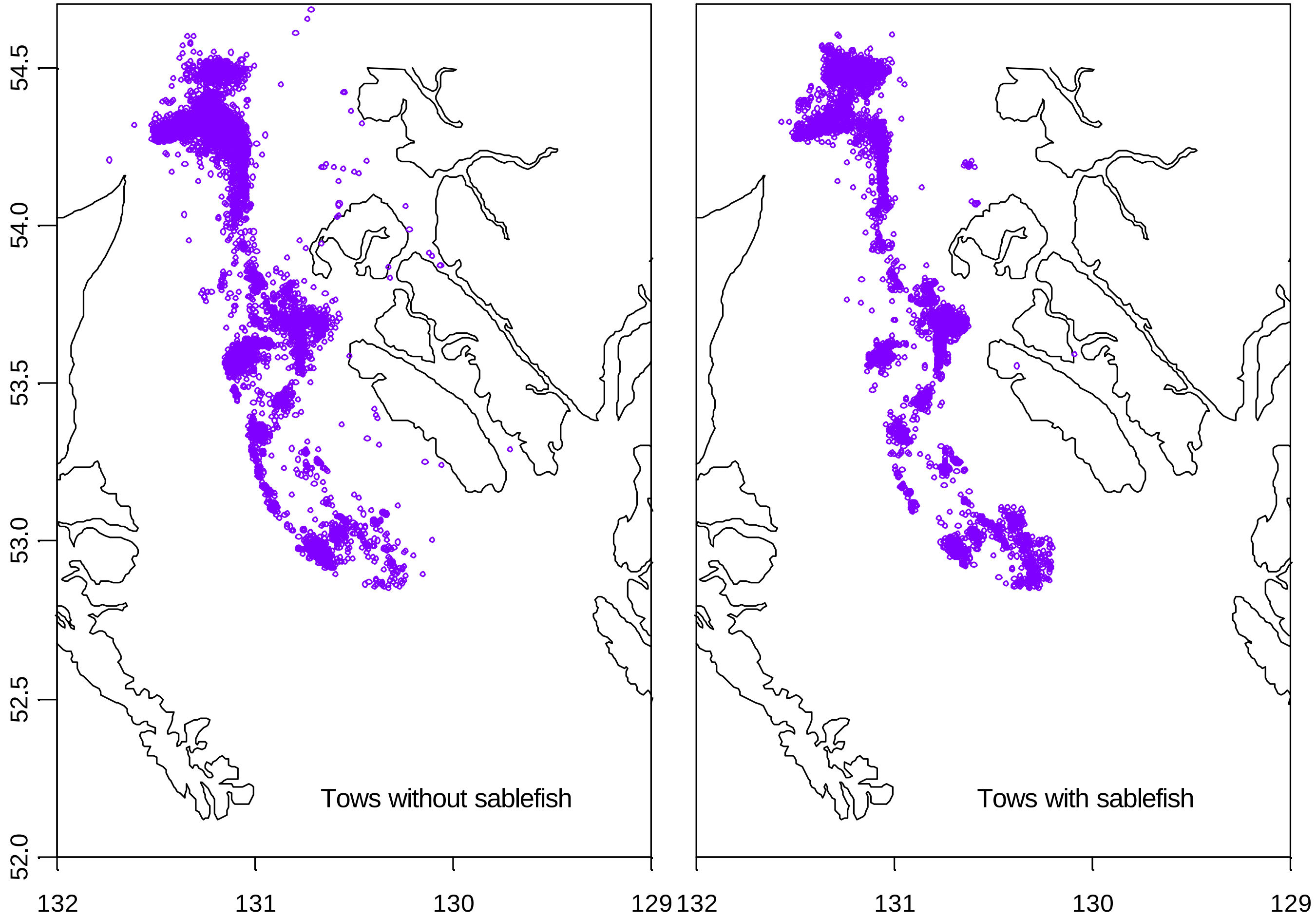


Figure 19 Distribution of observed Hecate Strait tows that did not catch sablefish (left panel) and observed tows that caught sablefish (right panel).

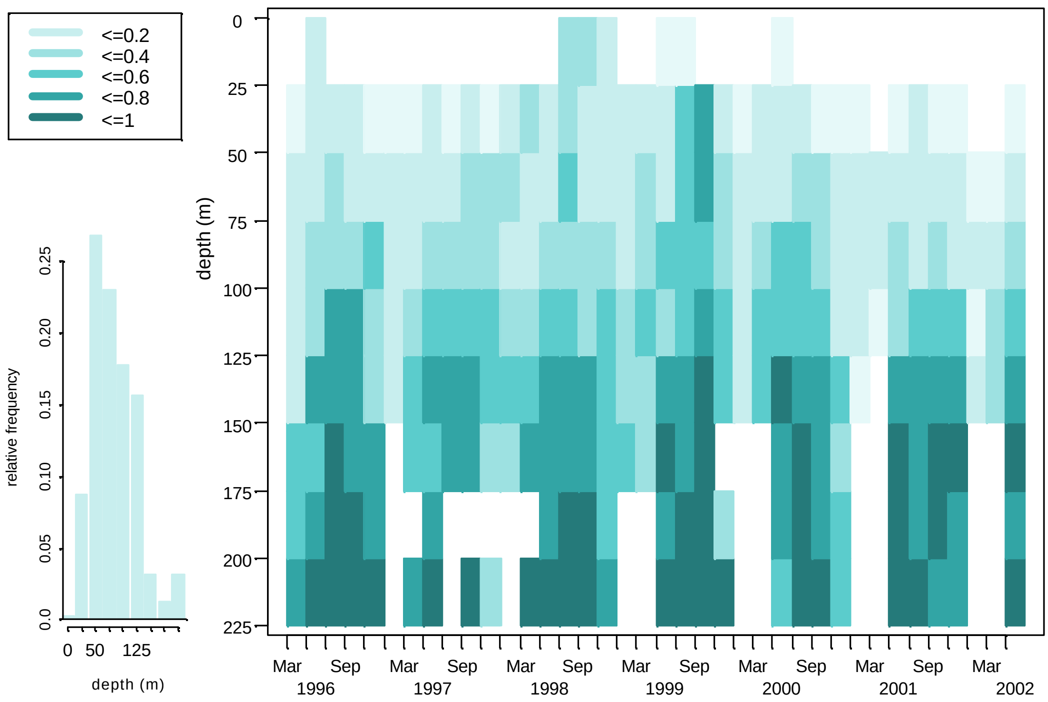


Figure 20 The proportion of fishing effort (hours towed) that resulted in positive sablefish catches, by period (2 month intervals), year and depth interval. The small figure on the left shows the distribution of fishing effort by depth interval for the observed tows.

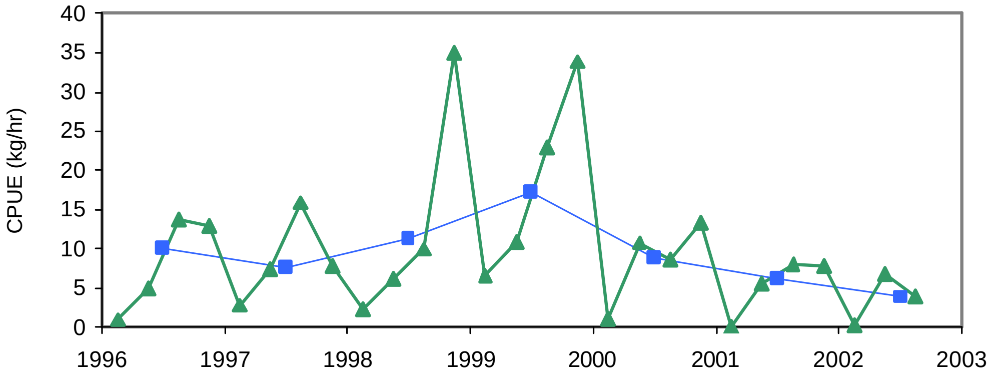


Figure 21 Hecate Strait trawl fishery CPUE (kg/hr), calculated on an annual and on a quarterly basis, 1996-2002

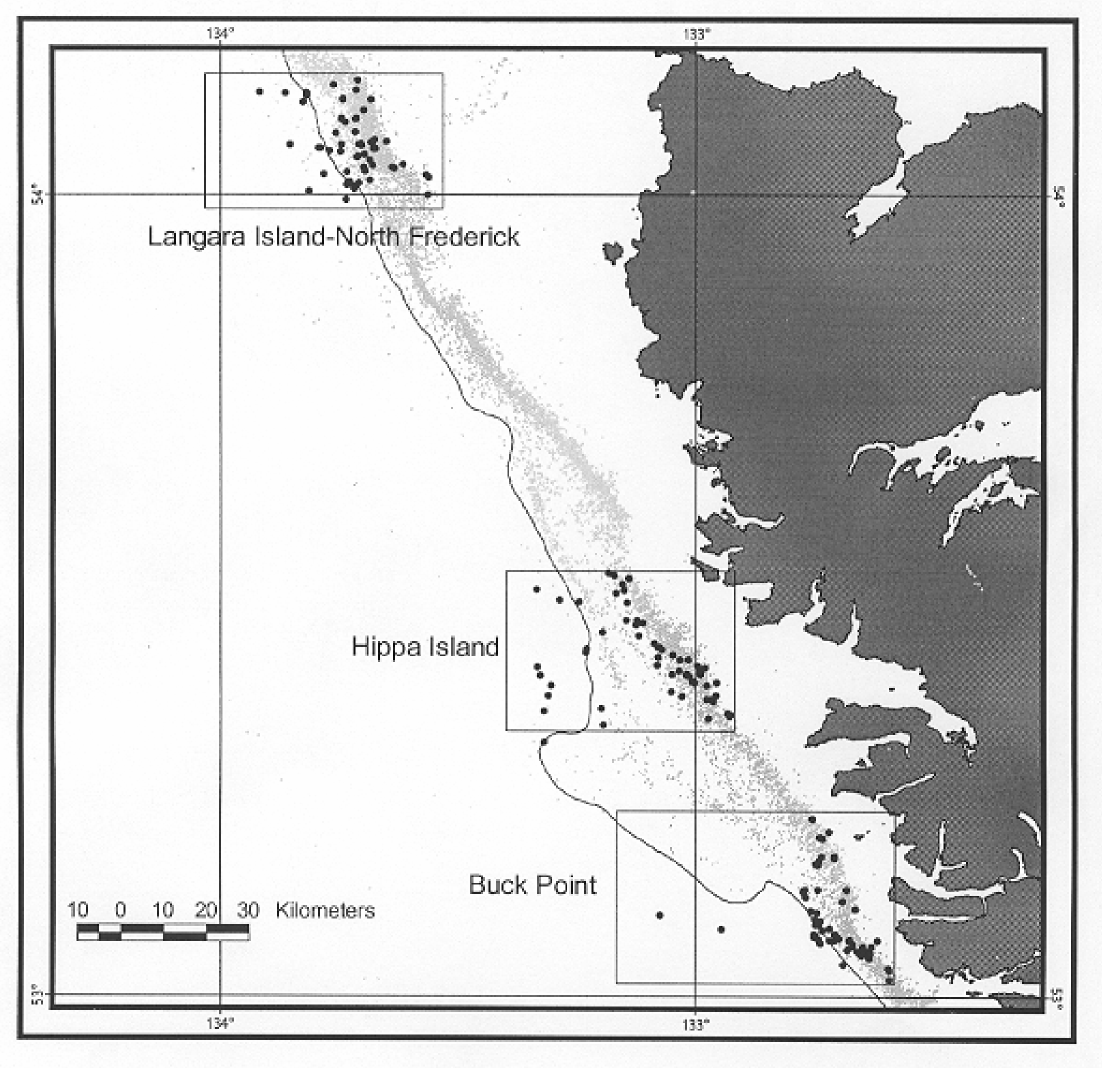


Figure 22 Sablefish indexing localities at Langara-Frederick Island, Hippa Island, and Buck Point. The rectangles indicate the locality boundaries. Large filled circles indicate the start position of each index set. Small grey circles indicate the start position of commercial sets. The 1000 m depth contour is shown as a curved solid line.

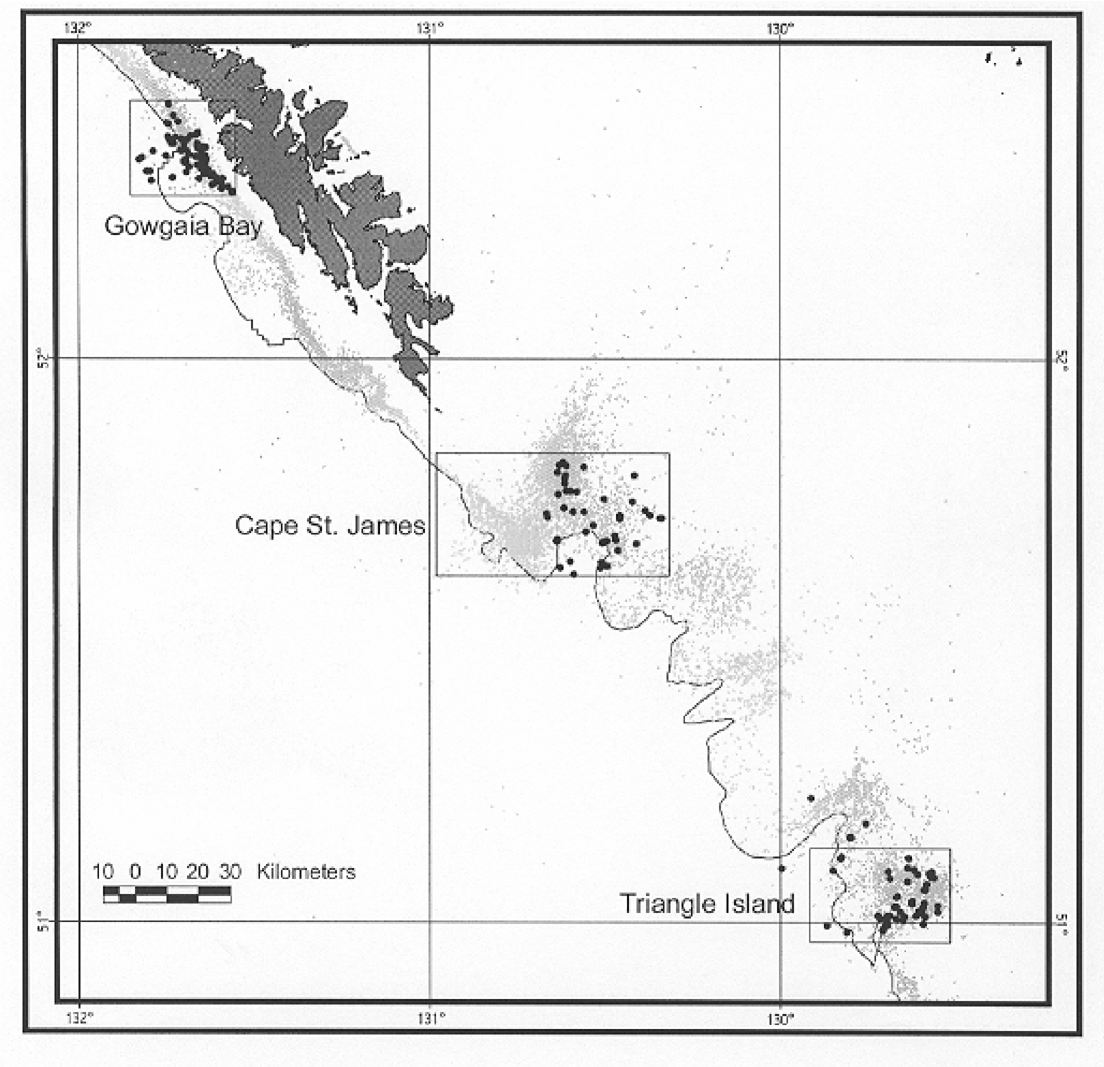


Figure 23 Sablefish indexing localities at Gowgaia Bay, Cape St. James, and Triangle Island. The rectangles indicate the locality boundaries. Large filled circles indicate the start position of each index set. Small grey circles indicate the start position of commercial sets. The 1000 m depth contour is shown as a curved solid line.

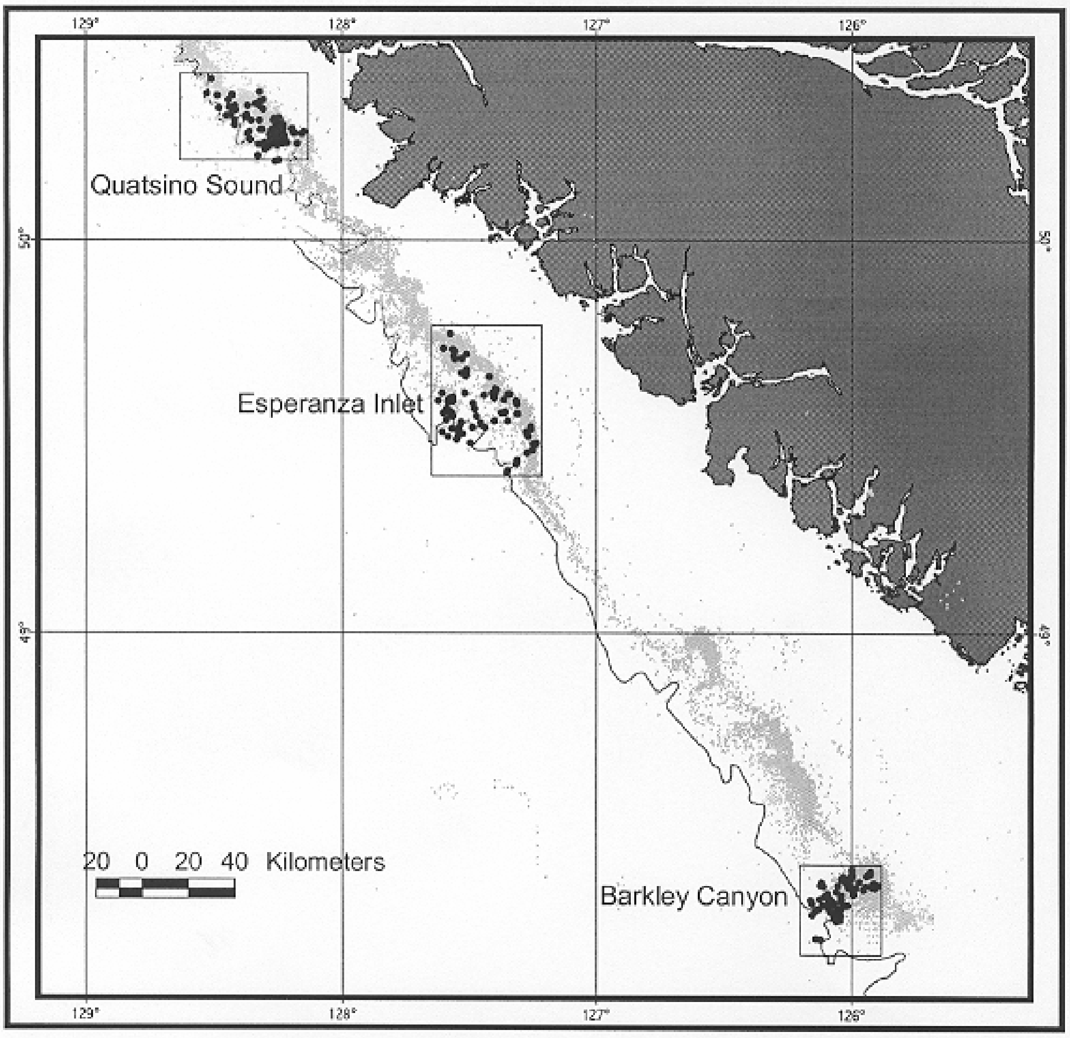


Figure 24 Sablefish indexing localities at Esperanza Inlet, Quatsino Sound, and Barkley Canyon. The rectangles indicate the locality boundaries. Large filled circles indicate the start position of each index set. Small grey circles indicate the start position of commercial sets. The 1000 m depth contour is shown as a curved solid line.

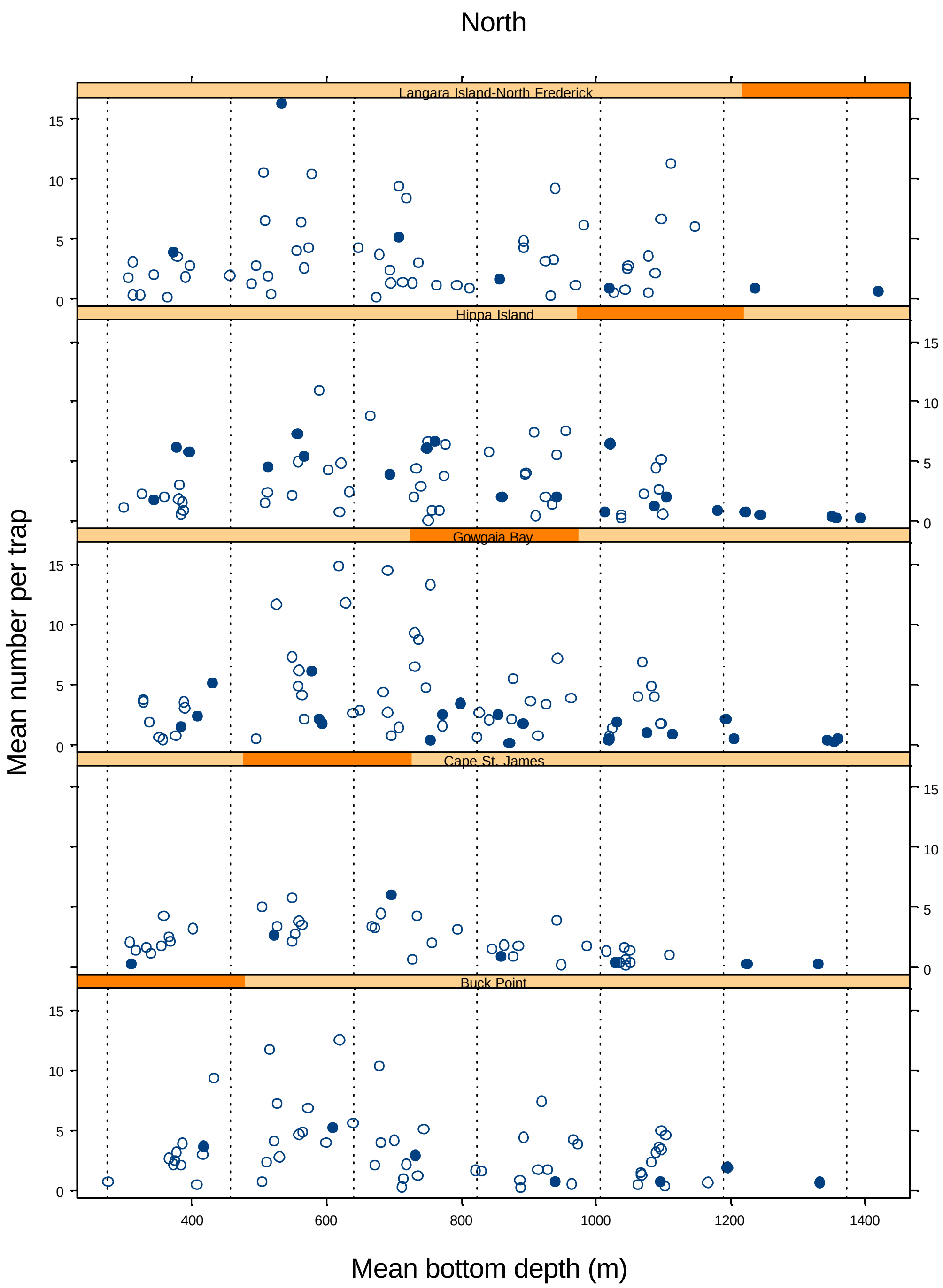


Figure 25 Catch rates for the northern localities plotted against mean bottom depth. Sets conducted in 2002 are shown as filled circles.

South

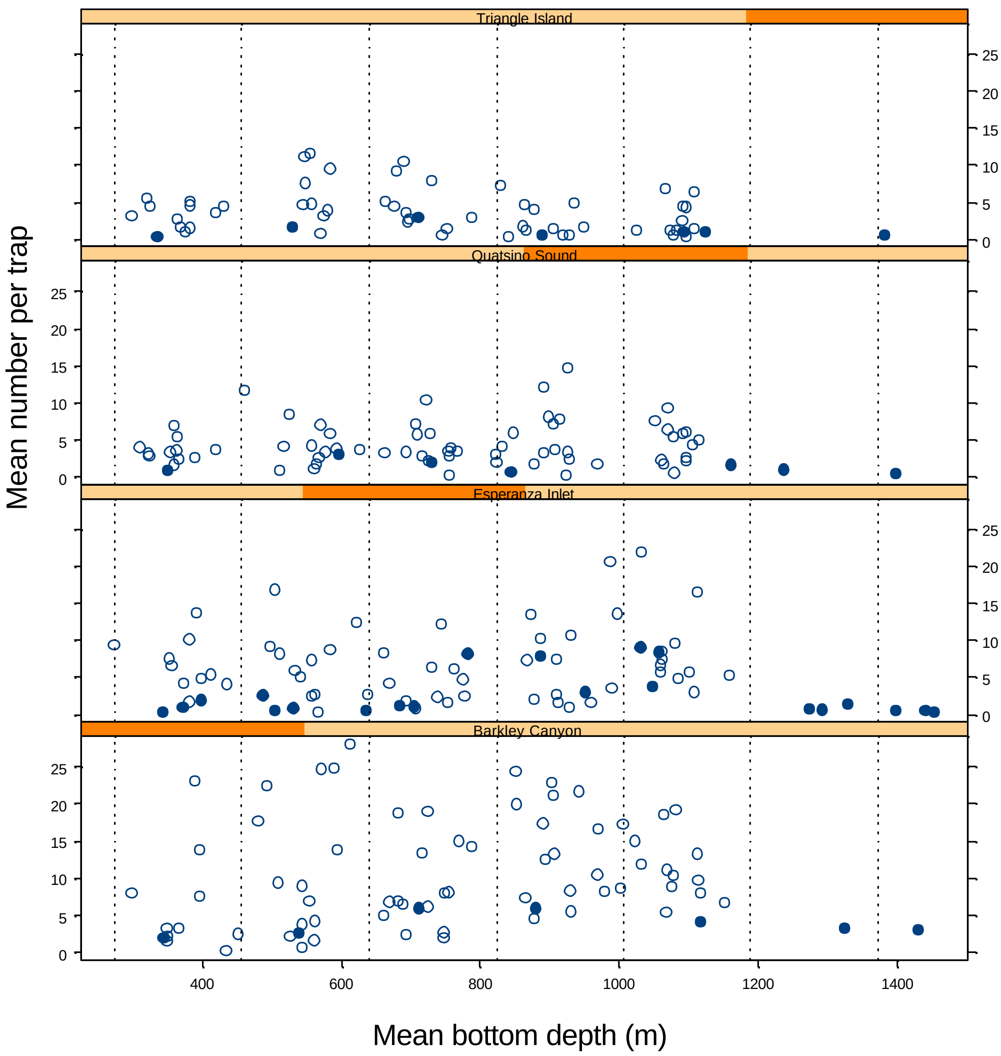


Figure 26 Catch rates for the southern localities plotted against mean bottom depth. Sets conducted in 2002 are shown as filled circles.

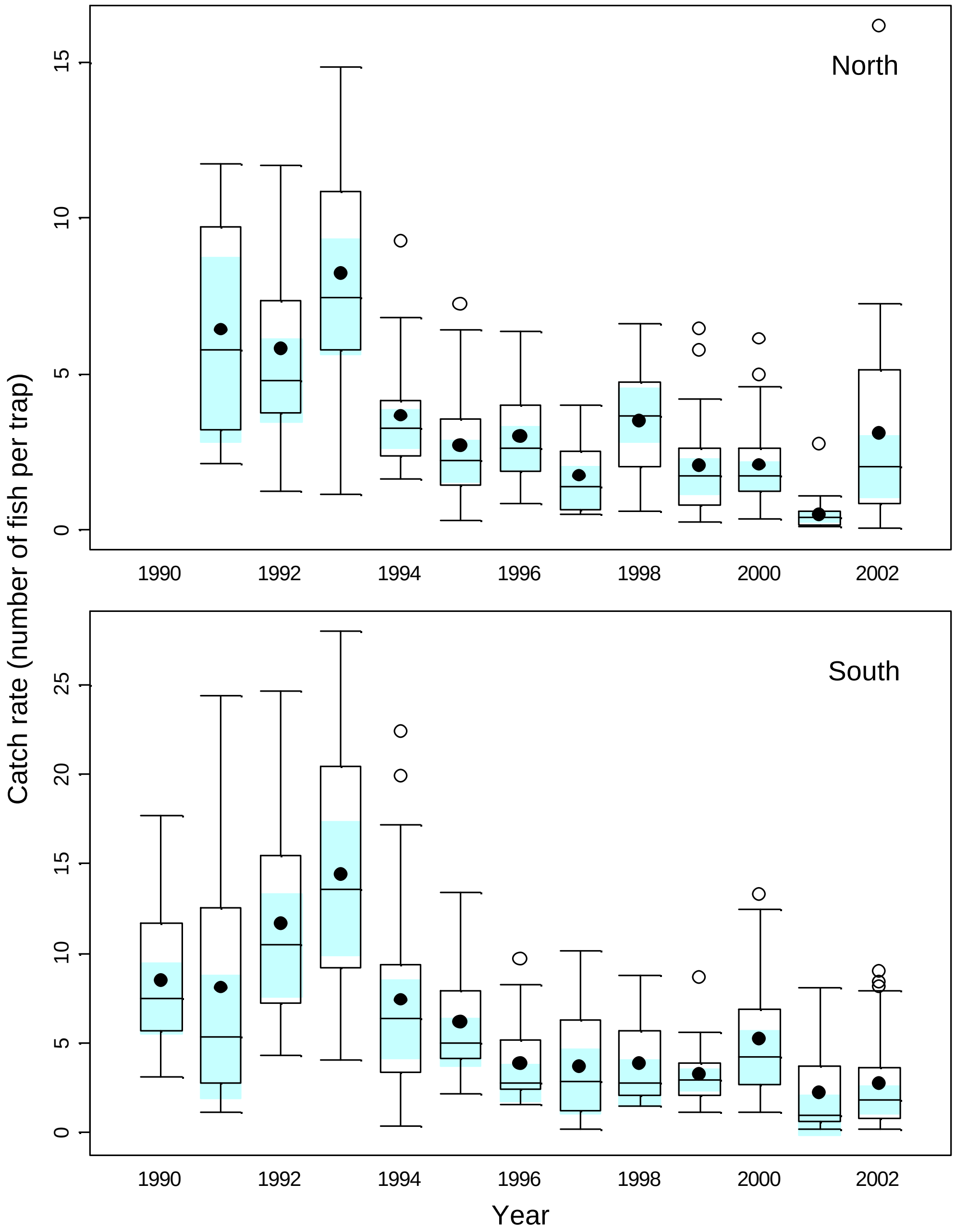


Figure 27 Distribution of catch rates for indexing sets summarized by boxplots for each year and stock area. The filled circles show the annual mean catch rate. The shaded rectangle for each year indicates an approximate 95 percent confidence interval on the median annual catch rate.

North

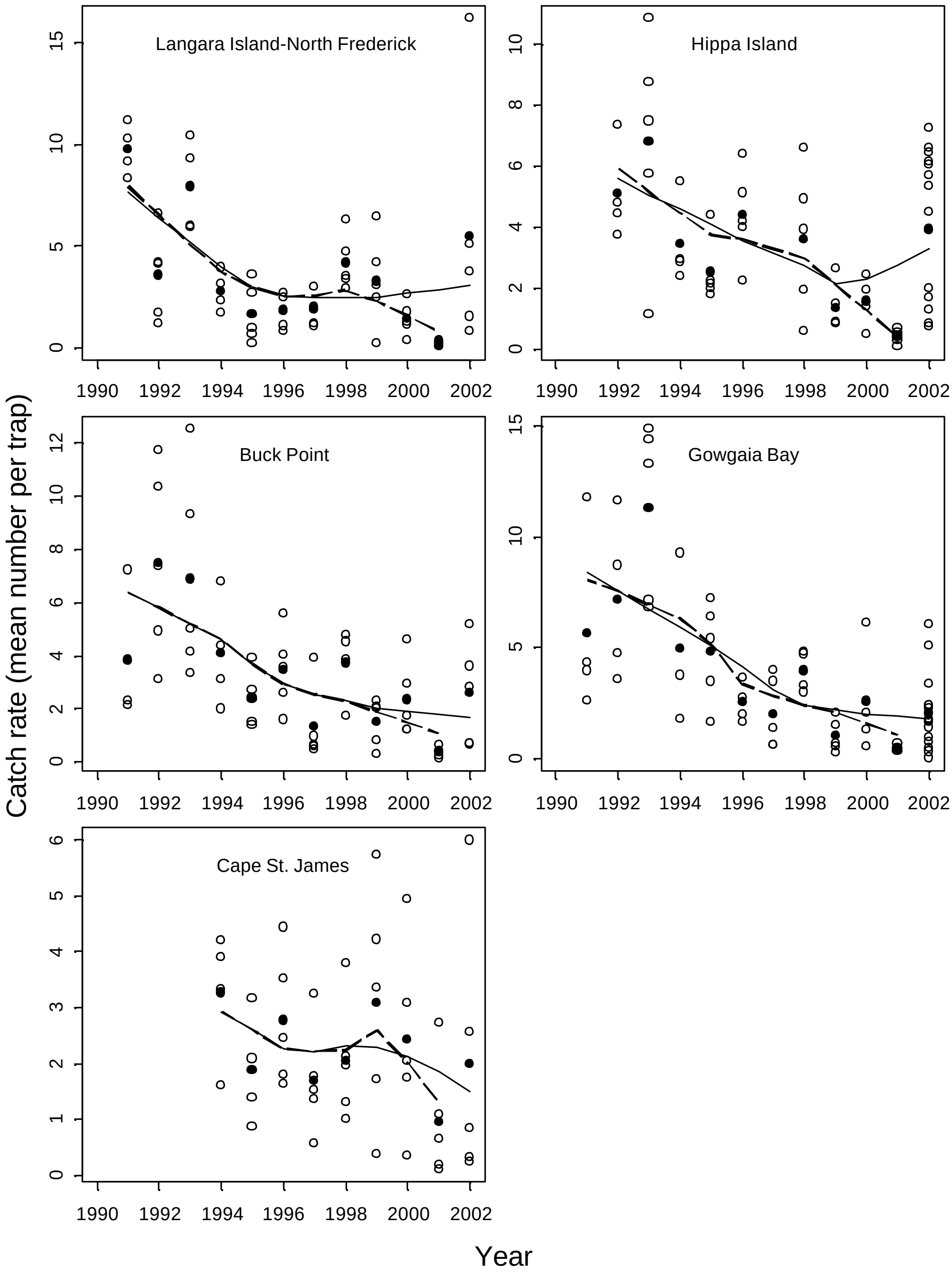


Figure 28 Catch rates for indexing sets by year and locality. Open circles represent the number of fish per trap for each indexing set. Filled circles indicate the annual mean of the catch rate observations. The solid curve shows a loess trend line fit to the entire data series while the dashed line excludes data for 2002.

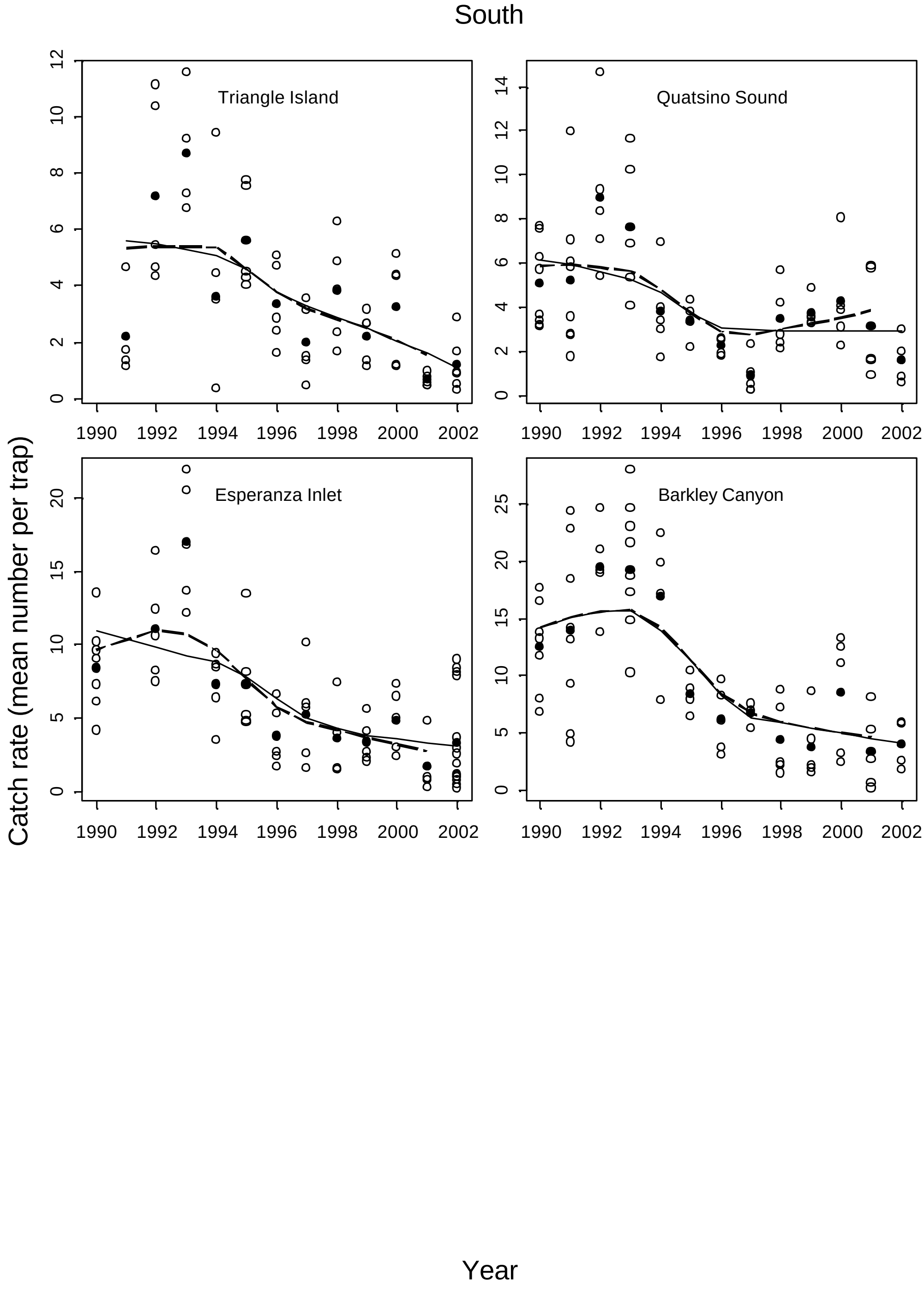


Figure 28 Continued.

