SOUTHEAST ALASKA SABLEFISH

STOCK ASSESSMENT ACTIVITIES 1988–2001

Prepared in Support of the Southeast Alaska Sablefish
Stock Assessment Program Review
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by

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ABSTRACT

The Alaska Department of Fish and Game (ADF&G) manages the sablefish fishery in the Northern Southeast Inside (NSEI) Management Area (i.e. Chatham Strait) of Southeast Alaska. A goal for management of the fishery is to use a harvest rate approach, wherein a harvest rate is applied to an estimate of biomass to determine an annual harvest quota. Assessment activities aimed at providing biomass estimates were initiated in 1988, focused on annual longline surveys which yielded catch per unit effort (CPUE) and age and size composition data to be used in age-structured population modeling. This continuing effort has been supplemented more recently with mark-recapture studies because of concerns about reliability of results from age-structured modeling for estimating Chatham Strait sablefish abundance. Between 1993 and 2000 there were marked declines in both survey and fishery CPUE in Chatham Strait. This apparent decline in Chatham Strait sablefish abundance, coupled with the evolving stock assessment program, prompted ADF&G to initiate an external review to aid in evaluating the stock assessment program. This report describes the Chatham Strait sablefish stock assessment program and was prepared in support of the external review, scheduled to occur during February 25–28, 2002 in Juneau.

Keywords: sablefish, Chatham Strait, stock assessment, age-structured analysis, mark-recapture, longline, Petersen estimate, CPUE, pots, port-sampling, abundance, tagging, tail clips, tag loss

PURPOSE OF REVIEW

The Alaska Department of Fish and Game (ADF&G) manages the sablefish fishery in the Northern Southeast Inside (NSEI) area of southeast Alaska (Figure 1). This fishery, commonly referred to as the Chatham fishery, has been prosecuted since the early 1900s (Figure 2; (Appendix A). This is currently a limited entry fishery with an equal-share allocation.

In the past, the annual fishery quota had been set based on catch histories and fishery and survey CPUE data. As the catch per unit effort (CPUE) increased with the influx of very strong year classes in the 1980s the fishery quota was increased. Since 1993 we have seen a 70% decline in CPUE in the commercial fishery and a 50% increase in relative effort (number of hooks), which is cause for concern (Figures 3 and 4). Sablefish are a long-lived species and therefore easily susceptible to over-exploitation. Because of declining fishery performance data, we substantially reduced the quota in 1999 (from 4.8 to 3.12 million pounds). The quota was again reduced in 2001 (from 3.12 to 2.18 million pounds) because of continued declines in fishery CPUE and preliminary estimates of exploitation rates that indicated the exploitation rate for the 2000 fishery was in excess of 20%. The fleet was given notice that ADF&G will reduce the quota further in 2002 if we continue to have concerns about stock condition. These actions have had significant impacts on the fleet and have caused considerable concern on the part of the industry.

A harvest rate approach is ADF&G's preferred management strategy for all groundfish fisheries. We are moving toward that goal with our current stock assessment program. Assessment of sablefish in Chatham Strait is complicated by several factors including, but not limited to, a relatively short-time series of survey data, potential problems with aging of sablefish, and movement of sablefish between inside and outside waters. We have made changes in our survey methods and stock assessment approach over time and have been evaluating several different approaches to assessment. We have been evaluating more than one stock assessment approach because of questionable performance and biomass estimates from initial methods based on abundance indices and age and length compositions.

We thought this would be an appropriate time to bring in a panel of outside experts to review our program, thus far, and aid in this evaluation. The panel members include Dr. Bruce Leaman (International Pacific Halibut Commission), Mr. Mark Saunders (Canada Department of Fisheries and Oceans, Pacific Biological Station), Dr. Gordon Kruse (University of Alaska, School of Fisheries and Ocean Sciences), and Drs. Michael Sigler and Jeff Fujioka (National Marine Fisheries Service, Auke Bay Laboratory). The panel is scheduled to convene for the review in Juneau during February 25–28, 2002.

The purpose of this document is to provide information to the panel of outside experts for evaluation of, and recommendations for, the stock assessment program for Chatham Strait sablefish. This report summarizes the history of the department's stock assessment program and the major changes in fisheries management.

SUMMARY OF STOCK ASSESSMENT ACTIVITIES

The Alaska Department Fish and Game's (ADF&G) stock assessment program for sablefish in Southeast Alaska's Northern Southeast Inside (NSEI) management area (Chatham Strait) began with inception of annual longline surveys in 1988. A primary objective of the surveys was to provide data for population modeling to estimate abundance of sablefish in NSEI. Data collected from the surveys included sablefish catch-per-unit effort (CPUE), age, weight, length, sex, and maturity information. The first modeling was conducted in 1995. Prior to that, we considered the time series of annual CPUE, age and length data too short to effectively model a population of a relatively long-lived (40+ years) species, such as sablefish. Initial modeling in 1995 yielded unsatisfactory results (i.e. unbelievably high abundance estimates). The marginal performance of the model prompted us to begin investigating supplementary and/or confirmatory approaches to estimating abundance, while maintaining the original surveys to provide data for further population modeling. In 1996 we briefly explored the possibility of using a depletion estimator. Since 1997 the department has been investigating the use of mark-recapture methods to estimate abundance, survival, exploitation rates, and movement of sablefish.

In this report we chronicle the evolution and details of our stock assessment activities from 1988 through 2001. We conclude with current and future plans for assessment of Chatham Strait sablefish.

ANNUAL LONGLINE SURVEY

Beginning in 1988, researchers from the ADF&G Southeast region groundfish project have conducted annual research longline surveys in the Chatham Strait portion of the NSEI management area (Figure 1). The objective of these surveys has been to provide CPUE and biological data to assess the abundance and general condition of the sablefish resource in Chatham Strait, primarily to support management of the NSEI sablefish fishery. The methods and geographic coverage of the surveys have evolved over time (Appendix B).

Initially, 24 fishing locations (stations) were selected randomly from three statistical areas within Chatham Strait where most of the harvest had occurred in previous years. To assure that the survey concentrated on sablefish habitat, only locations in depths greater than 199 fathoms (366 m) were retained as sample stations. Once established, the same stations were fished each year**,** and over time some stations were added to increase geographic coverage**.** The accuracy of station relocation has improved over the years with improvements in electronic navigation equipment.

One-thousand hooks were fished at each station for the 1988 survey. Fishing was conducted from a chartered, commercial fishing vessel. Snap-on longline gear was used and hooks were baited with chopped herring and spaced at approximately 3-meter intervals along the groundlines. Hooks were counted as they were deployed and a marker was attached to the groundline after every 100 hooks. Sets were made in the same direction as the tidal current and allowed to soak for one hour from the time the last anchor went over-board to the time the first buoy was retrieved and hauling began. The purpose of the one-hour, rather than longer, soak times was to alleviate or minimize gear saturation which might occur with longer soak times (B. Bracken personal communication).

During longline retrieval a researcher recorded the species of each hooked fish or noted the condition of empty hooks (i.e. "baited," "unbaited," or "broken"). The 100 hook subsections within a set were tallied separately to allow for analysis of variation of catch rate between the subsections. This also allowed inclusion of valid subsections for station-specific estimates of CPUE rather than excluding an entire set if major gears snarls occurred. Every tenth sablefish caught was sampled to obtain length, weight, sex, maturity, and age data. Otoliths were extracted for age determination. With the exception of tagged and released fish, all marketable fish were sold to recover charter expenses. Further details of the survey fishing process are provided in Appendix B.

In 1988 we estimated components of variance in CPUE among and within fishing stations. The among-set component of variance in CPUE was greater than the within-set component of variance. The variance component estimates were used to refine the apportionment of hooks within and among stations to reduce the overall variance in CPUE and promote adequate geographic survey coverage of the primary sablefish habitat.

Beginning in 1989 we increased the number of stations and reduced the number of hooks from 1,000 to 500 per station. A minimum of 38 stations were sampled annually in Chatham Strait from 1989 through 1992. The reduction in hooks per station and increase in the number of stations, allowed us to increase the geographic coverage and still complete the survey within the allowable 14-day period. During this period the surveys were conducted using chartered, commercial fishing vessels. State contract regulations limited short-term charters to no more than 14 days.

A main focus of the longline surveys was to provide data to model the population dynamics of sablefish in Chatham Strait and estimate abundance. In 1992, with four years of standardized surveys, the time series of CPUE and age and length data were too short to effectively conduct such modeling. However, we conducted analyses to estimate the power of a General Linear Multivariate Model (GLMM) to detect linear trends and year-to-year differences in CPUE over a span of four years.

We conducted power analyses to re-evaluate the survey sample size (i.e. number of stations) to determine if our 1989–1992 sample size was sufficient to detect specified levels of change in CPUE. A GLMM was used for power estimates because the same stations were measured repeatedly over four years and the autocorrelation inherent in repeated measures data is accounted for by the GLMM.

Power analyses indicated that an annual sample size of 40 stations was sufficient to detect a linear trend that resulted in approximately a 20% change in sablefish CPUE over 4 years, with a power of 0.80 (a = 0.1; Bracken et al. 1997). The number of stations we had been surveying was very close to 40, so we continued surveying the original 38 stations, rather than increase the number of stations to 40, to maintain consistency and allow inter-year comparability of CPUE estimates.

Longline surveys were conducted annually from 1993 through 1996 using the same methods and 38 stations fished from 1989 through 1992. However, beginning in 1993 and continuing through 1996**,** the state research vessel, *R/V Medeia*, was used to conduct the surveys. This change was implemented because a state research vessel, suitable for longlining, became available.

In 1995 we conducted a soak time experiment to determine a conversion rate for a 1-hour to 3-hour soak time. From the *R/V Medeia* we set 30 regular survey stations (1-hour soaks) and a second set near the survey set, which was soaked for 3 hours. There was an extremely low, and statistically insignificant (a = 0.1) correlation (r = 0.0062) of CPUEs between paired stations subjected to 1-hour and 3-hour soak times (Fig. 5). On average, 1-hour soak time CPUEs were about 43% lower than those associated with 3-hour soak times.

In 1996, in addition to the annual longline survey, we conducted a concurrent survey with a chartered, commercial vessel using conventional fixed long line gear with 2-m hook spacing, squid bait, and 3–11 hour soak times. The purpose of this concurrent survey was to evaluate the use of commercial vessels to conduct future surveys. A major advantage anticipated in using multiple commercial vessels simultaneously, was the ability to conduct the survey in one week, rather than the multiple weeks needed to complete the survey from the *R/V Medeia*. This prospective change would enable us to complete the survey within one tide cycle, reduce staff time at sea, and would be more economical by reducing sea duty pay and vessel operational costs.

The major anticipated disadvantage in switching to commercial vessels was the introduction of operational changes that could effect CPUE but be unrelated to fish abundance. Sigler's (1993) research suggested that the 1-hour soak time we had been using from 1988 through 1996 may have been insufficient for gear to sink to the prevailing depths (200–400 fm) in Chatham Strait and allow on-bottom soak time sufficient for CPUE to adequately reflect abundance. Sigler (1993) concluded that CPUE was not affected by soak time restricted between 3–11 hours. There was also interest in having Chatham Strait survey methods more similar, and results potentially more comparable, to the sablefish survey conducted in federal waters, which used a minimum 3-hour soak time, conventional gear, and squid bait (Sigler et al. 1993).