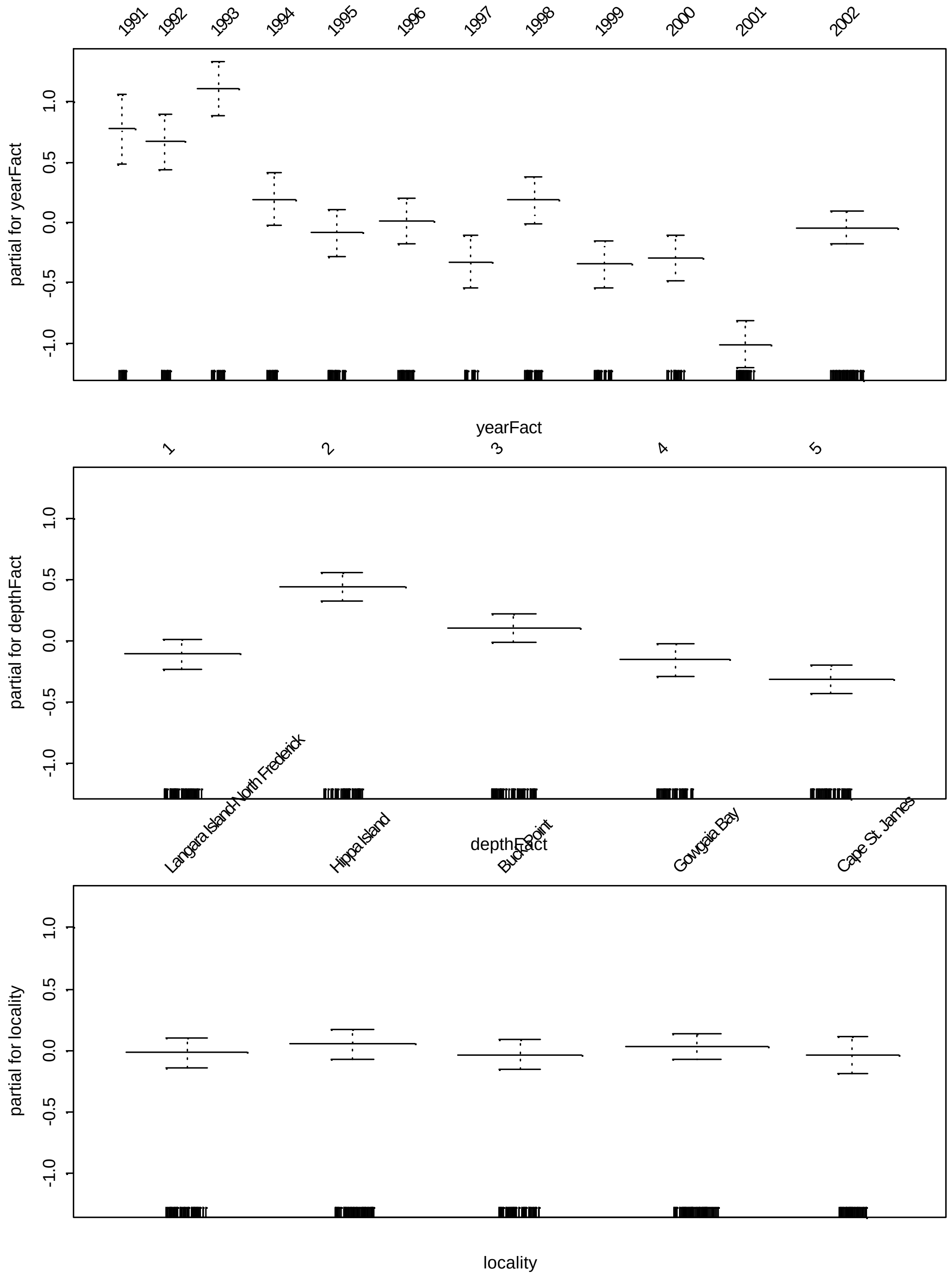


Figure 29 Contributions to the indexing model fit by factor for the north stock area.

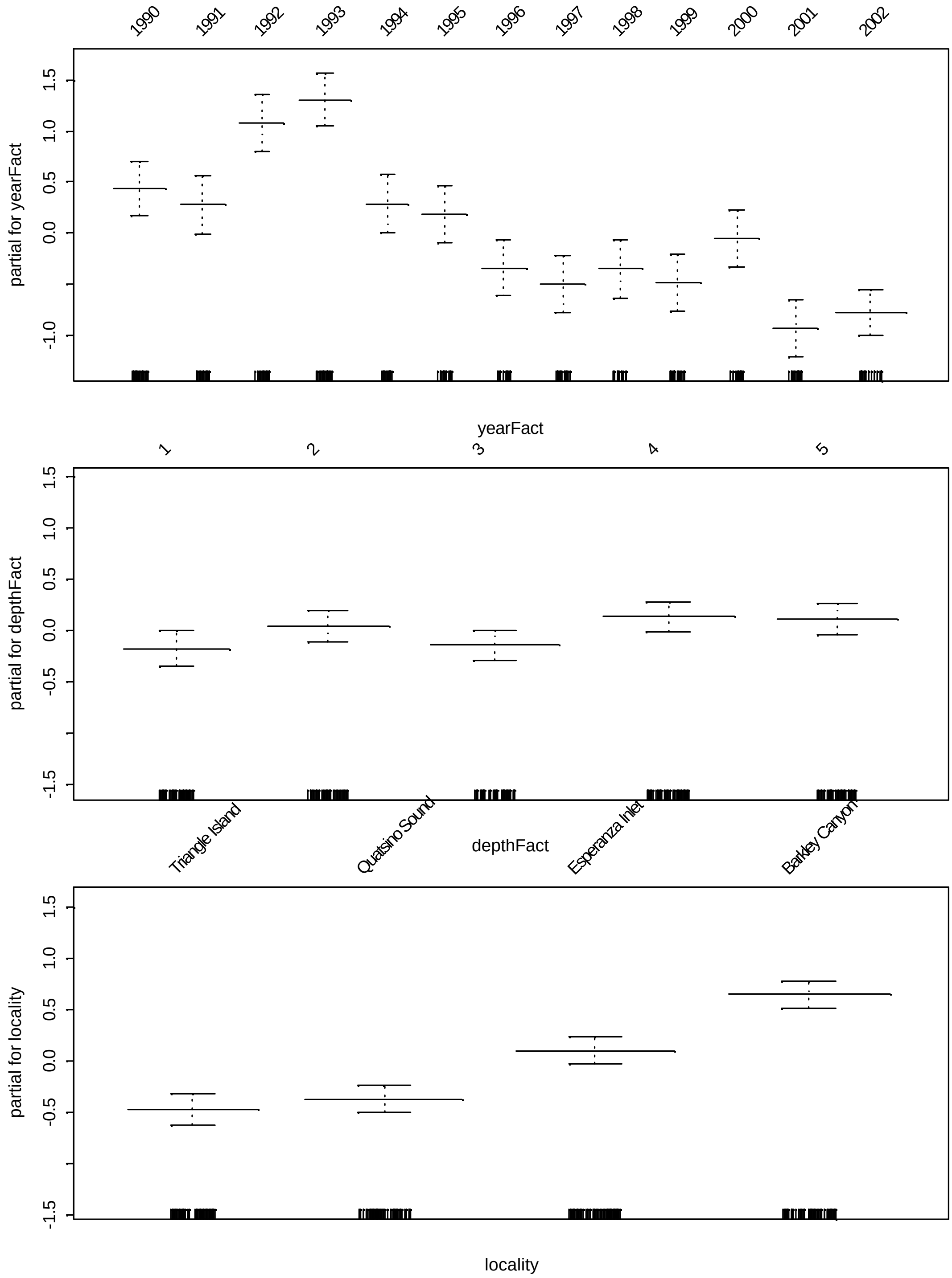


Figure 30 Contributions to the indexing model fit by factor for the south stock area.

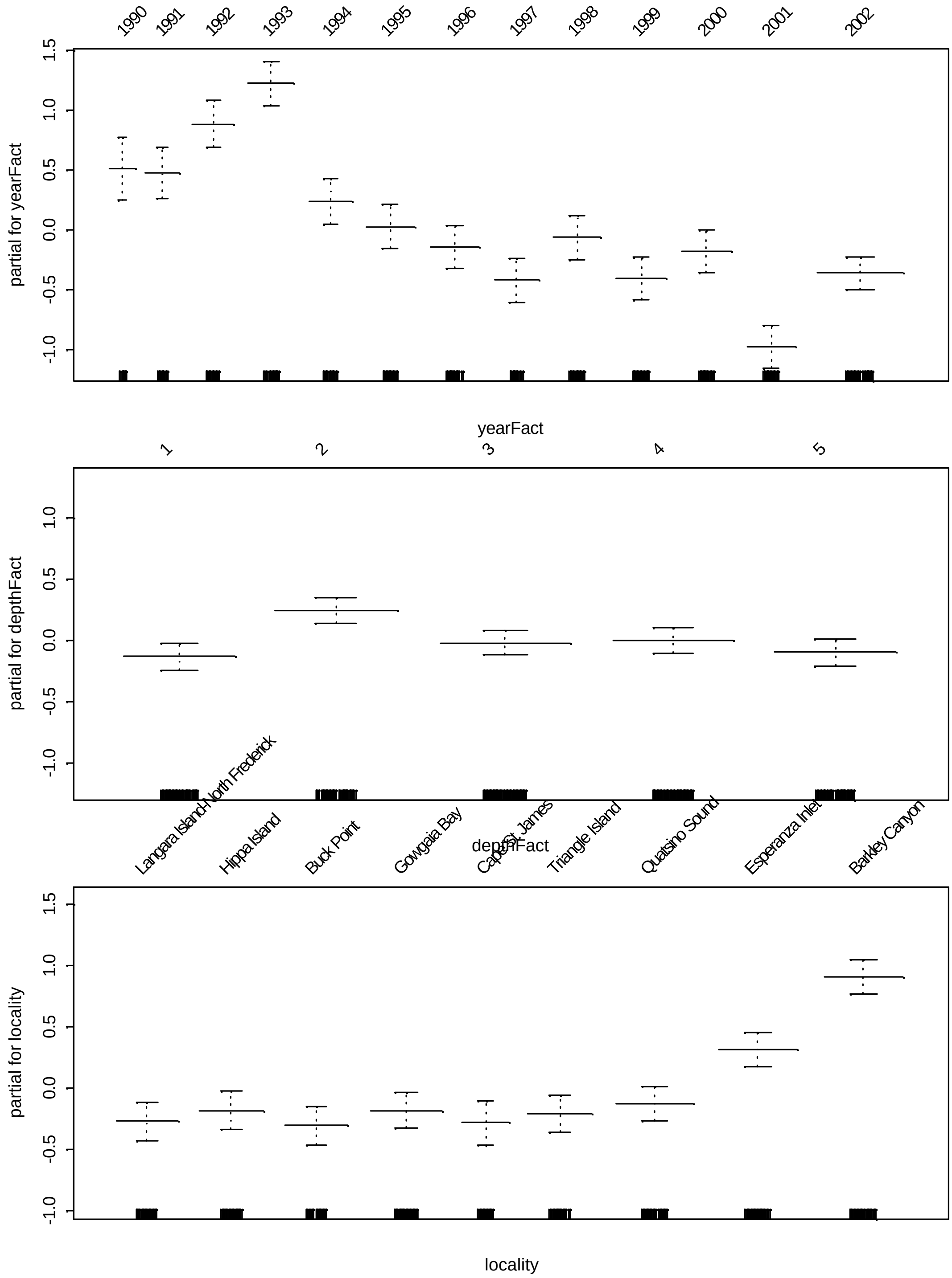


Figure 31 Contributions to the indexing model fit by factor for the coast.

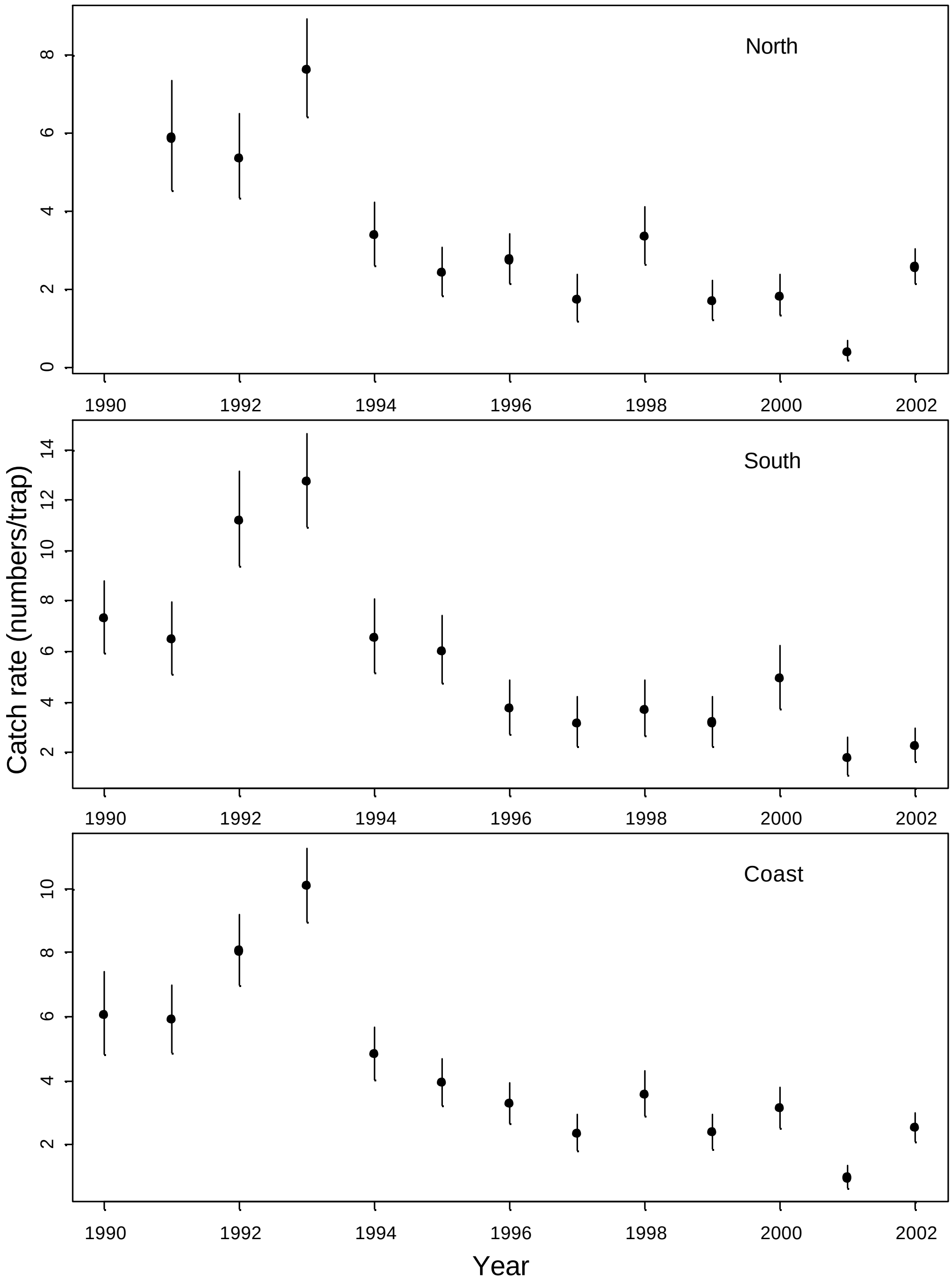


Figure 32 Marginal mean estimates for the year factor by area. Vertical bars represent plus/minus 2 standard errors.

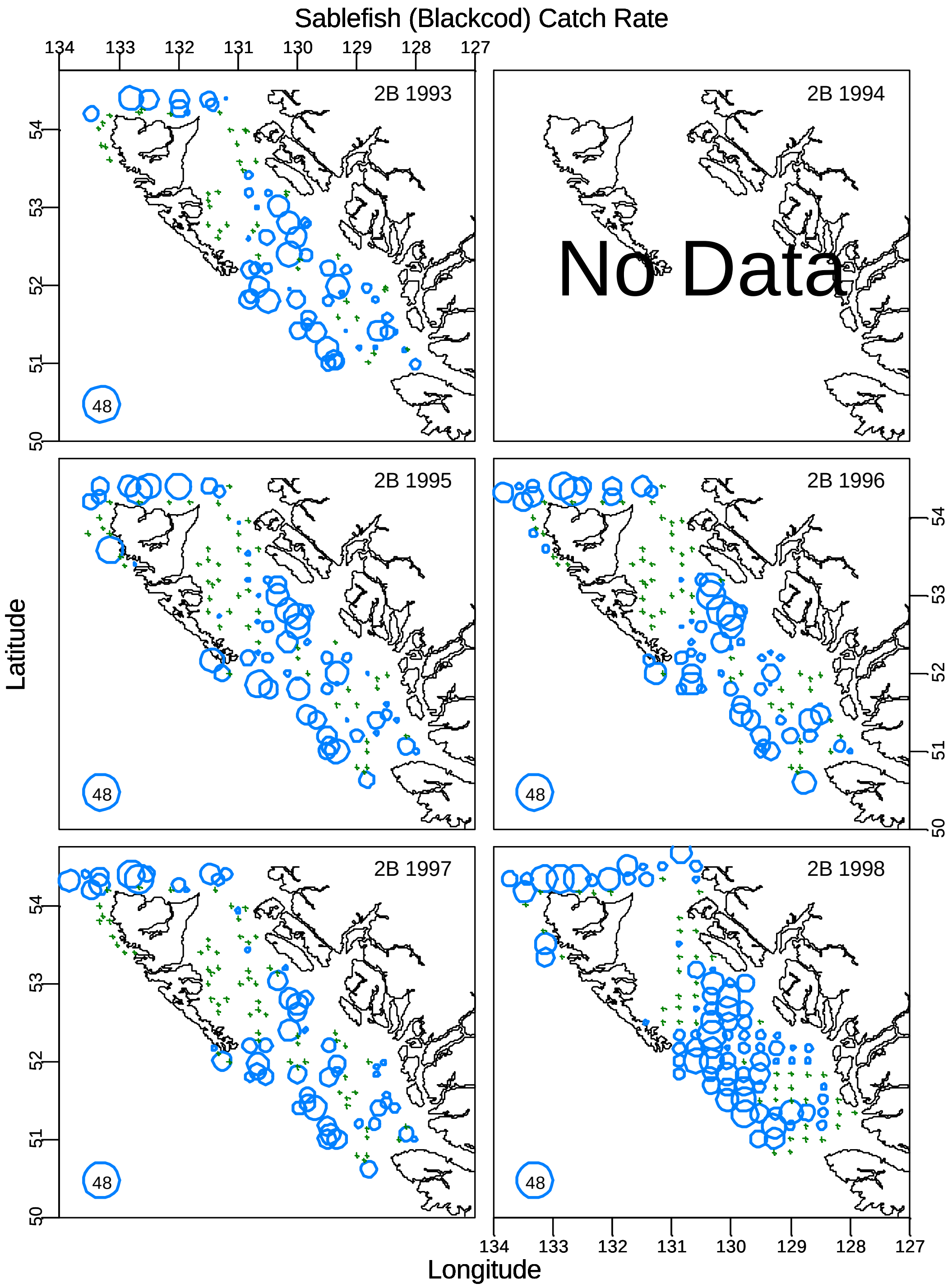


Figure 33 Spatial distribution of catch rates (number/effective skate) by year for sablefish captured during the IPHC SSA survey.

Sablefish (Blackcod) Catch Rate

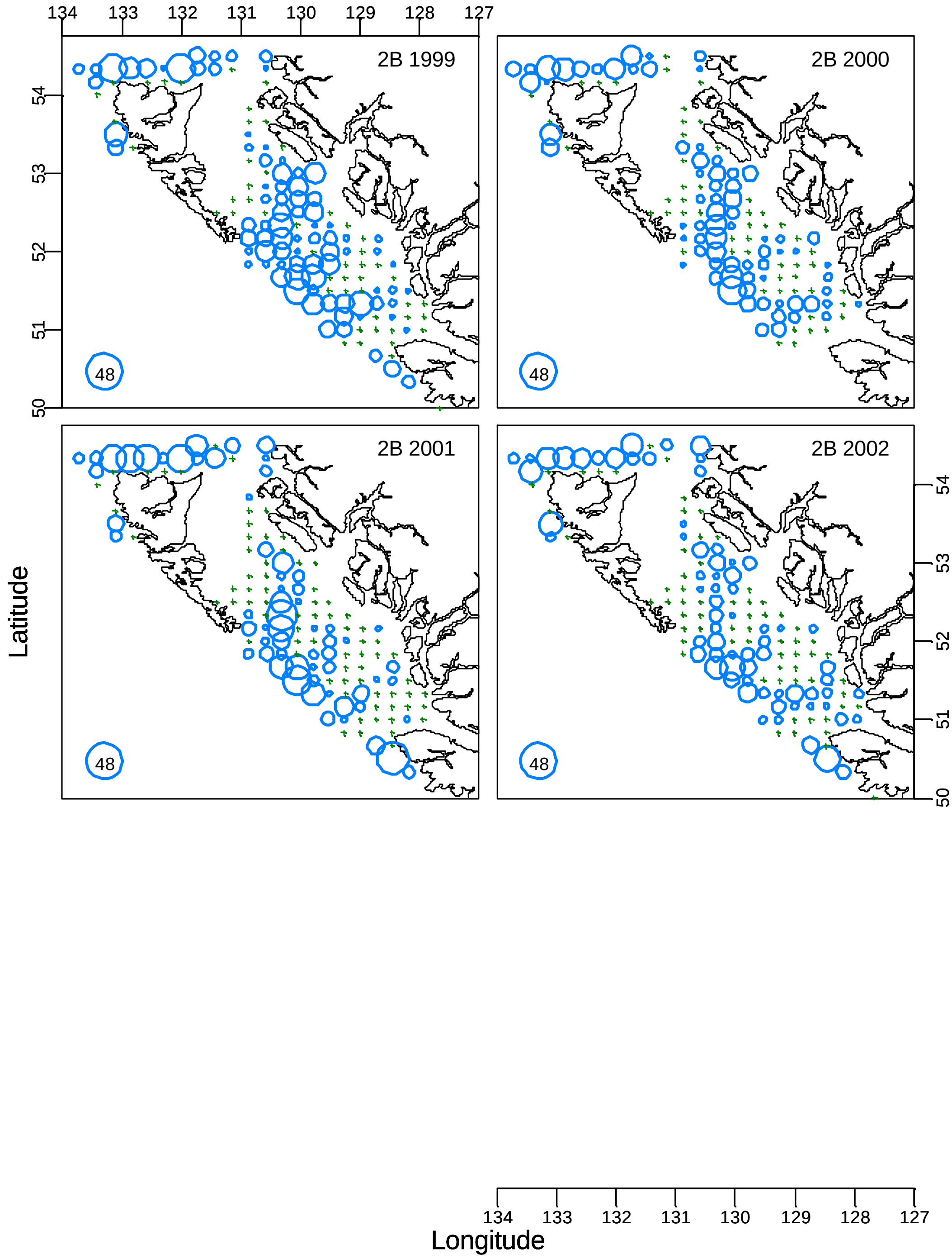


Figure 33 Continued.

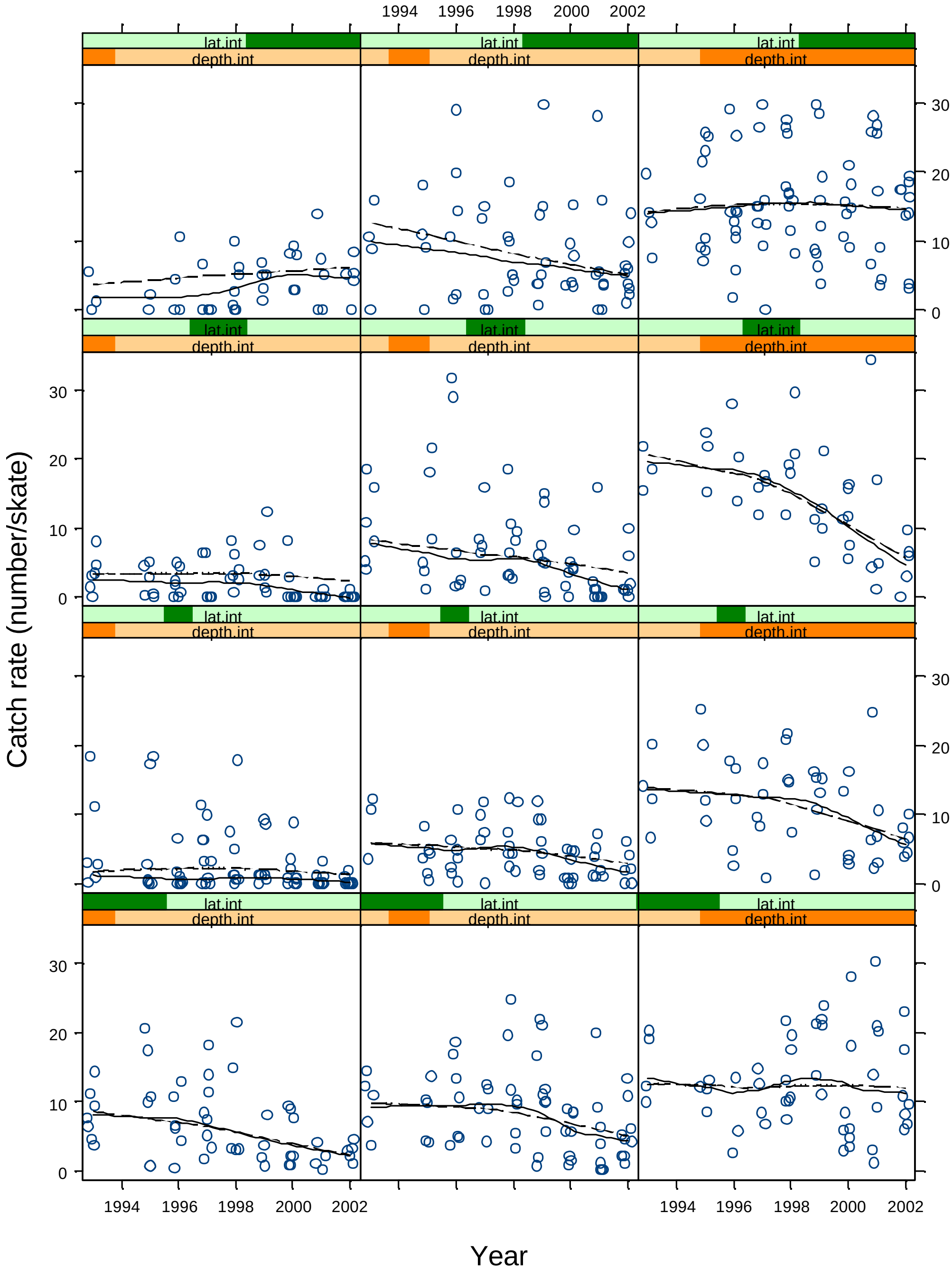


Figure 34 Trellis plot of sablefish catch rate (numbers/skate) against time given depth and latitude. The solid and dashed lines represent the fit of loess smoothing regressions for each panel with and without zero catches.

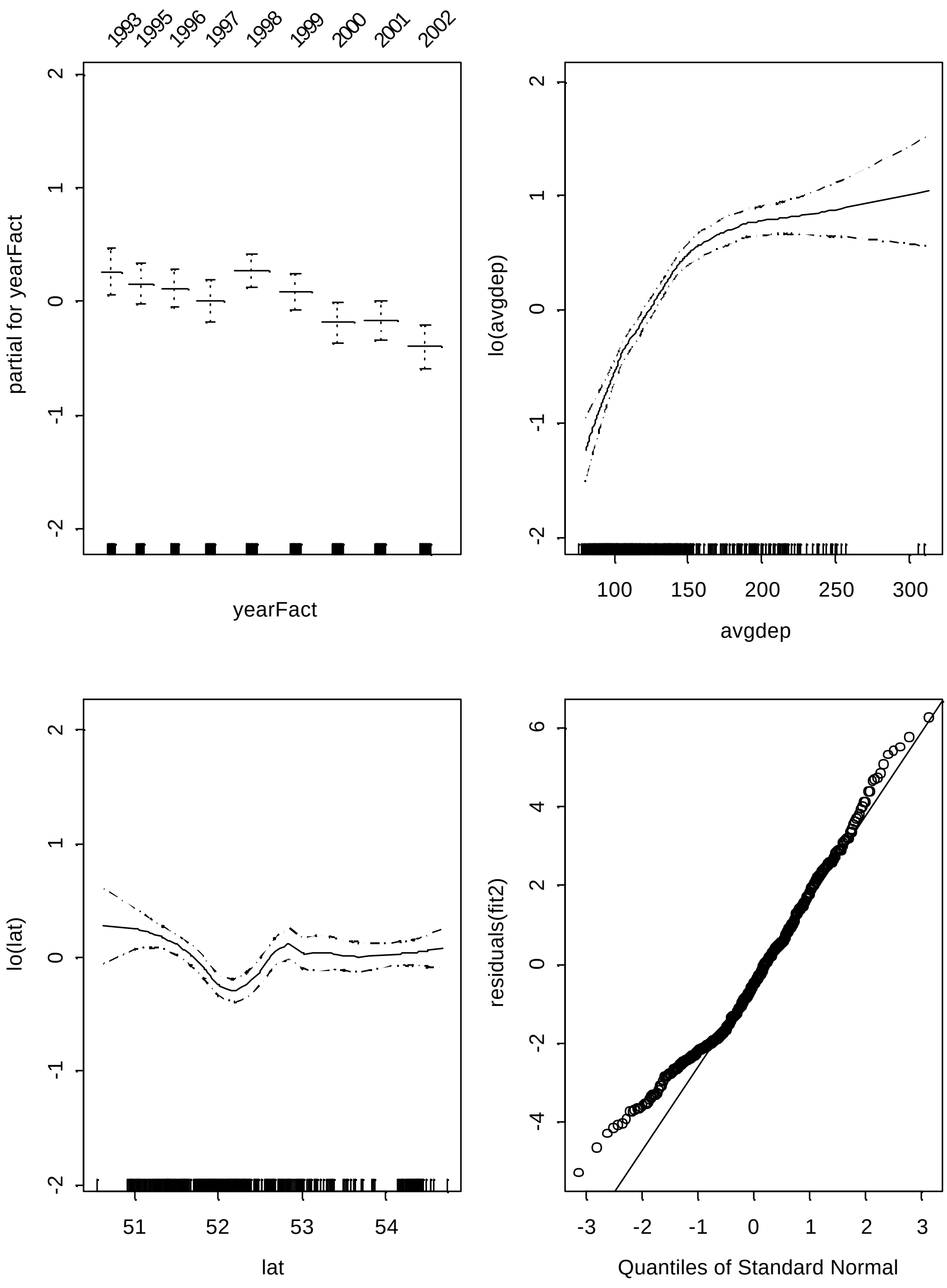


Figure 35 Contribution of each term to the fit of a generalized additive model to sablefish catch rates from the IPHC set line survey. A quantile-normal plot of the residuals is shown in the lower right panel.

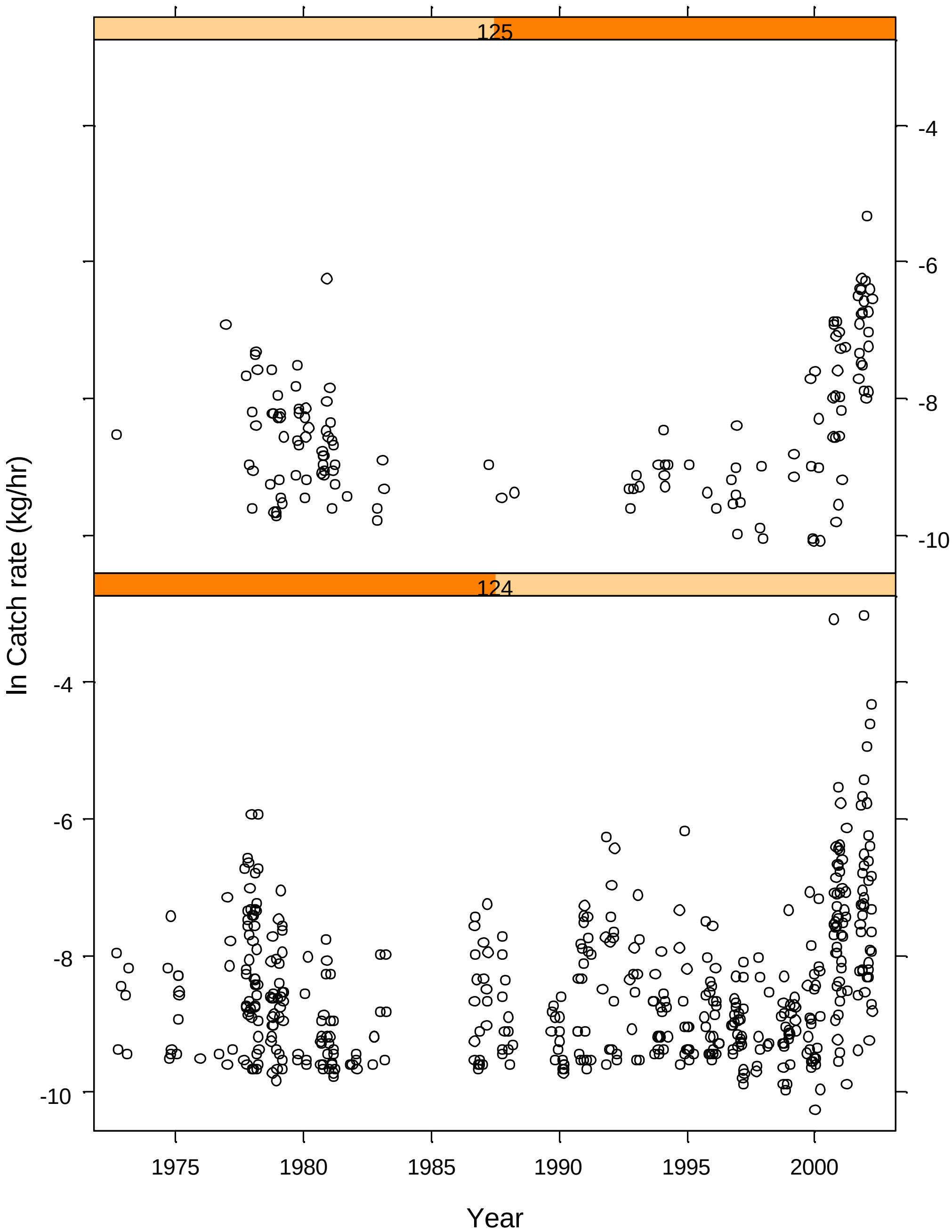


Figure 36 Sablefish (log) density (kg/m^2) estimates by year and area from the west coast shrimp survey. Observations have been jittered along the x-axis to expose the points.

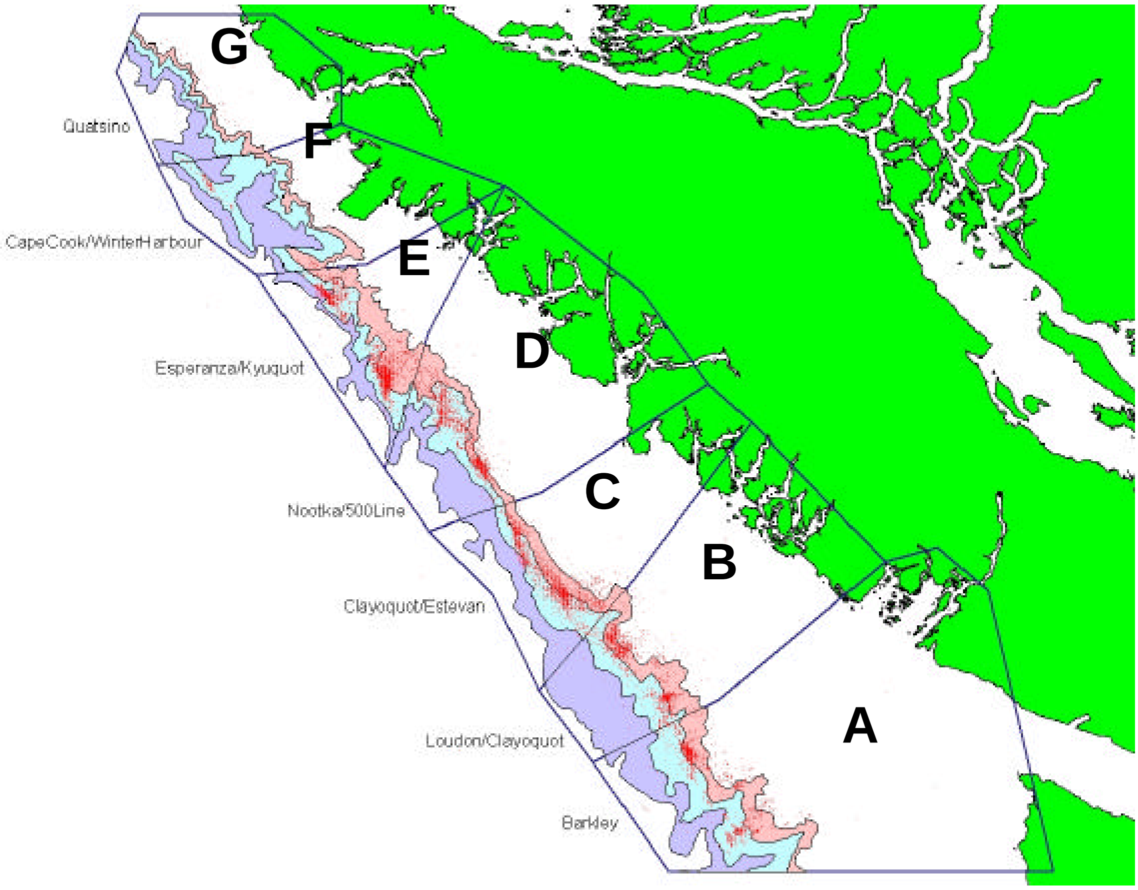


Figure 37 Map of the seven survey regions used for the 2002 thornyhead trawl survey. Note that region "G" was not fished in 2001. The three depth stratum are identified as different coloured areas, and most of the relevant tows in the PacHarvest database (over period 15 February 1996 to 01 April 2002) are shown as points.

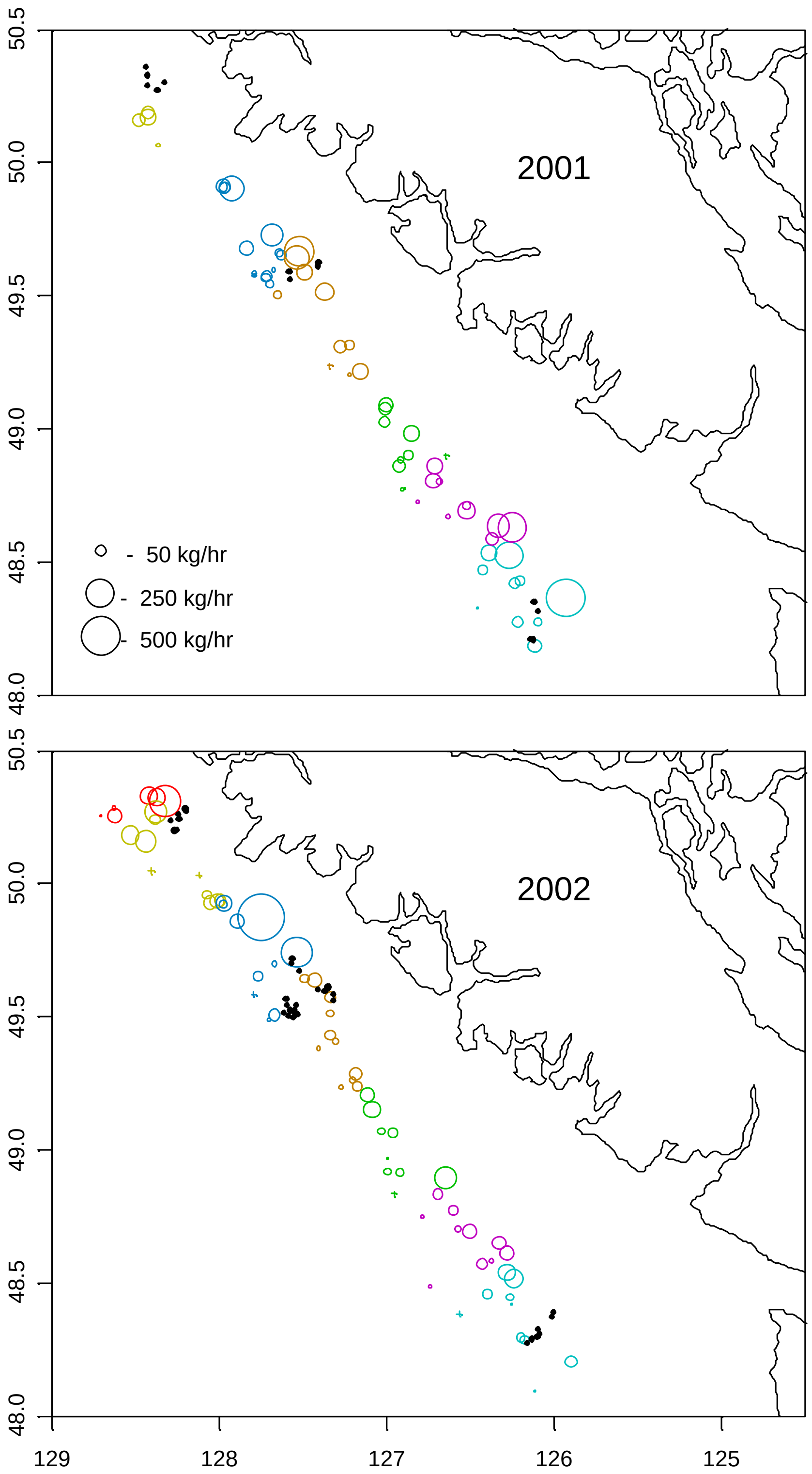


Figure 38 Location of thornyhead survey fishing tows (coloured circles, where circle size is proportional to CPUE), and sablefish index survey locations (black dots) for 2001 and 2002.

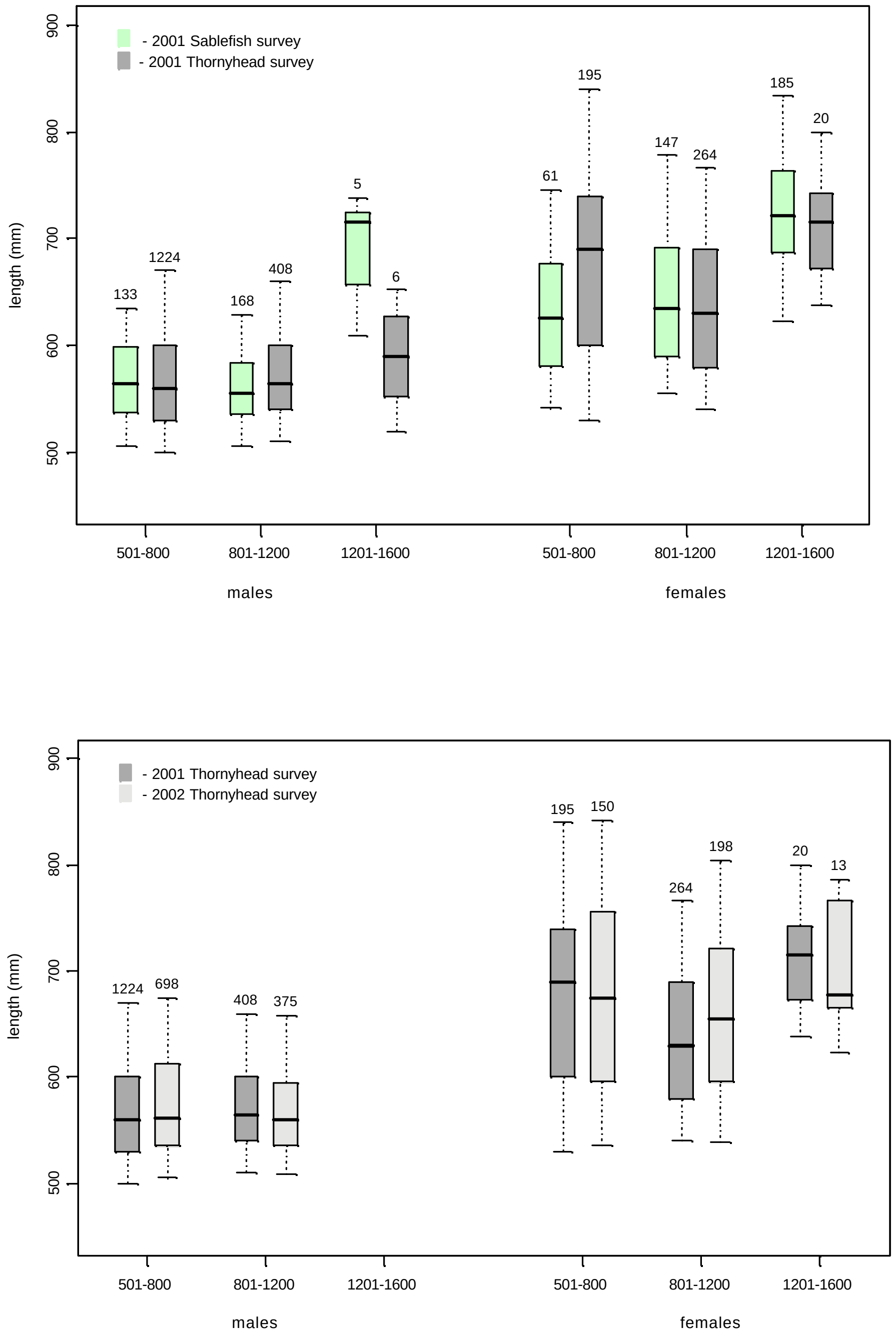


Figure 39 Quantile plots of the length distribution of sablefish sampled during the thornyhead and sablefish surveys in 2001 (upper panel) and the 2001 and 2002 thornyhead surveys (lower panel). The solid boxes show the inter-quartile range of the distributions (25th to 75th quantile) with the solid line indicating the median. The horizontal lines joined to the boxes with dashed vertical lines indicate the 5th and 95th quantiles of the distributions.

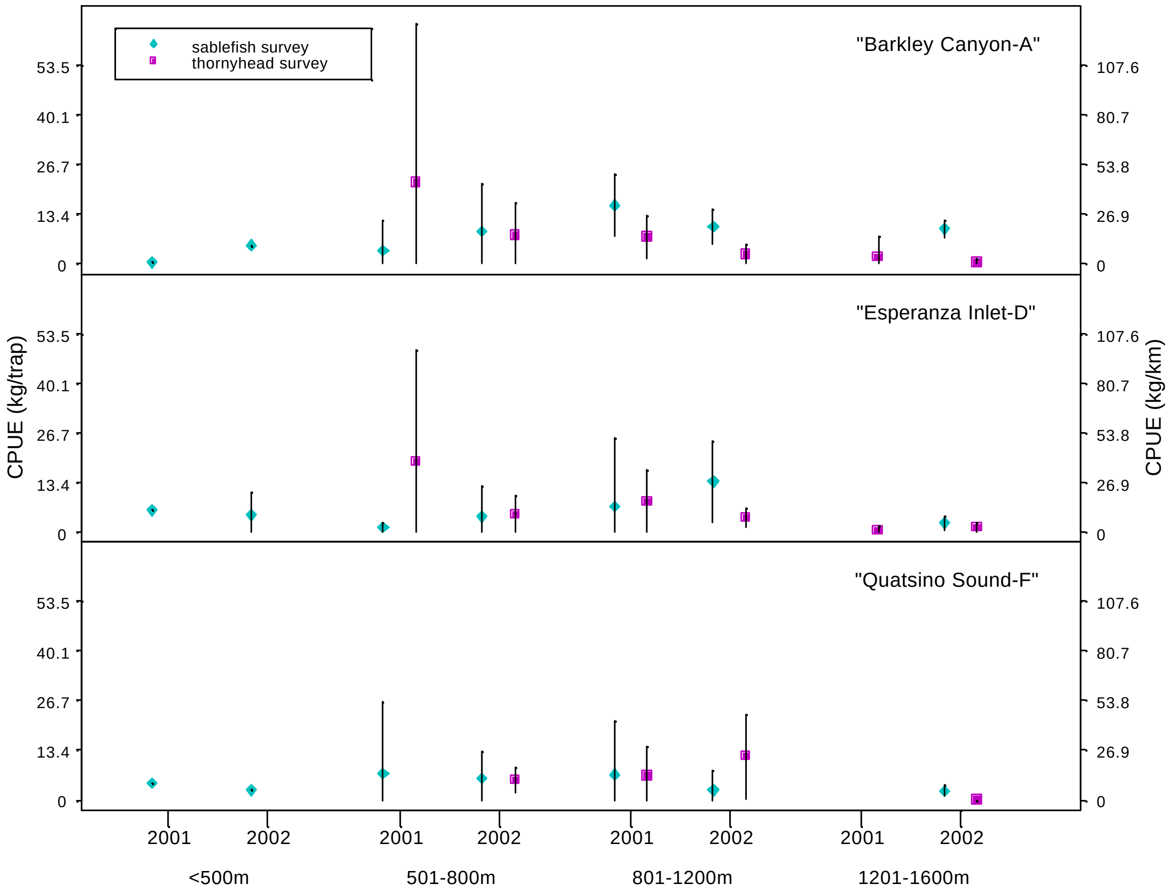
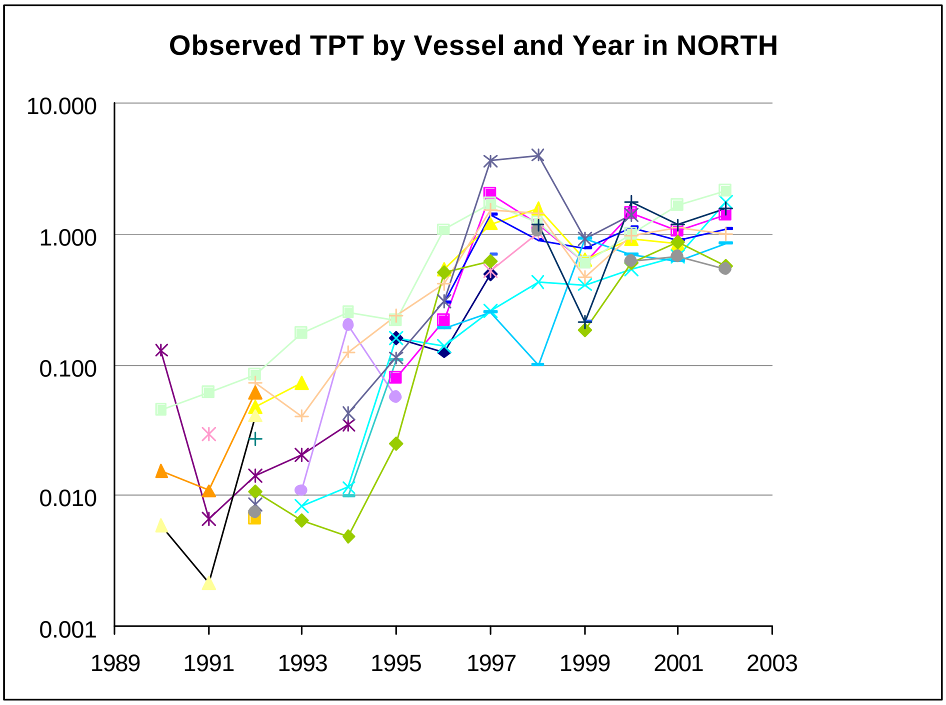


Figure 40 Average CPUE in the sablefish (kg/trap) and thornyhead (kg/km) surveys by region, depth stratum, and year. Vertical lines show the estimates plus or minus 2 standard errors for cases where there is more than one observation.



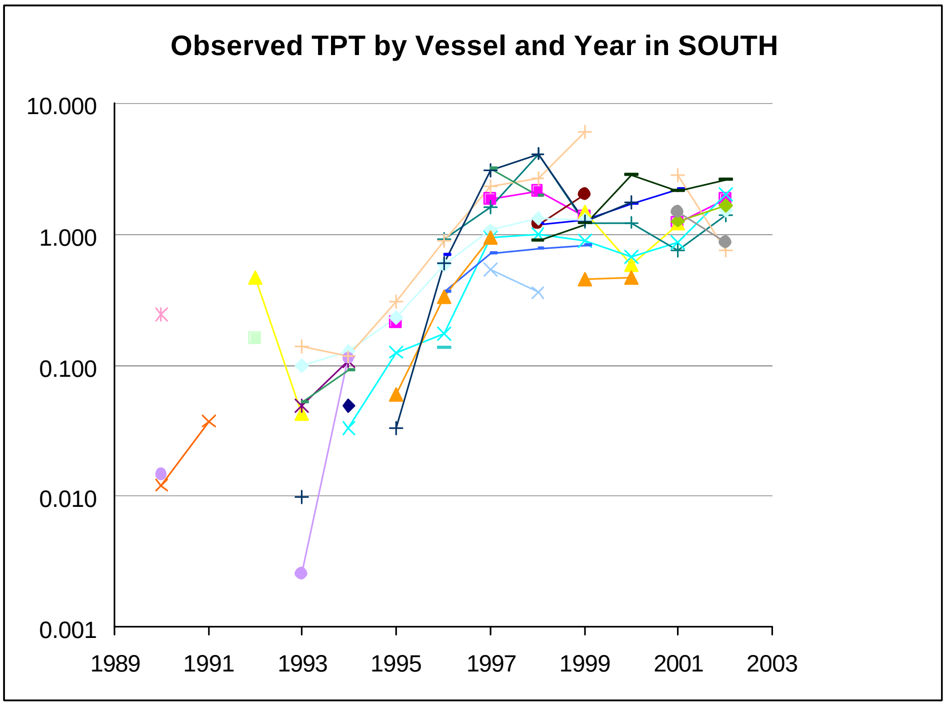


Figure 41 Observed tags per metric ton by vessel and year in the north (upper panel) and south (lower panel) stock areas.

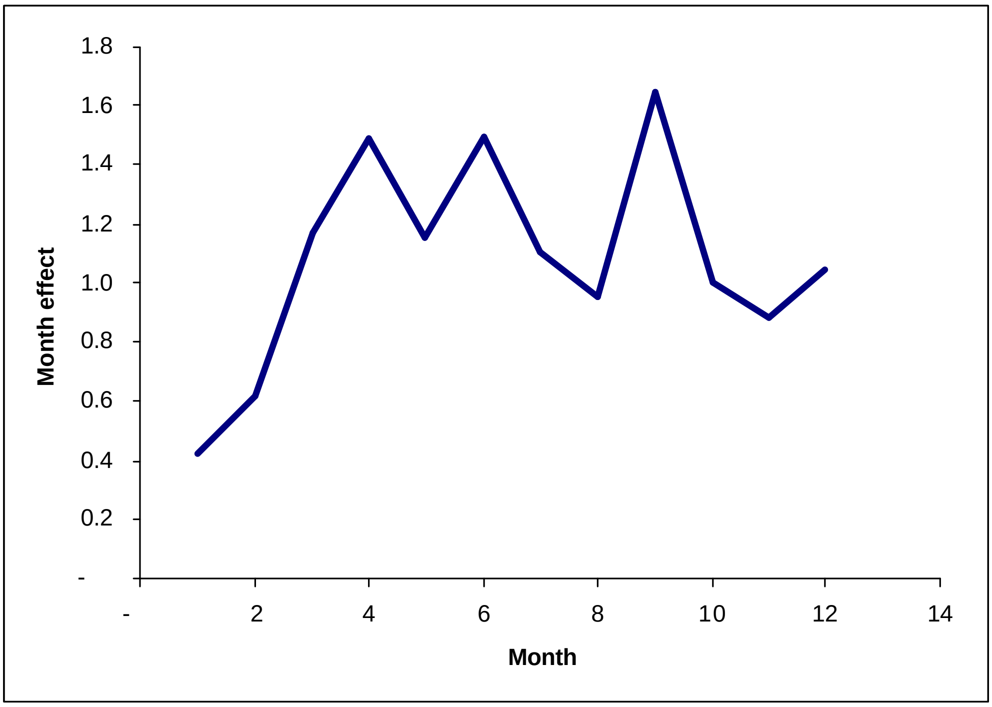


Figure 42 Month effect from monthly tag-recovery model.

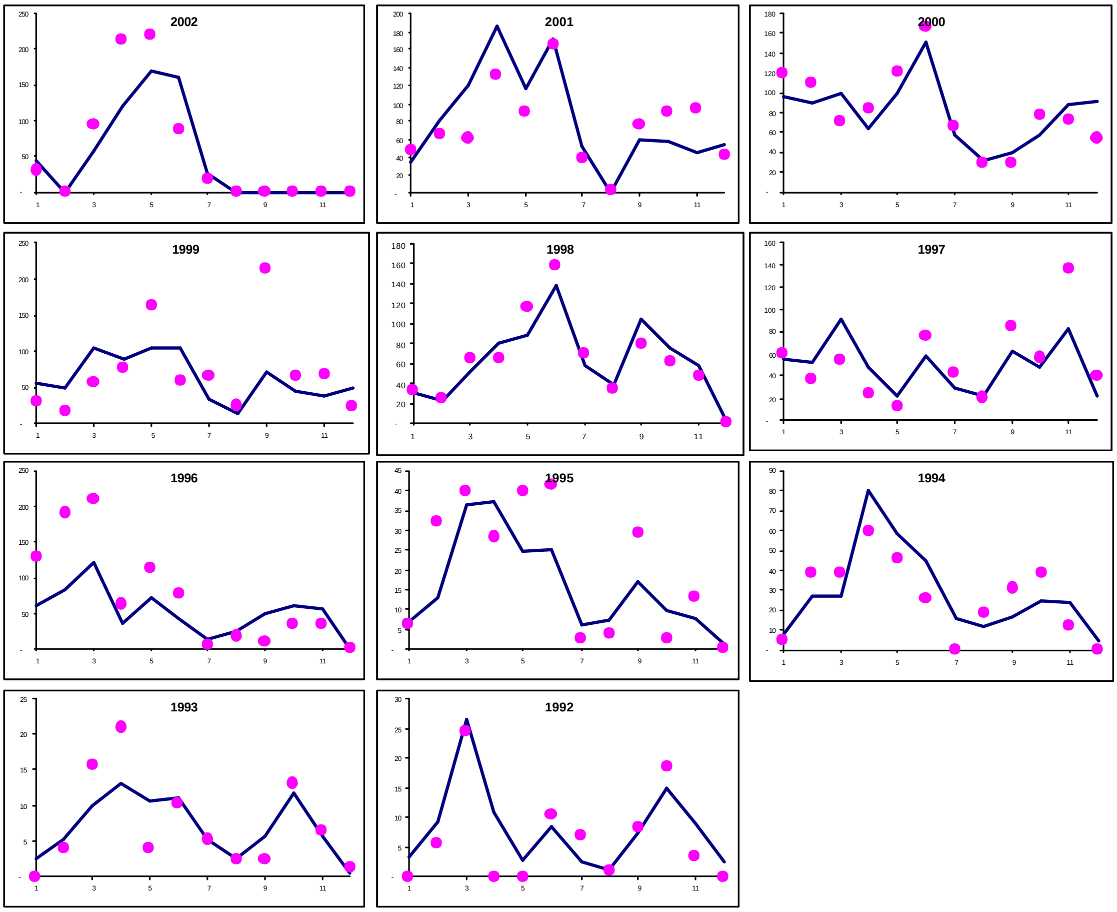


Figure 43 Monthly fits to number of tags from monthly tagging model.

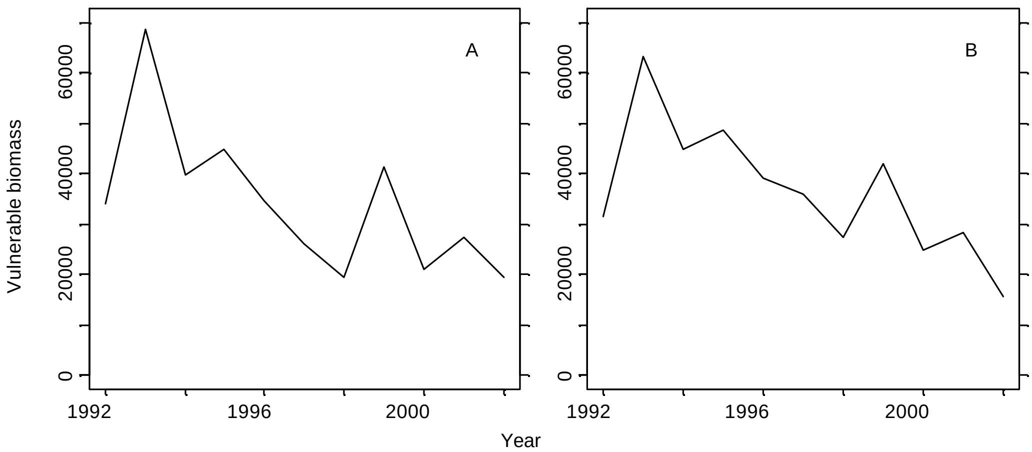


Figure 44 Predicted trend in abundance (mt) over time from monthly tagging model. Panel A uses the estimated tag reporting rates, while panel B uses the 1999 estimates.

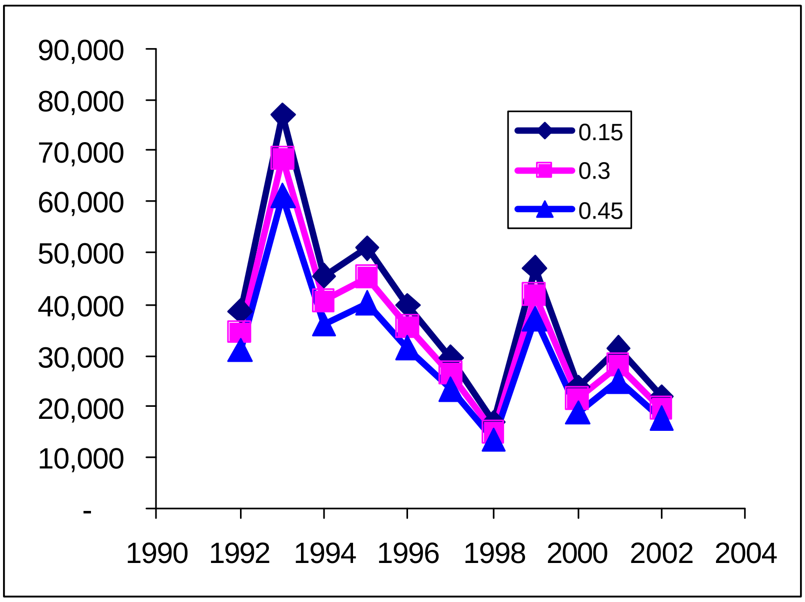


Figure 45 Sensitivity of monthly tag-recovery model to tag disappearance rate.

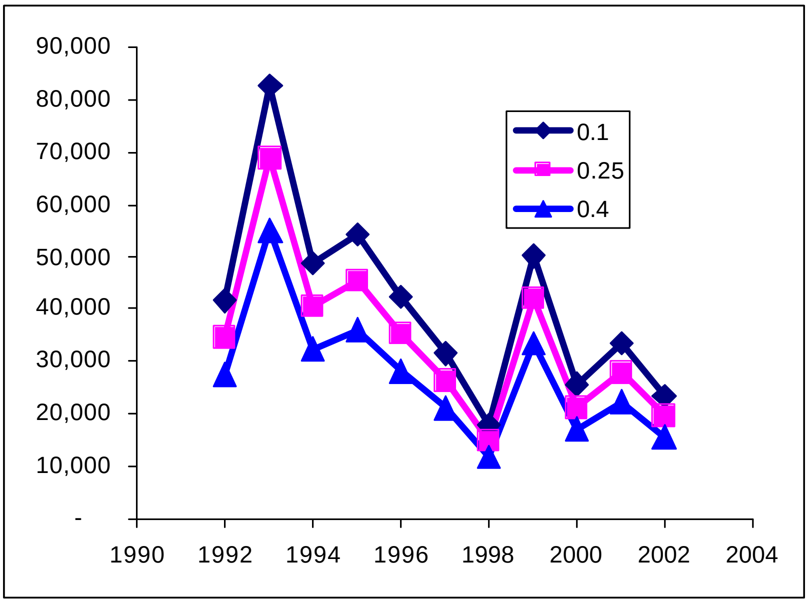


Figure 46 Sensitivity of monthly tag-recovery model to pre-season tag loss rate.

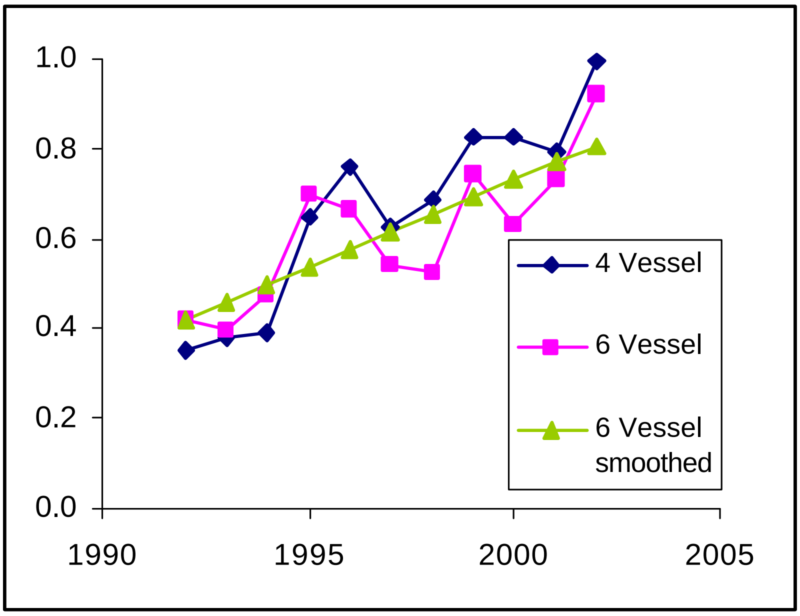


Figure 47 Choices of tag reporting rates for input to tag-recovery model.

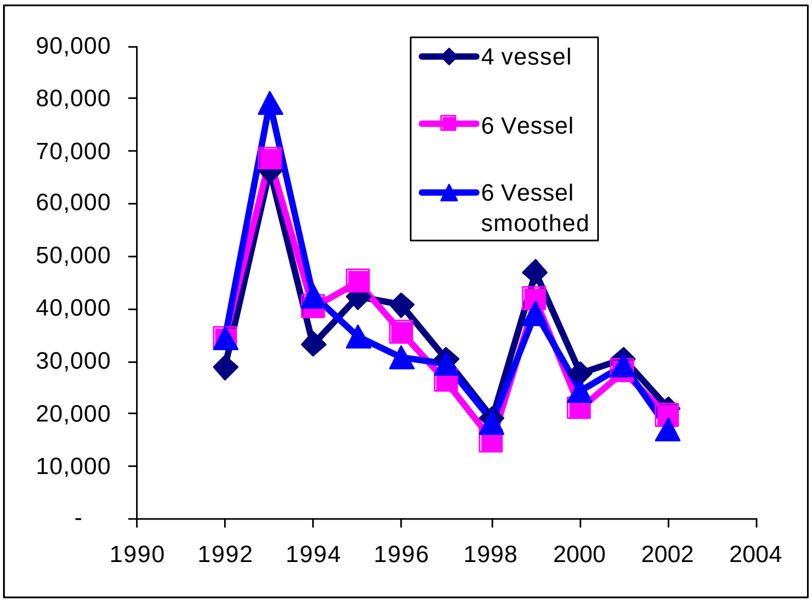


Figure 48 Sensitivity of monthly tag-recovery model to tag reporting rates.

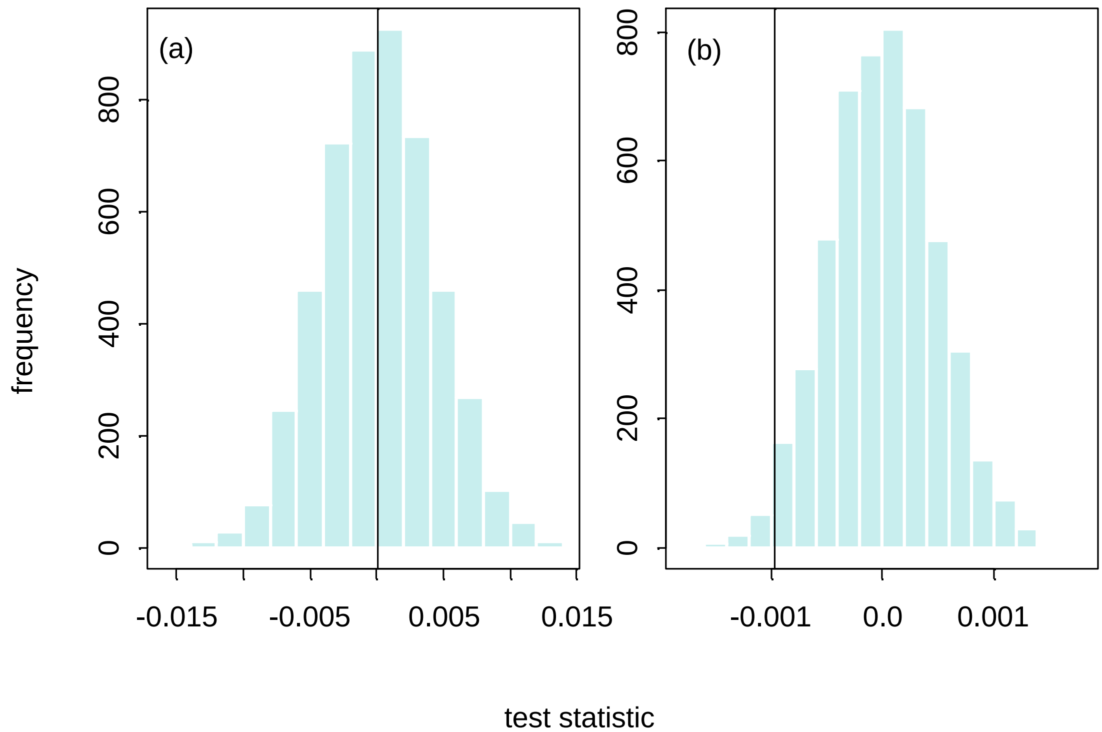


Figure 49 Rerandomization distributions of the test statistic under the null hypothesis for tag returns from Canadian fishermen (panel "a" and tag returns from U.S. fishermen (panel "b"). The observed test statistics are shown as vertical lines in the plots.

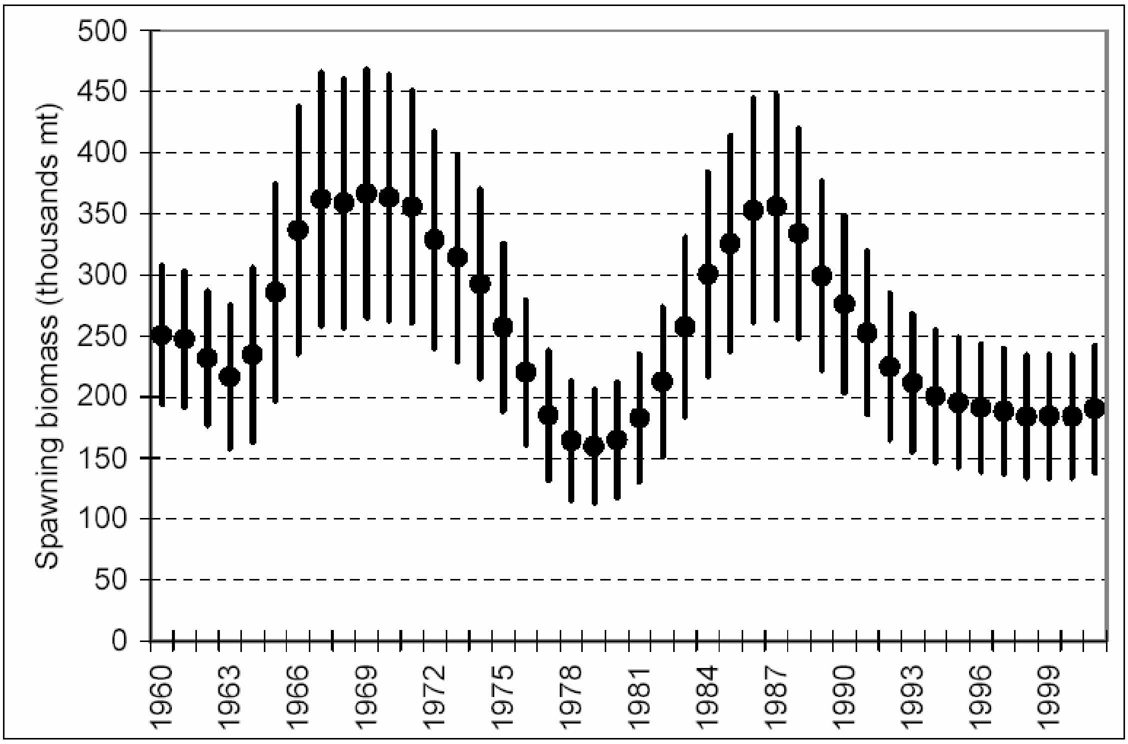


Figure 50 Gulf of Alaska model estimates of male and female spawning biomass (thousands mt) +/- 2 standard errors by year. Standard error estimates are based on covariance matrix from age-structured model output. The variability estimates do not include variability of the independently estimated parameters, so the variability is underestimated. From Sigler et al. (2002).

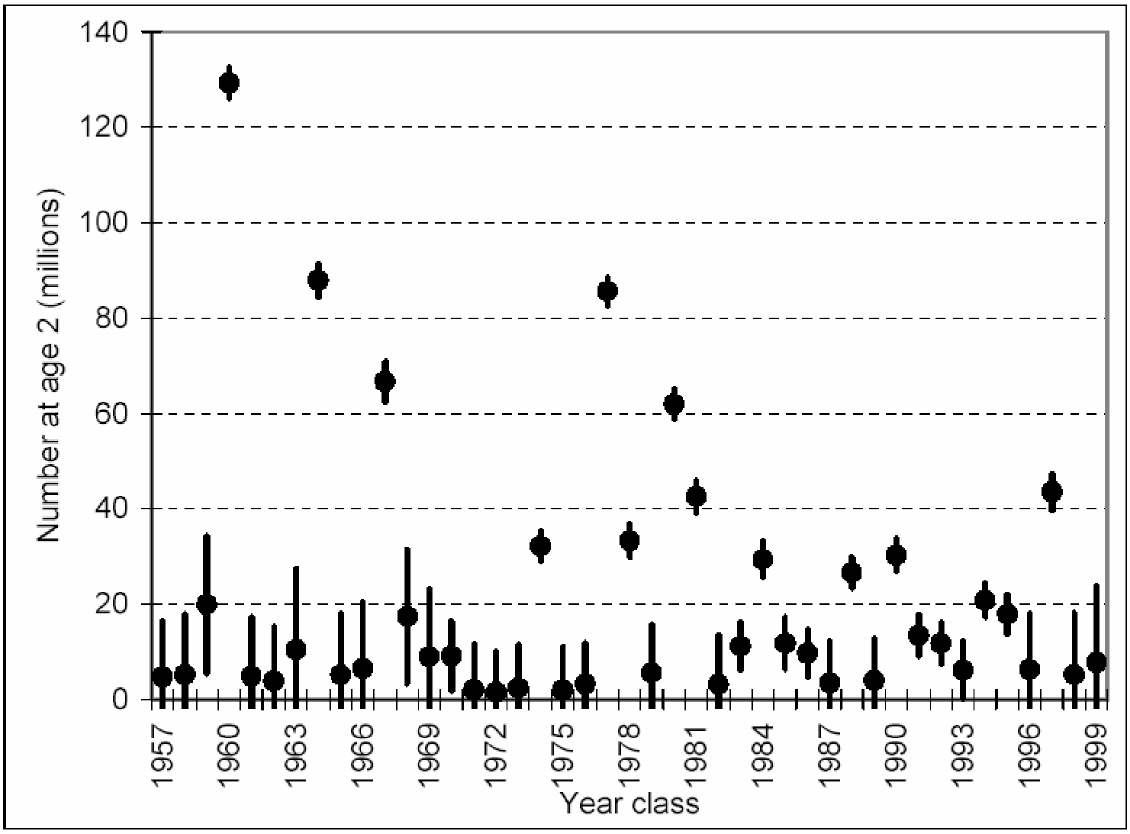


Figure 51 Gulf of Alaska model estimates of the number of age-2 sablefish (millions) +/- 2 standard errors by year class. Standard errors based on covariance from age-structured model output. The variability estimates do not include variability of the independently estimated parameters, so the variability is underestimated. From Sigler et al. (2002).

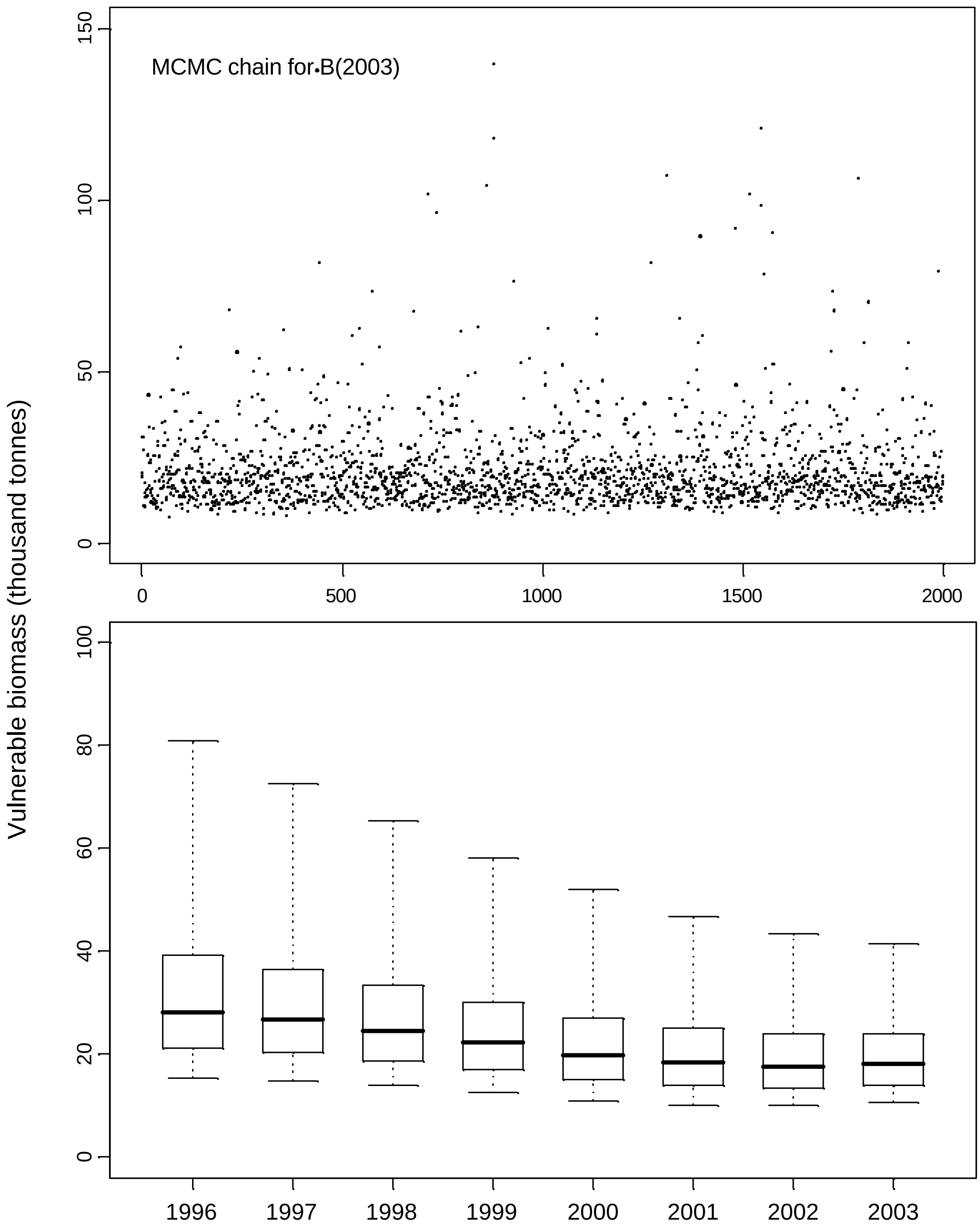


Figure 52 The MCMC chain for B_{2003} (upper panel), and quantile plots of the distributions of vulnerable biomass, 1996-2003 (lower panel). In the quantile plots the solid boxes show the interquartile range of the distributions (25^{th} to 75^{th} quantile) with the solid line indicating the median. The horizontal lines joined to the boxes with dashed vertical lines indicate the 5^{th} and 95^{th} quantiles of the distributions.