Although results of the 1995 soak-time study indicated no well-defined relationship between 1-hour and 3+-hour soak time CPUEs, which would complicate comparison of 3+-hour CPUEs with previous year's 1-hour soak time CPUEs, we increased soak times to 3+-hours starting in 1997. We chartered three commercial vessels to conduct concurrent longline surveys. We also added seven new stations to the survey in the southern portion of Chatham Strait (Statistical Area 345603) to increase geographic coverage. Previous surveys had not sampled south of Patterson Point, although during recent fisheries 25% of the commercial catch was being landed from this southern area.

Since 1997, 45 stations have been surveyed annually, using three survey vessels, except in 1999 when two vessels fished all 45 stations (Appendix B). Simultaneous use of three vessels enabled us to conduct the survey within one week. The compressed survey time may minimize changes in catchability due to changes in tide cycles.

From 1997 through 1999, survey vessels used conventional commercial longline gear with 2-m hook spacing and squid for bait. In 2000 we began using longline gear built to NMFS survey standards. This gear has 2-m spacing, 15" gangions (with beckets), is baited with squid, and soaked 3–11 hours. The shift to the same gear used by NMFS for their annual longline survey was made to improve our ability to compare results with NMFS survey results.

AGE-STRUCTURED ANALYSES

1999

Initial age structured analyses (ASA) were conducted in 1995 and 1998 (Appendix C). Questionable results from these initial analyses prompted us to investigate additional methods for estimating sablefish abundance.

However, in 1999 we again used an age-structured analysis (ASA) model, incorporating the 1999 survey and fishery data, to attempt to estimate abundance of Chatham Strait sablefish. The model was provided by Mike Sigler (National Marine Fisheries Service) and used the quasi-Newton algorithm in Microsoft EXCEL Solver to estimate the parameters needed for final estimation of sablefish abundance. The model uses maximum likelihood to estimate parameters. Multinomial error structure was assumed for age and length data and log-normal error for catch data. A weighting factor (λ) was included in the likelihood function that varies the relative influence of abundance indices and the age and length components of the likelihood (Sigler 1999). Like Sigler, we used a value of λ=1. Further details of the model are provided by Sigler (1999).

Model estimates included numbers of age-2 recruits for the years 1980 through 1999, the numbers of sablefish at ages 3 through 16+ for 1980, and two parameters which defined a logistic longline gear selectivity function. These estimates, along with an assumed or empirical estimate of natural mortality, and an estimate of age-2 recruitment for 2000 (mean of model-estimated, 1980–1999 age-2 recruits) were used to attempt to forecast Chatham Strait sablefish abundance in 2000. Full input data used in the estimation of these parameters included an independent estimate of natural mortality, annual age and length composition data from 1988 through 1999, 1980–1999 fishery CPUE, 1988–1999 survey CPUE, mean annual weights-at-age from the 1988 through 1999 surveys, and annual reported harvest.

The ASAs were conducted by tuning to various combinations of the age and length composition and survey and fishery CPUE data. As in 1995 and 1998 (Appendix C), we conducted validations of the ASA using Monte Carlo simulation (Sigler 1999). For these simulations the estimated parameters from the initial fitting process were designated the “actual” estimates. From these parameters the “exact” data were calculated. Many new data sets were then simulated based on an assumed log-normal error structure (CV=0.1) for the expected abundance indices and multinomial error (*n*=200) for the expected age and length data (Sigler 1999). Finally, the model parameters for the simulated data were estimated. If the parameter estimates from the simulated data were close to the “actual” estimates, then the model would be validated to some extent.

In addition, for the first time we also conducted retrospective analyses as a further attempt at validation and to determine the consistency of the ASA results over time as additional years of data were included in the analysis. This entailed running the model repeatedly, and adding one additional year's data each time the model was run. Examination of the ASA-estimated time series of biomasses from these runs provides some indication of the consistency of the model for estimating the historical biomass

We achieved the best results from the 1999 analysis by tuning only to the survey age composition and fishery CPUE (i.e. length compositions and survey CPUE omitted). By best results, we mean the ASA estimates of the CPUE and age composition showed the closest agreement with the observed CPUE and age composition data in general magnitude and trend (Figures 6 & 7). As with previous year’s ASA models, the greatest discrepancy between the ASA and fishery CPUEs was the period 1992–1994 (Figure 6). During this time, the survey CPUE increased markedly, reaching a peak in 1993, while the ASA-estimated CPUE exhibited a consistent decline. Although the model-estimated fishery CPUE generally follows the same gross trend as the observed CPUE, the pattern of model CPUEs seems almost too regular or smooth, lacking the degree of variability in recruitment that might be expected (Figure 6), and was reflected in the estimated time series of biomass in the Gulf of Alaska and Bering Sea/Aleutian Islands (Sigler et al. 1999).

Age composition estimates from the ASA fit the survey age composition marginally well (Figure 7). While observed and estimated age compositions for individual years do not show tight agreement, in general the compositions are similar, with the cohorts from the high recruit years in the late 1970s/early 1980s reflected in the age compositions for 1988 through about 1993 (Figure 7).

Monte Carlo simulations suggest consistency (Figure 8) of the model tuned to fishery CPUE and survey age compositions. Results of the simulations yielded the greater consistency of “true” and simulated data than either the 1995 or the 1998 applications of the model. The mean biomass time series from 40 simulations coincided very closely with the biomass from the original run of the model (Figure 8). While not confirming the accuracy of the biomass estimates, this process at least indicates that the model yields consistent results despite introduced variability around the input variables (i.e. fishery CPUE and survey age compositions).

The estimated selectivity functions differed noticeably in shape from that estimated for the Gulf of Alaska (GOA) and Bering Strait/Aleutian Islands (BS/AI) sablefish (Figure 9).

The shortest time series for the retrospective analysis included data from 1980 through 1996 (Figure 10). Estimated biomass from this ASA run indicated biomasses which varied from about 34.1 to 14.5 thousand mt in 1985 and 1996 (Figure 10). With addition of 1997 data, the biomass time series increased markedly, (Figure 10) with biomass estimates ranging from a high of 49.8 thousand mt in 1985 to a low of 23.5 thousand mt in 1997. Addition of 1998 data resulted in a modest increase in the biomass time series, followed by a slight decrease in the overall series when the 1999 data were included (Figure 10). The very similar estimated biomass time series for the three most recent years, particularly near the ends of the series (1997–1999), was noteworthy. As with the results of the Monte Carlo simulations, this indicates at least reasonable consistency, if not accuracy, in the estimated biomass time series based on the last three years.

Based on the best run discussed here, the estimated forecast exploitable biomass of Chatham Strait sablefish for 2000 would have been 14.8 thousand mt. Given a Chatham-specific $F_{40\%}$ exploitation rate of 0.101, this would have permitted a 2000 quota of 1,491 mt, or 3,286,655 round pounds. This quota is approximately 5% greater than the 1999 quota of 3,120,000 round pounds.

ALTERNATIVE METHODS OF ABUNDANCE ESTIMATION

The poor performance of the 1995 ASA model, based on the limited 1989–1995 data, prompted us to begin exploring alternative, or supplementary approaches for estimating abundance of Chatham sablefish. We continued annual surveys and collection of fishery data to provide additional data for future modeling.

1996 Sonic Tagging/Depletion Estimator

We considered using a Leslie-DeLury depletion estimator (Seber 1982) applied over multiple small areas, rather than a single large area, to estimate abundance of Chatham sablefish. Working in Chatham Strait, Clausen et al. (1997) evaluated a large geographic scale, single removal event, depletion estimator. They met with limited success in achieving their objective of estimating a catchability coefficient using a single removal. In contrast to a large geographic scale effort, we speculated that multiple, small-geographic-scale depletion surveys with multiple removals might be an effective method of estimating abundance.

For this approach, multiple bouts of fishing might be conducted over relatively small areas (1 to 4 km^2) with sufficient intensity and geographic focus to effect a temporary, but detectable, localized depletion of the population sufficient to estimate local abundance. A series of these localized depletion surveys distributed throughout the NSEI might then provide an overall estimate of abundance.

Our initial step in evaluating this estimation approach was to address the assumption of closure of small-scale geographic areas; the likelihood that sablefish would move in and out of an area over the 2–4 day period planned for depletion efforts. To begin to address this assumption, in 1997 we instrumented 20 sablefish with sonic tags and tracked their movements for approximately three weeks. The purpose of this study was to estimate daily distance movements.

The study was hampered by bad weather and vessel problems that restricted the amount of data collected. However, 58 separate relocations of 19 of the 20 instrumented sablefish yielded a mean, 24-hour, inter-fix distance of 0.9 km. Given the expected need for depletion efforts of 2–4 days in duration these results indicated short-term movement probably too large to justify the multiple, small area depletion approach, since sufficient short-term “closure” of the localized “populations” could probably not be achieved.

Although we judged short term movement of sablefish too great to justify further evaluation of the multiple, small scale depletion estimation approach, those results suggested that a Chatham-wide mark-recapture effort might be an effective, alternative approach for estimating abundance. The sonic tagging study suggested that the short-term (i.e. 1–2 weeks) movements of sablefish might be sufficiently limited that effective movement-related “closure” might be achieved for a Chatham-wide mark-recapture study conducted over a time period of a month or less. Previous sablefish tagging had occurred intermittently in Chatham Strait, though the purpose of those efforts was primarily to provide data on sablefish movement within the NSEI and between NSEI and the outside waters off Alaska, Canada, and the U.S. West Coast (Bracken 1982, Maloney and Heifetz 1997).

Mark-Recapture

1997

In 1997, as part of the annual longline survey, we caught, marked, and released sablefish from 20 stations. All sablefish that appeared to be in good condition (i.e. vigorous movement and absence of obvious external trauma from hooking, sand fleas, etc.) were tagged with individually-numbered T-bar tags, attached just below the anterior dorsal fin. A total of 5,600 sablefish were tagged with T-bar tags and 5,451 of those tagged fish were marked by clipping the upper lobe of the caudal fin as the primary mark for a mark-recapture study (Figure 11a).

For the recapture portion of the mark-recapture effort, we conducted port sampling at six processors in four Southeast ports: Sitka, Petersburg, Juneau, and Kake. Port sampling was conducted to look for marked (i.e. tail clipped) fish landed in the commercial fishery and to enumerate those fish checked for tail clips.

The objective of the 1997 port sampling was to examine 100,000–140,000 sablefish for clipped tails from the Chatham Strait sablefish fishery as early in the fishery as possible. The 100,000–140,000 target was designed to achieve a Peterson abundance estimate (i.e. number of sablefish in Chatham) that was within +/- 20% of the true abundance, with a probability of 90%, given that 5,451 fish had been tail-clipped. It was desirable to achieve the 100,000–140,000 examinations as early in the fishery as possible (preferably within the first week) to minimize the potential for bias in the abundance estimate which might be caused by increasing natural mortality, movement, and/or recruitment during the 2.5 month Chatham fishery.