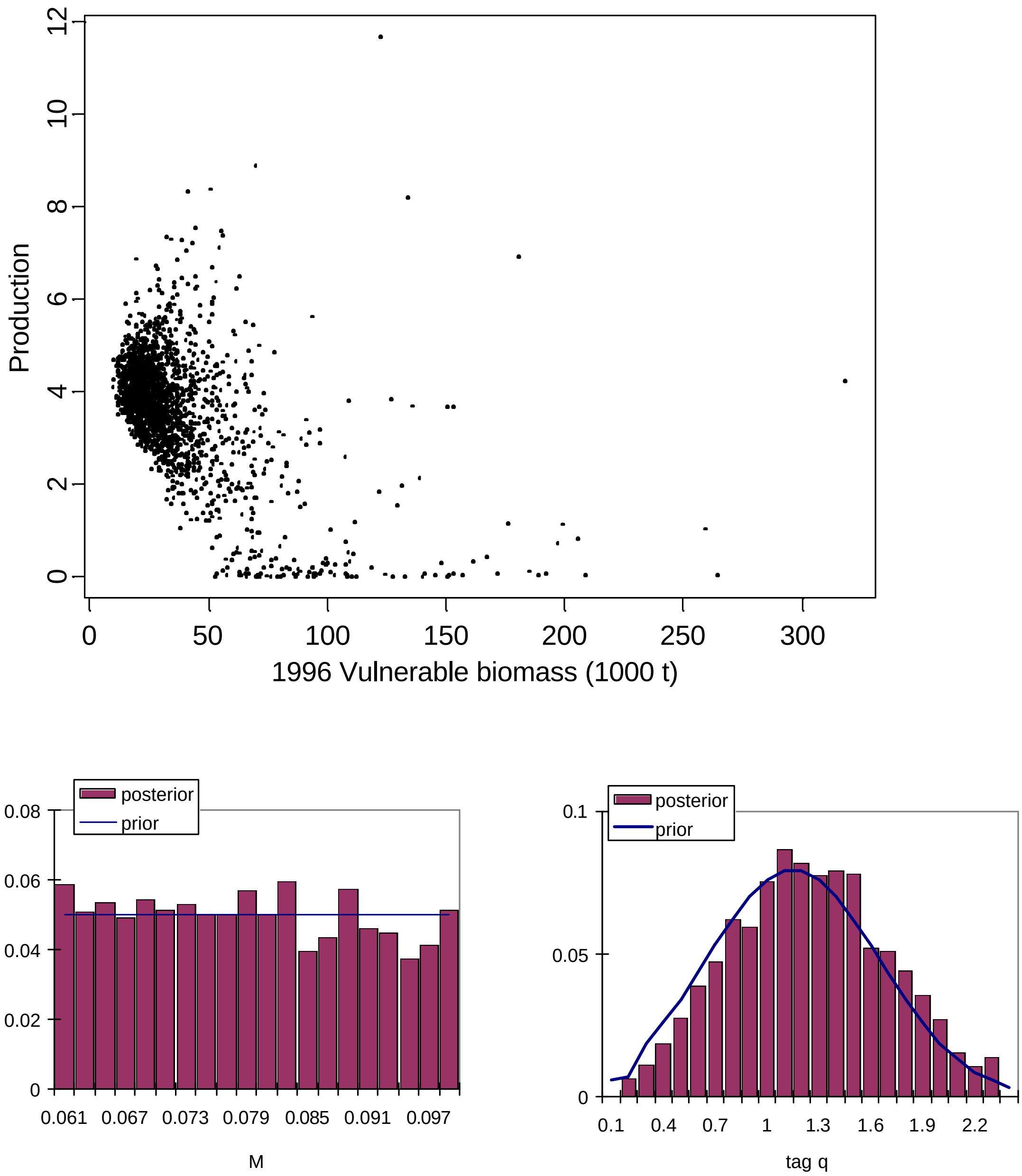


Figure 53 Posterior joint distribution for the model parameters, B_{1996} and $\overline{P}$ (production, upper panel), and prior versus posterior distributions for model parameters M and q^1.

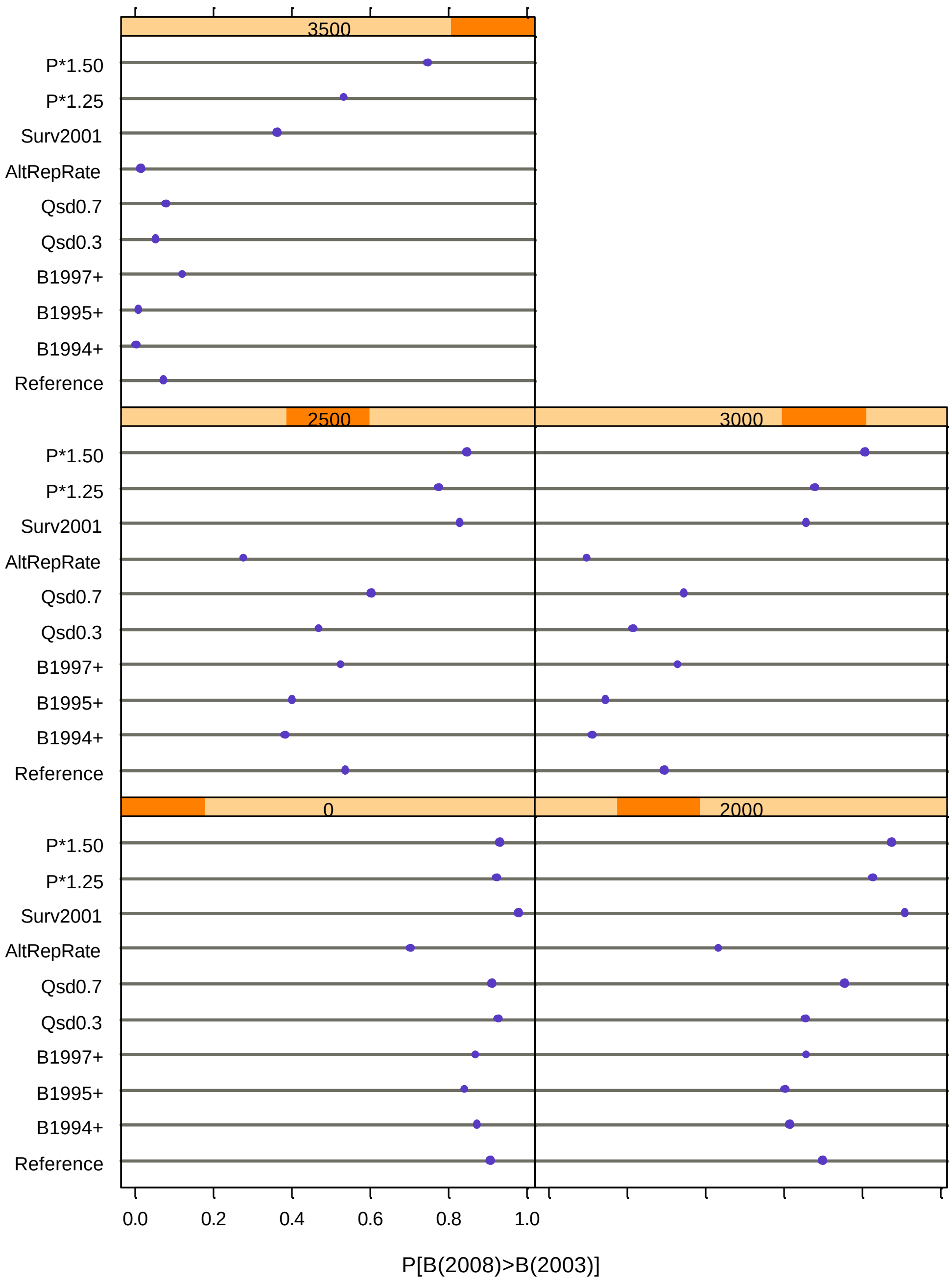


Figure 54 The probability that vulnerable stock biomass increases over the projection period $\left(P\left[B_{2008} > B_{2003}\right]\right)$, given fixed catch levels of 0, 2000, 2500, 3000, and 3500 t., for the sensitivity runs. Sensitivity runs are described in **Table 20**.

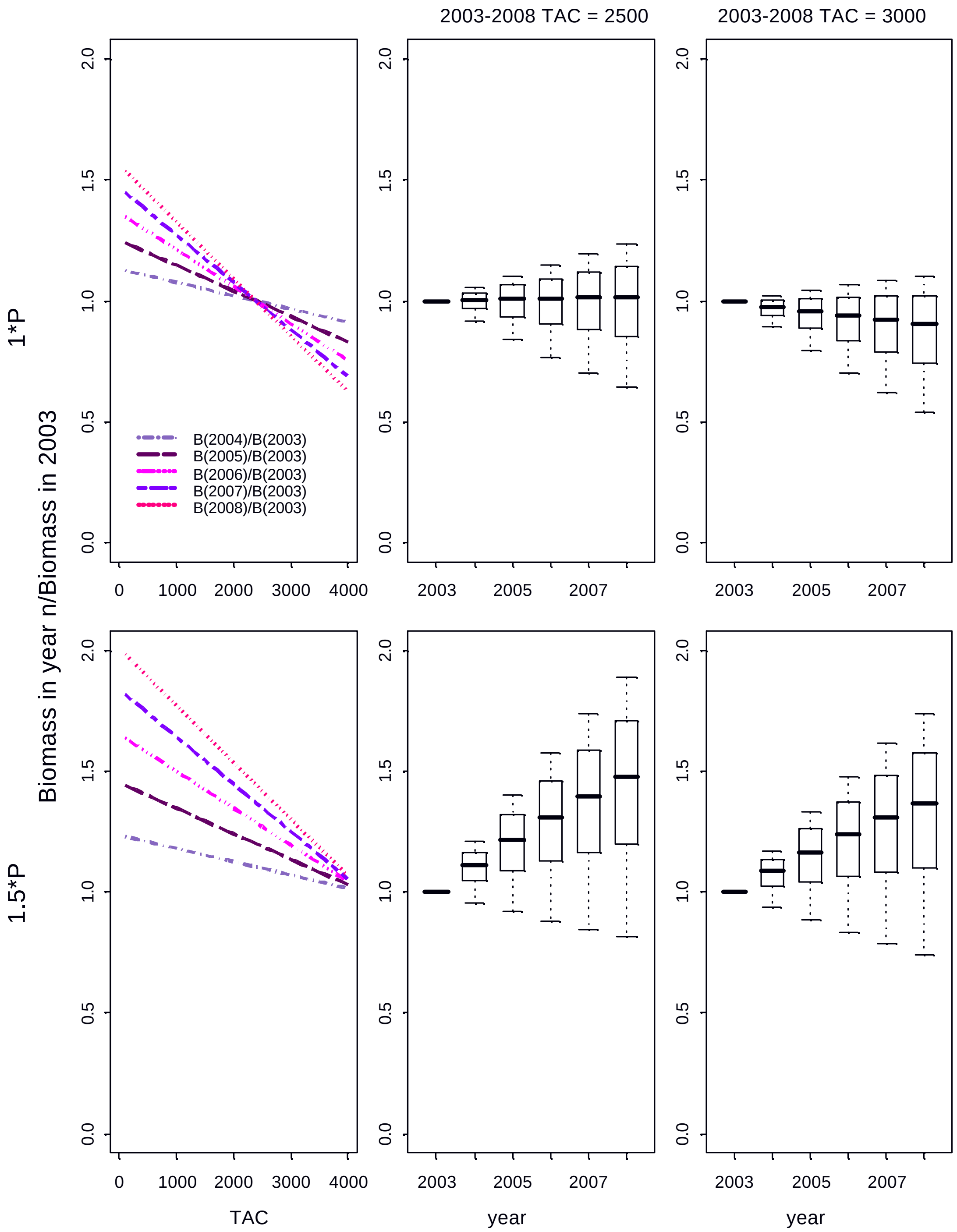


Figure 55 Expectation of vulnerable stock biomass in years 2004 through 2008, relative to vulnerable stock biomass in 2003 for catch (TAC) levels from 0 through 4000 t. (panels on left) and quantile plots of vulnerable stock biomass in years 2004 through 2008, relative to vulnerable stock biomass in 2003 for catch (TAC) levels of 2500 and 3000 t. (middle and right-hand panels). In the quantile plots the solid boxes show the interquartile range of the distributions (25th to 75th quantile) with the solid line indicating the median. The horizontal lines joined to the boxes with dashed vertical lines indicate the 10th and 90th quantiles of the distributions.

Appendix A. PSARC Groundfish Subcommittee Request for Working Paper

Date Submitted:

Individual or group requesting advice:

Proposed PSARC Presentation Date: January 15, 2003

Subject of Paper (title if developed):

Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2002 and Advice to Managers for 2003

DFO Stock Assessment Authors: A.R. Kronlund, M. Wyeth
External Authors: V. Haist, R. Hilborn

Fisheries Management Author/Reviewer:

Rational for request:

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

Objective(s) of Working Paper (author developed):

1. to analyse the indexing survey data and interpret derived abundance indices;
2. to analyse commercial catch and effort data for sablefish, comparing trends derived from these data to those obtained from the indexing survey data;
3. to update the tag-recovery analysis used to compute relative abundance of sablefish and consider sensitivity of results to model assumptions;
4. to provide yield recommendations for the 2003/2004 fishery and other advice to fishery managers where appropriate.

Appendix B. Sources of landings and catch data

Reconstructing historical catches and landings for sablefish involves collating data from multiple sources. The purpose of this appendix is to document the data sources, data characteristics and data selection criteria. Landings are defined as fish that are declared, or validated at dockside. Catch is defined as fish captured, which includes retained and discarded fish. Data are summarised by calendar year rather than by fishing year. As is usual for fisheries without at-sea observer coverage, enumeration of the discarded catch is problematic. The landings history is compared to previous summaries to document differences and provide rationale for the data selection choices.

Data Sources

McFarlane and Beamish (1983a): 1913 to 1981

Sablefish landings data for the period from 1913 to 1981 were collated and summarised by McFarlane and Beamish (1983). Their Tables 1 through 4 were adopted as accepted landings figures for years not covered by the database data sources outlined below. Landings were not separated by gear type until 1951, and a portion of the landings prior to 1951 may have been caught outside Canadian waters. In 1951, an increase in the resolution of data collection made it possible to distinguish fish caught outside of Canadian waters. Foreign catches are not separated by gear type and there is little information on USSR catches prior to 1973.

GFCatch: 1954 to 1994

The GFCatch database is maintained by DFO at the Pacific Biological Station in Nanaimo, British Columbia on a SQL Server platform (http://pacpbsgfdb/sql/). This database holds commercial groundfish catch and effort data recorded from 1954 to 1995. Fisher or observer logbooks, fisher interviews, offload observations, and landing records were reconciled to provide a "best" estimate of catch and effort for each fishing event. A fishing event is a single set or a group of sets within a common area. A landing record was either a sales slip or Dockside Monitoring Program (DMP) validation record. Sales slips are mandatory records produced by the fish buyers that indicate species, product, weight, landing date, vessel and some estimates of the area of capture and effort. Validation records obtained from the DMP were essentially more detailed and accurate sales slips with weights of fish unloaded independently observed at the dock. Details concerning the content, data sources, structure, and data processing can be found in Rutherford (1999).

Species catch weights for each fishing event are qualified by a utilization code that indicates the fate of the fish. Landings were defined to be all fates except "Discarded" and "Dumped".

Trawl

GFCatch holds groundfish trawl trips from 1954 to 1995. From 1954 to 1990, multiple tows in a management area were aggregated into a single fishing event. Submission of the logbook was voluntary, few discard data were recorded, and there was poor identification of similar species such as the rockfishes (*Sebastes*). In 1987, logbook submission became mandatory in the trawl fleet. In 1991 tow-by-tow records were entered, followed by the addition of geographic co-ordinates in 1994. The submission of detailed logbook information including geographic positions became mandatory in 1994. Data obtained from a few at-sea observer trips was also entered into GFCatch in place of the associated fisher logbooks. Trawl landings records are primarily sales slip but may have been augmented by observed landings. Dockside monitoring became mandatory for most landings in 1994 (Strait of Georgia and West Coast of Vancouver Island hake were excluded) and all landings in 1995.

Trap

GFCatch holds sablefish trap fishing trips from 1979 to 1995. From 1979 to 1989, logbook submission was voluntary and multiple sets in an area were combined into single events. In 1990 logbook submission became mandatory and set-by-set data were entered. From 1979 to 1989, landing records were primarily sales slips and in 1990 mandatory dockside monitoring to validate landings was implemented.

Longline

GFCatch holds most longline data from 1979 to 1986, with multiple sets in an area grouped into single fishing events. Landings records were primarily sales slips. Data entry ceased in 1986 due to staffing reductions.

PacHarvTrawl (http://pacpbsgfdb/sql/)

Trawl catch and effort data from 1996 until the present is maintained by DFO at the Pacific Biological Station, Nanaimo, B.C. The PacHarvTrawl database runs on a SQL Server platform. For each trip, the database contains DMP validation records as well as detailed tow-by-tow records from the fisher or observer logbooks. The logbook and DMP data are linked so it is possible to create an "official" catch based on a comparison of the logbook catch estimates to the actual weight of fish landed. Observer coverage is 100 percent for fishing that intercepts sablefish, thus there are detailed records of estimated discards.

PacHarvHL http://pacpbsgfdb/sql/

Longline catch and effort data from the rockfish and halibut fishery from 1991 to the present are maintained by DFO at the Pacific Biological Station, Nanaimo, B.C. The database is called PacHarvHL and runs on a SQL Server platform. For the Zn fishery, each trip has dockside validation records as well as set-by-set logbook records. Both observer and fisher logs are entered for the Zn fishery so there is the potential for catch duplication during a query. For the “L” halibut fishery, there are only observer logs and dockside validation data; fisher logbooks are maintained by the International Pacific Halibut Commission. Observer logbook records contain significant amounts of retained sablefish yet there is very little landed sablefish. This discrepancy is due to the fact that longline vessels typically fish combination trips and land sablefish under a “K” license. The landings records for the retained sablefish that occur in the PacHarvHL logbook data can be found in PacHarvSable where “K” fishery validation data are stored.

PacHarvSable (http://pacpbsgfdb/sql/)

PacHarvSable is a recently constructed database running on a SQL Server platform and maintained by DFO at the Pacific Biological Station in Nanaimo, B.C. PacHarvSable holds detailed set-by-set fishing records from trap and longline fisher logbook data for the K fishery from 1990 to the present. Validated landings from the DMP are available from 1995 to the present. Longline fisher logbook records are also stored in PacHarvSable for the period 1987 to 1989. Fisher logs and validation records are linked, so that “official” catch can be extracted based on comparison of the logbook catch estimates to the actual weight of fish landed.

PacHarv3.0

PacHarv3.0 is an ORACLE-based database that holds sales slip data from 1982 to the present. The DFO Catch Statistics Unit in Vancouver, B.C. maintains the database. Sablefish sales slip records are drawn from longline, trap, trawl, troll and handline gear types.

Reconstruction of Landings History

Data sources. For historical data from 1913 to 1950, and foreign landings from 1964 to 1981, the summaries of McFarlane and Beamish (1983a, their Tables 1 and 4, respectively) were adopted. For trawl landings from 1951 to 1953, Tables 2 and 3 from McFarlane and Beamish (1983a) were used. From 1954 to 1995, trawl landings were selected from GFCatch, and from 1996 to the present, PacHarvTrawl was the data source. For trap landings from 1951 to 1978, Tables 2 and 3 from McFarlane and Beamish (1983) were used. For trap landings from 1979 to 1995 the data were drawn from GFCatch, and from 1996 to the present, PacHarvSable data were selected. McFarlane and Beamish (1983, their Tables 2 and 3) were used for longline landings from 1951 to 1978. GFCatch was the source of longline landings from 1979 to 1986, and from 1987 to 1994, PacHarv3.0 was used. Longline landings from 1995 to the present are selected from PacHarvSable. For other gear types, the 1951 to 1981 data are drawn from McFarlane and Beamish (1983, their Tables 2 and 3), while data from 1982 onwards were obtained from PacHarv3.0. Data sources are summarized in the following table:

Period	Trawl	Trap	Longline	Other	Foreign
1913 - 1950	Table 1	Table 1	Table 1	Table 1	
1951 - 1953	Table 2,3	Table 2,3	Table 2,3	Table 2,3	
1954 - 1963	GFCatch	Table 2,3	Table 2,3	Table 2,3	
1964 - 1978	GFCatch	Table 2,3	Table 2,3	Table 2,3	Table 4
1979 - 1981	GFCatch	GFCatch	GFCatch	Table 2,3	Table 4
1982 - 1986	GFCatch	GFCatch	GFCatch	PacHarv3	
1987 - 1994	GFCatch	GFCatch	PacHarv3	PacHarv3	
1995	GFCatch	PacHarvSable	PacHarvSable	PacHarv3	
1996-present	PacHarvTrawl	PacHarvSable	PacHarvSable	PacHarv3	

Differences from previous assessment documents. There are numerous differences between the landings data presented in this document and previous assessments (e.g. Haist et al. 2001, their Table 1). Of those, 69 differ by less than 1 mt and were ignored. Table B.1 lists differences that are greater than 1 mt for data summarized to August 12, 2002. The differences reflect new data, auditing and correcting of historical data, and new electronic data retrieval capability for some data sources.

Distribution of catch by area

The proportion of catch by north and south stock areas over time is listed in Table B.2. The table also contains the proportion of catch with associated effort data for the north and south stock areas, and the corresponding coast-wide proportions.

Note that the total annual landings differ from the landings by area, year, and month used in the tag-recovery analyses. This is because the total annual landings are calculated based on the landing date, while the area and month of a landing are assigned based on the set date and position. If a fishing trip includes January 1, a set may occur in one year while the landing occurs in the following year. In addition, the total annual landings include fish captured during research trips, which are excluded from the tagging analyses.

"Official" Landed Weight

The "official" landed weight per set is calculated as follows:

1. From the fisher or observer logs, sum the total weight of each species caught and retained per trip and then calculate the proportion of this total caught in each set;
2. Multiply the proportions from Step 1 by the validated landed round weight of each species recorded at dockside, i.e. the landed weight is considered the true weight;
3. Assign species recorded at dockside, but not recorded by the fisher, to a dummy set number 999;
4. Species recorded by the fisher as discarded at sea are given a landed weight of 0.

Table B.1 Differences in landings history between this document and previous summaries.

Year	Column	New	Old	Difference	Reason for difference
1957	trawl	50.97	47.10	3.87	likely due to addition of data to GFCatch
1959	trawl	88.17	57.30	30.87	likely due to addition of data to GFCatch
1966	trawl	311.90	309.70	2.20	likely due to addition of data to GFCatch
1968	trawl	167.02	156.00	11.02	likely due to addition of data to GFCatch
1970	trawl	165.86	116.50	49.36	likely due to addition of data to GFCatch
1973	foreign	3,038.00	3,032.00	6.00	USSR catch was not included
1976	trawl	382.04	379.00	3.04	likely due to addition of data to GFCatch
1983	trap	3,610.52	3,678.00	-67.48	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1987	other	0.68	56.10	-55.42	
1987	longline	1,268.57	1,133.40	135.17	
1988	trawl	637.27	638.60	-1.33	old data included some sablefish captured on seamounts
1988	trap	3,488.50	3,509.70	-21.20	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1988	longline	1,273.59	1,194.30	79.29	
1989	trap	3,772.04	3,828.30	-56.26	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1990	trap	3,072.39	3,162.10	-89.71	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1991	trap	3,494.43	3,582.00	-87.57	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1991	longline	1,179.16	1,089.20	89.96	
1992	trap	3,710.23	3,789.20	-78.97	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1992	longline	847.50	889.10	-41.60	
1993	trap	4,142.38	4,168.40	-26.02	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1993	other	0.06	4.30	-4.24	

Year	Column	New	Old	Difference	Reason for difference
1993	longline	424.24	371.60	52.64	
1994	trap	4,050.72	4,090.60	-39.88	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1994	longline	467.69	511.00	-43.31	
1995	longline	474.3	281.7	192.6	
1995	trap	3,272.3	3,319.0	-46.7	if we use PacHarvSable
1995	trap	3,321.93	3,319.00	2.93	if we use GFCatch, likely due to addition of data
1995	trawl	427.42	406.50	20.92	likely due to addition of data to GFCatch
1996	trawl	190.82	211.00	-20.18	
1996	trap	2,999.5	2,914.4	85.1	
1996	longline	278.7	253.6	25.1	
1997	trawl	157.34	285.00	-127.66	
1997	trap	3,555.3	3,480.2	75.1	
1997	longline	430.6	412.8	17.8	
1998	trawl	376.63	328.00	48.63	possibly new data added to PacHarvTrawl
1998	longline	443.7	445.9	-2.2	
1998	trap	3,772.1	3,718.1	54.0	
1999	trawl	403.05	399.60	3.45	possibly new data added to PacHarvTrawl
1999	longline	628.1	608.1	20.0	
1999	trap	3,665.7	3,709.4	-43.7	
2000	trap	2727.5	2729.6	-2.1	

Table B.2 Distribution of annual landings by area, and the proportion of landings with associated effort data by area.

	Proportion of landings by area		Proportion of landings with effort by area		
Year	**North**	**South**	**North**	**South**	**Coast**
1979	0.62	0.38	0.89	0.68	0.81
1980	0.37	0.63	0.96	0.74	0.83
1981	0.64	0.36	0.91	0.88	0.90
1982	0.60	0.40	0.79	0.71	0.76
1983	0.66	0.34	0.84	0.76	0.81
1984	0.54	0.46	0.89	0.75	0.82
1985	0.46	0.54	0.90	0.73	0.81
1986	0.60	0.40	0.86	0.76	0.81
1987	0.49	0.51	0.69	0.55	0.62
1988	0.63	0.37	0.97	1.00	0.98
1989	0.54	0.46	0.81	0.94	0.87
1990	0.58	0.42	1.00	0.98	0.99
1991	0.87	0.13	1.00	1.00	1.00
1992	0.94	0.06	0.92	0.70	0.91
1993	0.73	0.27	0.90	0.91	0.90
1994	0.69	0.31	0.99	0.74	0.91
1995	0.63	0.37	0.81	0.57	0.72
1996	0.67	0.33	0.94	1.00	0.96
1997	0.62	0.38	1.00	0.98	0.99
1998	0.45	0.55	1.00	0.99	0.99
1999	0.69	0.31	1.00	1.00	1.00
2000	0.77	0.23	0.99	1.00	0.99
2001	0.57	0.43	1.00	1.00	1.00

Appendix C. Standardized CPUE data selection

Data source. Commercial logbook data reported by longline and trap vessels fishing under a sablefish "K" licence are stored in the PacHarvSable database. The data include fishing event information by set such as the vessel, date, time, position to decimal minute, and a gear description. Catch information is recorded for each set including the species, product and a use code to indicate whether the fish were retained or discarded, used as bait, etc. With few exceptions, at-sea observers do not validate logbook data, although dockside validation of the landed catch was instituted in 1990. However, only 1995 to 2002 data are currently available in PacHarvSable.

Data selection for standardized CPUE analysis. Data records were excluded from the analysis either because they represented catch that was outside the geographic range of the intended analysis, or because they contained information that was potentially erroneous. Records were excluded on the basis of the following criteria:

Location information	• fishing locations in Hecate Strait, Strait of Georgia, or Johnson Strait • fishing locations at Seamounts • minor area code or locality code was "blank" or "0" • latitude was <40 degrees or longitude was <120 degrees, or minutes was > 60
Research sets	• purpose code was "charter" • trip ID was 1940 [appears to be a charter trip, but not coded as such]
Other	• start or end bottom depth are <5 m • distance between the start and end of set or string is > 20 nm • for trap gear, the number of traps set is < 20 or >500 • for longline gear, the number of hooks set is <=0 or > 10,000 • for trap gear, the duration of the set is <= 0 or >30 days (Note: this criterion was not applied to the longline data because a high proportion of the records would be excluded)

Table C.2 summarizes the number of fishing records before and after the data grooming process.

For the CPUE standardization analysis a sub-set of these data were selected based on a "core" fishing master criterion (described in Section 6.1). At that point an additional 5 records, representing commercial trap fishing sets conducted without escape-rings during the 2000 fall charter program, were removed from the trap fishery data set. These were the only post-1997 trap fishery sets, recorded in the groomed data set, which had been conducted without escape-rings.

Table C.1 Ratios of the total weight of discarded sablefish to the total weight of landed sablefish, by fishing master (FM) and year. Cells that are empty indicate no logbook records for that year whereas cells that contain zero's indicate no discarded sablefish reported in the logbooks.

FM	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1	0.000	0.000	0.000										
2			0.000				0.000						
3	0.261	0.006	0.003	0.001	0.000	0.000	0.454	0.118	0.001	0.000	0.000	0.000	0.000
4						0.484	0.000						
5	0.051	0.193											
6	0.422	0.463	0.000										
7	0.000	0.128											
8					0.011	0.000	0.000	0.029					
9	0.000												
10	0.000												
11							0.000	0.000					
12						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000			
14			0.000	0.000									
15								0.002	0.000	0.000	0.000	0.000	
16	0.000	0.037		0.000								0.000	0.000
17											0.018	0.000	0.000
18	0.000	0.057		0.000					0.000				
19												0.000	0.000
20					0.000								
21					0.000	0.185	0.169	0.123	0.107	0.056	0.093	0.092	0.17
22									0.000	0.000	0.013	0.020	0.000
23	0.082	0.013	0.000	0.005	0.000				0.000				
24		0.041	0.047	0.047	0.083		0.283			0.005	0.007	0.044	
25						0.000	0.000	0.000	0.000	0.000			
26							0.000	0.000	0.000	0.000			
27	0.029	0.011	0.014	0.017	0.000	0.000				0.000		0.000	0.000
28			0.010	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.018	0.029		0.036	0.000	0.000			0.000				
30				0.005	0.000	0.000			0.099				
31									0.026				
32								0.000					
33		0.064	0.022	0.033	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.09
34			0.000	0.000	0.000	0.222			0.330	0.033			
35	0.005	0.013	0.018	0.004					0.000				
36		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37			0.000	0.000	0.000	0.370	0.264	0.549	0.477	0.234	0.376	0.306	0.61
38	0.037	0.033	0.045		0.080	0.086	0.087	0.082	0.070	0.044	0.029	0.032	0.05
39									0.000	0.000			
40											1.216	0.000	
41	0.040		0.102		0.249	0.245							
42							0.000						
43		0.000	0.000									0.000	
44											0.116	0.414	0.16
45								0.128					
46										0.000	0.000		

Table C.2 The number of sablefish logbook data records prior and post data grooming and data selection for standardized CPUE analysis.

Number of Records	Trap fishery	Longline Fishery
Extracted from PACHARV system	45,088	16,941
Post data grooming	37,505	15,326
Selected for CPUE analysis based on “Core” vessel masters	31,674	9,346
Selected for CPUE analysis, after removal of zero catch records	31,600	9,297

Table C.3 Number of trap-fishery sets reported in logbooks by fishing master and year. Masters with 5 or more years of experience were included in the GLM analysis.

Fishing master	inc.	Year 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1	1		50	348	374	366	224	273	408	510	426	213	570	223
2	1			42	437	473	601	570	390	341	317	296	304	27
3	1	181	276	256		278	317	230	417	349	400	225	266	230
4	1	90	131	212	266	253	21	269	417	402	276	406	144	157
5	1		101	127	207	234	280	238	372	342	371	56	385	122
6	1						154	192	414	592	531	248	476	136
7	1					65	57	97	42	314	441	556	480	261
8	1	283	55	151		401	204	220	370	92	249			
9	1									227	396	398	171	113
10	1	49	81	118	112	127	309				44		14	218
11	1			19	25	43	68	67	203	165	121	79	187	95
12	1								339	181	104	113	92	
13	1	88	132	99	145	71				210				
14	1		104	69	63	86		39			117	44	47	
15	1	134	49		41	164	17			91				
16	1						44	118	95	112	58			
17	1	105	125		37								56	86
18	1	60	159	20	40					98				
19	1			39	10	37	32			50	42			
20	0											276	413	223
21	0							440	283					
22	0					130	142	47	81					
23	0	215	89	65										
24	0								307					
25	0		82	109									99	
26	0	79	166	42										
27	0	69		52		118	45							
28	0											77	102	51
29	0	57	90		61					7				
30	0				72	62	29			51				
31	0							9	58	74	69			
32	0												43	124
33	0						84	76						
34	0										37	116		
35	0			100	33									
36	0											36	90	
37	0	76	42											
38	0								114					
39	0									29	81			
40	0	75												
41	0							62						
42	0					54								
43	0	11	34											
44	0									36				
45	0	30												
46	0			2										
Total sets		1602	1766	1870	1923	2962	2628	2947	4310	4273	4080	3139	3939	2066
Selected sets		990	1263	1500	1757	2598	2328	2313	3467	4076	3893	2634	3192	1668
Prop. selected		0.62	0.72	0.80	0.91	0.88	0.89	0.78	0.80	0.95	0.95	0.84	0.81	0.81

Table C.4 Number of longline-fishery sets reported in logbooks by fishing master and year. Masters with 5 or more years of experience were included in the GLM analysis.

Master		Year															
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1	1		84	87	150	121	118	170	201	181							
2	1				155	234						107	14	96	172	140	13
3	1											17		331	245	207	50
4	1		26	37	172		190	120		137						71	65
5	1		82	65	66				91	76	5		100	104	122		
6	1			39	58	55	37	33	42	55		58	53	67	58	72	14
7	1		63		63	152	167	110		66							
8	1					23	6	31	59	46	44	57	63	139	95		
9	1								113	55	61	77	73	48	92		
10	1		78	90	177	101			34								
11	1								101		183	45	38	30	46	23	
12	1				105	69	54							44	23	42	
13	1	31	37	54	59	61			7	13	3	4		6			
14	1				90	80		14							17	17	
15	1		18	14	52	27	41	33	22								
16	1		35	25	32		47	40	9			1					
17	1				94	26	7			8		6	3	12	13	13	5
18	1		57	56	14		2				21			19	3		
19	0			84	200	78				27							
20	0				219	42	93			1	34						
21	0		61	59	118	98											
22	0															243	66
23	0															125	157
24	0								79	27				74	74		
25	0					32	167				1	46					
26	0											84	144				
27	0								13	44		99			2		42
28	0										6		3	64	36	89	
29	0					75								26	12	78	
30	0				88	49	34										3
31	0														170		
32	0														132	30	
33	0													54	52	30	19
34	0									41					58	25	22
35	0													75	55		
36	0				81	48											
37	0		16		53			48									
38	0		67	44													
39	0										83			26			
40	0					68										28	12
41	0		79					26									
42	0														40	50	
43	0				36	52											
44	0		73														15
45	0														78		
46	0	77															
47	0				66												
48	0													66			
49	0							7	58								
50	0																63
51	0									60							
52	0			54									1				
53	0					46											
54	0		45														
55	0		20				23										

Master		Year															
		1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
56	0									39				2			
57	0														38		
58	0																37
59	0				31											4	
60	0					31											
61	0															30	
62	0												21				
63	0		20														
64	0				20												
65	0															17	
66	0		14					2									
67	0														4		7
68	0													3	2	5	
69	0														9		
70	0														9		
71	0																7
72	0																4
73	0					3											
74	0															3	
75	0														2		
76	0													2			
Total sets		108	875	708	2199	1571	986	634	829	876	441	601	513	1288	1659	1342	601
Selected sets		31	480	467	1287	949	669	551	679	637	317	372	344	896	886	585	147
Prop. selected		0.29	0.55	0.66	0.59	0.60	0.68	0.87	0.82	0.73	0.72	0.62	0.67	0.70	0.53	0.44	0.24

Table C.5 Total catch of all species recorded in the sablefish logbook data records, by catch utilization.

Spp.	Name	unknown	retained	dumped	bait	discarded
015	Unknown fish		815			40360
026	Cow sharks		272			762
027	Sixgill shark					445
038	Brown cat shark					1
041	Blue shark					158
043	Pacific sleeper shark					181
044	Spiny dogfish	45	25850			53664
051	Skates		273			8971
059	Longnose skate					317
066	Spotted ratfish					54
222	Pacific cod		290			91
225	Pacific hake					11
249	Grenadiers		100			9881
359	Prowfish					4
388	Scorpionfish		202444[1]			79751[1]
394	Rougheye rockfish		266287			69698
396	Pacific ocean perch		7574			4609
401	Redbanded rockfish		45439			1603
403	Shortraker rockfish		59744			1643
405	Silvergray rockfish		607			12
414	Greenstriped rockfish					1
417	Widow rockfish		27			
418	Yellowtail rockfish					4
421	Rosethorn rockfish		1842			7
433	Tiger rockfish		13			
435	Bocaccio		464			
437	Canary rockfish		4033			5
439	Redstripe rockfish		795			
440	Yellowmouth rockfish		758			12
442	Yelloweye rockfish		29409			72
451	Shortspine thornyhead		8965			1449
452	Thornyheads		185			1905
455	Sablefish		33411965			1102323
458	Skilfish		122			
467	Lingcod		8381			2316
595	Lefteye flounders		2196			56
602	Arrowtooth flounder		15681			79269
614	Pacific halibut		258277			122294
626	Dover sole		218			1789
638	Greenland halibut					921

[1] Possibly mis-coded rougheye rockfish

Appendix D. Indexing survey and data selection

Background. Documentation of sablefish abundance indexing surveys can be found in Smith et al. (1996) for 1988 to 1993, Downes et al. (1997) for 1994 and 1995, and Archipelago Marine Research (2000) for 2000. Surveys conducted from 1996 to 1999 and 2001 to 2002 are not documented in a published report. Tagging and biological studies conducted during 1982 to 1987 (Murie et al. 1995) are not considered comparable to the 1988 to 2001 surveys for the purpose of providing a time series of indexing data.

Survey locations. In 1988, eight indexing localities were purposively chosen for inclusion in an annual fishery-independent survey (Table D.1, Figure 22 to Figure 24). The survey was initiated to apply tags, collect biological data, and to establish index sites. The eight localities were selected because they were fished by commercial vessels and were spatially dispersed about 60 nm apart such that normal weather conditions would permit all localities to be occupied within a 30 day period. A ninth locality (Cape St. James) was added in 1994. Sets conducted at sporadically distributed times and locations have not been included in the indexing survey time series. Not all survey localities were visited in each year of the time series.

Survey timing. The timing of the survey sets from 1990 to 2001 has ranged from September 24 (1998) to November 20 (1990). Table D.2 lists the start and end dates of the survey by year and locality, where the start date is the day of the first survey index set and end date is the day of the last survey index haul. A given research cruise or charter may have been longer in duration than indicated in Table D.2 to accommodate tagging sets and a component of the work conducted in inlets. Figure D.1 shows the overlap in annual survey timing graphically, where each circle represents the start date of one survey set. The circles have been randomly perturbed, or jittered, along the y-axis of the plot to expose sets conducted on the same day. Survey timing shows a progressive enthusiasm for starting earlier in the fall until 1998. The timing of the 2002 survey was near the middle of the historical range, and similar to that achieved for the 2001 survey.

Survey gear. Surveys were conducted using trap gear as described by Smith et al. (1996). Trap design since 1990 has been a modified Korean trap consistent with that used by the commercial sablefish fleet. Beginning in 1990, a standardized string of 25 traps was deployed on each survey set. Traps were prepared prior to setting; bottoms were closed, tunnels stretched into place, and a bag of 1.0 to 1.5 kg of frozen squid fastened to the inside of the trap close to the tunnel entrance. Traps were attached to the ring and becket at 25 fm (46m) intervals along the groundline.

Trap bait. In 1988 and 1989 traps were baited with 1.0 to 1.5 kg of frozen squid in bait bags and four frozen hake (*Merluccius productus*) of 0.6 to 0.8 kg apiece. In 1988 approximately 100 traps were fished on each set so that the length of the string made it difficult to maintain traps within the designated depth stratum. In 1989, the number of traps on a string was reduced to approximately 70. Because of these differences, and pending analyses to standardize the 1988 and 1989 data to the 1990 through 2001 data, the 1988 and 1989 surveys were excluded from formal analyses. Kronlund et al. (2002) deemed this change in practice from previous assessments necessary because hake-baited traps are known to fish more successfully than traps baited with squid alone (Surry et al. *In prep*.). Haist et al. (2001, their Table 4) showed that catch rates (kg/trap) were substantially higher for the tagging sets baited with squid and hake than for survey index sets baited with squid alone. Furthermore, strings of gear with 70 or more traps might have different areas of sablefish attraction than strings of 25 traps, and the majority of traps set may not lie fully in a single depth stratum due to the length of the groundline.

Depth stratification. The indexing survey was depth stratified in the sense that sets in each locality were targeted within five depth ranges from 1990 to 2001 (three depth ranges in 1988 and 1989, Table D.3). In 1999, a sixth depth stratum was added to the Queen Charlotte Island localities between 600 and 800 fm. In 2000, three deep strata were added off the west coast of Vancouver Island: 650 to 700 fm, 750 to 800 fm, and 800 fm and deeper. A single 600 to 800 fm depth stratum was retained off the Queen Charlotte Islands due to the difficulty of setting gear accurately within 50 fm strata bounds in rugged bathymetric features. In 2002, depth strata at 650 to 750 fm and 750 to 999 fm were added to all survey localities. Deep strata at other sites not in the nine localities were discontinued (Table D.3). Data obtained from the first five depth strata were used in the computation of the index series since data were available for the entire time series.

Spatial distribution of sets. Spatial positions of the survey sets were not randomized, rather the fishing master had discretion to set gear within each designated depth stratum in each locality. With rare exceptions, there was no replication of sets by depth and locality during the 1990 to 2001 period; usually a single set was conducted within each depth stratum for a given locality (Table D.4). Also, due to the logistical difficulties of setting gear, a survey set may have been fished outside the intended depth stratum. Thus, some analyses use a mean observed depth to assign each set to a stratum rather than the target depth. The mean depth was determined by averaging the depth recorded at one-minute intervals between anchors.

Survey vessels. Table D.2 also lists the vessel and skipper used in each survey year. The R/V W.E. Ricker carried out the surveys in 1991 to 1993 under the on-board direction of an experienced skipper from the sablefish industry. Surveys in other years have utilized a commercial charter vessel and experienced skipper. Indexing surveys conducted in 1996 to 1999, and 2001 used the same vessel and skipper. Similarly, the 2000 and 2002 indexing survey shared a common vessel and skipper. Onboard scientific staff from Fisheries and Oceans Canada, or provided through contractors, have varied over the 1990 to 2002 series.

Biological sampling. Sablefish caught on survey sets, as opposed to sets designated for tag application, were sampled for length, sex, and maturity. Otoliths were excised for subsequent age determination. Sablefish weight and girth were measured at times, and stomachs were sometimes sampled for gut content analysis. Tags may have been applied to sablefish caught by indexing sets when large catches were achieved.

Data selection for analysis. Data from the fishery independent survey data were assembled from 1990 to 2002. Data were included in analyses if the gear was set for the standard index survey (REASON.CODE=13) and the trap usability code was 1, indicating that the gear was fishing correctly and not snarled or holed. Specific sets were excluded from the analysis as identified in Table D.5.

2002 Indexing survey data. Table D.6 is a summary of the catches and sampling for the 2002 sablefish indexing survey. In contrast to the survey data analysis, there are no selection criteria for the data in these tables. Entries in the tables show (1) the intended depth stratum rather than the depth stratum actually achieved, (2) the number of traps hauled rather than the traps fishing correctly, and (3) the nominal catch per trap by numbers and weight computed from the table entries. Note that the total number of sablefish recorded while hauling gear does not always equal the sum of sampled and recovered fish. In contrast to previous surveys, the indexing charter vessel did not conduct offshore tagging in 2002.

Summary of indexing time series. Mean catch rates per trap are reported for each survey locality in numbers per trap (Table D.7) and in weight (kg) per trap (Table D.8). Survey data were explored by separating the depth effect within each locality (Figure D.2). Panels in the figure show the catch rate (mean number of fish per trap) observed for each indexing set by year, locality, and depth stratum. The solid curve in each panel was independently determined using loess smoothing regression of catch rates conditioned on year. Patterns of decline from the early 1990s are similar to those observed using more aggregated views of the data. Catch rate observations for 2001 are clearly the lowest on record. Three features emerge from this presentation of the data (1) significant increases in catch rates occurred in the first three depth strata at Langara Island-North Frederick, Hippa Island, and to a lesser extent at Buck Point, (2) catch rates are without trend or decreasing at most depths from the mid-1990s at localities south of Buck Point; and (3) variation around the trend lines is relatively small.

Table D.1 Geographic boundaries of the standard survey locations.

Locality	Latitude North				Longitude West			
	Maximum		Minimum		Maximum		Minimum	
Langara Is.-North Frederick	54º	9’	53º	59’	134º	2’	133º	32’
Hippa Island	53º	32’	53º	20’	133º	24’	132º	55’
Buck Point	53º	14’	53º	1’	133º	10’	132º	35’
Gowgaia Bay	52º	27’	52º	17’	131º	51’	131º	33’
Cape St. James	51º	50’	51º	37’	130º	59’	130º	19’
Triangle Island	51º	8’	50º	58’	129º	55’	129º	31’
Quatsino Sound	50º	25’	50º	12’	128º	38’	128º	8’
Esperanza Inlet	49º	47’	49º	24’	127º	39’	127º	13’
Barkley Canyon	48º	24’	48º	10’	126º	12’	125º	53’

Table D.2 Indexing vessel timing, and skipper, for 1988 to 2002. Start Date is the date of the first indexing set and End Date is the date of the last indexing haul.

Year	Vessel	Skipper	Start Date	End Date	Trip ID
1988	F/V Vicious Fisher	Fletcher	October 31	November 23	43990
1989	F/V La Porsche	Brynjolfsen	October 21	November 17	43910
1990	F/V Viking Star	Farrington	November 08	November 18	43750
1991	R/V W.E. Ricker	Farrington	October 10	October 28	43673
1992	R/V W.E. Ricker	Roberts	October 15	November 03	43670
1993	R/V W.E. Ricker	Farrington	October 23	November 10	43650
1994	F/V La Porsche	Beauvais	October 15	October 25	43630
	F/V Western Viking	Jones	October 19	November 07	43390
1995	F/V Victor F	Derry	October 15	October 28	43330
	F/V Viking Sunrise	Oslen	October 10	October 25	43350
	F/V Ocean Pearl	Fraumeni/Gold	October 08	October 18	43270
1996	F/V Viking Star	Elvan	October 08	October 20	43210
	F/V Ocean Pearl	Derry	September 27	October 06	43039
1997	F/V Ocean Pearl	Derry	September 27	October 14	42699
1998	F/V Ocean Pearl	Derry	September 24	October 10	41122
1999	F/V Ocean Pearl	Derry	September 29	October 17	40589
2000	F/V Pacific Viking	Melynchuck	October 08	November 11	40517
2001	F/V Ocean Pearl	Derry	October 07	October 29	43233
2002	F/V Pacific Viking	Melynchuck	October 03	November 06	NA

Table D.3 Depth strata boundaries by survey year.

Year	**Stratum**	**Start depth fm (m)**	**End depth fm (m)**
1988-1989	1	200 (366)	300 (549)
	2	300 (549)	400 (732)
	3	400 (732)	500 (915)
1990-2001	1	150 (275)	250 (457)
	2	250 (458)	350 (641)
	3	350 (642)	450 (824)
	4	450 (825)	550 (1006)
	5	550 (1007)	Deeper
2002	1	150 (274)	249 (457)
	2	250 (457)	349 (641)
	3	350 (641)	449 (824)
	4	450 (824)	549 (1006)
	5	550 (1006)	649 (1189)
	6	650 (1189)	749 (1389)
	7	750 (1372)	999 (1827)

Table D.4 Number of indexing sets at each survey locality by depth stratum and year. The number of intended sets is shown followed by the number of sets achieved and included in the analysis in parentheses. The achieved depth stratum was calculated based on the mean of depth observations taken at one minute intervals.

Locality	**Depth Stratum**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Barkley Canyon	1			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)
	2	2 (2)	2 (2)	1 (1)	2 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)
	3	2 (2)	2 (2)	1 (1)	2 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	4	2 (2)	2 (2)	1 (1)	2 (2)	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (1)
	5	2 (1)	2 (2)	1 (1)	2 (2)	1	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)
Esperanza Inlet	1			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	2	2 (2)		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)	1	1 (1)	1 (1)	1 (1)	3 (4)
	3	2 (2)		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	4	2 (3)		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (2)
	5	2 (1)		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
Quatsino Sound	1			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	2	2 (1)	2 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	3	2 (2)	2 (2)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	4	2 (2)	2 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	5	2 (2)	2 (2)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Triangle Island	1			1 (1)		1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)
	2		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1	1 (1)	1 (1)
	3		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	4		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	5		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)

Table D.4. continued.

Locality	Depth Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Cape St. James	1					1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	2					1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	3					1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	4					1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)
	5					1	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)
Gowgaia Bay	1					1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	2		1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	3		1 (1)	1 (1)	2 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	3 (3)
	4		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1	3 (3)
	5		1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	3 (4)
Buck Point	1			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	2		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	3		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)
	4		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
	5		1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Hippa Island	1				1 (1)	1 (1)	1 (1)	1 (1)		1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	2			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)		1 (1)	1 (1)	1 (1)	1 (1)	3 (3)
	3			1 (1)	1 (1)	1 (1)	1 (1)	1 (1)		1 (1)	1 (2)	1 (1)	1 (1)	3 (3)
	4			1 (1)	1 (2)	1 (1)	1 (1)	1 (1)		1 (1)	1	1 (1)	1 (1)	3 (2)
	5			1 (1)	1	1	1 (1)	1 (1)		1 (1)	1 (1)	1 (1)	1 (1)	3 (5)

Table D.5 List of index sets excluded from survey data analysis.

Year	Location	Set	Depth Stratum	Reason for exclusion
1990	Barkley Canyon	23	5	only 3 traps hauled, remainder of the string lost
1994	Cape St. James	3	5	bridge log indicates extra 25 set for vessel, but not in data report, baiting unclear
1994	Gowgaia Bay	6	5	extra 50 traps for vessel, catch not recorded, baiting unclear
1994	Gowgaia Bay	11	2	extra 35 traps for vessel baited with hake and squid bait
1994	Hippa Island	18	5	extra traps for vessel, catch not recorded, baiting unclear
1994	Langara Island-North Frederick	24	5	extra 33 traps for vessel baited with hake and squid bait
1995	Cape St. James	11	3	trap set every second becket
1998	Esperanza Inlet	13	1	unsure count of traps
1998	Buck Point	57	3	tangled with another string
2001	Gowgaia Bay	66	4	set across another vessel’s string

Table D.6 2002 indexing survey data for south and north stock areas.

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish					Nominal CPUE	
				LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Fish/Trap	kg/Trap
Barkley Canyon	1	1	24	44	0	0	44	120.8	1.83	5.03
	2	2	25	frozen	0	0	63	137.4	2.52	5.50
	3	3	25	147	0	4	146	297.5	5.84	11.90
	4	4	26	152	0	2	153	289.0	5.88	11.12
	5	5	25	101	0	0	100	219.8	4.00	8.79
	6	6	25	81	0	1	81	221.9	3.24	8.88
	7	7	25	75	0	0	75	251.6	3.00	10.06
Esperanza Inlet	1	14	24	45	0	0	45	139.4	1.88	5.81
	1	28	25	6	0	0	6	17.0	0.24	0.68
	1	119	25	25	0	0	25	97.6	1.00	3.90
	2	13	25	64	0	0	64	196.6	2.56	7.86
	2	27	25	14	0	0	13	31.5	0.52	1.26
	2	120	25	19	0	0	20	62.3	0.80	2.49
	3	12	25	13	0	0	13	30.9	0.52	1.24
	3	26	25	26	0	0	26	55.8	1.04	2.23
	3	121	25	30	0	0	30	75.7	1.20	3.03
	4	11	26	74	0	3	75	165.12	2.88	6.35
	4	25	25	67	136	0	204	363.6	8.16	14.54
	4	122	25	72	126	0	197	334.0	7.88	13.36
	5	10	25	63	25	0	88	206.6	3.52	8.26
	5	24	25	64	147	1	210	469.2	8.40	18.77
	5	123	25	114	97		225	518.3	9.00	20.73
	6	9	26	19	0	0	19	66.6	0.73	2.56
	6	23	25	43	0	0	44	143.1	1.76	5.72
	6	124	25	14	0	0	15	60.3	0.60	2.41
	7	8	25	11	0	0	11	44.9	0.44	1.80
	7	22	25	11	0	0	11	43.9	0.44	1.76
	7	125	25	8	0	0	8	32.2	0.32	1.29
Quatsino Sound	1	16	25	21	0	0	21	68.0	0.84	2.72

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Nominal CPUE Fish/Trap	kg/Trap
	2	15	25	75	0	0	75	192.2	3.00	7.69
	3	17	25	49	0	0	49	100.0	1.96	4.00
	4	18	25	14	0	0	14	30.3	0.56	1.21
	5	19	25	40	0	0	40	99.8	1.60	3.99
	6	20	25	23	0	0	23	70.7	0.92	2.83
	7	21	25	11	0	0	11	47.7	0.44	1.91
Triangle Island	1	29	25	7	0	0	7	20.3	0.28	0.81
	2	30	25	frozen	0	0	42	111.1	1.68	4.44
	3	31	25	71	0	1	72	164.4	2.88	6.58
	4	32	25	13	0	0	13	43.9	0.52	1.76
	5	33	25	23	0	0	23	77.3	0.92	3.09
	6	34	25	22	0	0	22	82.8	0.88	3.31
	7	35	24	12	0	0	12	48.8	0.50	2.03
Cape St. James	1	43	25	6	0	0	6	18.6	0.24	0.74
	2	44	25	63	0	0	64	166.2	2.56	6.65
	3	45	25	132	0	0	130	316.3	5.20	12.65
	4	46	25	21	0	0	21	54.1	0.84	2.16
	5	47	25	8	0	0	8	38.1	0.32	1.52
	6	48	25	2	0	0	2	6.6	0.08	0.26
	7	49	25	5	0	0	5	22.2	0.20	0.89
Gowgaia Bay	1	42	25	34	0	0	34	100.3	1.36	4.01
	1	56	25	56	0	0	57	193.6	2.28	7.74
	1	71	25	81	46	2	127	489.2	5.08	19.57
	2	41	26	50	0	0	51	142.5	1.96	5.48
	2	55	24	41	0	0	41	114.8	1.71	4.78
	2	72	25	57	94	1	152	475.2	6.08	19.01
	3	40	25	80	0	1	84	211.1	3.36	8.44
	3	54	25	8	0	0	8	19.4	0.32	0.78
	3	73	25	60	0	1	61	190.4	2.44	7.62
	4	39	25	43	0	0	42	105.6	1.68	4.22
	4	53	25	2	0	0	2	7.0	0.08	0.28
	4	74	25	60	0	0	60	163.6	2.40	6.54
	5	38	25	41	0	0	41	138.4	1.64	5.54

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Nominal CPUE Fish/Trap	kg/Trap
	5	52	25	24	0	0	24	70.8	0.96	2.83
	5	75	25	12	0	0	12	43.1	0.48	1.72
	6	37	25	20	0	0	20	89.3	0.80	3.57
	6	51	25	12	0	0	12	65.2	0.48	2.61
	6	76	25	52	0	0	52	244.5	2.08	9.78
	7	36	25	11	0	0	11	51.4	0.44	2.06
	7	50	25	5	0	0	5	23.5	0.20	0.94
	7	77	25	8	0	0	8	41.5	0.32	1.66
Buck Point	1	70	27	60	28	0	90	302.3	3.33	11.20
	2	69	25	74	50	2	129	337.7	5.16	13.51
	3	68	25	75	0	1	71	193.7	2.84	7.75
	4	67	25	16	0	1	17	43.5	0.68	1.74
	5	66	25	18	0	0	18	57.4	0.72	2.30
	6	65	25	46	0	0	46	123.5	1.84	4.94
	7	64	25	15	0	0	15	51.7	0.60	2.07
Hippa Island	1	57	26	43	0	0	43	152.9	1.65	5.88
	1	84	26	48	93	0	143	439.7	5.50	16.91
	1	98	25	73	80	1	154	532.7	6.16	21.31
	2	58	25	65	69	0	134	418.1	5.36	16.72
	2	83	25	50	126	0	181	612.6	7.24	24.50
	2	97	25	69	43	0	112	342.9	4.48	13.72
	3	59	25	101	47	0	151	447.4	6.04	17.90
	3	82	25	117	48	0	165	485.8	6.60	19.43
	3	96	25	69	29	0	98	277.7	3.92	11.11
	4	60	25	50	0	0	50	113.9	2.00	4.56
	4	81	25	19	0	0	19	73.7	0.76	2.95
	4	95	25	50	0	0	50	176.7	2.00	7.07
	5	61	26	57	100	3	161	271.6	6.19	10.45
	5	80	25	32	0	0	32	116.8	1.28	4.67
	5	94	25	50	0	0	50	172.9	2.00	6.92
	6	62	25	13	0	0	13	55.6	0.52	2.22
	6	78	25	22	0	0	22	93.4	0.88	3.74
	6	93	25	21	0	0	21	80.1	0.84	3.20

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Nominal CPUE Fish/Trap	kg/Trap
	7	63	25	9	0	0	9	33.7	0.36	1.35
	7	79	24	7	0	0	7	36.6	0.29	1.53
	7	92	25	6	0	0	6	30.0	0.24	1.20
Langara Island-	1	85	25	72	22	0	95	382.3	3.80	15.29
North Frederick	2	86	25	163	232	0	404	1339.2	16.16	53.57
	3	87	25	64	64	0	128	403.6	5.12	16.14
	4	88	25	38	0	0	39	130.9	1.56	5.24
	5	89	25	21	0	0	21	81.2	0.84	3.25
	6	90	25	21	0	0	21	91.6	0.84	3.66
	7	91	26	14	0	0	15	67.2	0.58	2.58

Table D.7 Sample mean catch rate (number fish per trap) of survey index sets by depth stratum, locality, stock, and year. Sets assigned to depth strata based on the mean of depth observations taken at one minute intervals. Fouled or holed traps excluded from summary.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Barkley Canyon	1			13.76	23.04		7.92	3.12	7.52	1.46	2.15	2.78	0.16	1.83
	2	15.74	6.73	24.65	26.32	22.42	8.92	3.72	6.92	2.16	1.56		0.64	2.52
	3	7.38	9.50	18.92	16.78	7.84	6.40	6.08	6.88	2.36	1.87	13.28	2.64	5.84
	4	14.85	23.60	21.04	19.44	18.54	10.40	8.24	5.44	7.21	6.53	12.48	8.13	5.88
	5	11.72	15.82	19.16	12.56		7.92	9.68	6.64	8.76		11.04	5.28	4.00
	Mean	12.52	13.91	19.51	19.25	16.83	8.31	6.17	6.68	4.39	3.73	8.47	3.37	4.02
Esperanza Inlet	1			7.48	13.63	9.40	4.84	5.32	10.12	4.04	4.13	6.48	1.68	1.04
	2	8.16		12.40	16.76	8.64	8.17	2.40	4.28		2.67	5.00	0.29	1.10
	3	5.14		8.24	12.16	6.36	4.72	1.72		1.63	2.32	2.42	0.81	3.47
	4	10.33		10.60	20.48	3.52	13.45	2.72	1.58	1.52	2.04	7.33	0.96	5.42
	5	9.60		16.36	21.88	8.44	5.25	6.64	5.70	7.42	5.61	3.00	4.81	7.02
	Mean	8.40		11.02	16.98	7.27	7.29	3.76	5.19	3.65	3.35	4.85	1.71	3.32
Quatsino Sound	1	3.68		5.38	6.88	3.96	3.30	2.52	2.33	2.75	3.50	3.08	1.57	0.84
	2	5.70	2.66	8.36	11.63	6.96	3.76	2.56	1.04	4.20	3.28	4.08	0.88	3.00
	3	3.30	2.76	7.08	10.24	3.20	2.16	1.88	0.21	5.68	3.32	3.84	5.76	1.96
	4	5.40	9.50	14.64	4.08	1.72	3.32	1.76	0.24	2.36	3.60	8.05	5.88	0.56
	5	6.90	5.94	9.32	5.32		4.30	2.52	0.52	2.12	4.88	2.24	1.64	1.60
	Mean	5.07	5.21	8.96	7.63	3.81	3.37	2.25	0.96	3.42	3.72	4.26	3.15	1.59
Triangle Island	1			5.44		3.52	4.48	5.08	2.30	1.64	2.68	4.36	0.96	0.28
	2		4.67	11.12	11.56	9.44	7.52	4.72		3.84	3.16		0.78	1.68
	3		1.33	10.36	9.20	4.42	7.76	2.84	3.56	2.36	2.67	5.12	0.48	2.88
	4		1.71	4.64	7.25	0.36	4.00	1.60	0.44	4.88	1.36	1.12	0.56	0.52
	5		1.13	4.32	6.76	0.36	4.28	2.40	1.37	6.28	1.14	1.21	0.44	0.90
	Mean		2.21	7.18	8.69	3.62	5.61	3.33	1.99	3.80	2.20	3.23	0.65	1.19
Southern Stock	**Mean**	8.50	8.09	11.66	14.39	7.41	6.14	3.88	3.68	3.82	3.25	5.20	2.22	2.74
Coast	**Mean**	8.50	7.46	8.88	11.61	5.49	4.26	3.39	2.70	3.64	2.58	3.47	1.27	2.96

Table D.7 Continued.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Cape St. James	1					1.62	3.17	2.44	1.56	2.13	4.22	2.04	1.08	0.24
	2					3.32	2.08	3.52		3.80	5.74	4.95	2.72	2.56
	3					4.20		4.43	3.24	1.96	3.36	3.08	0.64	6.00
	4					3.91	0.88	1.80	1.52		1.71	1.74	0.17	0.84
	5						1.38	1.64	0.56	1.15	0.38	0.35	0.11	0.32
	Mean					3.26	1.88	2.77	1.67	2.04	3.08	2.43	0.95	1.99
Gowgaia Bay	1					1.81	3.48	3.67	3.48	3.00	0.68	0.58	0.36	2.93
	2		11.75	11.62	14.83		7.24	2.56	4.00	4.84	2.09	6.13	0.42	3.28
	3		4.33	8.71	13.81	9.25	6.40	2.76	1.36	4.72	1.03	2.61	0.69	2.04
	4		2.63	3.56	7.12	3.76	5.40	2.00	0.64	3.29		2.08		1.37
	5		3.96	4.76	6.84		1.68	1.68	0.60	3.92	0.28	1.32	0.35	1.01
	Mean		5.67	7.16	11.28	4.94	4.84	2.53	2.02	3.95	1.02	2.54	0.45	1.73
Buck Point	1			3.12	9.32	2.00	2.40	2.62	0.64	3.85	2.09	2.96	0.44	3.60
	2		7.21	11.71	12.50	6.80	2.72	4.80	3.92	4.80	2.32	4.60	0.67	5.16
	3		2.13	10.32	5.00	4.09	3.92	1.60	0.96		2.04	1.20	0.24	2.84
	4		3.79	7.35	4.16	4.36	1.50		0.48	1.72	0.80	1.72	0.16	0.68
	5		2.29	4.92	3.36	3.12	1.40	3.54	0.60	4.52	0.31	1.24	0.40	0.72
	Mean		3.85	7.48	6.87	4.07	2.39	3.47	1.32	3.72	1.51	2.34	0.38	2.60
Hippa Island	1				1.14	2.96	1.80	2.27		1.96	0.88	1.56	0.56	4.53
	2			4.79	10.84	2.40	2.16	4.21		4.92	1.48	2.44	0.72	5.69
	3			3.76	8.76	2.88	4.40	6.38		6.60	0.84	1.96	0.08	5.52
	4			7.36	6.62	5.52	2.00	4.00		3.92		1.40	0.43	2.00
	5			4.44			2.24	5.13		0.58	2.64	0.52	0.28	2.26
	Mean			5.09	6.80	3.44	2.52	4.40		3.60	1.34	1.58	0.41	3.91
Langara Island-North Frederick	1			1.72		1.74	0.28	1.88	2.48	3.40	0.24	2.67	0.08	3.80
	2		10.29	4.16	10.43	3.96	2.71	2.52		6.29	6.44	1.50	0.36	16.16
	3		8.33	1.24	9.28	2.32	2.34	0.98	1.24	2.96	4.20	1.33	0.11	5.12
	4		9.13	4.20	6.04	3.16			1.12	4.76	3.08		0.16	1.56
	5		11.16	6.60	5.92		0.68	2.72	2.08	3.52	2.48	0.44	0.40	0.84
	Mean		9.73	4.05	7.92	2.79	1.67	1.82	1.88	4.38	3.29	1.49	0.22	5.50
Northern Stock	**Mean**		6.42	5.79	8.23	3.66	2.69	3.00	1.73	3.49	2.05	2.08	0.48	3.10
Coast	**Mean**	8.50	7.46	8.88	11.61	5.49	4.26	3.39	2.70	3.64	2.58	3.47	1.27	2.96

Table D.8 Sample mean catch rate (kg/trap) of survey index sets by depth stratum, locality, stock and year. Sets assigned to depth strata based on the mean of depth observations taken at one minute intervals. Fouled or holed traps excluded from summary.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Barkley Canyon	**1**			33.44	54.84		28.44	12.08	23.90	5.21	7.55	8.30	0.38	5.03
	2	39.86	12.65	74.00	65.82	58.54	26.33	13.04	20.76	5.84	4.91		1.53	5.50
	3	18.98	16.34	39.67	49.46	24.76	21.64	16.20	14.65	6.68	4.26	25.68	5.70	11.90
	4	30.24	41.54	41.80	46.64	37.70	26.76	21.28	13.13	14.63	15.14	25.60	17.97	11.12
	5	25.40	33.40	39.96	32.58		18.32	23.28	15.71	17.12		27.48	13.71	8.79
	Mean	29.10	25.98	45.77	49.32	39.68	24.30	17.18	17.63	9.89	9.40	19.07	7.86	8.47
Esperanza Inlet	**1**			25.48	51.63	24.84	15.08	19.04	28.92	13.00	14.02	20.92	5.84	3.46
	2	21.80		36.56	39.12	15.52	26.71	7.80	6.29		7.21	15.42	0.89	3.21
	3	13.12		24.16	40.60	15.68	13.60	4.52		4.67	5.90	5.21	1.60	6.61
	4	21.13		27.24	54.88	9.56	28.65	7.36	2.90	3.33	4.79	15.46	2.19	9.98
	5	18.28		38.12	59.40	21.60	14.55	14.00	10.84	16.23	14.29	7.80	11.50	16.04
	Mean	18.94		30.31	49.13	17.44	19.72	10.54	11.05	9.31	9.24	12.96	4.40	7.41
Quatsino Sound	**1**	12.56		20.29	26.96	17.72	11.04	8.04	6.72	10.75	14.41	8.50	4.59	2.72
	2	12.00	5.92	27.52	34.93	19.20	12.04	8.60	2.72	13.36	9.62	10.00	2.20	7.69
	3	9.72	7.02	20.48	33.36	9.14	5.64	5.00	0.49	14.80	9.05	9.32	11.96	4.00
	4	15.94	18.79	35.32	16.08	3.96	8.68	5.88	0.41	8.00	12.58	15.41	10.57	1.21
	5	14.72	14.92	22.96	19.96		15.70	8.72	0.86	6.28	14.43	5.96	3.29	4.00
	Mean	13.16	11.66	25.31	26.26	11.83	10.62	7.25	2.24	10.64	12.02	9.84	6.52	3.92
Triangle Island	**1**			23.96		9.36	14.48	17.28	8.31	5.48	8.76	13.30	3.34	0.81
	2		13.79	33.16	36.04	22.60	24.61	14.92		11.32	8.26		2.06	4.44
	3		3.63	26.56	25.20	12.25	26.72	9.24	10.73	7.76	7.88	11.52	1.11	6.58
	4		6.96	18.04	33.29	0.76	15.96	7.52	1.25	16.56	4.08	4.12	1.78	1.76
	5		5.42	15.20	29.40	1.40	17.28	9.36	5.66	26.00	5.26	4.79	1.53	3.17
	Mean		7.45	23.38	30.98	9.27	19.81	11.66	6.85	13.42	6.85	9.41	1.97	3.32
Southern Stock	**Mean**	20.02	16.54	31.20	41.07	18.50	18.61	11.66	9.44	10.90	9.38	12.82	5.19	6.23
Coast	**Mean**	20.02	19.34	25.57	36.51	15.57	13.66	11.26	7.72	12.04	7.72	9.30	3.09	8.21

Table D.8 Continued.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Cape St. James	**1**					6.88	11.42	8.11	5.40	7.22	13.67	6.54	3.14	0.74
	2					9.56	7.42	13.20		13.20	17.34	14.27	6.51	6.65
	3					13.20		14.57	8.86	5.58	9.32	8.79	1.49	14.32
	4					16.23	3.08	6.56	4.74		5.22	6.30	0.49	2.16
	5						6.54	8.32	2.37	4.73	1.53	1.22	0.42	1.52
	Mean					11.47	7.11	10.15	5.36	7.09	9.42	7.43	2.41	5.08
Gowgaia Bay	**1**					7.67	14.08	15.00	12.13	10.76	2.43	2.08	0.94	10.50
	2		47.04	41.96	62.25		24.88	8.72	12.22	18.20	5.30	17.63	1.35	9.83
	3		15.54	20.25	52.17	35.71	21.20	10.04	3.94	17.08	3.46	8.04	2.20	5.61
	4		11.58	11.52	29.56	17.44	19.96	7.52	2.30	13.25		6.36		3.62
	5		17.25	18.24	31.64		6.96	6.60	2.78	16.75	1.20	4.52	0.97	3.41
	Mean		22.85	22.99	45.36	20.27	17.42	9.58	6.67	15.21	3.17	7.73	1.36	6.39
Buck Point	**1**			12.65	44.12	7.20	9.16	9.19	2.08	14.35	6.63	10.04	1.31	12.09
	2		26.75	40.42	33.00	20.28	9.20	13.84	11.05	16.12	5.86	13.24	1.74	13.51
	3		5.58	27.36	14.40	11.65	11.68	4.44	2.49		4.12	2.96	0.56	7.75
	4		11.33	24.30	15.56	15.80	4.29		1.55	6.20	2.50	5.00	0.49	1.74
	5		7.67	16.00	12.84	11.80	4.68	11.04	1.91	14.04	1.20	3.96	1.17	2.30
	Mean		12.83	24.15	23.98	13.35	7.80	10.47	3.82	12.68	4.06	7.04	1.06	7.48
Hippa Island	**1**				3.95	9.52	6.80	7.82		7.33	2.64	4.72	2.06	15.00
	2			18.46	30.68	9.68	6.76	18.25		17.50	4.12	9.68	1.65	18.31
	3			11.64	30.68	9.52	13.52	26.13		22.52	1.73	5.56	0.16	16.15
	4			24.64	24.54	13.40	6.77	15.72		15.80		5.08	1.49	5.81
	5			14.48			7.56	18.75		2.63	11.13	2.00	0.83	5.72
	Mean			17.30	22.88	10.53	8.28	17.33		13.16	4.27	5.41	1.24	11.79
Langara Island-North Frederick	**1**			6.68		7.91	0.84	7.67	12.99	17.16	0.78	9.75	0.44	15.29
	2		37.79	14.84	45.61	14.48	12.33	11.84		26.21	23.65	4.42	1.09	53.57
	3		30.00	4.64	32.16	7.96	8.64	3.74	4.48	11.88	13.29	3.58	0.17	16.14
	4		34.34	14.72	22.72	9.96			3.47	15.56	8.74		0.51	5.24
	5		42.92	24.92	27.12		2.60	8.80	6.83	11.80	8.82	1.76	1.12	3.25
	Mean		36.26	13.16	31.90	10.08	6.61	7.16	8.15	16.52	11.06	4.79	0.67	18.70
Northern Stock	**Mean**		23.98	19.32	30.98	12.79	9.54	10.94	6.00	12.94	6.39	6.48	1.35	9.52
Coast	**Mean**	20.02	19.34	25.57	36.51	15.57	13.66	11.26	7.72	12.04	7.72	9.30	3.09	8.21

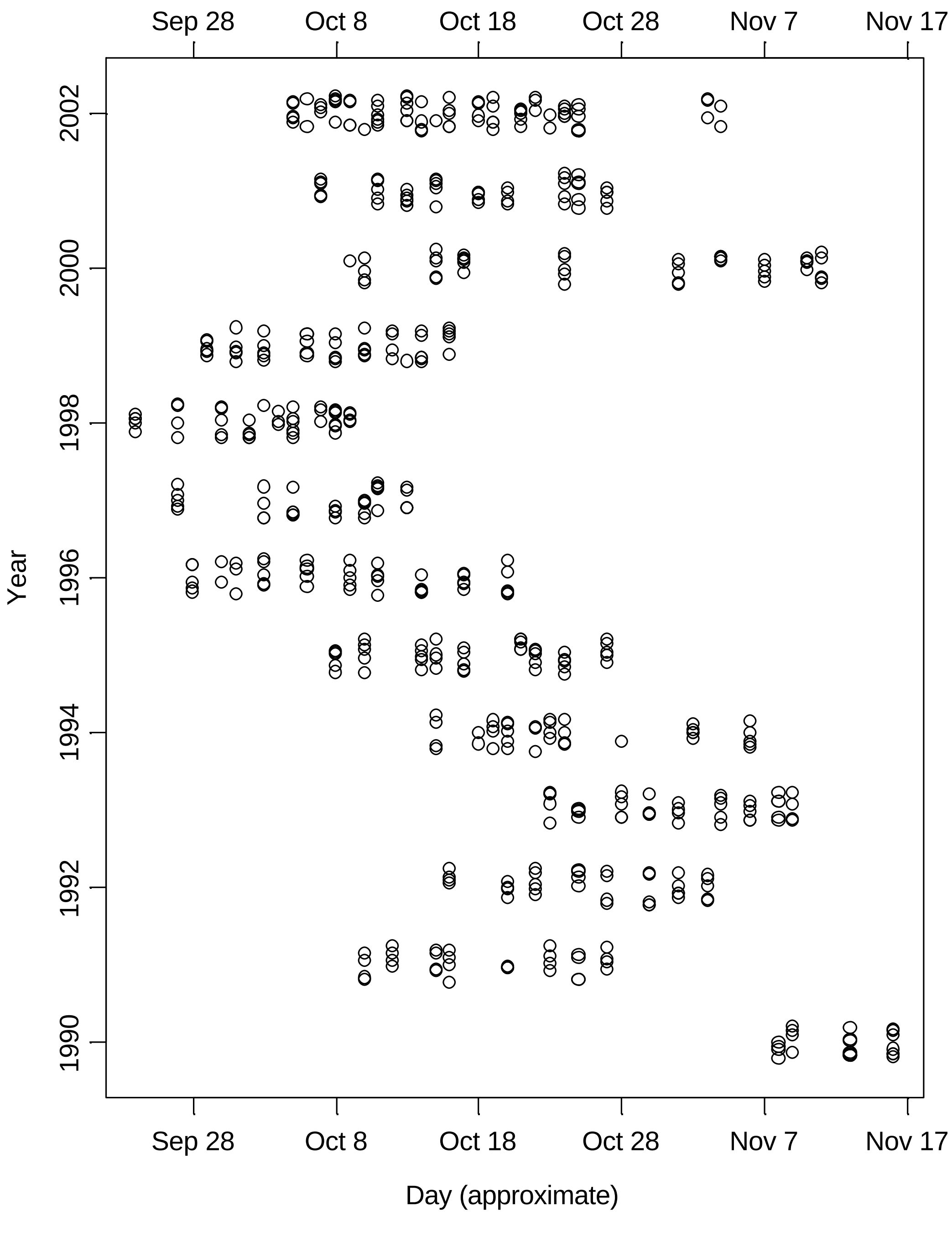


Figure D.1 Timing of indexing survey sets from 1990 to 2002.

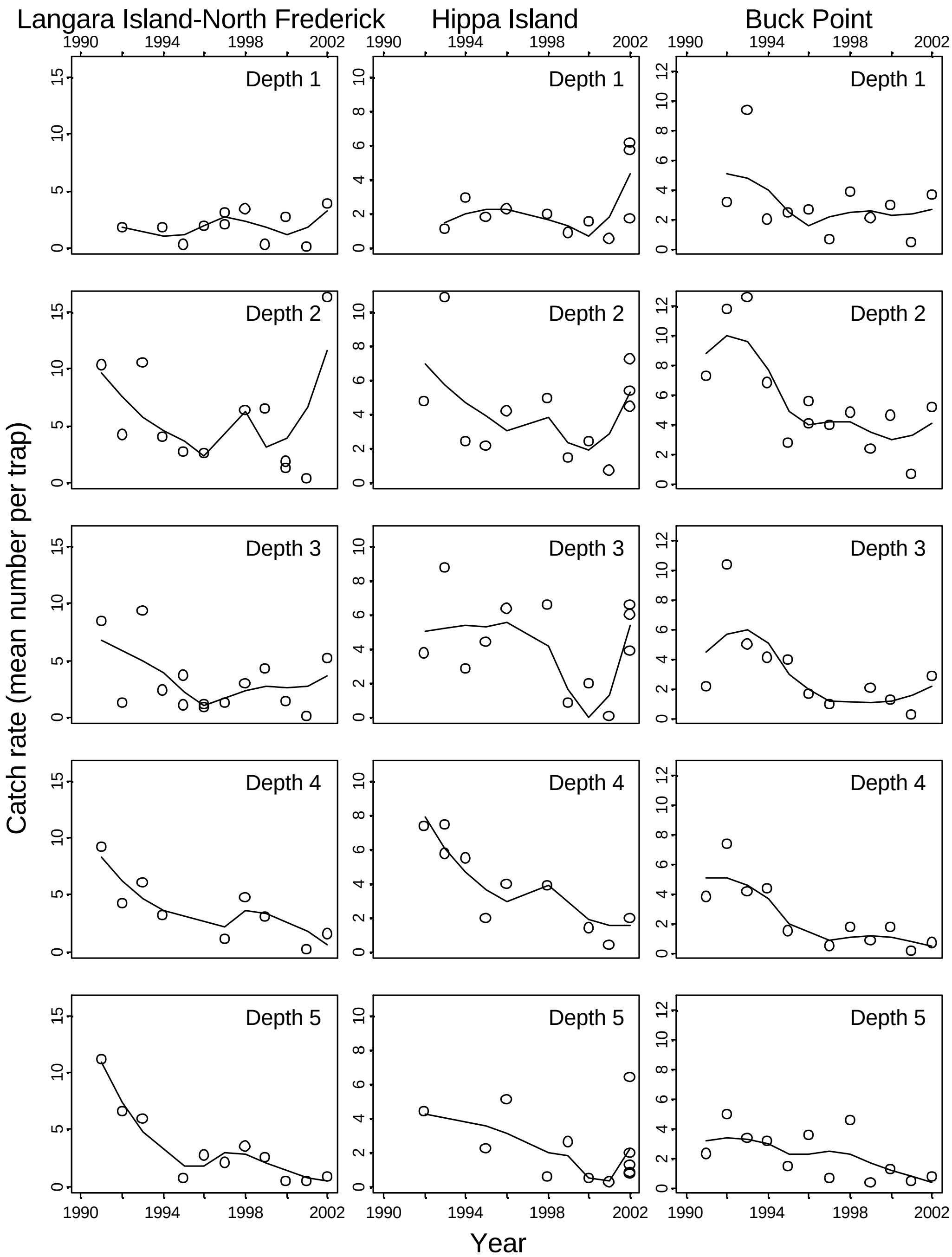


Figure D.2 Survey catch rates (number of fish per trap) for each year, depth stratum and locality. The solid curve is a loess regression smooth through the observations.

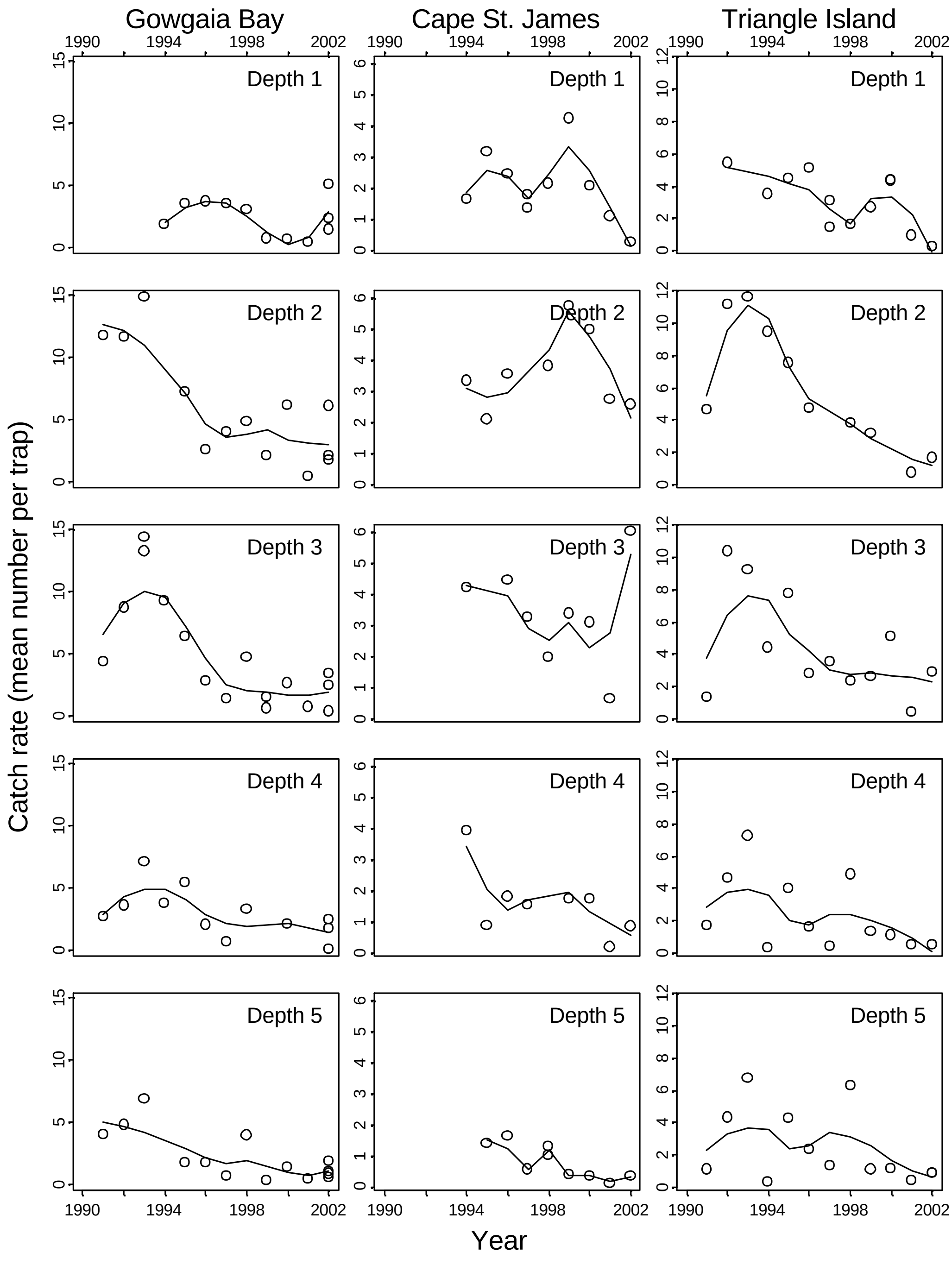


Figure D.2 Continued.