In 1997 port sampling was conducted for nine days. Cumulative daily tallies of marked and unmarked sablefish were used to estimate abundance of sablefish based on tallies up through the day of sampling after the opening of the fishery. Daily estimates of number of sablefish ranged from 8.4 to 16.7 million sablefish (Figure 12). Based on a 1997 mean survey weight of 3.9 kg per sablefish, these estimates correspond to biomass estimates of 32.9 to 65.0 thousand metric tons. Coefficients of variation (CV) in Petersen estimates of abundance declined sharply from days 1 to 3 of sampling, less sharply from days 3 to 4 and thereafter declined only slightly through day 9, the last day of sampling (Figure 13). The higher CVs during the first several days of sampling may be attributed largely to the relatively few marked fish observed by port samplers during the opening days of the fishery. A detailed discussion of the assumptions associated with Petersen estimates as applied with the 1997 data is provided in Appendix D.

Based on tests and evaluation of assumptions (Appendix D), there was no indication that any of the necessary assumptions had been violated sufficiently to invalidate application of a Petersen estimator with these data to estimate sablefish abundance.

A total of 183,365 sablefish were counted and examined for tail clips by port samplers at four ports during September 2–10, 1997. Of that total, approximately 21,398 sablefish from Petersburg were counted but not used in the analysis because it was possible that some previously-counted samples had been mixed with this load. An additional 15,397 sablefish were counted that were caught in Frederick Sound, outside of the Chatham Strait marking area. Also 4,294 sablefish from one vessel, counted in Juneau, were associated with a count of 15 tail-clipped fish. Judging from the unusually high incidence of tail-clipped fish, this count probably included a substantial number of fish mis-identified as being tail-clipped, perhaps due to natural tail injuries or deformities. Finally, 4,738 sablefish were landed from an area at the south end of Lynn Canal, between the Mansfield Peninsula on Admiralty Island and the southern end of the Chilkat Peninsula (Figure 1). All of these samples were omitted from the analysis. The remaining counts of (n_2 =) 137,538 sablefish were deemed valid. Of that number, 137,494 sablefish were unmarked, and (m =) 44 sablefish were marked with tail clips.

We obtained a series of running estimates of abundance by sequentially adding each additional daily count of marked and unmarked fish to all of the previous days counts and re-estimating abundance with a Petersen estimator. Running estimates of abundance tended to increase daily from the first to the last day of port sampling, varying from a low of 8,423,340 (Chapman 95% CLs = 3,536,827 – 22,871,480) sablefish, based only on the first day's port sampling counts, to a high of 16,663,614 (95% CLs = 12,265,413 – 22,813,969) noted previously and based on all nine days of port sampling counts (Figure 12). Coefficients of variation (CV) among these estimates ranged from a high of 35.3% for the estimate from the first day's sampling to a low of 14.7% for day 9 of sampling (Figure 13).

Based on all valid counts during the 9-day port sampling period, there were an estimated 16,663,614 (Figure 12) sablefish in Chatham Strait during August and the early part of September, 1997. Using a normal approximation to obtain confidence intervals around this point estimate yielded a 95% confidence interval of 11,868,758 – 21,458,470 sablefish (Figure 12). However, Seber (1982) suggests use of an alternative method (Chapman 1948) for estimating confidence intervals, based on the Poisson distribution, which may yield slightly better results. This method yields slightly higher 95% confidence limits of 12,265,413 – 22,813,969 sablefish.

The estimates of abundance were based on all valid counts of sablefish during the 9-day port sampling period. Statistical tests of equal capture probabilities of marked and unmarked sablefish tended to support the closure assumption. However, returns of external tags confirmed that some sablefish moved out of the Chatham Strait marking area between the marking and recapture phases of this survey. Each additional day between the marking and recapture phases would increase the likelihood that the closure assumption was violated because of the increasing time after marking, and therefore, opportunity for changes in abundance due to movement, recruitment, or mortality. Therefore earlier recoveries during the recapture phase may have yielded data more consistent with the closure assumption.

Increasing estimates of abundance may reflect a variety of conditions which might violate assumptions necessary for a Petersen estimate. For example, this pattern of increasing abundance estimates may indicate immigration of sablefish from outside the Chatham Strait survey area inflating the number of unmarked sablefish thereby causing an increase in the abundance estimate. To further address this possibility we conducted a series of tests of equal capture probability (Skalski and Robson 1982) of marked versus unmarked sablefish, by sequentially adding each additional daily count of marked and unmarked fish to all of the previous days counts and re-testing. This series of tests indicated no statistically significant differences (a = 0.05) in capture probabilities based on capture data for any of the increasingly longer periods of port sampling. One period, from September 2 through September 6, 1997 had an observed significance level of (p =) 0.068, indicating a significant difference (a = 0.1). Another period, September 2 through September 7, 1997 had an observed significance level of (p =) 0.092, indicating a significant difference (a = 0.1). Despite these isolated instances of statistical significance, the results tend to suggest equal capture probabilities throughout the port sampling period and no serious violation of the closure assumption. However, the power of these tests of equal capture probabilities is unknown and the tests are not definitive.

Although there was no evidence of serious violation of any of the necessary assumptions underlying the Peterson estimates, for management purposes we viewed results of this survey with caution. This was due partly to the fact that other studies have highlighted the often poor performance of the Petersen and other mark-recapture estimators in situations where the accuracy of the estimator(s) and/or the assumptions were more definitively tested (Buck and Thoits 1965, Cone et al. 1988).

Because this was the first year of the mark-recapture effort, and as a conservative measure, we used the lower 95% confidence limit of the estimated N, as the most management-appropriate estimate of sablefish abundance in Chatham Strait. The lowest bound among the series of Chapman 95% confidence limits was 3,536,827 sablefish, associated with counts from the first day of sampling. However, this estimate was based on a count of only 10,814 fish and a total of (m =) 6 marked fish. Undoubtedly because of the relatively small sample size for the first day's sampling, the CV of this estimate was relatively high compared to estimates derived from additional days of sampling (Figure 13). In general CVs declined with each additional day of port sampling and attendant increase in the number of sablefish examined for marks (n_2). The largest declines in CVs occurred between days 1 and 2, and 2 and 3. Thereafter, declines in CVs with each additional day's data were relatively modest. Because of the relatively small sample sizes and large CVs associated with the abundance estimates from the first two days of sampling, we chose to use the estimate of the lower 95% CL from the third day of sampling as the best estimate of Chatham Strait sablefish abundance during the late summer/early fall of 1997. For management, our recommended estimate of the number of Chatham Strait sablefish was 8,717,400. The mean weight of sablefish sampled from the 1997 longline survey was 3.9 kg. Applying this mean weight to the estimated of numbers of sablefish yielded an estimate of exploitable biomass of 33,998 metric tons. Applying a Chatham-specific $F_{40\%}$ harvest rate to this biomass estimate resulted in a possible 1998 quota of 3.43

thousand metric tons, or 7.57 million pounds. This candidate quota was substantially higher than the 4.8 million pound quota that had been in place since 1994. For 1998 we maintained the 4.8 million pound quota because the mark-recapture abundance estimate was based on data and analysis of only a single year's data, and because both the survey and fishery CPUE were declining. There was presumably some added, but unknown, level of conservatism built in to the estimate of abundance and our management decision because the area of the NSEI sablefish fishery also included Frederick Sound and the northern end of Chatham Strait. Biomass for these areas was not included in the Peterson estimate nor included in the estimate of the total biomass of sablefish exploitable by the fishery.

1998

We continued mark-recapture work in 1998, tagging 5,004 sablefish with T-bar tags and clipping the lower lobe of the caudal fin as the primary mark. (Figure 11b). Although the target precision for the Petersen abundance estimate was the same as in 1998 as in 1997 (i.e. +/- 20% of mean, 90% of time), the port sampling target increased to 217,000 sablefish. This was due partly to a decrease in the number of fish marked, 5,004 in 1998 versus 5,451 in 1997, and partly to an upward revision of the estimate of sablefish abundance in Chatham based on the 1997 Petersen estimate of abundance. An advance estimate of abundance is needed for Petersen sample size calculations. The larger the advance estimate, the more fish need to be checked for marks during the recapture phase to achieve estimates of specified precision.

In 1998 port sampling was conducted daily for the first 20 days of the fishery, and intermittently thereafter in at least one port through day 44 of the fishery. As with the 1997 analysis, cumulative daily tallies of marked and unmarked sablefish were used to estimate abundance of sablefish. As in 1997, port sampling was conducted in Sitka, Petersburg, and Juneau. An additional port, Hoonah, was also sampled.

For comparison with 1997, daily estimates of sablefish abundance ranged from 5.8 million sablefish, based on data from day 1, to 57.9 million sablefish, based on data from day 3 of sampling (Figure 12). As in 1997, the 1998 mean weight of sablefish was 3.9 kg. Applying this average weight to the abundance estimates provided estimates of total sablefish biomass ranging from 22 to 220.2 thousand metric tons.

For 1998, CVs in Petersen estimates of abundance declined sharply from days 2 to 4 of sampling, much less between days 4 and 5 and thereafter declined only slightly through day 9, the last day of comparison with 1997 (Figure 13). As in 1997, the higher CVs during the first several days of sampling are attributed largely to the relatively few marked fish observed by port samplers during the opening days of the fishery.

Because of the higher CVs through about day 3 of both the 1997 and 1998 fisheries, we focused on estimates after day 3 as more acceptable, certainly more precise estimates of abundance for the two years.

The substantial increase in the number of external tags from 1997 returned from the 1998 fishery, compared to the 1997 fishery (Figure 14), cast doubt on the whether the assumption of equal capture probabilities for marked and unmarked fish was met in 1997 or in 1998. In 1997, 77 external tags were returned from fish tagged during the summer of 1997 (Figure 14). In 1998, 167 tags from the 1997 tagging effort were returned. Because of mortality, a decline in number of returned tags would be expected with each ensuing year after tags were released. One possible reason for this unexpected pattern of higher second year returns may be "hook shyness" — an aversion by marked sablefish to take baited longline hooks in the fishery within as little as three weeks after they were caught on baited hooks, marked, and released (Figure 15). Evidence of possible hook shyness in 1997 suggests that it may have also occurred in the 1998 fishery. In 1998, hook-shyness may have been even more pronounced than in 1997 due to the shorter interim period between the end of the 1998 marking period and the onset of the 1998 fishery when recaptures of marked fish would have commenced (Figure 15). This shorter period of recovery from the marking period until recaptures started may have resulted in a greater proportion of sablefish being "hook shy" in 1998, due to the more recent trauma associated with the marking process compared to 1997. To the extent that hook shyness may have been prevalent among marked sablefish, it would tend to bias the Petersen estimates of abundance, resulting in overestimates of abundance in 1997 and 1998.