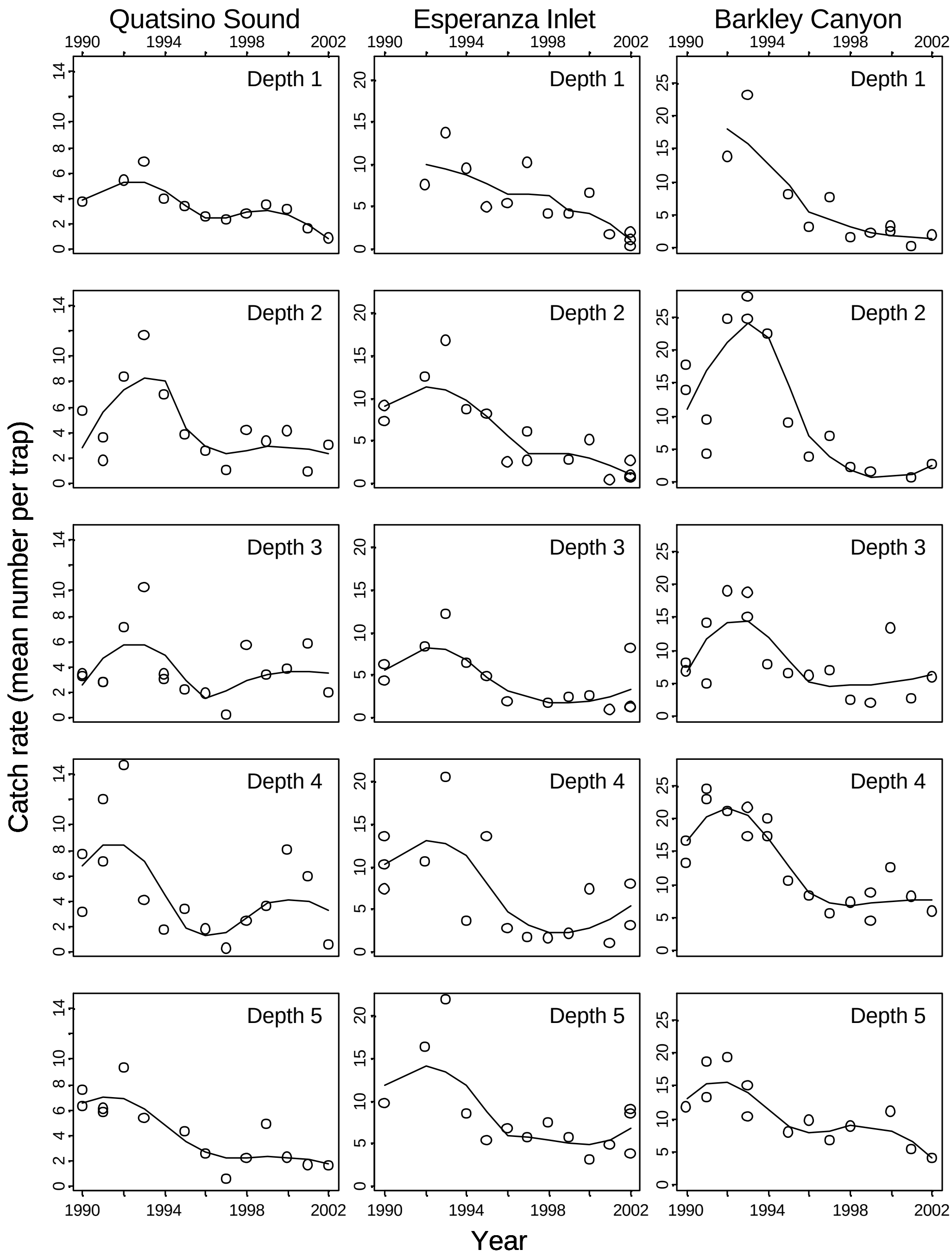


Figure D.2 Continued.

Appendix E. Indexing survey model diagnostics

Diagnostics for the indexing survey model fits include trellis plots of the model fit and residuals against fitted values, and a normal probability plot of the studentized residuals (Figure E.1 to Figure E.7). Trellis plots for fitted values and residuals are arrayed by locality and depth stratum. The observations, or residuals, are shown using open circles. In the case of the model fit plots, the solid line superimposed on each panel joins the model estimates for each year. The solid line on the residual plots is a loess smooth trend line to help diagnose pattern in the residuals.

Normal probability plots of the studentized residuals for model fits corresponding to north, south, and coast data are shown in the three panels of Figure E.7. A simulation envelope (dotted lines) set at the 95 percent probability level is used to enhance each plot. Residuals that do not conform to a normal distribution fall outside the envelope.

For the north stock area the high catch rate achieved at Langara-North Frederick in depth stratum 2 in 2002 is a clear statistical outlier and could be removed from the model fit. In fact, most year coefficients do not change much when the outlier is removed from the fit; the largest change occurs for the coefficient for 2002, which drops from a marginal mean of 1.603 to 1.551 on the square root scale. In general, the detailed model diagnostics indicate that interaction terms would likely increase the amount of variation explained by the model. However, such analyses will necessarily await the accumulation over time of replicates for each combination of model factors, or an alternative survey design.

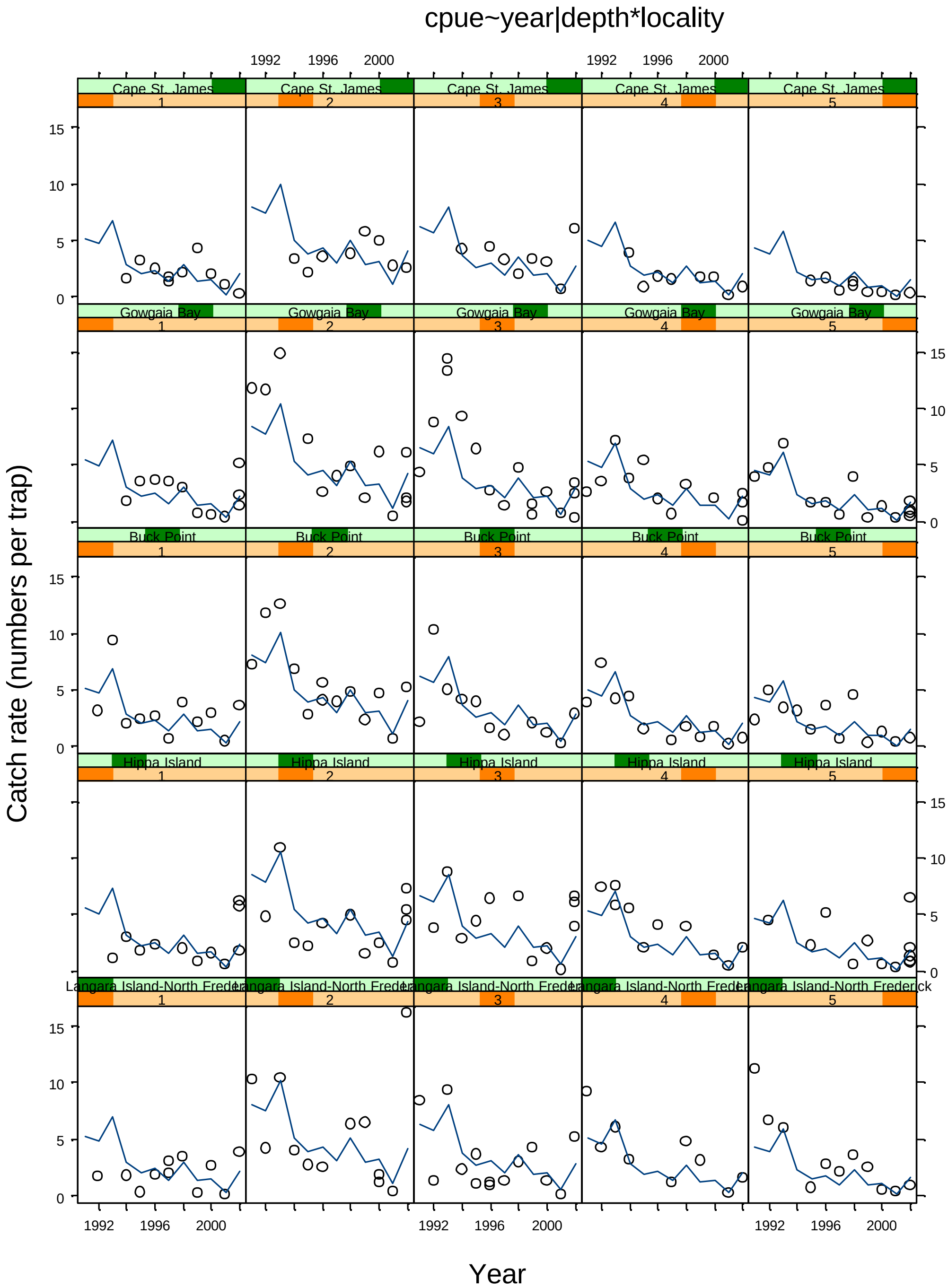


Figure E.1 Fitted and observed indexing survey catch rates for the north stock area.

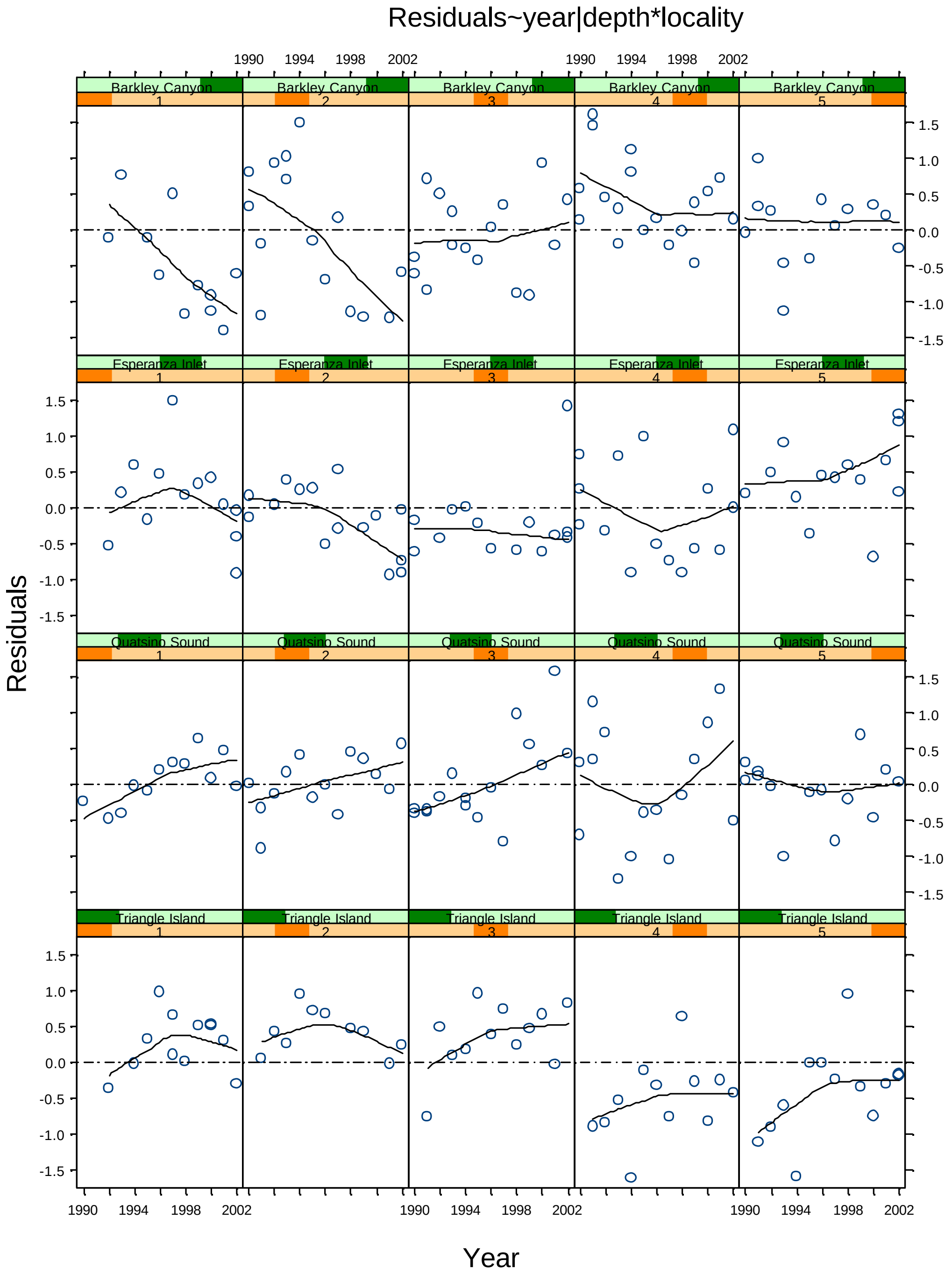


Figure E.2 Residuals for the indexing survey model for the north stock area.

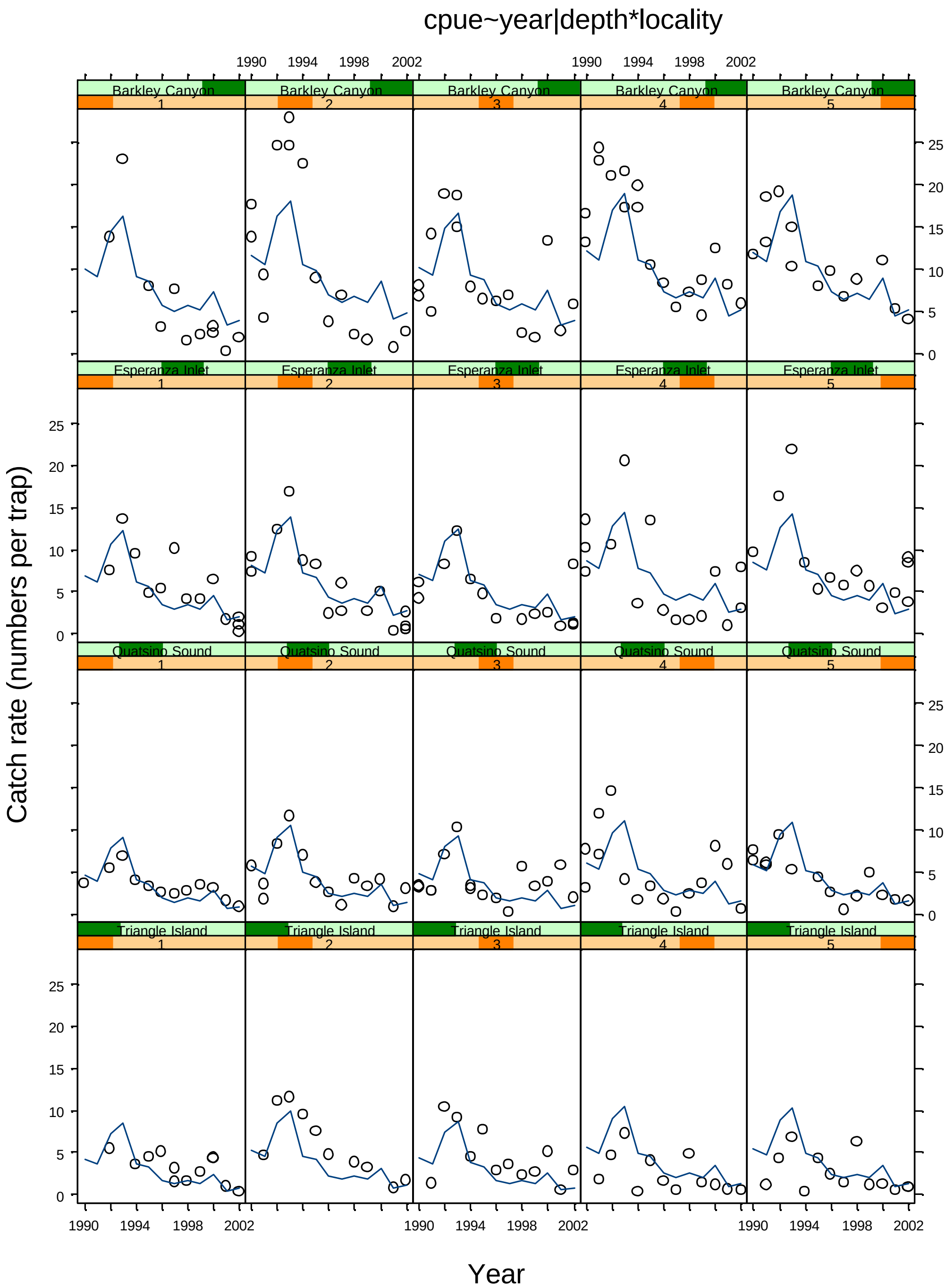


Figure E. 3 Fitted and observed indexing survey catch rates for the south stock area.

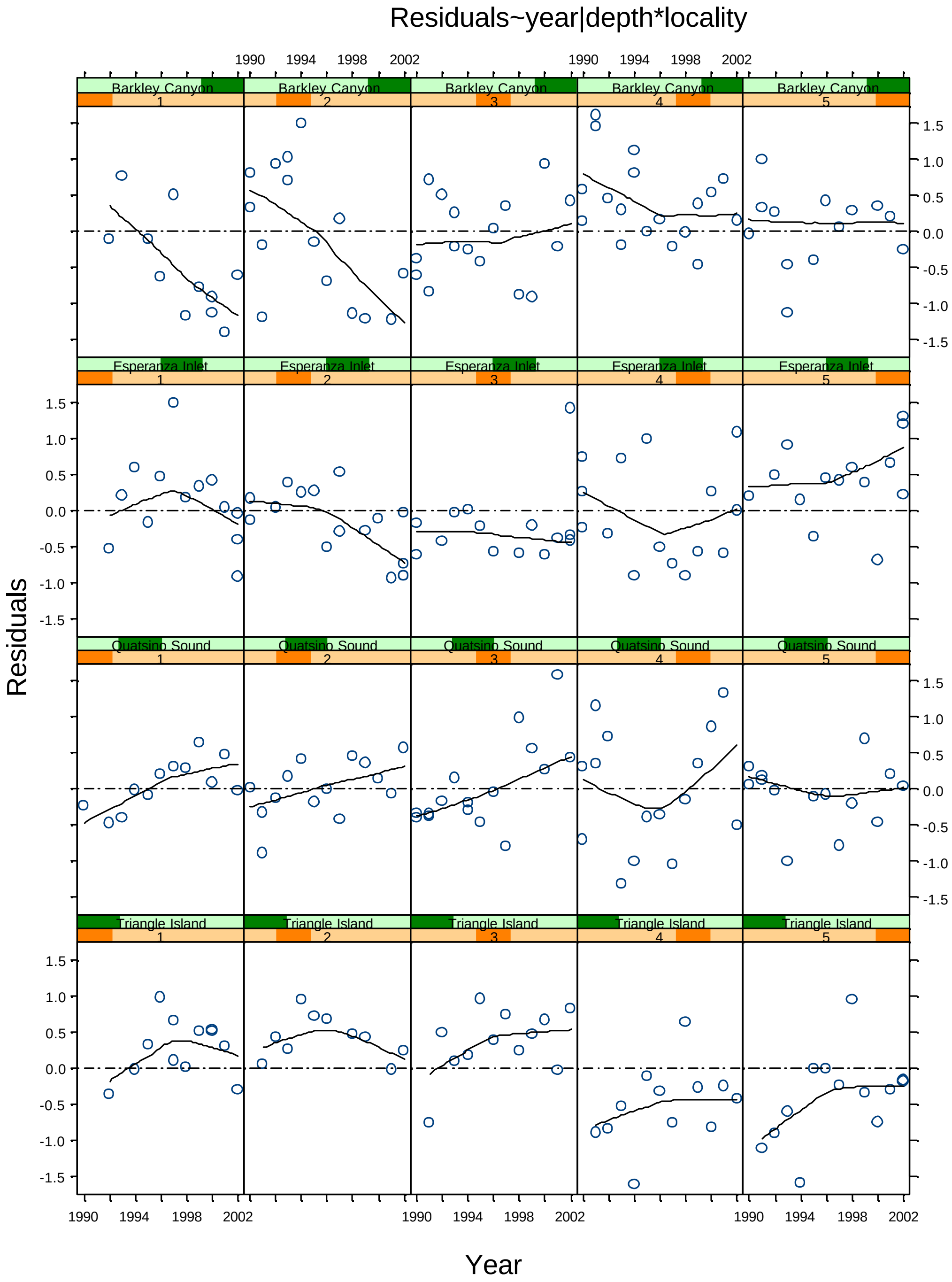


Figure E.4 Residuals for the indexing survey model for the south stock area.

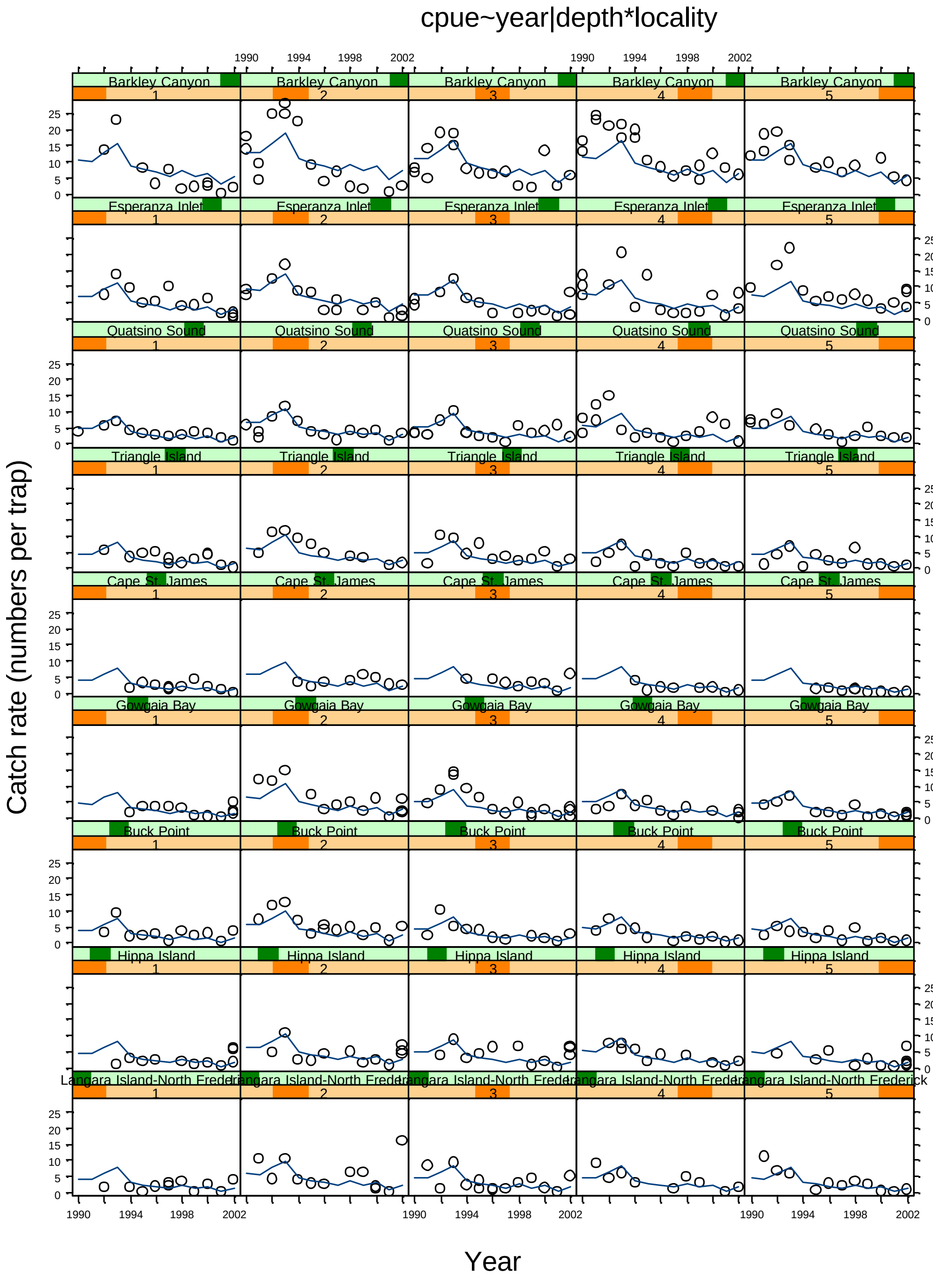


Figure E.5 Fitted and observed indexing survey catch rates for the coast.

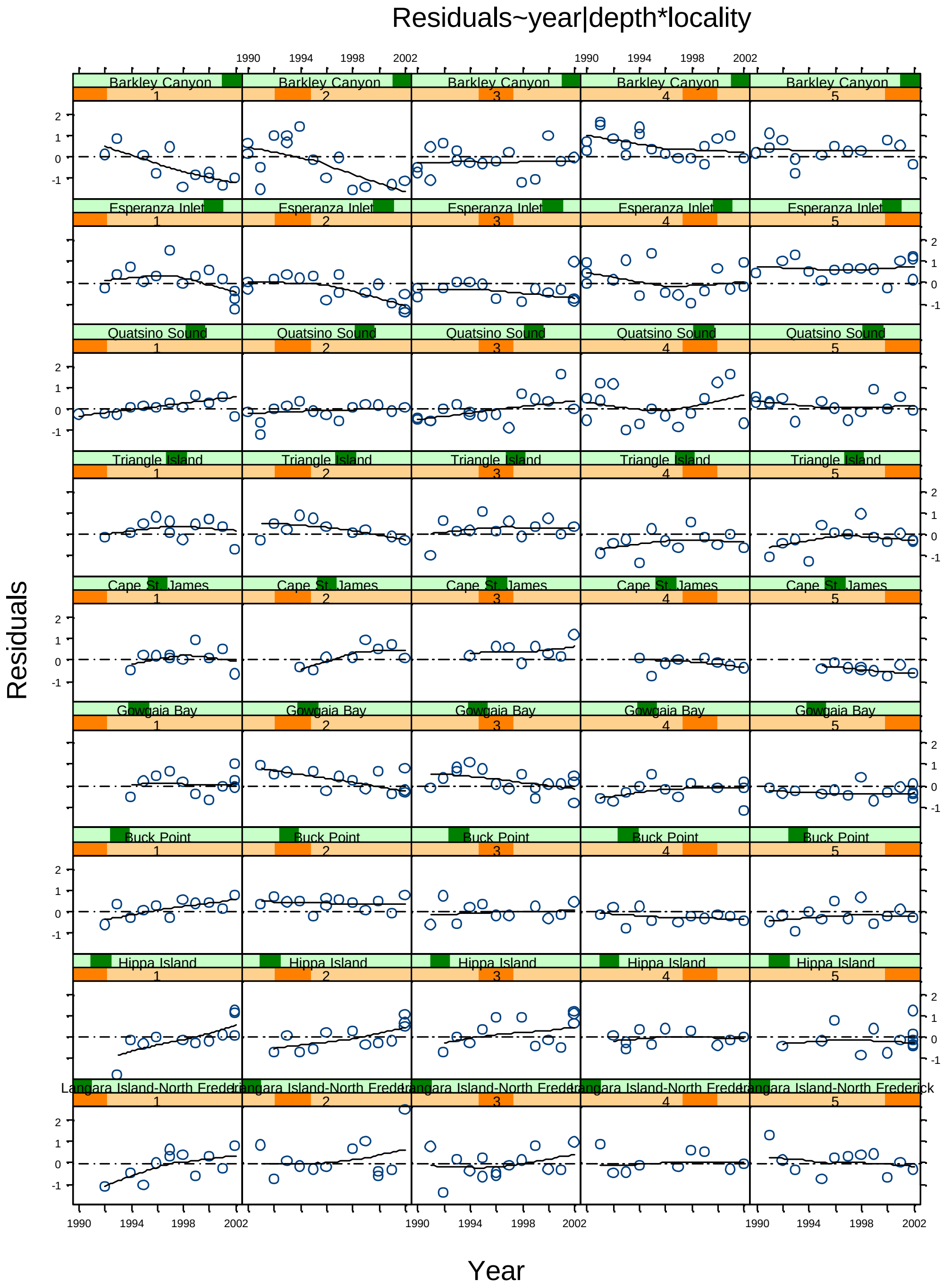


Figure E.6 Residuals for the indexing survey model for the coast.

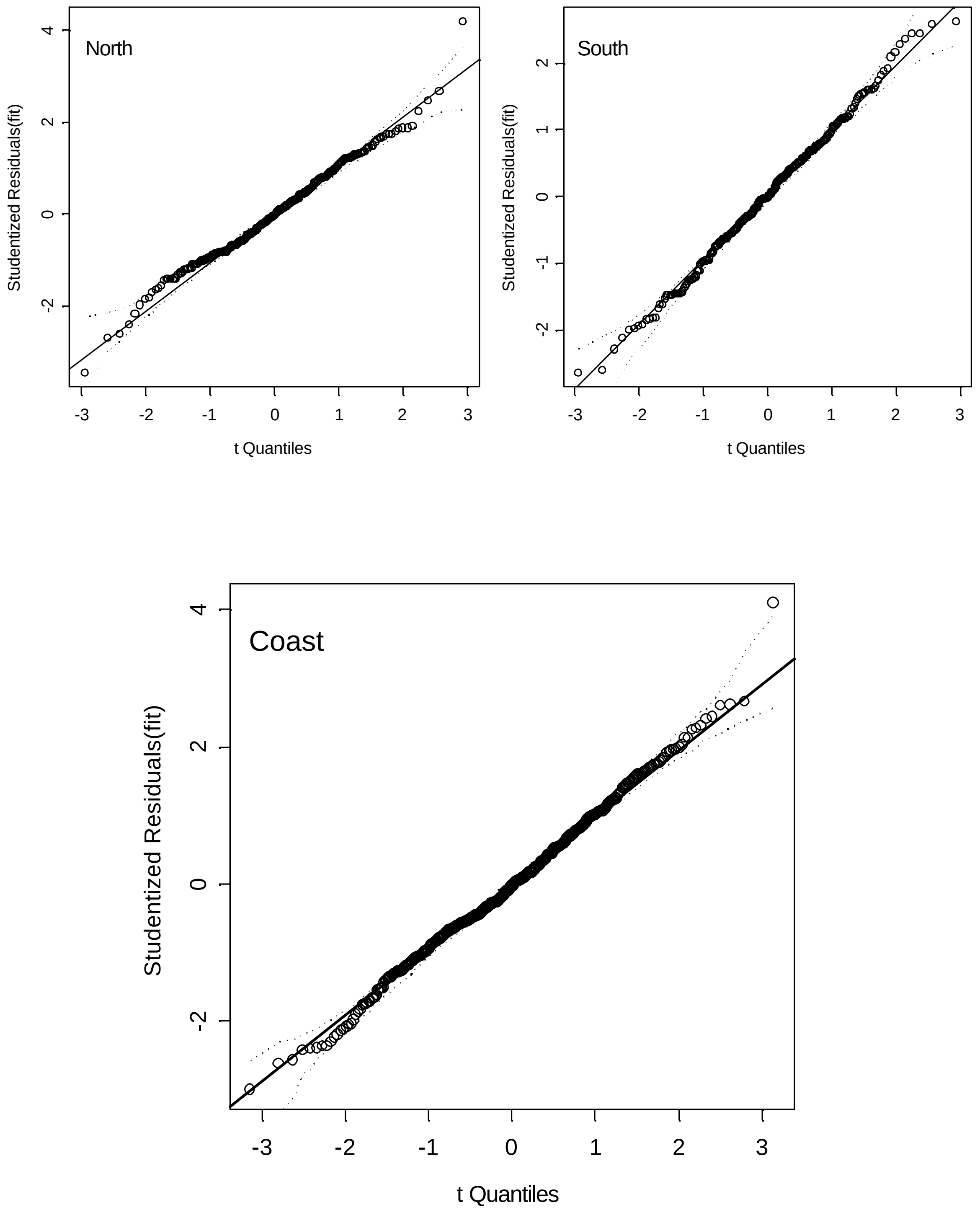


Figure E.7 Quantile-normal plots of the studentized residuals for the north, south, and coast model fits. The dotted lines indicate a 95 percent simulation envelope to detect the presence of outliers.

Appendix F. Tagging data selection

Background: The sablefish tag-recovery program began in 1977 for the purposes of stock identification (Beamish and McFarlane 1988), and was described in previous stock assessments (Haist et al. 1999, 2000, 2001). The program continued into the mid 1980s with tagging effort directed at different components of the population in response to specific program objectives. Beginning in 1991, a tagging component was integrated into the fall sablefish surveys designed to release tagged fish at each survey locality and at depths where most commercial fishing effort occurs (Haist et al. 2001). Sablefish were tagged at each of the indexing localities and depth strata. Additional tagging sites were added after 1994, however most of these sites are positioned in the 250-450 fm depth stratum. Sets designated for tag releases were distinct from those used as abundance indexing sets, although fish excess to biological sampling requirements caught by indexing sets may have been tagged and released.

Tagging sets generally included more than 25 traps per string and were baited with hake in addition to squid to maximize the number of tags released per set. A Floy FD-68B T-bar anchor tag was used until 2000, but was succeeded in 2001 by a Floy FD-94 tag that has very similar characteristics but has an improved coating to prevent wear of the tag label. The tag is inserted approximately 1 cm below the anterior insertion of the first dorsal fin and angled back to be streamlined. Two tag labeling schemes were released in the course of tagging. The tags differ in the information printed on the tags, for example:

B-type	REWARD PACIFIC BIO. STATION NANAIMO, B.C. CANADA B99 38805
CSA-type	REWARD CANADIAN SABLEFISH ASSOC. NANAIMO, B.C. CANADA CSA 08864

The CSA-type tag was introduced in 2000. Due to concerns over differential return rates between tag types (it was not clear where to return the CSA-type tag), release of two different tag types was discontinued in 2002 with the introduction of a single tag type, for example:

PBS/CSA-type	CSA REWARD PACIFIC BIO. STATION NANAIMO, B.C. CANADA A00 123 456

Haist et al. (2001, their Section 5.4, this document) reported little difference in the proportion of recovered of B-type and CSA-type tags from data where equal numbers of both types had been released over 7 tagging sets in southern British Columbia.

Data overview: The number of releases by area and year is listed in Table F.1. Tags recovered by all gear types are displayed by year of recovery and release year in Table F.2. Similar tables of tag recoveries by trap, longline, and trawl gear are shown in Tables

F.3 through F.5. Table F.6 shows tag recoveries where the fishery type is “other” or unknown. For some recovered tags the fishery type is known but the year of recovery is unknown (Table F.7).

Data source: Sablefish tag release and recovery data are stored in a number of databases maintained by DFO at the Pacific Biological Station in Nanaimo, B.C. Tag release data are stored in the Microsoft Access database *Tag_Releases.mdb*. The recovery data comes from a variety of databases. The recovered tag and biological sampling data are stored in the Microsoft Access database *Tag_Recoveries.mdb*. This database has a number of fields which uniquely identify the database source and set within that particular database. These fields are linked to the GFBio, PacHarvHL, PacHarvTrawl, and PacHarvSable databases to obtain the recovery location. GFBio is maintained on an ORACLE platform while the PacHarvHL, PacHarvTrawl, and PacHarvSable databases are all maintained on SQL Server platforms.

Data selection for tag-recovery estimation: The tag-recovery model used to compute vulnerable biomass and exploitation rates utilizes tag returns in the year following release. Data used in the analysis were current to the end of July, 2002. Fish tagged and released were included in the analysis if the following criteria were met:

- the release took place from 1991 to 2001 (consistency of tagging program);
- the released fish was greater than 450 mm fork length or unknown length (adult fish);
- the released fish was not identified as a juvenile (adult fish);
- tag application took place in offshore waters outside of coastal inlets (Fisheries and Oceans Major Area 3 to 6 and 9 (3C to 5B and 5E), excluding Fitzhugh Sound) (offshore vulnerable population);
- tag application did not take place at seamounts (offshore vulnerable population);
- tag application occurred from August through December (tags released at consistent time as part of annual survey).

Sablefish recovered were included in the analysis provided the following criteria were met:

- the recovery occurred in the first year after release for release years 1990 to 2001;
- the tagged fish was recovered by a commercial sablefish trap vessel (vulnerable adult population);
- the tagged fish was not recovered as part of the annual tagging survey (survey sets have higher probability of tag recapture than fishery);
- the tagged fish was not recovered at a seamount (offshore vulnerable population).

Table F.1 Number of tagged sablefish released by year and area.

Year	Hecate Strait	North	South	Inlet	Seamount	Dixon Entrance	Queen Charlotte Sound	Strait of Georgia
1977		5,159	5,505					
1978		5,960	4,342				594	
1979	10,417	6,621	9,112				15,121	26
1980	12,039	4,141	5,217	7,020		466	1,187	18
1981	2,983	10,430					9,323	
1982		3,008	3,436				596	
1983		4,002	4,023					
1984	654	7,698	1,359				1,019	
1985		3,025	5,303					
1987			1,101		616			
1991		958	1,489					
1992		1,308	2,276					
1993		2,487	4,531					
1994		1,622	1,982	3,435				
1995		7,564	5,144	3,199				
1996		11,764	12,617	3,898				
1997		6,557	9,936	3,144				
1998		3,010	12,945	6,009				
1999		7,031	10,760	9,620				
2000		6,738	13,063	3,114				
2001		4,088	10,065	4,095				

Table F.2 Number of tagged sablefish recovered by all gear types in each year by year of tag release.

	Recovery Year																										
Release Year	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Total**
1977	138	631	267	200	131	73	47	41	27	19	8	12	6	4	9	7	8	1	1	2	10	5	4	2	8	1	**1662**
1978		221	319	286	128	51	43	30	9	8	5	9	11	5	3	4	2	1		1	2	3	4	2	1	1	**1149**
1979			831	1384	617	409	206	169	169	224	65	89	55	34	20	33	27	7	3	21	23	40	20	6	21	9	**4482**
1980				1078	980	646	388	313	103	113	50	60	71	44	28	23	32	6	1	25	20	16	10	15	24	3	**4049**
1981					273	583	343	188	99	97	47	53	53	48	32	34	27	4		26	13	16	14	13	9	2	**1974**
1982							665	356	91	60	18	32	39	24	13	23	15	1		7	11	8	8	5	7	1	**1384**
1983								106	39	55	26	19	18	11	3	3	6	1		3	6	1	3	6	4		**310**
1984								252	166	165	57	39	24	24	25	22	10	2		14	13	17	13	9	7	8	**867**
1985									114	348	72	62	43	35	15	31	19	2	1	7	16	25	9	6	9	2	**816**
1987											6	25	21	8	5	2				1	1	2		2	1		**74**
1991															16	100	48	39	29	17	17	15	8	9	11	5	**314**
1992																13	121	97	64	42	29	44	32	9	20	4	**475**
1993																	6	421	218	70	90	95	72	45	41	18	**1076**
1994																		13	416	206	227	216	127	76	61	25	**1367**
1995																			85	1277	916	593	374	246	162	54	**3707**
1996																				437	2134	1341	673	454	369	131	**5539**
1997																					1208	2260	907	491	364	144	**5374**
1998																						321	1741	1105	743	279	**4189**
1999																							234	2272	1415	559	**4480**
2000																								149	2037	501	**2687**
2001																									133	939	**1072**
Total	**138**	**852**	**1417**	**2948**	**2129**	**1762**	**1692**	**1455**	**817**	**1089**	**354**	**400**	**341**	**237**	**169**	**295**	**321**	**595**	**818**	**2156**	**4736**	**5018**	**4253**	**4922**	**5447**	**2686**	**47047**

Table F.3 Number of tagged sablefish recovered by trap gear in each year by year of tag release.