Estimates of Tag Retention/Reporting From 1997 and 1998 Chatham Sablefish Mark-Recapture Studies

Estimates of tag retention and/or reporting from our 1997 and 1998 mark-recapture studies were 0.52 and 0.44, respectively (Figure 16). That is, for example, in 1997 52% of the sablefish marked with tail clips and observed by port samplers had associated external tags recovered and turned in to ADF&G by the fishing industry (fishers or processors). These estimates are based on a simple binomial proportion. The high variance associated with each of these estimates (Figure 16) is due to the relatively low numbers of tail-clipped fish observed and to the estimates being close to 0.5, the binomial proportion with inherently greatest variance.

Overlap of the confidence intervals associated with the 1997 and 1998 estimates of tag retention/reporting indicate that there is no statistically significant difference (a = 0.05) between these rates. These estimates may be useful for a variety of applications, including estimating sablefish exploitation and natural mortality rates (Pollock et al. 1991). Further discussion of tag retention and reporting rates are provided in Appendix E.

1999

For 1999, capture and tagging with T-bar tags occurred during August 14–25. Because of evidence of hook-shyness in 1997, and possibly 1998, we did not fin clip or port sample in 1999. We continued external tagging to provide tag return data for possible estimates of exploitation rate and to further investigate apparent hook-shyness.

Over the three years, starting in 1997, the decreasing time periods between the initial marking and the subsequent recapture dates (Figure 15) was intended to promote adherence to the closure assumption. A shorter period between mark and recapture presumably would allow less time for losses or gains to the population due to movement, mortality, or recruitment. As occurred with 1997 tag releases, there were more 1998 tags returned the year after release than during the year of release (Figure 14), a pattern consistent with hook shyness.

CURRENT APPROACH – POT CAPTURE-LONGLINE RECAPTURE

2000

With the intent of alleviating or reducing the suspected hook-shyness possibly experienced during previous year's mark-recapture efforts, from July 5 to 14, 2000 we double-marked (external tags and tail clips) and released 5,768 sablefish caught in sablefish pots. We used a chartered, commercial pot-fishing vessel to capture sablefish for marking. Previous marking efforts relied on longlines for capturing fish for marking. For the first time, this survey effort was independent of the regular, annual longline survey. Capture and recapture of animals using different gears is a commonly-prescribed approach to try to reduce gear shyness (Seber 1982). As in previous years, recaptures of marked fish were made by the commercial longline fleet during the September 1 – November 15 NSEI fishery. Records of recaptures consisted of both external tags returned by industry (fleet and processors) and counts of tail-clipped fish by ADF&G port samplers at fish-processing facilities. Like prior year's mark-recapture efforts, the main objective of the 2000 marking was to provide data to estimate sablefish abundance with a Peterson mark-recapture estimator.

Equal Capture Probability: Size Selectivity

Size selectivity of the capture and/or recapture gear in mark-recapture studies violates the equal capture probability assumption and can result in biased population estimates. Since we used different gear for the capture and recapture phases of the study in 2000, for the first time we tested for size selectivity using Kolomogorov-Smirnov tests. We tested for equal cumulative size distributions of fish marked during the first capture event and recaptured during the second capture event (i.e. test for size selectivity of first sampling event) and for fish captured during the first event and captured during the second event (i.e. test for size selectivity for second sampling event) Tests for size selectivity indicated significant (a = 0.01) size selectivity during both the capture (Figure 17) and recapture (Figure 18) phases.

Peterson Abundance Estimate

The size-selectivity of capture and/or re-capture gears indicates differential vulnerability of the mark and recapture samples due to the different gears. (Figure 19). In this circumstance, the marked population available to the recapture gear is effectively less than the original number of fish marked. This differential vulnerability may be accounted for in an approximate fashion (Ketchen 1953).

Another approach for addressing the apparent unequal capture probability indicated by the significant size selectivity is to estimate abundance by specific size strata and combine the stratified estimates of abundance to yield an overall estimate. This approach is possible when the recaptures (m) can be individually identified and assigned to a designated size stratum. We were unable to assign individuals to size strata because our method of marking, tail clipping, did not allow us to identify individual fish recaptured from the initial marking phase, and we did not measure the length of tail clipped fish counted in the processing plants. In many instances, it was only possible to examine fish for tail clips after they had been headed and gutted, precluding the option of measuring total lengths. Therefore, we did not use 2000 mark-recapture data to try to estimate abundance directly with the Peterson estimator.

Exploitation Rates and Abundance

As an alternative to estimating abundance with a Petersen estimator, we estimated a simple exploitation rate based on returns of external (T-bar) tags from the fishery, adjusted to account for tag loss and non-reporting.

Return rates of external tags from the commercial fishery were notably higher for the 2000 fishery than in previous years (Figure 14). This may have resulted from several factors. Use of pots for initial capture and marking, followed by recapture with longlines may have had the intended effect of reducing the incidence of hook-shyness, thereby increasing the capture probability of marked fish over previous years. The time between completion of marking and the fishery was longer in 2000 than any previous mark-recapture effort (Figure 15). The longer time between initial capture and recapture, compared to previous years, allowed more time for marked fish to recover from the trauma of the marking process and may have increased capture probability of the marked fish.

The 2000 tag retention/reporting rate of 76% (95% CL 69.5%–81.7%) was higher than in previous years, based on observations of double-marked (i.e. caudal fin clip and external tags) fish in processing lines. This higher rate probably contributed to the overall greater return of 2000 tags. The returns of more tags which may be indicative of equal capture probabilities of marked and unmarked fish suggested the possibility of using returns of external tags to estimate annual exploitation rate. However, to the extent that it might have occurred in 2000, hook shyness might also result in a biased estimate of exploitation rate, just as indications of hook shyness in 1997–1999 could have biased Petersen estimates of abundance.

Exploitation Rate Estimate

We considered three candidate estimators of exploitation rates based on external tag returns. These included a mark-recapture, catch-effort estimator advanced by Chapman (1961), Wetherall’s double-tagging estimator (Wetherall 1982) and Paulik’s (1963) maximum likelihood estimator, based on grouped tag recovery times.

Chapman’s (1961) regression model theoretically can provide estimates of natural and fishing mortality based on the tagged portion of the population and effort data. We analyzed our tag return data using Chapman’s model as one alternative approach to estimating exploitation rates.

Wetherall’s (1982) double-sampling model was a candidate model since we could rely on the double marking which we had done in the past (e.g. external tags and fin clips). To apply this model, we would need to use data from those landings which were 100% observed (i.e. for fin clips or PIT tags). We would only be able to use those external tag returns which we could associate directly with landings that were 100% observed. We have used such data in the past to estimate tag retention/reporting rates. To use this approach, it would have been highly desirable to have weekly processing line observations throughout the fishery. In 2000, data with these traits were somewhat limited, so we did not use the Wetherall model with our data.

Paulick's (1963) maximum likelihood estimator provided the most straightforward method of estimating annual exploitation rate. Based on this model, dividing the total number of tags returned from the 2000 fishery by the total number of fish tagged provided an annual exploitation rate estimate.

We divided the 2000 catch of 3.13 million pounds by estimated exploitation rates to provide estimates of biomass. Assuming abundance in 2001 similar to that in 2000, the products of biomass estimates and associated exploitation rate yielded candidate quotas for 2001.

Equal Capture Probability: Hook Shyness

Data available through 1999 reflected the pattern of external tag returns from 1997 through 1999 that could be attributable to "hook-shyness". That is, the number of tags returned was greater during the year after tag release than it was during the year of tag release. The recurrent pattern of tag returns consistent with possible hook shyness reinforced the desirability of investigating alternative methods that may have alleviated or reduced hook shyness, such as the use of pots in 2000 (Figure 14).

Tag Loss/Non-reporting

We had no data that allowed us to separately evaluate the specific assumptions about tag loss and non-reporting. We do know that tagged sablefish lose their tags and/or that all recovered tags are not reported. Our double marking and processing line observations allowed us to compare the number of external tags returned from those landings which we observed completely, and the number of tail-clipped fish detected by our observers. Counts of tail clips in excess of returned tags reflect the level of tag retention and/or reporting. However the extent to which retention and reporting contribute to the differential can not be separated. The two conditions, less-than-100% tag retention and reporting, would effect estimates of exploitation in the same way; they would result in underestimates of exploitation rate. Some of this bias can be reduced by estimating a tag retention/reporting rate and applying this to either correct the original count of tags released (M_o), or to the count of tags returned (m) to estimate the number of tagged fish recovered. If we assumed that all of the discrepancy between tag and tail-clip counts was due to tag loss, the retention/reporting rate would be applied to adjust M_o down. Assuming that the discrepancy was due solely to non-reporting of some recovered tags, the retention/reporting rate would be applied to the number of reported tags (m) to adjust this number upward and yield an estimate of the actual number of tags recovered.

In 2000, of the 33 landings for which all of the catch was examined for tail clips and which had one or more tail clips and/or tags reported, 9 landings resulted in greater tag counts than tail clips observed. These types of discrepancies most probably resulted either from observers overlooking tail-clipped fish or fishers or processing line workers reporting tags from one particular landing, when in fact the tags came from some other landing. Omitting these 9 cases yields an overall tag retention/reporting rate of 76%. While some of this rate was probably influenced by tag loss, it may be more likely that the rate is influenced primarily by non-reporting. If we assume that the tag retention/reporting rate is influenced totally by reporting, the 76% reporting rate can be used to adjust upward the number of tags reported (m) to estimate the probable actual number of tags recovered. We made this assumption and corrected m accordingly to estimate some annual exploitation rates under varying conditions (Table 1; Figure 20).

Exploitation Rates and Abundance – Chapman Model

Chapman's (1961) model applied to our 2000 pot tagging data yielded a natural mortality (M) estimate of 0.35. This estimate seemed unreasonably high, given estimates of sablefish natural mortality from other sources that are between 0.10 and 0.22 (Sigler 1998). This high estimate of natural mortality cast doubt on the estimated annual exploitation rate of 0.35 from this model.

Exploitation Rates and Abundance – Paulick Model

Using Paulick's model, dividing the total number of tags returned from the 2000 fishery by the total number of fish tagged provided an annual exploitation rate estimate of 0.12 (95% CI: 0.11–0.13) (Table 1; Figure 20).

This simplest application of the model was not appropriate because of probable violation of three assumptions. The assumptions are: 1) tagged fish do not lose their tags, 2) all recovered tags are reported, and 3) instantaneous mortality rates (F) for the tagged and untagged portions of the population are the same. We addressed the assumptions about tag loss and reporting by estimating a combined rate (see "Tag Loss/Non-reporting" above).

Differences in length distributions between the marked fish captured with pots, and fish caught in the commercial longline fishery (Figure 19) indicate that vulnerabilities for certain size classes of sablefish were not the same for the two gear types. This differential violates the assumption of equal instantaneous exploitation rates (F) for the tagged and untagged portions of the population. To address this, we estimated size-specific exploitation rates using only those size classes in common to both gear types (Figure 20). We then weighted the size-specific exploitation rates by the size-specific length compositions from our sampling of the commercial longline fishery to estimate an overall weighted exploitation rate. We estimated weighted exploitation rates for recaptures both unadjusted and adjusted for tag reporting (Table 1; Figure 20). Fishery-size-composition-weighted, unadjusted and adjusted exploitation rates were 0.16 and 0.21 respectively.

Differential availability of marked fish in various areas of Chatham Strait could bias estimates of an overall, Chatham-wide exploitation rate. To use an extreme example of the potential problem, if all of the tagged fish had been released in one statistical area, no sablefish movement occurred among statistical areas between marking and the onset of the fishery, and the fishery took place completely in statistical areas other than the one in which tagged fish were released, no tagged fish would be caught in the commercial fishery and the estimated exploitation rate would be 0. For the three statistical areas that received marked fish in 2000 the disparity is not this extreme. However, the numbers of tagged fish released in two of the statistical areas, 345701 and 345631, were markedly disproportionate to the catch from those statistical areas (Figure 21). For example, 75% of the tagged fish were released in Statistical Area 345701, while only 29% of the catch came from that statistical area. This disparity in tagging and catch proportions is not necessarily problematic, as long as capture probabilities and underlying mortality rates of tagged and untagged portions of the population are equal within a statistical area. In this case differences among statistical areas in the numbers of tagged fish released and recaptured could still provide unbiased estimates of exploitation rates, though the variances of the rates would be influenced by the sample sizes of tagged fish released into the different statistical areas. Of greater concern is the fact that 20% of the 2000 Chatham sablefish quota was caught in Statistical Area 345603, where no tagged fish were released. A disparity of this magnitude may be more likely to bias an overall, Chatham-wide estimate of exploitation rate, since the exploitation rate in Statistical Area 345603 cannot be estimated directly. As an alternative to the length-distribution-weighted exploitation rate described above, we also estimated an overall exploitation rate based on combining statistical area-specific exploitation rates weighted by the proportion of the 2000 Chatham catch from the various statistical areas. Using the 3 Statistical Areas, 345731, 345701, and 345631 which received tagged fish and contributed to the catch, we estimated an exploitation rate of 0.166, adjusted for non-reporting (Figure 22; Table 1).

As a final method, we estimated the exploitation rate based on simultaneous weighting of both the proportion of the catch by size category and by proportion of the catch from among the three statistical areas in which tagged fish were released. This resulted in an exploitation rate of 0.173 (Table 1). This simultaneously-weighted exploitation rate is between the size-composition-weighted rate of 0.210 and the statistical areas catch-composition-weighted rate of 0.166.

Annual exploitation rates, adjusted for non-reporting, varied from 0.152 to 0.210. Assuming 2001 biomass was the same as that in 2000 and applying an $F_{40\%}$ annual exploitation rate (i.e. $U_{40\%}$) of 0.101 to the estimated biomasses, yielded 2001 candidate quotas ranging from 1.5 to 2.1 million pounds (Table 1).

<u>Conclusions</u>

Based on exploitation rates and biomass estimates from those exploitation rates, we lowered the 2001 Chatham Strait sablefish quota from 3.12 to 2.18 million pounds with the caveat that the quota would be lowered to 1.7 million pounds in 2002, in the absence of new information that would indicate a more appropriate quota. This prospective 2002 quota was derived from the estimate of exploitation rate in 2000 of 0.187 and a catch of 3.13 million pounds yielding a biomass estimate of 16.78 million pounds. An $F_{40\%}$ harvest rate (0.101) applied to a biomass of 16.78 million pounds would yield a quota of 1.69 million pounds.

2001

Marking: Potential For Bias Arising From 2000 Management Action

In 2000, based on the significant size selectivity of capture and recapture gear and the inability to readily estimate abundance within size strata, we opted not to estimate abundance with a Petersen estimator. Instead, we used the returns of external tags in combination with an estimate of tag retention/reporting to estimate a simple exploitation rate and, along with recorded total catch, biomass. Based on these estimates we reduced the 2001 Chatham fishery quota from 3.12 to 2.18 million pounds.

For the 2001 mark-recapture effort, we were attentive to the possibility that, as a result of the lowered quota for 2001, some fishers might be inclined to discard 2001 tags and/or tagged fish because our decision to lower the 2001 quota had been based on analysis of the 2000 external tag return data. As a method for addressing, if not definitively testing for, this possible bias, in 2001 we caught and marked 9,170 sablefish (Richardson 2001). Of that total, 4,545 were double marked with a T-bar tag and by clipping the upper lobe of the caudal fin (Figure 11a). Another 4,625 were single-marked by clipping the lower lobe of the caudal fin (Fig 11b). The purpose of differentially marking sablefish was to try to determine if a significant number of fishers might have discarded the more readily-identifiable, externally-tagged sablefish in 2001, compared to the presumably less-identifiable lower-lobe clipped fish, to reduce the possibility of another quota reduction based on external tag returns.

To test for possible intentional bias, we conducted a large sample, normal approximation Fisher's test (Marascuilo and McSweeney 1977) to test for difference in the proportion of upper and lower lobe-clipped sablefish landed in the 2001 Chatham fishery. If there was a significant tendency to discard more tagged, upper-lobe-clipped fish compared to untagged, lower-lobe-clipped fish, that bias might be manifest as a lower proportion (*p*) of tagged, upper lobe tail-clipped fish landed compared to untagged, lower lobe tail-clipped fish. Although a greater proportion of untagged, lower-lobe-clipped sablefish were landed (p=0.070) compared to tagged, upper-lobe-clipped (p = 0.054), the difference was not statistically significant (a = 0.1).

Equal Capture Probability: Size Selectivity

Size selectivity of the capture and/or recapture gear in mark-recapture studies violates the equal capture probability assumption and can result in biased population estimates. As in 2000, we again tested for size selectivity using Kolomogorov-Smirnov tests. We tested for equal cumulative size distributions of fish marked during the first capture event and recaptured during the second capture event (i.e. test for size selectivity of first sampling event) and for fish captured during the first event and captured during the second event (i.e. test for size selectivity for second sampling event)

Unlike in 2000, in 2001 there was no significant difference (a = 0.1) in the cumulative length distribution of sablefish marked during the capture phase of the study and those recaptured in the recapture phase. (Figure 23). This outcome indicates that size selectivity, at least during the recapture phase of the study, would not contribute to a violation of the equal capture probability assumption necessary for valid application of a Petersen estimator.

There was a highly significant difference (a = 0.01) in the cumulative distributions of sablefish marked during the capture phase of the study and sablefish sampled from the commercial fishery (Figure 24). The pots used for the initial capture may have selected for smaller fish. However, seasonal changes in size of available fish may also have contributed to the disparity in length distribution between sablefish caught during the pot survey and the commercial fishery. During the pot survey in June and July (Figure 15) we chartered a commercial longline vessel to fish several longline sets in the immediate vicinity of some of our pot sets. Albeit from a relatively small sample (n=276), the length distribution of these longline-caught sablefish was similar to those fish captured with pots (Figure 25). The length distributions of longline-caught sablefish sampled during the June–July (pot) survey period differed noticeably from those of the regular longline survey in August and the commercial fishery which took place from September through November (Figure 25). The distributions of the regular longline survey and the commercial longline fishery were very similar. This pattern suggests the possibility of a seasonal shift in length composition, which may have contributed to the difference in the length compositions of sablefish caught in pots and those sampled from the commercial fishery. Discards of smaller fish during the commercial fishery may have also contributed to the difference in length distributions of sablefish from the pot survey and the commercial fishery. However, this factor is presumably minor since the length distributions of fish sampled from the August longline survey (which had no discards of smaller fish) and the September through November commercial longline fishery are very similar (Figure 25). These results suggest no size selectivity during the commercial longline recapture phase of the study, but size selectivity during the initial capture phase with pots.

Equal Capture Probability: Hook Shyness

Tag returns in 2001, from fish tagged in 2000 were greater in 2000 than they were in 2001 (Figure 14). This pattern of relative numbers of tags from the first two years of tag returns from a particular year, differ from the pattern of returns for tags released between 1997 and 1999. During those years there were more tags returned the year after tagging than during the year of tagging. As suggested previously, this pattern of returns may be indicative of hook shyness of longline-caught sablefish during the year of tagging; a phenomenon that could violate the assumption of equal capture probability.

Unlike patterns from previous years, the pattern of returns from the 2000 tagging, while not indicating unequivocally that there was not “hook shyness,” do not suggest outwardly a potential problem with hook shyness. The number of tags returned in 2001, relative to 2000 returns, could have been influenced by the original numbers of tags released in the respective years (5,768 in 2000 versus 4,545 in 2001). In addition, to some degree, the lower number of 2000 tags returned in 2001 may have been influenced by the management decision to lower the quota based on the return of tags in 2000. Some fishers may have been more reluctant to turn in recovered tags, perhaps concerned that another reduction in quota based on tag returns would occur. This possible phenomenon may have also suppressed the return rate of 2001 tags in 2001.

Petersen Estimates of Abundance

We used a Petersen estimator (Seber 1982) to estimate abundance of Chatham Strait sablefish at the time of the commercial fishery in 2001. Based on the results of the Fisher’s test, we concluded that there was no significant difference in the proportion of tagged and untagged fish landed and therefore there was no need to distinguish between the method of marking — upper lobe versus lower lobe of tail clipped — for estimating abundance. Therefore we initially included all 9,170 sablefish that were marked in the capture phase of the study. However, prior to the 2001 fishery, during the annual longline survey in August, survey vessels caught 28 of the tagged, upper-lobe-clipped sablefish. Therefore, to estimate abundance, we subtracted these 28 fish from the initial number of fish marked to yield an initial marked number (n_{11}) of 9,142 at the onset of the commercial fishery.

In addition to the 28 tagged fish captured, some lower-lobe-clipped fish were probably also captured during the longline survey. Since there were no external tags to call attention to these fish, it is unknown how many were captured. As an alternative to the abundance estimate based on the number of fish marked minus the 28 tagged fish caught during the longline survey (i.e. n_{11} = 9,142), we also estimated the number of lower-lobe-clipped fish that were caught during the longline survey. Since the proportions of upper- and lower-lobe-clipped fish landed were not significantly different, we assumed the capture rate of lower-lobe-clipped fish in the longline survey was the same as that for the upper-lobe-clipped fish. That rate was 0.6%. We applied this estimated capture rate to the initial number of lower-lobe-clipped fish (n_L = 4,625) to yield an estimate of 28 lower-lobe-clipped fish caught in the longline survey, the same as the number of upper-lobe-clipped fish. Adjusting n_{11} for this additional loss of marked fish prior to the commercial fishery recapture phase yielded an alternative estimate of marked fish of (n_{12} =) 9,114.

During port sampling of the 2001 commercial catch, samplers at three ports (Petersburg, Sitka, and Juneau) observed a total of 109,734 sablefish for marks as of October 22, 2001. Of those fish observed, a total of 497 tail clipped fish were observed; 212 upper-lobe-clipped, and 285 lower-lobe-clipped.