Release Year	Recovery Year 1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
1977	122	578	188	163	115	66	35	36	17	15	4	9	2		2	3	2			1	5	3		1	3		**1370**
1978		200	246	257	113	47	30	26	7	5	1	3	7	4		2	1				2	1	1			1	**954**
1979			617	1146	517	338	132	118	122	180	13	48	17	8	7	10	8	2		9	13	21	9	2	10	6	**3353**
1980				992	832	527	283	264	66	56	14	17	20	13	12	6	11	3		7	13	6	5	4	7		**3158**
1981					207	453	231	140	55	45	7	14	8	8	6	11	6	2		12	5	5	6	5	3		**1229**
1982							521	321	60	34	5	13	13	8	2	5	3	1		4	6	4	3	4	4		**1011**
1983								72	24	36	4	8	2	1		1				1	3	1	1	1	3		**158**
1984								229	122	114	20	19	5	6	9	7	3	1		9	8	12	8	8	1	4	**585**
1985									75	292	29	44	15	18	5	10	7		1	5	12	23	4	4	3		**547**
1987											3	14	5	2	2	1						1		1			**29**
1991															13	71	30	18	19	9	13	13	7	2	1	4	**200**
1992																10	75	58	41	27	23	25	20	5	12	3	**299**
1993																	2	261	139	45	56	70	44	13	27	11	**668**
1994																		11	317	163	183	184	93	46	43	16	**1056**
1995																			80	1077	743	505	270	142	86	30	**2933**
1996																				333	1851	1110	454	261	216	69	**4294**
1997																					1125	1985	666	301	243	94	**4414**
1998																						296	1381	729	491	170	**3067**
1999																							148	1571	931	385	**3035**
2000																								100	1585	337	**2022**
2001																									116	738	**854**
Total	**122**	**778**	**1051**	**2558**	**1784**	**1431**	**1232**	**1206**	**548**	**777**	**100**	**189**	**94**	**68**	**58**	**137**	**148**	**357**	**597**	**1702**	**4061**	**4265**	**3120**	**3200**	**3785**	**1868**	**35236**

Table F.4 Number of tagged sablefish recovered by longline gear in each year by year of tag release.

Release Year	Recovery Year 1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
1977	14	33	52	25	15	6	10	4	5	2	4	2		1	2	2	4		1	1	4		2		4		**193**
1978		21	64	26	15	4	11	3		3	4	4		1	1	1	1						2	2	1		**164**
1979			174	89	71	56	57	34	28	26	32	21	15	15	5	14	11		2	8	4	10	7	1	4	1	**685**
1980				57	106	93	94	37	27	40	28	27	23	20	10	9	14	1	1	14	4	8	3	9	11	1	**637**
1981					26	105	93	34	26	29	28	18	23	22	16	12	9			8	7	9	6	8	3	2	**484**
1982							125	22	21	18	10	13	6	8	7	11	6			2	5	3	3	1	2		**263**
1983								6	6	10	16	8	8	5	3	2	3			2	2		1	2	1		**75**
1984								10	24	35	25	11	6	12	12	9	2			5	2	4	3		3	4	**167**
1985									7	32	17	9	11	11	3	13	7			2	3	1	3	2	3	1	**125**
1987												4	4	2	1					1	1	1		1			**15**
1991															1	13	15	8	6	6	3	1	1	6	6	1	**67**
1992																2	23	19	15	10	6	14	4	4	7		**104**
1993																	1	63	53	17	32	18	21	21	12	4	**242**
1994																			73	31	38	27	22	27	14	6	**238**
1995																			3	153	136	72	81	80	53	12	**590**
1996																				82	222	171	162	140	102	38	**917**
1997																					63	209	179	153	94	28	**726**
1998																						9	226	288	195	61	**779**
1999																							46	572	392	99	**1109**
2000																								28	314	74	**416**
2001																									6	91	**97**
Total	**14**	**54**	**290**	**197**	**233**	**264**	**390**	**150**	**144**	**195**	**164**	**117**	**96**	**97**	**61**	**88**	**96**	**91**	**154**	**342**	**532**	**557**	**772**	**1345**	**1227**	**423**	**8093**

Table F.5 Number of tagged sablefish recovered by trawl gear in each year by year of tag release.

Release Year	Recovery Year																										
	1977	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Total**
1977		8	4	8		1	1	1	2					2	1						1	1	2	1	1	1	**35**
1978													1										1				**2**
1979			26	135	21	14	9	11	7	7	3	3	1	3	1	1	1			3	5	9	4	3	7	2	**276**
1980				26	37	22	9	6	2	1		1	1	3	1	1					1	1		2	5	1	**120**
1981					37	23	14	7	4	2	1	3	2	1	1	2	2				1				3		**103**
1982							16	7	1	1		1	2	1	1		1						1		1		**33**
1983								19	2	2	1	1	1				1	1			1		1	3			**33**
1984								9	6	3	1	2		1	2		1				3		1	1	2		**32**
1985									27	4	6	4	2	1	1	2		1			1		2		3	1	**55**
1987											2	2	3		1	1									1		**10**
1991																3		1		2	1			1	4		**12**
1992																1	1	2	1	1		4	4		1	1	**16**
1993																		18	1	1	1	4	4	6	2	2	**39**
1994																			1	2	6	3	8	2	3	2	**27**
1995																				14	31	13	16	18	20	10	**122**
1996																				19	57	55	45	37	46	21	**280**
1997																					17	56	52	30	22	16	**193**
1998																						8	121	61	48	34	**272**
1999																							39	86	73	61	**259**
2000																								21	119	75	**215**
2001																									11	97	**108**
Total	**0**	**8**	**30**	**169**	**95**	**60**	**49**	**60**	**51**	**20**	**14**	**17**	**13**	**12**	**9**	**11**	**7**	**23**	**3**	**42**	**126**	**154**	**301**	**272**	**372**	**324**	**2242**

Table F.6 Number of tagged sablefish recovered by other or unknown gear types in each year by year of tag release.

Release Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
	Recovery Year																										
1977	2	12	23	4	1		1		3	2		1	4	1	4	2	2	1				1					**64**
1978			9	3			2	1	2			2	3		2	1		1		1		2					**29**
1979			14	14	8	1	8	6	12	11	17	17	22	8	7	8	7	5	1	1	1						**168**
1980				3	5	4	2	6	8	16	8	15	27	8	5	7	7	2		4	2	1	2		1	1	**134**
1981					3	2	5	7	14	21	11	18	20	17	9	9	10	2		6		2	2				**158**
1982							3	6	9	7	3	5	18	7	3	7	5			1		1	1			1	**77**
1983								9	7	7	5	2	7	5			2										**44**
1984								4	14	13	11	7	13	5	2	6	4	1				1	1		1		**83**
1985									5	20	20	5	15	5	6	6	5	1				1					**89**
1987											1	5	9	4	1												**20**
1991															2	13	3	12	4			1					**35**
1992																	22	18	7	4		1	4				**56**
1993																	3	79	25	7	1	3	3	5		1	**127**
1994																		2	25	10		2	4	1	1	1	**46**
1995																			2	33	6	3	7	6	3	2	**62**
1996																				3	4	5	12	16	5	3	**48**
1997																					3	10	10	7	5	6	**41**
1998																						8	13	27	9	14	**71**
1999																							1	43	19	14	**77**
2000																									19	15	**34**
2001																										13	**13**
Total	**2**	**12**	**46**	**24**	**17**	**7**	**21**	**39**	**74**	**97**	**76**	**77**	**138**	**60**	**41**	**59**	**70**	**124**	**64**	**70**	**17**	**42**	**60**	**105**	**63**	**71**	**1476**

Table F.7 Number of tags recovered by known gear types but in unknown years by year of tag release.

Release Year	Trap	Longline	Trawl	Other and Unknown Gear	All Gear Types
1977				3	**3**
1978				1	**1**
1979	1		1	13	**15**
1980	2	1		2	**5**
1981		1		1	**2**
1982	1			3	**4**
1983				1	**1**
1984	2			4	**6**
1985	1		1	5	**7**
1987					
1991	1	1		1	**3**
1992	1		4	9	**14**
1993	10	3	3	3	**19**
1994	3	1	1	3	**8**
1995	36	10	14	25	**85**
1996	51	7	23	27	**108**
1997	66	7	17	21	**111**
1998	5	2	3	16	**26**
1999		1		13	**14**
2000	1			6	**7**
2001				7	**7**
Total	**181**	**34**	**67**	**164**	**446**

Table F.8 Summary of selected 2000 and 2001 sablefish tag releases by tag-type and release set and subsequent tag recoveries by Canadian and American fishermen.

Tag Releases					Canadian Recoveries		American Recoveries	
Year	Stat.	Loc	B-type	C-type	B-type	C-type	B-type	C-type
2000	24	6	306	284	37	37	1	2
2000	24	6	366	374	41	18	2	3
2000	24	6	414	400	17	19		2
2000	25	1	304	299	13	19	1	2
2000	25	1	323	398	6	16	1	1
2000	25	1	482	465	25	23	2	2
2000	25	4	200	489	9	38	1	3
2001	23	10	262	377	14	13		1
2001	24	6	146	138	5	2		
2001	24	6	273	276	7	4		
2001	23	12	208	242	2	5		
2001	24	6	246	235	1	4		
2001	25	1	240	227	8	7	1	
2001	25	1	361	331	20	22	1	
2001	25	1	361	323	13	10		
2001	25	1	387	378	4	7		
2001	25	4	114	189	3	5		
2001	27	6	245	226	45	37		
2001	11	11	141	119	26	16		
2001	11	6	199	188	32	23		1
2001	11	11	116	276	11	50		
2001	11	11	71	61	15	10		
2001	11	7	242	255	39	30		
2001	11	12	269	260	20	19		
2001	11	12	349	361	15	25		
2001	11	12	481	406	29	21		
2001	08	14	247	279	31	30		
2001	34	3	33	53	5	4		
2001	34	4	79	136	5	11	1	1
2001	31	13	131	107	9	10		1
2001	31	13	207	125	23	17		1
2001	31	13	165	174	15	17	1	2
2001	31	3	261	296	27	24		1
2001	31	14	222	183	10	8	1	
2001	31	14	125	144	8	6		
2001	31	14	117	197	4	8		
2001	31	14	197	173	11	10	2	1
2001	31	1	158	112	7	5	1	
2001	35	2	61	80		6		
2001	04	12	207	83	1			
2001	04	12	160	157	1	1		1
2001	04	10	149	133	3	2		2
2001	04	10	94	78	3	1		1
2001	04	10	99	91	5	4	1	
2001	06	6	151	117	6	5		
2001	06	6	119	109	2	4		
2001	06	6	114	102	2	2		1
2001	06	6	144	123	9	4		
2001	06	6	139	183		3		
2001	07	3	96	84	3	6		
2001	07	3	15	45		1		
2001	07	3	117	118	4	3		
2001	07	3	126	110	4	4		
2001	07	3	110	90	4	3		1
2001	08	8	25	41		1	1	
2001	08	8	103	164		3		
2001	08	8	57	63				
2001	08	8	64	57				
2001	08	8	5	53				
Totals			11203	11637	659	683	18	30

Appendix G. Update of simple tag-recovery model

Background. A simple Petersen-type mark recapture model was applied to sablefish tag recoveries in the 2000 through January 2002 stock assessments to estimate vulnerable biomass and exploitation rates (Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2002). For a Petersen model, it is assumed that a sample n_1 of fish are tagged and released into the population at time *t*=1. A second sample n_2 of fish is taken at time *t*=2 and the number of marked fish m_2 is recorded. An estimator of abundance is obtained by assuming the ratio of marked fish to unmarked fish in the population tagged at time 1 is the same as that observed in the sample taken at time 2, $N = n_1 n_2 / m_2$. In this case, the estimator uses the number of tags recovered by the sablefish trap fishery in the year following release, a practice initiated by Haist et al. (1999). For the sablefish data, various corrections are applied to the basic Petersen estimator to adjust for factors such as tag loss, tagging-induced mortality, and for tags from unknown sources.

Data Selection. The tagging analysis uses returns in the year following release. All tag-recovery data used in the calculation of abundance and exploitation rates are obtained from “adult” offshore releases in Fisheries and Oceans Canada Major Statistical Areas 3 to 6 and 9 (3C to 5B and 5E, Rutherford 1999), excluding Fitzhugh Sound. Releases, returns, and catch from seamounts are not included. Juvenile sablefish (those coded as “J”) tagged primarily in inlets are not utilized. Only tag-recoveries obtained from the sablefish trap fishery are used in the calculations. Tag recoveries obtained from sablefish longline, groundfish trawl, halibut longline, and other hook and line fisheries (eg. rockfish, lingcod, dogfish) are not included in calculation of abundance and exploitation rates (Appendix F). Tag release and recovery data included in the analysis are listed in Table G. 1.

Model Description. Notation required for statement of the model is listed in Table G.2. The observed data include the annual catch C_t landed by trap vessels in year *t*, and the total annual catch D_t from all fishery sources. The number of tags released X_{t-1} in year *t*-1 and the number of tags returned by the sablefish trap fishery R_t in year *t* comprise the observed tagging data.

Tags are returned in British Columbia by the sablefish trap and longline fisheries, and by the groundfish trawl fishery. However, a number of tags are returned from unknown sources in British Columbia. Tags from unknown recoveries are allocated to the trap fishery by computing the proportion of unknown tags among all tags recovered in year *t*, and prorating the trap tag recoveries.

The number of tagged fish n_t alive at the beginning of year *t* is computed as the number of tags released in the previous year adjusted for tag loss, *l*, and tagging mortality, *m*:

(G.1) $\hat{n}_t = X_{t-1}(1-l)(1-m)$.

Natural mortality, and fishing mortality, in the two to three months between the time of tagging and the beginning of the year is ignored. The estimated number of fish recovered and examined for tags in year t+1 is computed as the number of fish in the population, N_t, adjusted by the proportion of the tagged population examined for tags

(G.2) $\hat{n}_{t+1} = N_t\left(\frac{s_t w_t C_t}{B_t}\right)$.

The estimated number of tags recovered in year t is computed by correcting the number of tags recovered from the trap fishery by the reporting rate

(G.3) $\hat{m}_{t+1} = R_t / r_t$.

The usual Petersen estimator of population size in at the beginning of year t is given by

(G.4) $\hat{N}_t = \frac{\hat{n}_{t-1}\hat{n}_t}{\hat{m}_t} = \frac{X_{t-1}(1-l)(1-m)N_t s_t w_t C_t / B_t}{R_t / r_t}$.

Algebraic manipulation of (G.4) gives an estimate of vulnerable biomass in year t

(G.5) $\hat{B}_t = \frac{X_{t-1}(1-l)(1-m)s_t w_t C_t r_t}{R_t}$.

An estimate of the exploitation rate on the vulnerable population is given by

(G.6) $h_t = \frac{D_t}{B_t}$.

Model assumptions. Model assumptions are described in the following list:

3. *Allocation of tags from unknown fishery sources*. The proportion of tag-recoveries from unknown sources was used to inflate the number of tags returned by the trap fishery, R_t. This is a conservative assumption that assigns unknown source tags to the trap fishery.
4. *Tag loss*. Tag loss fixed at l=0.066. Beamish and McFarlane (1988) estimated tag loss at 10 percent over the first year, and two percent thereafter, based on data from sablefish tagged with one Floy anchor tag and one suture tag and for data collected until 1985. Haist and Hilborn (2000, their Appendix D) examined a similar data set and estimated an 8 percent rate of tag loss in the first year and an instantaneous loss

rate of 0.036. Lenarz and Shaw (1997) analyzed U.S. sablefish recovery data from double-tagged fish and estimated tag loss in the first year to be 5 percent and instantaneous tag shedding rates of 0.03 and 0.069 for Floy anchor tags positioned anterior and posterior to the first dorsal fin, respectively. A period of 8.5 months between tag application and recovery was assumed for the current analysis, which implies a tag loss rate of 6.6 percent (1-l=0.933) using the model of Haist and Hilborn (2000).

5. *Tagging mortality*. Mortality from tagging fixed at m=0.1 based on Beamish and McFarlane (1988).
6. *Tag reporting rates.* Originally based on analysis of Haist and Hilborn (1999, their Appendix B). Tag reporting rates were assumed to be 0.75 since that analysis. Revised estimates of tag reporting rates available from analysis in this document are compared to the Haist and Hilborn (1999) estimates.
7. *Adjustment for the number fish inspected for tags.* The adoption of escape rings by the sablefish trap fishery impacted the size frequency and therefore the mean weight of sablefish captured. The change in size frequency altered the number of fish sampled for tags and the conversion of biomass landed to numbers landed. Haist and Hilborn (2000, their Appendix C) analyzed data from an escape ring study to estimate the ratio of the number of fish sorted to those landed, s_t.
8. *Mean weight in the tagged population versus mean weight landed*. Estimation of w_t, the ratio of the mean weight of sablefish in the tagged population and the mean weight of sablefish in the landings for year t, was based on the analysis of an escape ring study by Haist and Hilborn (2000, their Appendix C). The study compared the performance of trap gear fitted with 3 1/2 and 3 7/8 inch escape rings to control traps without escape rings at different locations and for various soak times (Saunders and Surry 1998). The number of fish landed per metric tonne with and without escape rings was estimated by north and south stock areas, and for shallow, medium, and deep depth strata. The number of fish sampled per metric tonne landed with, and without, escape rings was estimated from observer data collected in 1992 and 1993 by Haist et al. (1999) for the same stratification.

Model Results. The trajectories of estimated vulnerable biomass and exploitation rates were computed for two cases: (1) the reporting rates used in the last three assessments (Haist et al. 2000, 2001, Kronlund et al. 2002), and (2) the revised reporting rates presented in this document. Figure G.1 shows the results of the calculations with Case 1 shown in the left panels and Case 2 in the right panels. Estimates of vulnerable biomass are shown in the top panels, with exploitation rate estimates in the lower panels. The dashed horizontal line in each panel is the mean of estimates. Table G.3 shows the data and estimates for Case 1, with results for 2002 italicized to indicate partial year results to July 31, 2002.

Comparison with revised tag model. Several analyses revised in this document differ from analyses conducted in the November 2001 (Haist et al. 2001) and January 2002 (Kronlund et al. 2002) stock assessments:

1. A monthly tagging model was developed to provide estimates of relative trap-vulnerable biomass, and explained significantly more variation than the Petersen-type expansion used from 2000 to January 2002;
2. Estimates of annual tag reporting dating from the 1999 stock assessment (Haist et al. 1999) were updated;
3. Three primary stock indices were integrated into a simple biomass dynamics model to evaluate 2008 biomass relative to 2003 biomass. A range of catch levels were evaluated under assumed levels of production for the 2003 to 2008 projection period relative to the 1996 to 2002 reference period.

Estimates of vulnerable biomass using a Petersen-type expansion were first provided in the 2000 stock assessment (Haist and Hilborn 2000), and updated in assessments by Haist et al. (2001) and Kronlund et al. (2002). Computation of annual harvest rate by dividing the total catch by the estimated biomass is valid provided the biomass estimates are regarded as absolute values. The PSARC yield advice in 2002 (Cass 2002) recommended a yield range of 2,100 to 4,000 t. The low end of the range was obtained by applying a harvest rate of 0.06 to the mean vulnerable biomass from 1995 to 2001 of 35,000 t, assuming the biomass estimate was an absolute value. The high end of the yield range was obtained from the tag-recovery analysis of Haist et al. (2001). The PSARC advice noted that the stock indicators were contradictory, and suggested that a yield of 2,800 t corresponded to a harvest rate of 0.08 and provided an approximate equal weighting of the indices.

A comparison that most closely matches the January 2002 analysis is to compute an estimate of biomass using the 1999 estimates of tag reporting rate and the Petersen type tag-recovery model. However, tag-reporting rates were updated in 2002 and a new monthly tagging model was introduced. Thus, the estimates of trap vulnerable biomass (mt) for the Petersen expansion and monthly tag-recovery model are provided in Table G.4 using both the 1999 and 2002 tag reporting rates. Note that estimates of vulnerable biomass for 2002 must be regarded as preliminary, since they are based on data current to July 31, 2002 rather than the entire calendar year.

Yields in Table G.4 range from about 2,300 to 2,700 metric tons for the various model combinations provided (1) the estimate of trap vulnerable biomass is regarded as absolute, (2) only the tag-recovery data are used to determine yield, and (3) the harvest rate is 0.08. Inspection of the table shows that if the annual estimates of vulnerable biomass were used to determine yield each year, there would be considerable variability among years. Therefore an average of biomass estimates since the mid 1990s was used in the January 2002 assessment, following the period of rapid decline in estimated abundance in the early 1990s.

Haist et al. (2001) argued that estimates of the vulnerable biomass were underestimates of the actual sablefish population abundance due to the effects of various scaling factors and reliance of the tagging program on adult sablefish vulnerable to trap gear in offshore waters. Kronlund et al. (2002) pointed out that basic assumptions of the Petersen-type estimator, such as random tag application, random recovery or complete mixing, were not met by the sablefish tagging program. Thus, this document explicitly considered the time series of trap vulnerable biomass estimates to be a relative index in the simple biomass dynamics model and harvest rates were not computed. The simple biomass dynamics model represented an attempt to integrate stock indices derived from commercial fishery, indexing survey, and tag-recovery data into decision making and avoid reliance on one index as suggested by PSARC (Cass 2002).

Table G. 1 Summary of tags recovered in the year following release by gear.

Year		Gear				
Release	**Recovery**	**Trap**	**Longline**	**Trawl**	**Unknown**	**All Gears**
1991	1992	69	12	3	13	97
1992	1993	70	22	1	22	115
1993	1994	253	63	18	79	413
1994	1995	227	56		15	298
1995	1996	860	139	13	32	1044
1996	1997	642	75	37	1	755
1997	1998	748	79	26	2	855
1998	1999	861	165	111	6	1143
1999	2000	991	398	72	19	1480
2000	2001	892	268	112	17	1289
2001	2002	658	76	94	9	837
All years		6271	1353	487	215	8326

Table G.2 Notation for deterministic tag-recovery model.

Symbol	Description
	Index
t	year index $(t = 1991, \ldots, 2002)$
	Data
C_t	catch landed by the "K" trap fishery in year t
D_t	catch landed from all fisheries in year t
R_t	number of tags returned by the trap fishery in year t that were released in year t-1
X_{t-1}	number of tags released in year t-1
	Parameters
B_t	biomass of the population tagged in year t
l	tag shedding rate (l=0.07 from Haist and Hilborn 2000, Appendix D)
m	tagging mortality rate (m=0.1 from Beamish and McFarlane 1988)
r_t	proportion of tags examined that are returned in year t
s_t	ratio of the number of fish sorted to the number of fish landed by the trap fishery in year t
n_t	number of tagged fish alive at the start of year t released in year t-1
N_t	number of fish in the population in year t
u_t	proportion of tagged population examined for tags in trap fishery in year t
w_t	ratio of the mean weight of fish in the vulnerable population to the mean weight of fish landed by the trap fishery in year t

Table G.3 Summary of tag-recovery data and calculations for Case 1.

Release Year	Recovery Year	Number tagged	Next Year Trap Recoveries	Expanded for unknown	Expanded for tag shedding	Reporting rate	Trap catch	Trap catch corrected for sorting	Total landings	Vulnerable Biomass	Exploitation rate
1991	1992	2439	69	80	95	0.39	3710	4603	5006	45990	0.109
1992	1993	3581	70	87	103	0.37	4142	5376	5110	68881	0.074
1993	1994	7012	253	313	374	0.53	4051	5300	4992	52703	0.095
1994	1995	3603	227	239	286	0.76	3254	4309	4155	41317	0.101
1995	1996	12703	860	887	1060	0.74	2984	3920	3449	34768	0.099
1996	1997	9144	642	643	768	0.75	3554	4717	4139	42122	0.098
1997	1998	7137	748	750	896	0.75	3772	5169	4587	30889	0.149
1998	1999	15953	861	866	1034	0.75	3677	3662	4707	42374	0.111
1999	2000	17785	991	1004	1199	0.75	2744	2714	3818	30187	0.126
2000	2001	19776	892	904	1080	0.75	2431	2447	3212	33613	0.096
2001	*2002*	*14774*	*658*	*665*	*795*	*0.75*	*1040*	*1050*	*1429*	*14645*	*0.098*

Table G.4 Estimates of trap vulnerable biomass (mt) for two tagging models.

	Petersen	Petersen	Monthly	Monthly
Year	**1999 reporting rates**	**2002 reporting rates**	**1999 reporting rates**	**2002 reporting rates**
1995	41,317	38,055	48,705	44,860
1996	34,768	31,009	39,010	34,792
1997	42,122	30,328	36,080	25,978
1998	30,889	21,828	27,435	19,388
1999	42,374	41,809	41,908	41,349
2000	30,187	25,357	24,873	20,893
2001	33,613	32,717	28,272	27,518
2002	*14,645*	*17,964*	*15,777*	*19,353*
Mean	33,740	28,884	32,758	29,267
Yield	2,699	2,391	2,621	2,341

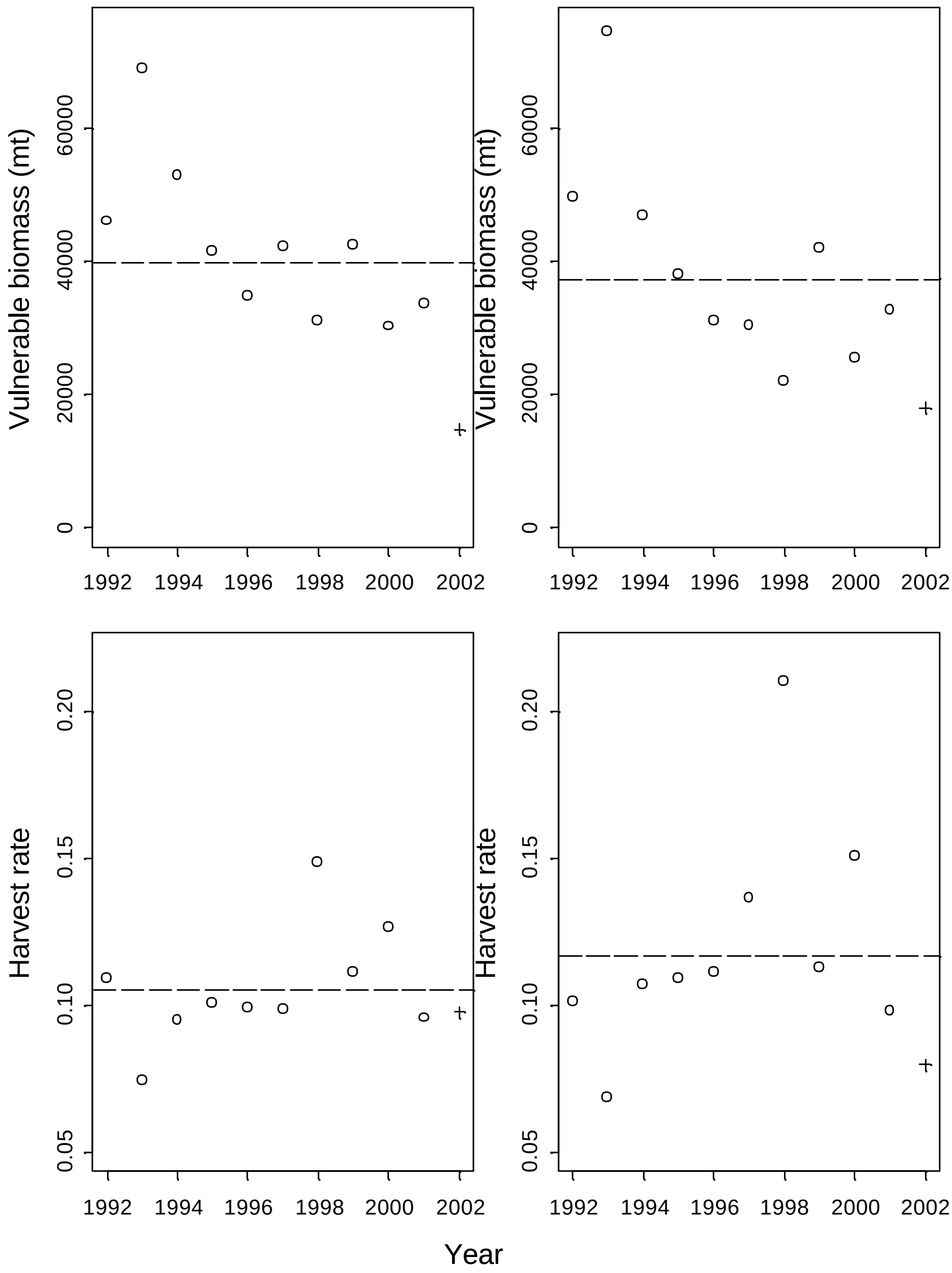


Figure G.1 Estimated vulnerable biomass and exploitation rates over time for Case 1 (left panels) and Case 2 (right panel). The differences show the effect of a change in the reporting rates. A "plus' symbol indicates partial year data for 2002.

Appendix H. Management history

The history of sablefish fishery management is summarized in Table H.1. The table contains a list of the total allowable catch, and quota allocations to the directed sablefish "K" fleet, the non-directed trawl "T", First Nations, and science projects for each fishing year. A narrative of the management history of sablefish by fishing year is provided in Table H.2. Material in this section was drawn from management plans (see, for example, Fisheries and Oceans Canada 2002) and unpublished file material.

Directed sablefish "K" fishery

Fishing under a "K" licence is permitted using trap and/or hook and line gear. A generalised gear description follows. Both methods involve attaching baited gear at intervals along a groundline secured to the ocean floor using anchors. Buoylines are attached at both ends of the groundline and floats and flags are attached to the ends of the buoyline to mark the location of the gear. Traps are Korean conical traps of either 54 or 48 inch bottom hoop diameter with a single webbed tunnel entrance. Traps are baited with a combination of frozen California squid (*Loligo* sp.) in mesh bait bags and frozen hake (*Merluccius productus*) loose in the trap. Fifty to eighty traps are attached at 25 fm (46 m) intervals along a groundline. Traps are required to have a section of mesh closed with a single length of thin, untreated natural fibre that will deteriorate if the trap is lost. Since 1998 traps are also required to have two escape openings with an inside diameter of 3.5 inches (8.9 cm). Hook and line gear consists of 500 to 1500 hooks baited with squid on short leader lines attached at 1-2 fm intervals to the groundline.

Management by total allowable catch

The sablefish fishery was unregulated prior to 1981. Beginning in 1981, a total allowable catch (TAC) fishery control policy was used for a fishing year beginning Jan 1 and ending Dec 31. Management tactics applied to the fishery have varied considerably over the last two decades (Table H.1, Table H.2). Fishing was unrestricted until the TAC was achieved from 1981 to 1984. The total number of calendar days required to attain the TAC declined from 245 to 181 days during this period. From 1985 to 1987 the fishery was split into two openings, with provision for a third opening if required to achieve the TAC. However, increases in fishery participation and fleet efficiency made it difficult to predict the duration of the fishery. In 1988 and 1989 fishers were given a choice of one of seven 20 day openings (1988) or eight 14 day openings (1989). Alternative fishing times (Table H.1) were offered to allow individuals to choose an opening to take advantage of market conditions and to reduce conflicts with other fisheries such as Pacific herring (*Clupea harengus pallasi*) or Pacific halibut (*Hippoglossus stenolepis*). Fishery duration remained difficult for fishery managers to estimate because of variable participation by license holders and continued increases in fleet efficiency. As a consequence, total quota overruns increased to 29.8% and 21.6% in 1988 and 1989, respectively.

Management by individual vessel quota

In 1990, individual vessel quota (IVQ) management was introduced and remains in effect through the 2002/2003 fishing year. Vessels were allocated proportions of the quota using a formula based on historical vessel catch and overall vessel length:

- 70 percent of license holder's highest landing in 1988 and 1989 divided by the total catch multiplied by the quota;
- 30 percent of overall vessel length divided by total length of all licensed vessels multiplied by the quota.

The IVQ policy included temporary and permanent transferability of quota among quota holders as described in management plans (e.g. Fisheries and Oceans 2002, their Appendix 1). The discrepancy between K fleet TAC and landings has been small since the inception of the IVQ program

The directed sablefish "K" fishery was closed January 18, 2002 due to concern invoked by significantly reduced catch rates observed during the fall 2001 annual survey. The fishery was re-opened on March 18, 2002 with a revised quota of 2,800 mt for the 2001/2002 fishing year, down 1,200 mt from the 4,000 mt quota adopted prior to the start of the fishing year. Furthermore, a 2,450 mt quota was adopted for the 2002/2003 fishing year. These fishing year quotas were implemented over a two year period in the following manner:

- Fishery managers combined the 2001/2002 and 2002/2003 TACs of 2,800 and 2,450 mt, respectively, to yield a two-year sablefish TAC of 5,250 mt.
- The directed sablefish "K" fleet allocation of the two-year TAC was 4,540 mt after allocations to First Nations, scientific purposes, and the non-directed trawl fleet;
- A total of 3,567 mt of sablefish was allocated to the quota holders at the start of the 2001/2002 fishing year, leaving 973 mt for the 2002/2003 fishing year;
- Quota holders were permitted to allocate a total of 910 mt of their 2001/2002 fishing year quota to the 2002/2003 fishing year;
- In addition, IVQ shortfalls in 2001/2002 of 10% were allowed to be "carried forward" into the 2002/2003 fishing year, i.e. sablefish that did not get caught in 2001/2002 was allocated into 2002/2003 in keeping with the rules of the IVQ program.

The objectives of these management measures were to (1) maintain fairness in the operation of the IVQ program, and (2) to distribute the two-year TAC over the 2001/2002 and 2002/2003 fishing seasons.

Overage/Underage Rules

A management tactic was introduced in 1994 to accommodate individual quota overruns and shortfalls. The tactic allowed fish taken in excess of an individual's allowable quota (an "overage" rule) to be subtracted from quota allocated in the next fishing year. An "underage" rule was also introduced by allowing a "carry-forward" of uncaught fish into the next fishing year. For example, the 2002/2003 management plan (Fisheries and Oceans 2002, Appendix 1, Section 1.5.4) described the following rules:

1. **Overage or overrun rule**. A licensed sablefish vessel may exceed its IVQ by the greater of up to five (5) percent of the vessel IVQ or one thousand pounds. The amount of the overrun will be subtracted from the vessel IVQ in the following fishing year. Sablefish landed in excess of these limitations are relinquished to the managing agency and the amount is subtracted from the vessel IVQ in the following fishing year.
2. **Underage or shortfall rule**: A licensed sablefish vessel that is ten (10) percent or less under the vessel IVQ may add the shortfall to the vessel IVQ in the following fishing year. Any shortfall in excess of ten percent is forfeited.

Any overage must be made up in the fishing year following the overrun, and quota shortfalls can be carried forward only into the fishing year following the shortfall. From 1990 to 1993, revenue from all overages was relinquished to the Government of Canada, as is now the case for overages in excess of the allowable limits.

The overage and underage rules were intended to impart flexibility to individual fishers such that the net departure from the TAC each year is zero. In actual practice, overage and underage rules have acted at the individual level as intended. Consider Figure H.1, where the top two panels show each vessel's landings plotted against individual quota for the 2000/2001 and 2001/2002 fishing years, respectively. Departures from the solid line in each panel represent an individual quota overage or underage. The distribution of differences between the landings and the allocated quota are summarized using boxplots in the two lower panels of the figure. The sum of the overages and underages is less than zero in both fishing years, with most quota holders landing less than their actual allocations.

The details of the rules have changed in two ways since their inception. First, the allowable percentages of overage and underage have been assigned various combinations of 5 and 10 percent over time (Table H.2). Second, the percentage overage was applied to the quota *remaining* to the vessel when the overage occurred until 1999, when the percentage was applied to the vessel's *total* quota (Table H.2).

If all quota holders behave similarly in a given fishing year, the following scenarios bound the extremes of the total harvest possibilities within the directed sablefish fishery *for a given year*:

1. the catch is 10 percent less (possibly more if quota is forfeited) than the current TAC provided no quota was carried forward from the previous fishing year, i.e. all quota holders have a 10 percent shortfall in the current year but landed their quotas exactly in the previous year;
2. the catch is greater than the TAC by 5 percent of the current fishing year quota using the overage rule, plus an additional 10 percent of the previous fishing year TAC by virtue of fish carried forward using the underage rule.

In the latter scenario, the percentage by which the current TAC is exceeded depends on the relative magnitude of TACs in the current and previous fishing years. If the current TAC were smaller than the previous TAC, the percentage overrun of the current TAC would be greater than 15 percent, and vice versa. Under scenario 2, and assuming that all permitted sablefish are caught in the current year, each IVQ in the succeeding fishing year would be reduced by an amount equivalent to 5 percent of the current year IVQ.

Other management tactics

A minimum size limit of 55 cm fork length (39 cm from origin of first dorsal fin to the fork of the tail) was introduced in 1994. In 1999 the fishing year was 19 months long to accommodate a change in the fishing year from a January 1 to December 31 period to an August 1 to July 31 period. A requirement for all traps to be equipped with two openings (typically stainless steel escape rings) in the side-walls of not less than 89 mm (3.5 in) diameter was initiated in 1999. This change followed voluntary use of escape rings by some fishers in 1998 and was intended to reduce the catch of juvenile sablefish. The market preference is for a sablefish of about 65 cm fork length or greater.

Fishery monitoring measures

Independent monitors at designated landing sites have validated all sablefish landings since 1990. Data collected by the dockside monitoring program (DMP) include landings by species, product type, vessel, gear, and area fished. Fisher logbooks were mandatory beginning in 1990. Data recorded include set location, gear, effort, set and haul date/time, catch weight by species, product and use.

There has been relatively little at-sea observer coverage in the offshore sablefish fishery, excluding fishing at seamounts. For the 2002/2003 fishing year, at-sea observer coverage was initiated with the objective of observing approximately 15 percent of the fishing days. Observer coverage was initiated to provide improved estimates of catch by species, although it is anticipated that opportunities to collect information on the number and size of retained and discarded sablefish and biological samples will assist stock assessment as the observer program matures.

Commercial trawl vessels that fish under a “T” category license receive an allocation of the sablefish TAC (Table H.1). A 100 percent at-sea observer program was regulated for the trawl fishery beginning in 1996, with the exception of vessels operating under the Option B fishery in the Strait of Georgia and those vessels fishing the domestic hake fishery. Dockside validation of landings has been regulated since 1994 for most trawl landings except for Pacific hake and Strait of Georgia Option B (Rutherford 1999).

Table H.1 Sablefish management history. Note that the 2002/2003 data are current to December 3, 2002.