Based on the initial marked number, n_{11} = 9,142 we estimated 2.02 (90% CI = 1.9-2.2) million sablefish within the area surveyed with pots in the summer of 2001 (Figure 1). We used the ArcView geographic information system (GIS) to estimate the surface area of this area at depths greater than 100 fm, as 2,020 km^2. This area encompasses much, but not all, of the main waters of the NSEI management area where the sablefish fishery is conducted. Based on the abundance estimate, and the estimated area, the density of sablefish in waters 100 fm or greater was 997.5 sablefish/km^2 (90% CI = 926.4 – 1068.5 sablefish/km^2). The estimated area of the portion of the NSEI management area that supports almost the entire commercial catch is 3,920 km^2. Applying the density estimate to this entire area yields an estimated 2001 abundance of 3.91 million sablefish (90% CI = 3.63–4.19 million sablefish). The product of this abundance estimate and the mean weight of sablefish from the 2001 Chatham Strait longline research survey (3.03 kg; 90% CI = 2.95 - 3.14 kg) provided a biomass estimate of 11,902 metric tons, or 26,239,011 pounds.

We also estimated an alternative abundance by applying a different sablefish density to those areas in which tagging did not occur in 2001. The overall 2001 fishery CPUE for those areas was 0.07 sablefish/hook, about 84% of the 0.083 sablefish/hook estimated for the areas in which tagging occurred in 2001. Assuming that fishery CPUE provides some measure of abundance, and is linearly related to abundance, we estimated the non-tagging area sablefish density as 84% of the 997.5 sablefish/km^2 tagging area density, or 834.4 sablefish/km^2. Applying the tagging and non-tagging area estimated densities to their respective areal estimates of water deeper than 100 fm yielded an overall estimate of 3.7 million sablefish, or 24,869,923 pounds.

Using n_{12} = 9,114 as the initial marked number of fish resulted in an estimate of 2.01 (90% CI = 1.9–2.2) million sablefish in the pot-surveyed area. Applying this estimate to the entire area yielded a density of 994.4 sablefish/km^2. The estimated biomass for the entire Chatham fishery area was 11,865 metric tons, or 26,157,241 pounds.

Based on differential sablefish densities for main and minor fishery statistical areas, the n_{12} based estimate of biomass was 11,245 metric tonnes, equivalent to 24,792,419 pounds. Among the four alternative approaches for estimation, biomass estimates ranged between 24,792,419 and 26,239,011 pounds. Applying an $F_{40\%}$ harvest rate to this range of biomass estimates resulted in candidate 2002 quotas of between 2.45 and 2.50 millions pounds.

BIOLOGICAL SAMPLING AND REFERENCE FISHING MORTALITY RATES

Approximately 5%–10% of the sablefish captured during annual longline surveys were sampled for biological data. Weights and lengths of each sablefish were recorded and otoliths removed for later age determination in the laboratory. Aging was done using the break-and-burn method.

Parameters for defining the weight-at-age relationship were estimated using Schnute's (1985) simplified growth model, an equivalent of the von Bertalanffy growth model. The relationship for females was, $W_{k+j} = 1.72 + 1.95(1\text{-}.98^{1+j})/(1\text{-}0.98)$, for males, $W_{k+j} = 1.37 + 1.58(1\text{-}.92^{1+j})/(1\text{-}0.92)$, and $W_{k+j} = 1.36 + 1.65(1\text{-}.92^{1+j})/(1\text{-}0.92)$ for the sexes combined, where W_{k+j} is the mean weight of $k + j$ year olds, and k is the age of recruitment.

We estimated spawning stock biomass per recruit (Gabriel et al. 1989) to determine the reference fishing mortality rates of $F_{30\%}$, $F_{35\%,}$ and $F_{40\%}$. These rates were determined to be, 0.149, 0.125, and 0.101, respectively.

SABLEFISH STOCK STRUCTURE

Tag returns indicate movement of sablefish between Chatham Strait, Clarence Strait, the Gulf of Alaska, and British Columbia (Maloney and Heifetz 1997). Although movement occurs, a high percentage (89%; Figure 26) of sablefish tagged in Chatham Strait are recaptured in Chatham, suggesting a non- or minimally-migratory component of sablefish in Chatham Strait (Maloney and Heifetz 1997), at least at some stage(s) in the life cycle. Chatham tag returns from sablefish tagged in areas along the coast of Southeast Alaska ranged between 7% and 22% (Figure 27). In the Gulf of Alaska and adjacent waters, those sablefish that do migrate tend to exhibit size-specific movement, with larger fish tending to move eastward and southward and smaller fish northward and westward in the Gulf of Alaska (Bracken 1982, Heifetz and Fujioka 1991, Maloney and Heifetz 1997). Based on analysis of sablefish tagging data and oceanographic data, Kimura et al. (1998) concluded that sablefish north of northwest Vancouver Island, B.C. probably constitute a single stock of sablefish, while those south of that area constitute a separate stock.

PLANNED ACTIVITIES

In 2002, we plan to continue mark-recapture surveys using pot gear to capture sablefish. Rather than using external tags or tail clipping, we plan to investigate the use of passive integrated transponder (PIT) tags to mark sablefish. Our intent in exploring the use of PIT tags is to minimize or alleviate potential problems associated with misidentification of clipped fins and intentional discards of fish with external marks by individuals, perhaps intending to influence management decisions based on returns of marked fish. There were two separate incidents in the past five years where processing line workers were caught cutting the tails of fish “upstream” of the point where observers were observing fish for tail clips.

Use of PIT tags may also reduce the incidence of non-detection of marked fish by port samplers which occurred occasionally during port sampling. The ability to identify individual marked fish for both the capture and recapture phases will also allow us to estimate abundance by size-strata if gear related size-selectivity recurs. Automated detection of PIT tagged sablefish may also increase the efficiency of the recapture phase of the mark-recapture study.

We have multiple intended applications for current and future Chatham Strait mark-recapture data. These include stand-alone estimates of abundance, based on closed or open-population abundance estimators; integration of mark-recapture data into an age-structured model (Haist and Hilborn 2000); and estimates of survival, exploitation rates (White and Burnham 1999) and movement.

Sample sizes for age, weight and length estimates will be increased to achieve an approximate 15% sampling of the survey catch, rather than the historical 5-10% sampling target.

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Table 1. Exploitation rates and quotas.

Type Of Exploitation Rate	Exploitation Rate	Exploitation Rate 95% CI	Biomass Estimate From Exploitation Rate (Million Pounds)	Quota (Million Pounds; Based on $F_{40\%}$, age-2 Recruit Target Exploitation Rate)
Target F40% exploitation; age-2 recruitment	0.101	-	-	-
Target F40% exploitation; age-5 recruitment	0.113	-	-	-
Simple exploitation rate, unadjusted for non-reporting.	0.120	0.112 - 0.129	26.06	2.62
Simple exploitation rate, adjusted for non-reporting.	0.158	-	19.80	1.99
Size-specific, fishery-size-composition-weighted exploitation rate, unadjusted for non-reporting.	0.160	0.133 - 0.186	19.61	1.98
Size-specific, fishery-size-composition-weighted exploitation rate, adjusted for non-reporting	0.210	-	14.90	1.50
Stat. area-specific, stat area catch composition-weighted exploitation rate, adjusted for non-reporting. Exploitation data included only from 3 stat. areas in which fish were tagged.	0.166	-	18.92	1.91
Stat. area-specific, stat area catch composition-weighted exploitation rate, adjusted for non-reporting. Exploitation data included from 3 stat. areas in which fish were tagged, and assumed low exploitation rate from Stat Area 345603, which received no tagged fish.	0.152	-	20.57	2.07
Stat. area-specific, stat area catch composition-weighted exploitation rate, adjusted for non-reporting. Exploitation data included from 3 stat. areas in which fish were tagged, and assumed high exploitation rate from Stat Area 345603, which received no tagged fish.	0.170	-	18.40	1.85
Stat. area-specific, stat area catch composition- and size composition-weighted exploitation rate, adjusted for non-reporting. Exploitation data included only from 3 stat. areas in which fish were tagged.	0.187		16.78	1.69

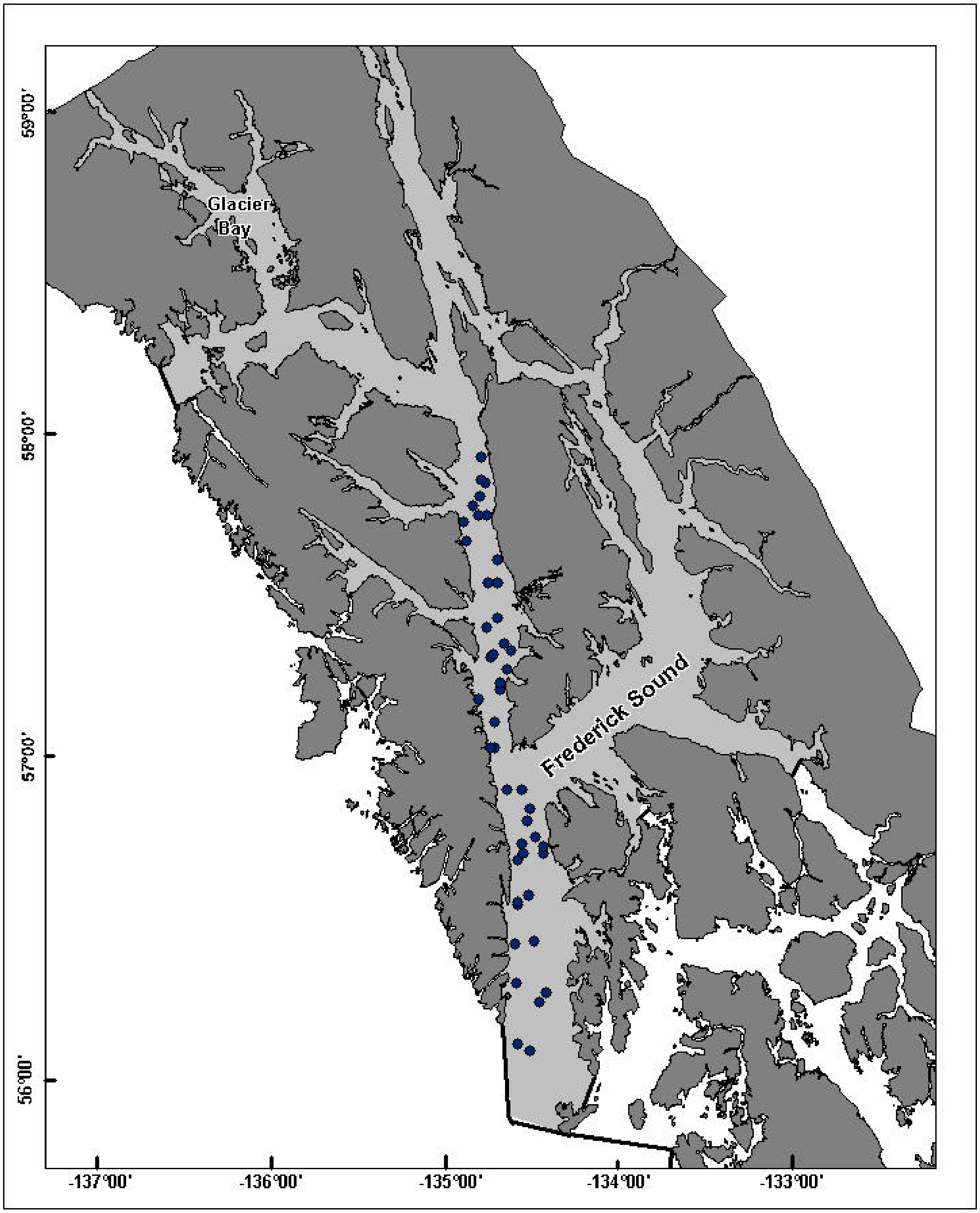

Figure 1. Northern Southeast Inside (NSEI) management area.