Year	Fishery	Yield	TAC	K Quota	T Quota	First Nations	Science	Total Landings	Date Open	Date Closed	Days Open	FY Days	"K" Vessels Trap	"K" Vessels Longline
1981	Derby		3500	3190	310			3830.2	01-Feb-81	04-Oct-81	245	245	16	
1982	Derby		3500	3190	310			4027.4	01-Feb-82	22-Aug-82	202	202	15	
1983	Derby		3500	3190	310			4336	01-May-83	26-Sep-83	148	148	14	
1984	Derby		3500	3190	310			3827.4	01-Mar-84	22-Aug-84	174	174	13	
1985	Derby		4000	3650	350			4192.7	01-Feb-85	08-Mar-85	35	92	17	
									29-Mar-85	02-May-85	34			
									19-Jul-85	11-Aug-85	23			
1986	Derby		4000	3650	350			4448.1	17-Mar-86	21-Apr-86	35	63	20	
									12-May-86	09-Jun-86	28			
1987	Derby		4100	3740	360			4630.5	16-Mar-87	10-Apr-87	25	45	19	
									01-Sep-87	21-Sep-87	20			
1988	Derby		4400	4015	385			5402.6	06-Mar-88	26-Mar-88	20	140	24	
									05-Apr-88	25-Apr-88	20			
									05-May-88	25-May-88	20			
									05-Jun-88	25-Jun-88	20			
									05-Jul-88	25-Jul-88	20			
									02-Aug-88	22-Aug-88	20			
									04-Sep-88	24-Sep-88	20			
1989	Derby		4400	4015	385			5324	14-Feb-89	28-Feb-89	14	112	30	
									14-Mar-89	28-Mar-89	14			
									14-Apr-89	28-Apr-89	14			
									10-May-89	24-May-89	14			
									10-Jun-89	24-Jun-89	14			
									06-Jul-89	20-Jul-89	14			
									04-Aug-89	18-Aug-89	14			
									15-Sep-89	29-Sep-89	14			
1990	IVQ		4670	4260	410			4904.9	21-Apr-90	31-Dec-90	255	255	15	18
1991	IVQ	2,900-5,000	5000	4560	440			5112.4	01-Jan-91	31-Dec-91	365	365	14	14
1992	IVQ	2,900-5,000	5000	4560	440			5007.5	01-Jan-92	31-Dec-92	366	366	16	11

Year	Fishery	Yield	TAC	K Quota	T Quota	First Nations	Science	Total Landings	Date Open	Date Closed	Days Open	FY Days	"K" Vessels Trap	"K" Vessels Longline
1993	IVQ	2,900-5,000	5000	4560	440			5109.8	01-Jan-93	31-Dec-93	365	365	14	9
1994	IVQ	2,900-5,000	5000	4521	433			5001.5	01-Jan-94	31-Dec-94	365	365	15	9
1995	IVQ	2,725-5,550	4140	3709	356		29.48	4174.1	01-Jan-95	31-Dec-95	365	365	16	14
1996	IVQ	690-2,580	3600	3169	304		81.65	3464.8	01-Jan-96	31-Dec-96	366	366	12	11
1997	IVQ	6,227-16,285	4500	4023	386		45.36	4260.4	01-Jan-97	31-Dec-97	365	365	13	13
1998	IVQ	3,286-4,761	4500	4023	386		45.36	4534.2	01-Jan-98	31-Dec-98	365	365	13	12
1999/ 2000	IVQ	2,977-5,052	4500	6395	386		45.36	6803.9	01-Jan-99	31-Jul-00	578	578	12	19
2000/ 2001	IVQ	3,375-5,625	4000	3555	350		45.36	3914.7	01-Aug-00	31-Jul-01	365	365	12	23
2001/ 2002	IVQ	4,000	2800	2657	342	45	45.36	2349.1	01-Aug-01	31-Jul-02	365	365	12	20
2002/ 2003	*IVQ*	*(4,000) 2100-2800*	*2450*	*1883*	*206*	*45*	*45*	*1181.8*	*01-Aug-02*	*31-Jul-03*	*365*	*365*	*6*	*14*

Table H.2 Annual narrative of significant events in the sablefish fishery.

Fishing Year	Management Events
1981	• Fishing season defined Jan 1 to Dec 31 • Limited-entry (48 licenses) "K" license tab introduced • Longline hook or trap gear • Fishery unrestricted until TAC achieved
1988	• Each "K" licensed vessel permitted to fish in one of seven scheduled 20 day openings between Mar and Sep
1989	• Each "K" licensed vessel permitted to fish in one of eight scheduled 14 day openings between Mar and Oct
1990	• Individual vessel quotas introduced in directed sablefish "K" fishery • Fishery reduced to 48 quota holders • Mandatory fisher logbooks instituted • Mandatory dockside validation of landings instituted
1994	• Overage of up to maximum of 1,000 lbs or 5 percent of vessel's remaining quota permitted; • Underage of 5 percent or less of vessel's total quota permitted; • Minimum size limit of 55 cm fork length introduced (39 cm from origin of first dorsal fin to fork of the tail)
1995	• Overage of up to maximum of 1,000 lbs or 10 percent of vessel's remaining quota permitted; • Underage of 10 percent or less of vessel's quota permitted; • 29.48 mt removed from TAC for scientific purposes
1996	• Overage/underage rules unchanged; • Underage of 10 percent or less of vessel's total quota permitted; • 81.65 mt removed from TAC for scientific purposes •
1997	• Overage/underage rules unchanged; • Individual vessel quotas introduced in non-directed trawl "T" fishery • Trawl fishing year changed to Apr 1 to Mar 31 from Jan 1 to Dec 31 • 45.36 mt allocated from TAC for scientific purposes
1998	• Overage/underage rules unchanged; • Underage of 10 percent or less of vessel's total quota permitted; • Voluntary use of escape rings in traps by some fishers • 45.36 mt allocated from TAC for scientific purposes

Fishing Year	Management Events
1999	• Overage/underage rules unchanged; • "K" fleet fishing year changed to Aug 1 through Jul 31 from Jan 1 to Dec 31 • Fishing season defined as 19 months long, quota adjusted accordingly • Escape rings in traps regulated of inside diameter not less than 8.89 cm (3.5 inches) and 2 rings per trap • 45.36 mt allocated from TAC for scientific purposes
2000/2001	• Overage up to 5 percent of vessel's total quota permitted; • Underage of 10 percent or less of vessel's total quota permitted; • 45.36 mt allocated from TAC for scientific purposes
2001/2002	• Overage/underage rules unchanged; • Fishery closed Jan 18, 2002 following preliminary survey results that suggested significant decline in abundance coastwide • Annual TAC adjusted mid-season from 4,000 mt to 2,800 mt • Fishery re-opened March 18, 2002 • Trawl allocation adjusted to accommodate mid-season adjustment • 25 mt allocated from TAC for scientific purposes
2002/2003	• Overage/underage rules unchanged; • Mandatory at-sea observer coverage instituted for about 15 percent of fishing days • Government-industry collaborative management agreement signed for 5 year period • 45 mt allocated from TAC for scientific purposes

Table H.3 Revised TACs in the 2001/2002 and 2002/2003 fishing years.

TAC Parameters	2001/2002	2002/2003	2-Year Totals
TAC	2800	2450	5250
Scientific purpose	25	45	70
First Nation allocation	45	45	91
Trawl "T" allocation	342	206	548
Sablefish "K" Allocation	3567	973	4540
Carry Forward	(910)	910	0
Final "K" Allocation	2657	1883	4540

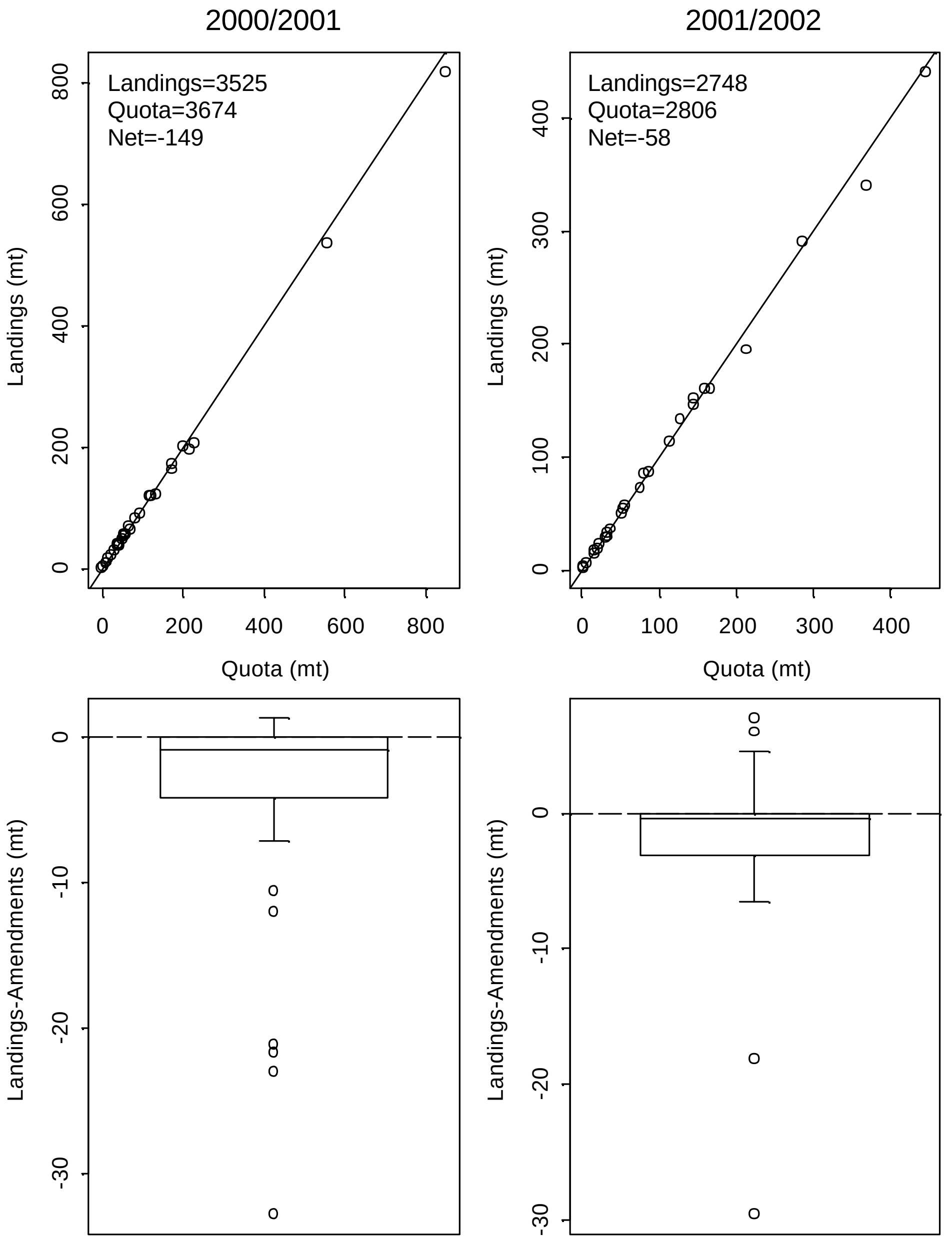


Figure H.1 Quota overages and underages for the 2000/2001 and 2001/2002 fishing years.

Appendix I. IPHC Set line survey and catch rate estimators

Background. The International Pacific Halibut Commission (IPHC) has conducted longline surveys in various configurations since 1963. The IPHC maintains experimental, tagging and survey data in a Microsoft Access database at the Commission offices in Seattle, Washington (http://www.iphc.washington.edu/halcom). The database includes detailed information from the Standardized Stock Assessment (SSA) survey, which was provided to Fisheries and Oceans Canada courtesy of the IPHC for use in this analysis. Documentation of the SSA survey prior to 1993 can be found in IPHC Annual Reports and unpublished survey manuals 1963 to 1965, 1976 to 1986, 1993 to 2000, IPHC Report of Assessment and Research Activities 1993 to 2000, and Hoag et al. (1980). Documentation of the SSA survey since 1993 can be found in the IPHC Report of Assessment and Research Activities 1993 to 2000 (e.g IPHC 1993, IPHC 1999a, 1999b, IPHC 2000). The collection of species composition data prior to 1993 was conducted sporadically and often for selected species. Indeed, surveys in regulatory area 2B (Canadian zone) and 3A were reinstated in 1993 after a seven-year gap in survey activity (Sullivan et al. 1999). Thus, the analysis presented in this paper is restricted to data collected between 1993 and 2002 when species composition data were regularly collected.

Survey protocol. The survey protocol was a fixed station scheme, however, various changes have occurred in the choice and relative positioning of stations as described in annual IPHC Report on Assessment and Research Activities documents (1993 to 2000, in particular the 1998 report). To summarize, from 1993 to 1997 stations were grouped in triangular clusters with stations at the triangle vertices and a station centered in the triangle. Each cluster was sized to fit within a square of 10 to 12 nm depending on the year. Clusters of stations were positioned approximately 12 nm apart along a regular grid. Beginning in 1998, the survey design was based on a 10 nm square grid, with stations positioned at the vertices of the grid.

Survey gear. The longline fishing gear usually consisted of 5 to 8 (range 3 to 10) skates of about 100 hooks (IPHC 1999). Hooks were fixed, with 18 ft (5.5 m) spacing so that each skate was 1,800 ft (548 m) long. Size 16/0 circle hooks have been used since 1984. In practice, the number of hooks varied slightly on each skate, and there may be small variation in the number of skates set within a survey year. Variation in hooks per skate and the number of skates set may be greater among years, with average hooks per skate as low as about 80 in some years. Soak time was a minimum of 5 hours, and was not permitted to exceed 24 hours. At each survey station, the gear was set in a predetermined direction (IPHC 1999a) regardless of the prevailing bathymetry; there was no attempt to maintain a target depth along the set. All Pacific halibut were enumerated at gear retrieval. The status of each hook was recorded, but not the species composition, *i.e.* Pacific halibut present, returning bait, gear failure, etc.

Species composition. In general, composition of the catch was determined by inspecting 20 hooks at, or near, the beginning of each skate as the gear was retrieved. The species count for each skate was recorded, often with a visual estimate of total species weight for the set. Thus, the number of hooks observed in the subsample from a set can be determined by summing the species counts and hook status counts over all skates. The order of retrieval of the species was not typically recorded. Thus, total catch per set (or skate) must be estimated for species other than Pacific halibut. In contrast, surveys conducted in 1993 through 1996 included complete enumeration of all species. All hooks were inspected for species or hook status as they were retrieved, so that the total catch and catch per skate is known for these survey years. No biological data have been collected for sablefish, so characteristics of fish selected by the gear have not been reported (but are typically 5-8 lbs in B.C., Tracee Geernaert, IPHC, *pers. com.*).

Data selection. Data used in the analysis were restricted to those records that had a purpose code corresponding to SSA survey data and latitude north of 50.8 N. This restriction effectively limited the data available in British Columbia to Hecate Strait and Queen Charlotte Sound for the majority of available years. Sets were conducted in other areas of the British Columbia coast, but may have consisted of research sets or other experimental fishing that was not considered part of the SSA survey. Sets rendered ineffective were excluded - only survey sets that were designated to be "effective" sets by the IPHC were included in the analysis. Secondary species, those species that attacked an animal already hooked, were not considered since their occurrence was infrequent.

Catch rate estimation. For this analysis, total catch by species was derived for each set by multiplying the species proportion observed on the skates by the number of hooks. Specifically, the proportion of target species *k* observed per set was estimated by

$$\text{(I.1)} \qquad \hat{p}_{ki} = \frac{\sum_{j \in S_i} y_{kij}}{n_i} \quad ,$$

where y_{kij} is the number of the target species *k* observed on skate *j* of set *i*, and n_i is the sum of the number of hooks examined on each skate of the set, namely $\sum_{j=1}^{m_i} n_{ij}$ for all skates m_i for the set. The total catch for the set was estimated by multiplying the species proportion by the total number of hooks for the set

$$\text{(I.2)} \qquad \hat{t}_{ki} = \hat{p}_{ki} m_i \bar{h}_i \quad ,$$

where m_i is the number of skates for the set and $\bar{h}_i$ is the mean number of hooks per skate for the set. The total number caught of the target species *k* was obtained by summation over the sets

$$\text{(I.3)} \qquad \hat{t}_k = \sum_{i=1}^{n} \hat{t}_{ki} \quad .$$

There is no need to adjust the total by a sampling fraction due to sets, since all sets are inspected for bycatch. However, some bias and/or error may be incurred from using the mean number of hooks per skate in equation (2) rather than the actual number of hooks per skate, h_i .

For this analysis, catch rates were calculated in units of pieces per IPHC "effective skate" stored in the SSA database. The "effective skate" is defined as a skate of 100 circle-hooks with 18 foot spacing. For gear that departs from the standard, an adjustment is applied to yield the number of "effective skates" (Sullivan et al. 1999). Although part of the adjustment incorporated into computing effective skates is specific to Pacific halibut, the adjustment was used to provide a common standard to correct for the numbers of hooks per skate and because adjustments specific to other species are not available. Catch rate per set in numbers per skate was defined as the total catch per set divided by the effective skates for the set

$$\text{(I.4)} \qquad U_{ki} = \frac{\hat{t}_{ki}}{E_i} \quad ,$$

where k indexes the species and i indexes the set. Summary statistics of catch rates by species were computed by forming the annual mean, median or other percentile of the catch rates per set over all available sets. For example, the mean catch rate for a given species k and year was computed as

$$\text{(I.5)} \qquad \bar{U}_k = \frac{1}{n}\sum_{i=1}^{n}\frac{\hat{t}_{ki}}{E_i} \quad .$$

Appendix J. Sablefish assessment history

Background

The Regional Management Executive Committee directed Science Branch staff to develop a framework to address how all available sources of data will be included in the assessment of British Columbia sablefish (Summary minutes, RMEC meeting February 12, 2002). Development of a long-term approach to sablefish stock assessment depends on understanding the evolution of assessment methodology in B.C. and why various data selection and modeling choices were made over time. It also depends fundamentally on the specification of fishery objectives for sablefish. In this section the history of sablefish assessment in B.C. is reviewed. Structural impediments to integration of available assessment data are identified, and steps to resolving these difficulties through existing or planned work are described.

Management and assessment of sablefish in British Columbia is currently conducted under the auspices of a collaborative agreement (Joint Project Agreement 2002) between the Government of Canada and the Canadian Sablefish Association. This legal agreement is in effect from August 1, 2002 to July 31, 2006, and provides for collaborative development of research, stock assessments and management advice. Goals for the sablefish fishery, as listed in the fishery management plan (Fisheries and Oceans Canada 2002), include the following:

1. To ensure conservation and protection of sablefish stocks through the application of scientific management principles applied in a risk averse and precautionary manner based on the best scientific advice available;
2. Provide opportunities for commercial fishers to harvest sablefish while employing adequate controls and monitoring in the commercial fishery to ensure the commercial TAC is not exceeded.

We adopt the terminology of Quinn and Deriso (1999) who defined *goals* as broad, conceptual statements of fisheries management desires. Management *objectives*, in the sense of the specific elements of the management system that allow the goals to be achieved, were not stated in the sablefish management plan (Fisheries and Oceans Canada 2002) or in the text of the Joint Project Agreement. Population and control parameters (e.g. harvest) used in quantitative stock assessments are not determined by goals, and objectives may only peripherally lead to suitable choices of decision rules or reference points through mention of terms such as sustained, maximum sustained, or optimal yield. For example, the fishery management objectives defined by the U.S. Congress state that the "optimum yield" is determined on the basis of maximum sustainable yield, as reduced by relevant economic, social or ecological factors, and provides for harvest to promote rebuilding of overfished stocks to levels that produce maximum sustained yield. This objective in turn leads to decision rules such as the F_{40} rule for sablefish in Alaska, and the F_{40} rule with 40-10 adjustment for sablefish off the continental U.S. states or for Pacific hake (*Merluccius productus*), both of which serve as proxies for F_{MSY}. Discussion of management requirements for sablefish in British Columbia has not produced objectives that can be translated into operational fishery decision rules, although various reference points have been applied in the course of sablefish assessment as described below.

Review of stock assessment approaches in British Columbia

Beginning in the early 1990s, sablefish assessment methodology in B.C. witnessed a notable increase in the complexity of models applied to the catch-at-age and tag-recovery data. This work culminated in an integrated catch-at-age mark recapture model presented in the late 1990s, after which the analyses became markedly simpler. An historical synopsis of data inputs, assessment methodology, PSARC advice, yield, and TAC is presented in Table J.1. Information presented in Table J.1, and in the remainder of this section, was drawn from unpublished stock assessment working papers, Canadian Stock Assessment Secretariat Research Documents, annual reports of the Pacific Stock Assessment Review Committee, and Canadian Science Advisory Secretariat Proceedings. The "Year" column of the table lists both the year of the stock assessment and the fishing year (italics) to which the assessment applied. The "Data Sources" columns lists only data actually used in analyses that determined yield options; other data analyses may have been presented in the document that provided ancillary results or contributed to assessing the validity of assumptions made in the course of yield determination.

Impediments to assessment and integration of data sources

Ageing data. Ageing of sablefish at the Pacific Biological Station was halted in 1997 due to concerns over the reliability of the burnt-otolith section method, which meant that catch-at-age information is not available after 1996 for assisting the estimation of relative year class strength.

Tagging program. Assessments of sablefish through the late 1990s relied primarily on tag-recovery information to index stock abundance due to concerns over the use of commercial catch rates as an abundance index. Furthermore, tagging data has the potential advantage of indicating movement both spatially and temporally. Implausible model results prompted the adoption of a simplified tag-recovery model in 2000 that only utilized tag returns in the year following release.

Tag releases have been large, and tag-reporting rates are thought to be high (Haist et al. 1999, their Appendix B). Haist et al. (2001) argued that since the tags are applied primarily at the same depths where most of the fishing takes place, the estimated exploitation rates for the entire stock are biased high and the true exploitation rates are lower. In turn, this implies the biomass estimates are biased low (they reflect the vulnerable adult component of the stock) and the true biomass is higher than indicated by the tagging model.

The tag-recovery data fail to meet the assumptions of the tagging model, at least one of which must be satisfied:

1. *Random tag application.* Tags are applied in locations and depth zones that represent the "core" of commercial fishing effort (over 80 percent of tags are applied between 250 and 450 fm);
2. *Random tag recovery.* Only recoveries from the trap fishery are utilized which has restricted spatial and depth distribution relative to the population distribution.
3. *Complete mixing of tags.* Haist et al. (2001, their Table 9) documented high correlation of tag recoveries with the site of tag release so that complete mixing does not apply to at least one component of the fish tagged.

Furthermore, it is assumed that the population is closed, so that emigration or immigration of fish are not incorrectly interpreted as mortality or recruitment. The northern B.C. stock, in particular, is not a closed population due to exchange of fish with Alaska (see McFarlane and Beamish 1983b, McFarlane and Saunders 1997, Kimura et al. 1998, Haist et al. 1999). Thus, if the tagging program is to reflect the offshore population and meet basic model assumptions, the design of the program must be changed and Alaskan tag return data utilized.

Tag disappearance rates. Young fish tagged in Hecate Strait in the late 1970s had a high probability of emigration from B.C. (McFarlane and Saunders 1997, McFarlane and Beamish 1983b). This effect has been demonstrated most strongly at smaller sizes and younger ages than those at which sablefish recruit to the adult vulnerable biomass. Thus, the emigration has the same net effect as a size and age-dependent rate of natural mortality that is higher for pre-recruits than for adults. Indeed, attempts to cope with this effect involved a two-stage mortality function that attempted to mimic the higher emigration rates of pre-recruited sablefish (Saunders et al. 1995, 1996). However, this approach was abandoned after 1996 due to incomplete information on the age-specific characteristics of the emigration.

Haist et al. (1999, their section 2) conducted an analysis of tag-recovery data that concluded tag disappearance rates in the first five years after release are high (Z=0.5) but decline considerably thereafter to about=0.2. This feature of the data is consistent with a hypothesis of fish moving to an unfished area, or to an area of reduced vulnerability. The possibility of abundance of sablefish in B.C., particularly in the north, being driven by fluctuations in the much larger Alaskan sablefish population meant that immigration into or emigration from B.C. waters needed to be much better understood to properly reconstruct population abundance. Said another way, the integrated catch-at-age and tag-recovery models of 1996 and 1997 treated the B.C. population as closed, and could not quantitatively accommodate fluxes of fish from outside the defined stock area. An attempt to address movement out of the Canadian zone was developed for 1998 (Haist et al. 1999), but the model tried to resolve the high disappearance rate of fish in the first five years after tagging by assigning large amounts of biomass into deep-water strata. This was considered implausible, and further attempts to resolve tag movement were placed in hiatus until the underlying data can be improved.

Indexing Survey. The design of the survey series is weakened by the lack of replication within each combination of depth stratum and locality, and the shortness of the time series relative to the longevity of sablefish. The protocol for selecting fishing sites is *ad hoc*, and does not require random set location or repeated visits to the same set locations over time. However, the credibility of the survey as an abundance index is drawn from the consistency in survey protocol over time and by similarities in the pattern of the catch rate time series from 1990 to 2002 among most locations and within most depth strata. Also, the general coincidence of the survey catch rates, commercial trap catch rates, and tagging-based abundance estimates noted by Haist et al. (2001) and reiterated in this document provides support for the indexing survey trends.

Steps to resolving impediments

Development of fishery objectives. No specific comments. Status of objective-based fishery management project for sablefish initiated by Fisheries and Oceans is unknown. A triennial review of sablefish science programs planned for mid-2003 may provide guidance for discussion of fishery objectives.

Ageing data. Routine ageing of sablefish was halted in 1997 due to concerns over the accuracy of ages determined through the otolith burnt section method. An alternative method using otolith thin sections was proposed and investigated (Beamish and McFarlane 2000) using OTC marked fish that had been at liberty for a known number of years. Although the method appears appropriate for older fish, the methodological criteria have not been fully developed and documented for the entire range of ages and potential growth patterns that will be encountered. Also, the two methods differ in cost with thin section ageing being more expensive. In order to resume production ageing of sablefish using a method that optimizes accuracy/precision and cost, a research project was funded under the 2002 Joint Project Agreement to (1) conduct comparative ageing on individual fish using the two methods, (2) document the method and criteria for the thin section method, and (3) train technicians at the Fish Ageing Unit (Pacific Biological Station) in the preparation and interpretation of thin section otoliths. A report by the researchers involved with the first phase of this project is anticipated in early 2003. When direction on the appropriate ageing method(s) is available, plans for resuming production ageing and processing otoliths archived since 1996 will be developed.

Tagging program. It is not possible to randomize tag-recoveries and there is evidence to refute complete mixing of sablefish (Haist et al. 2001). Thus, random tag application is the only avenue available to meet the basic assumptions of the current tag-recovery analysis. Two steps were taken in 2002 to move towards satisfying the random tag application assumption. First, tagged sablefish were released using two protocols:

1. a "**traditional**" tag release protocol, consistent with historical practice, to allow future analyses consistent with previous analyses, and
2. a new "**systematic**" design that attempts to distribute the tagged sablefish throughout the offshore population in proportion to local abundance.

The 2002 assessment survey marked the beginning of attempts to emulate the "traditional" spatial and depth distribution of tag releases since 1999, but with a reduced number of releases. For the new systematic tagging protocol, the localities and depth strata used for the indexing program were adopted, but traps were baited with squid and hake to optimize the number of releases per set. Note that this change in protocol has the potential to yield a second index of abundance based on combined squid and hake bait in trap gear provided the gear and bait remains standardized over time.

The second step taken in 2002 was to test the potential to conduct tagging and indexing sets at randomly selected fishing locations using trap gear. In the future, an improved design for tag application under consideration is to distribute releases at fishing sites selected using a stratified random design. However, this approach has not been used in previous sablefish surveys in British Columbia. Thus, it would be premature to implement this design change without a basis for area and depth stratification, and a pilot study to assess the possibility of random selection of fishing sites for trap gear.

Tag disappearance rates. To date, all models that have been developed to investigate movement of tagged B.C. sablefish have been based on transition matrices and assuming a Markovian process (Haist et al. 1997, 1998, 1999, Haist and Hilborn 2000). Movement was modeled as an annual process with large-scale areal and depth strata. This type of model cannot investigate certain aspects of sablefish dynamics that may be operating. These aspects include: (1) an apparent high probability that some sablefish remain close (scale of meters) to locations where they were originally caught for tagging (Haist et al. 2001), and (2) seasonal movement. These dynamics could be age and/or sex specific. A continuous model, based on diffusion dynamics and incorporating location-specific data on fishing effort, would allow investigation of alternative hypotheses about sablefish movement dynamics.

Indexing survey. The placement of survey sets is not randomized, but rather is left to the discretion of the fishing master subject to positioning a set within each prescribed depth stratum. The adoption of randomized fishing locations would decrease potential bias created by purposive selection of sites. However, randomly positioned sets are likely to result in lower catch rates, on average, and would essentially restart the survey time series. Thus, a change to a randomized survey must be carefully planned prior to implementation; perhaps using a period of overlap with set locations selected by the fishing master and randomly selected locations.

Stratified random sampling designs are commonly used in fisheries and other types of surveys, and the possibility of moving to a probability sample design (Cochran 1977) is being investigated for both the sablefish indexing survey and the tag release programs. Random sampling is a requisite design feature for unbiased estimation of the annual indices and construction of design-based confidence intervals for annual index points. Stratification can increase the precision of survey estimates, provide administrative convenience, and insurance against loss of the entire survey should problems be experienced in a particular stratum.

To develop a stratified random design for sampling the sablefish population two issues need to be addressed: (1) the current inability to measure the area of each designated stratum; and (2) problems that will arise in fishing at specified random locations. For sablefish, stratification of the B.C. offshore waters will certainly include a bathymetric as well as a spatial component. At this time we do not have accurate information on the offshore bathymetry at the scale that would be required for accurate stratification. Ideally, accurate data for 100m depth contours would be available and would require geographic information system expertise for computation of area estimates to support survey planning.

Research and assessment planning is conducted through the Joint Scientific Committee and Stock Assessment Working Group under the auspices of the Sablefish Joint Project Agreement. A Triennial Review of sablefish science programs, conducted by an independent panel, scheduled for mid 2003 is expected to provide guidance on directions for sablefish stock assessment.

Table J.1 Historical synopsis of assessment methodology, yield, and TAC for British Columbia sablefish from 1990 to 2002. The **Year** column indicates both the year of the assessment and the fishing year (italics) to which the assessment applied. Yields for south (S) and north (N) stock areas are listed as provided in that year's assessment.

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1989 *1990*	• 1979-1989 total landings • 1979-1989 "K" trap landings and effort • 1979-1989 "K" logbook catch and effort • 1979-1987 age composition	• Examination of qualified trap CPUE data using a General Linear Model (GLM) by year, month, area, and skipper • Age-structured virtual population analysis (VPA) undated from 1988 assessment • VPA evaluated at *M*=0.1 and *M*=0.15 • Yield range based on application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules to a forward projection under low, medium and high recruitment assumptions	• Advisory document not available • Later Working Papers suggest standardization procedure criticized because variation explained was low (~30%)	2,900-5,000	4,670
1990 *1991*	• 1979-1990 total landings • 1979-1990 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1979-1988 age composition	• Examination of observed CPUE series • Age-structured VPA forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment	• No explicit recommendations, endorsement of recommended yield by default	2,900-5,000	4,400
1991 *1992*	• 1979-1990 total landings • 1979-1990 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1986, 1988-1990 trap survey catch and effort, fish age, length and maturity data • 1979-1989 age composition	• Age-structured VPA unchanged, forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Biomass estimated using CPUE from 1989, 1990 trap surveys expanded for area of depth strata, mean weight of survey fish and assumed fishing area of a trap (not used for yield determination) • Preliminary results of 1990 logbook data presented, noted set by set data available starting 1991	• Endorsed yield range but recommended against adopting high risk yield until incoming recruitment more fully assessed and model revised • Sequential VPA criticized due to data limitations, unreliable fishery-based abundance index	2,900-5,000	5,000

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1992 *1993*	• 1979-1991 total landings • 1979-1991 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1986, 1988-1991 trap survey catch and effort, fish age, length and maturity data • 1979-1990 age composition	• Age-structured VPA , forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Biomass estimation used 1989 and 1991 trap survey data (not used for yield determination)	• Concluded no basis for modifying yield recommendations from 1991, but suggested managers avoid high risk catches • Reiterated criticism of VPA and lack of uncertainty estimates	2,900-5,000	5,000
1993 *1994*	• 1979-1992 total landings • 1979-1992 "K" trap landings • 1979-1992 "K" logbook catch and effort • 1986, 1988-1992 trap survey catch and effort, fish age, length and maturity data • 1979-1990 age composition	• Age-structured VPA unchanged with forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Bayesian stock age/sex-structured model tested that included Beverton-Holt stock-recruitment, tuned to commercial CPUE (not used for yields) • Biomass estimation used 1989, 1991, and 1992 trap survey data (not used for yield determination)	• Endorsed yield recommendations on basis of lack of evidence to modify 1992 yields • Expressed concern that stock might be at lower abundance than previously believed, due to management and fishery impacts on commercial CPUE	2,900-5,000	5,000
1994 *1995*	• 1979-1993 "K" trap catch • 1979-1993 "K" trap CPUE conditioned on 250-450 fm and Apr-Dec • 1980-1993 catch at age proportions • Stock and sex-specific length at age data • Stock and sex-specific maturity at age • Pooled stock and sex length-weight data	• New stock synthesis (Methot 1990) stock reconstruction adopted to integrate commercial CPUE, catch-at-age, ageing precision, sex-specific, size-based selectivity (availability), time-based availability stanzas • Model tuned to abundance trend derived from selected commercial CPUE data • Yield derived using $F_{0.4}$ fishing mortality applied with M set to 0.05 and 0.1 • Biological and tagging data suggest north and south stock areas thus yields provided for south, north, and coast for first time	• Endorsed coast wide yield options • Recommended further development of stock synthesis model, particularly related to grouping of age classes and treatment of ageing errors	1,400-2,900 (S) 1,325-2,650 (N) 2,725-5,550	5,000

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1995 *1996*	• 1979-1994 catch • 1979-1994 "K" trap CPUE conditioned on 250-450 fm and Apr-Dec • 1980-1994 catch at age proportions • Stock and sex-length at age data • Stock and sex-specific maturity • Pooled stock and sex length-weight data	• Stock synthesis stock reconstruction with two-stage natural mortality function, catch-at-age, ageing imprecision, sex-specific size-based selectivity (availability), time-based availability stanzas • Model tuned to abundance trend derived from selected commercial CPUE data • Yield derived using $F_{0.4}$ fishing mortality applied with M set to 0.05 and 0.1 • Biological and tagging data suggest north and south stock areas	• Endorsed yield recommendation on basis of decline in reconstructed biomass and TAC set at high risk yields in recent years • Requested support for north and south stock areas be provided due to increased management complexity • Noted independent review of assessment was requested by industry	465-1,580 (S) 225-1,000 (N) 690-2,580	4,100
1996 *1997*	• 1980-1995 total catch • 1980-1995 catch at age proportions • 1991-1992 tag releases • 1991-1995 tag recoveries related to 1991-1992 releases	• New catch-at-age stock reconstruction with age-sex specific selectivity, plus group at age class 15 (down to age class 10) • Model tuned to new abundance index based on exploitation rates from independent tag-recovery model • Commercial CPUE questioned as abundance index due to frequent changes in management regime (IVQs), change in baiting practices (hake added to squid) • Yield derived using F=0.12 corresponding to $F_{0.40}$ to $F_{0.45}$ range identified by spawning stock biomass per recruit analysis as appropriate • Stock synthesis model of 1994-1995 run in parallel produce similar biomass trajectory but lower yield ranges	• Advisory document not available • Other documentation suggests concern about high sensitivity of model to number of age classes modeled, lack of depth stratification, impacts of changes in depth distribution on age samples	2,643-8,575 (S) 3,584-7,710 (N) 6,227-16,285	3,600

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1997 *1998*	• 1980-1996 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1996 catch at age proportions primarily from research surveys • 1990?-1996 index survey CPUE • 1980-1996 tag releases and associated tag recoveries	• New mark-recapture model incorporating fish movement between spatial and depth strata • New integrated catch-at-age mark-recapture model limited to movement out of the assessment region • Separate analyses for north and south stock areas on evidence from tag returns that recruitment is from different sources	• Concern expressed about difference in results from mark-recapture model (abundance decline) and integrated catch-at-age recapture model (abundance stable) • Noted model-derived abundance trend contradicted CPUE trends from survey and fishery • Noted need for further model development but questioned whether data contained enough information for this purpose • Suggested base model should not be used for management • Recommended spawner-recruit analysis be updated	2,131-3,176 (S) 1,155-1,585 (N) *3,286-4,761*	4,500
1998 *1999*	• 1980-1997 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1995 catch at age proportions primarily from research surveys • 1988(?)-1997 index survey CPUE • 1979-1997 tag releases and associated tag recoveries, treated as a reduced (1991-1996 releases) and full (add 1979-1996 releases) tagging dataset	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement • Spatially and sex disaggregated age-structured model (age 15+ group) • Availability of fish, including tagged fish, was a function of age and sex • Single stock model with movement between BC regions and BC and US • Coast treated as 6 regions: south and north by shallow, mid, and deep depths • A 7th region was the US (AK+lower48) • Assumed recruitment restricted to two shallow depth regions • Model tuned using tagging based exploitation rates (reduced & full datasets split by 1979-96 and 1991-1996 releases • Natural mortality fixed at *m*=0.08	• Working paper recommended a yield from low-mid recruitment options as stock predicted to decline slowly under all scenarios (3,518 to 3972 mt at current *F*, 2977 to 4527 mt over all scenarios) • PSARC noted model was highly complex and the large discrepancy in biomass trajectories between the two tagging data sets • PSARC recommended yield options over full range of scenarios presented in working paper	2,977-5,052	4,500

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1999 *2000/ 2001*	• 1980-1998 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1995 catch at age proportions primarily from research surveys • 1990-1998 index survey CPUE • 1979-1997 tag releases and associated tag recoveries, treated as a reduced (1991-1996 releases) and full (add 1979-1996 releases) tagging dataset	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement as in 1998 • Model modified for alternative migration (proxy for immigration into Canada) • Altered trap retention selectivity • Age classes changed to 2 through 13+ • Analysis of tag reporting rates, and first use of recoveries in first year of release only in deriving exploitation rates	• Cautious endorsement to analyses presented, noted model needed development citing high uncertainty • Concluded no evidence to alter 1999 yield recommendation • Noted current removals from north may not be sustainable • Recommended consideration of different exploitation rates for north and south stocks	1,275-2,125 (S) 2,100-3,500 (N) 3,375-5,625	4,500
2000 *2001/ 2002*	• 1992-2000 tag-recoveries in 1st release year • 1988-1999 index survey CPUE • 1990-1999 total catch • 1990-1999 "K" trap catch • 1990-1999 "K" trap logbook CPUE	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement as in 1999 • Impacts of escape rings on fish sorted for tags analyzed • Tag shedding rate estimated • Estimated abundance trends based on tag returns in the year following tagging using a simple Petersen-type estimator.	• Concurred catches in range 3,700 to 4,500 tons unlikely to decrease stock biomass in 2001/2002 • Accepted yield recommendation of 4,000 t • Recommended review of stock structure implications of distinct north and south stock management units	4000	4,000 Revised March 2002 to 2,800

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
2001 *2002/ 2003*	• 1992-2001 tag-recoveries in 1st release year • 1988-2000 index survey CPUE • 1990-2000 total catch • 1990-2000 "K" trap catch • 1990-2000 "K" trap logbook CPUE	• Complex tagging and integrated catch-at-age mark-recapture models of 1997-2000 in hiatus • Comparison of CPUE trends and tag derived exploitation and abundance trends • No age-structured population dynamics • Modified spawning biomass per recruit simulation identified vulnerable biomass harvest rates of 0.06-0.11 (south) and 0.07-0.14 (north) • Estimated abundance trends based on tag returns in the year following tagging using a simple Petersen-type estimator. • Tag analysis estimates of harvest rate are 0.1-0.13 over 1990s	• Accepted low and stable stock status • Accepted yield recommendation of 4,000 t • Agreed future management should incorporate decision rules	4,000 (Nov 2001) 2,800 (Jan 2002)	2,450
2002 *2002/ 2003*	• 1992-2002 tag-recoveries in 1st release year • 1990-2001 index survey CPUE • 1990-2000 total catch • 1990-2001 "K" trap catch • 1990-2001 "K" trap logbook CPUE	• Comparison of CPUE trends and tag derived exploitation and abundance trends • No age-structured population dynamics • Tag analysis estimates of harvest rate are 0.1-0.13 over 1990s • Increased emphasis on indexing survey • Cautionary yield reduction recommended to address concerns over continued decline in abundance since mid-1990s	• Recommended approximately equal weighting of bounds implied by indexing survey (2,100 t) and tag recovery model (4,000 t) respectively, i.e. 2,800 t. • Recommended that yield adopted for 2001/2002 be carried forward into 2002/2003 • Cautioned against using most recent survey or tagging datum • Requested all relevant data to be considered for new analyses	2,800	2,450

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
2003 *2003/ 2004*	• 1992-2002 tag-recoveries in 1st release year • 1990-2002 index survey CPUE • 1990-2000 total catch • 1990-2002 "K" trap catch • 1990-2002 "K" trap logbook CPUE	• Evaluation of commercial trap, indexing survey, tag derived abundance indices • No age-structured population dynamics • Simple biomass dynamics model combining 3 indices used to project biomass under assumed future production • Decision tables for summarizing performance measures related to stock increase	• Decision table accepted as advice • Endorsed view that production likely to increase in 2003 to 2008 period, supported selection of harvest advice under assumption that 2003-2008 production is 1.25x that of 1996-2002. • Noted that annual data collection and stock assessment should mitigate risk to stock by allowing required adjustments to TAC.	N/A	3,000