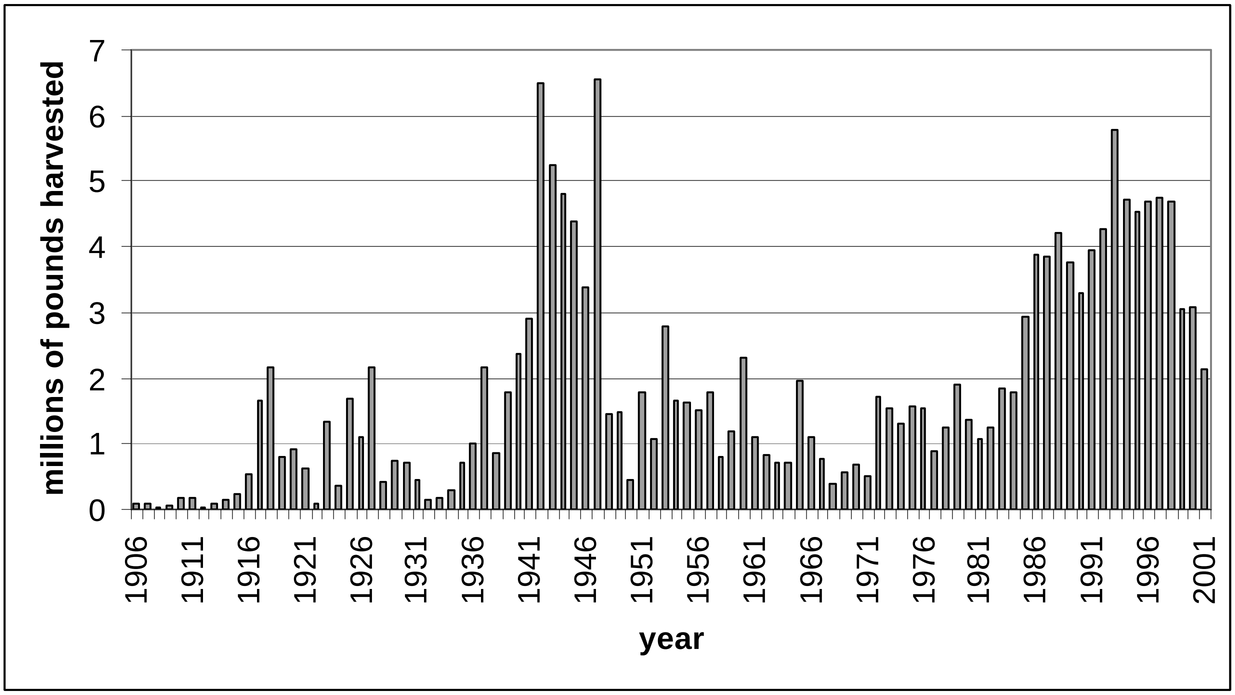

Figure 2. Historic harvest of sablefish in the Northern Southeast Inside area of Southeast Alaska, 1906–2001.

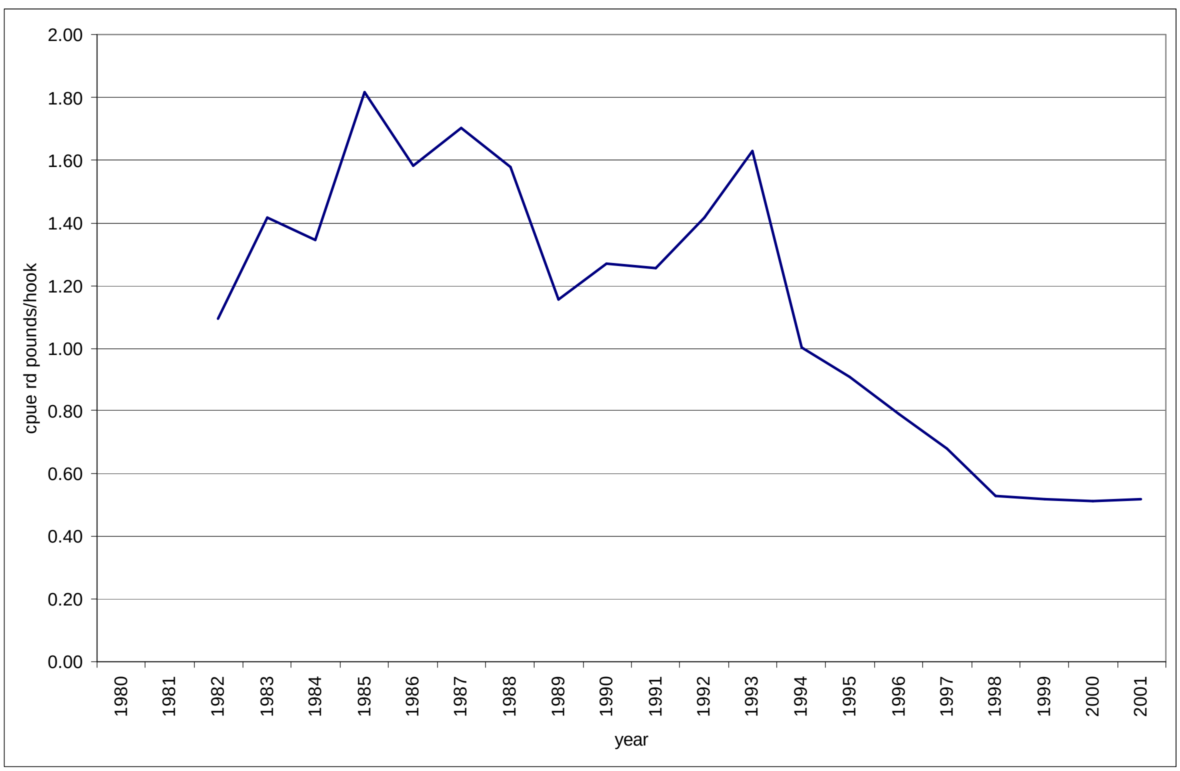

Figure 3. Sablefish catch per unit effort (CPUE), round pounds/hook for the Chatham Strait commercial fishery, 1980–2001.

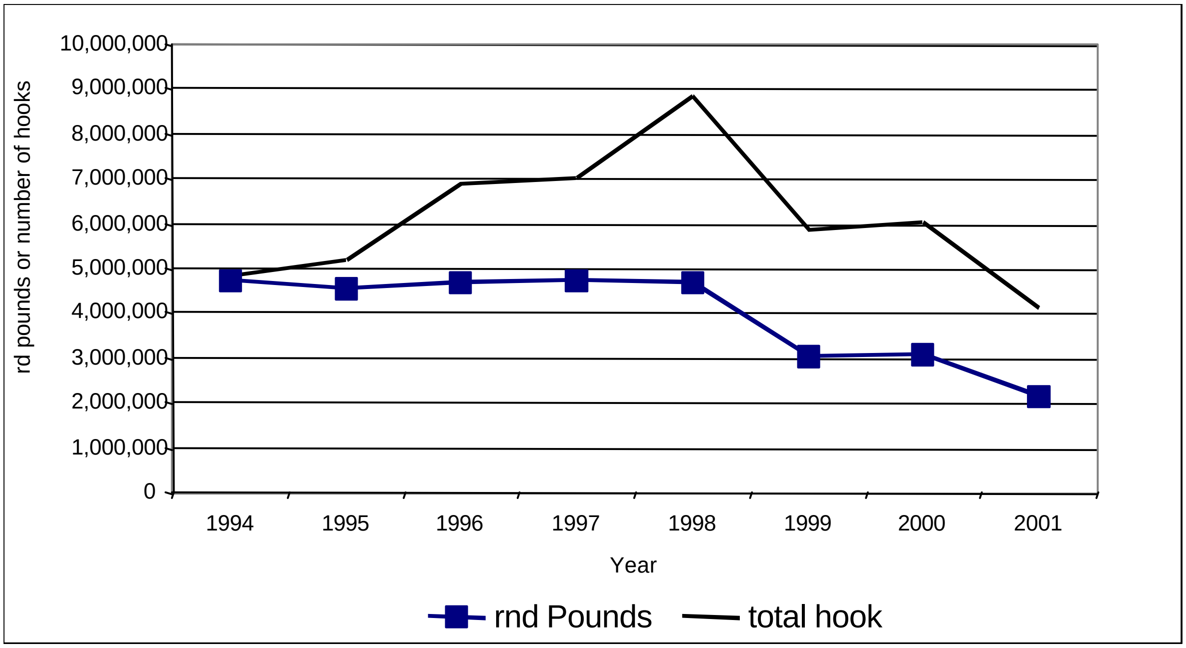

Figure 4. Comparison of total pounds sablefish landed versus total hooks set, Chatham Strait sablefish fishery, 1994–2001.

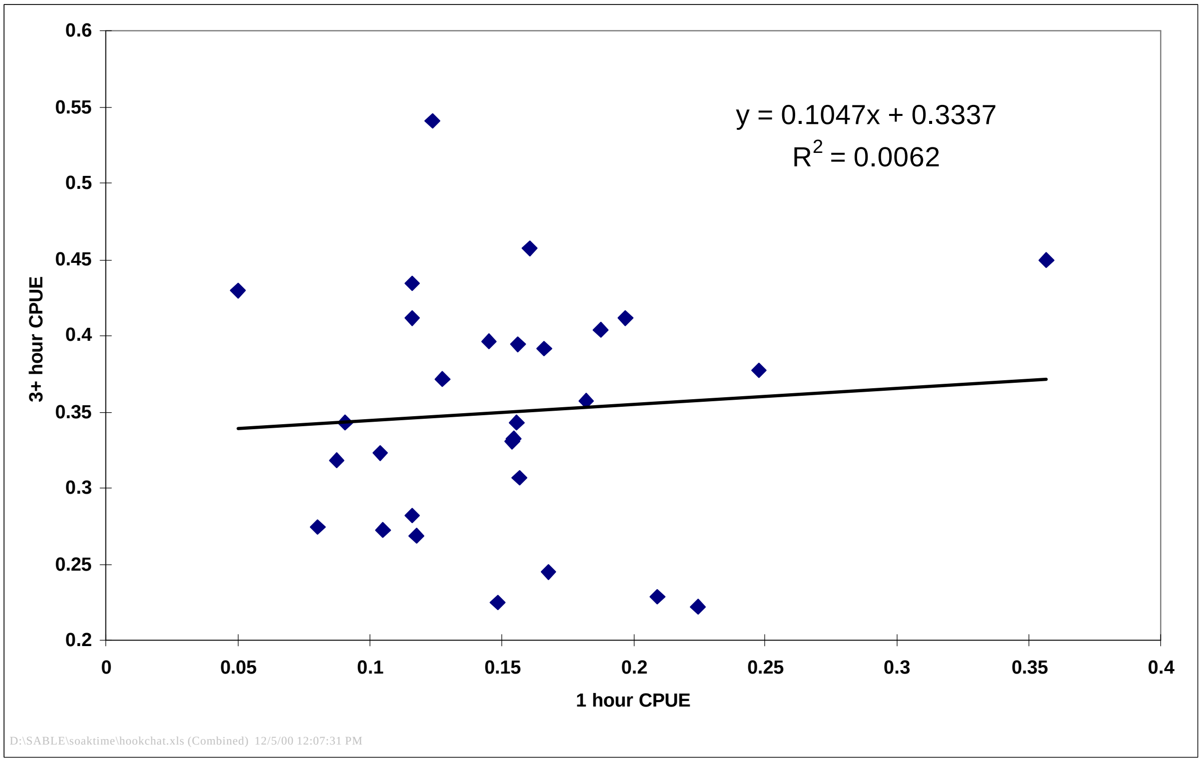

Figure 5. Catch per unit of effort for 3+ - hour CPUE vs. 1 hour CPUE from 1995 soak time experiment

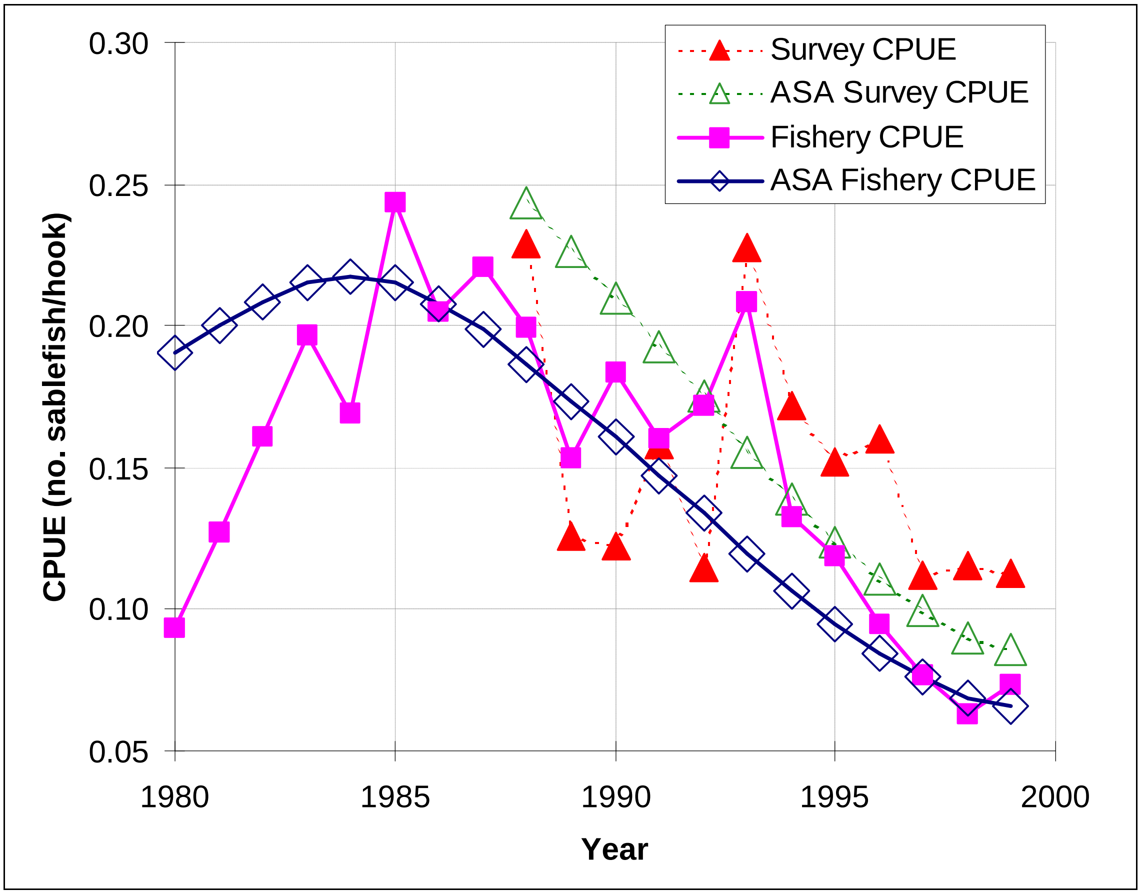

Figure 6. Goodness of fit of ASA-estimated CPUE to observed Chatham fishery and survey CPUE, 1999.

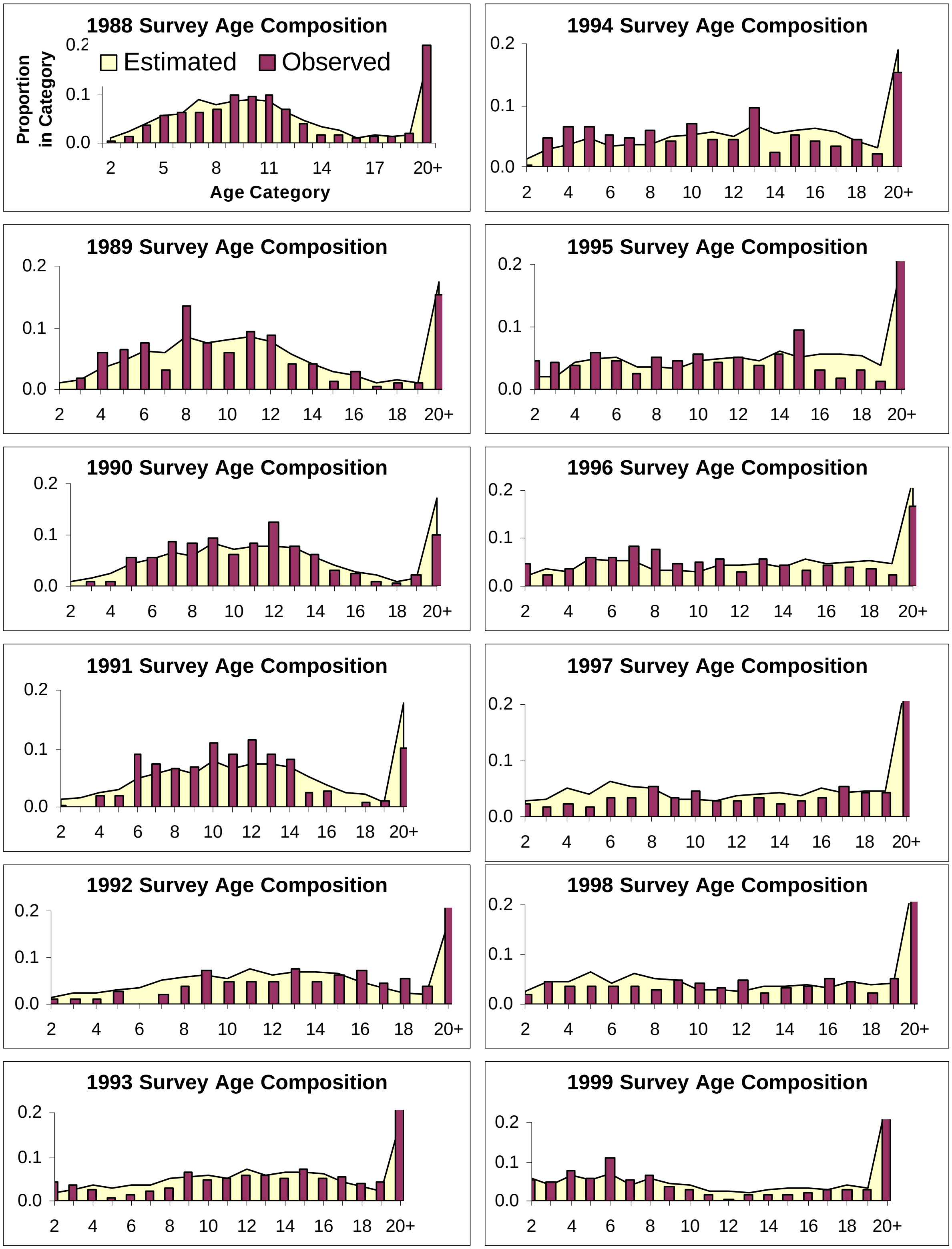

Figure 7. Survey (observed) and 1999 ASA (estimated) age composition of Chatham Strait sablefish.

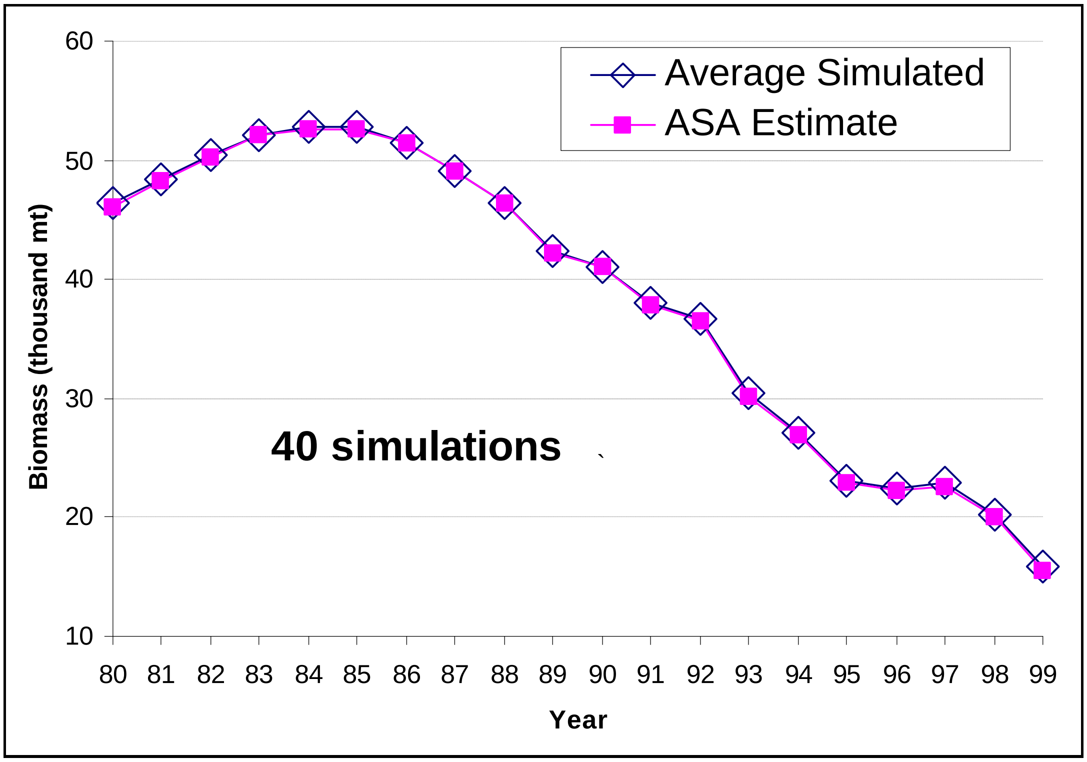

Figure 8. Comparison of 2000 ASA-estimated Chatham Strait sablefish biomass versus simulated biomass.

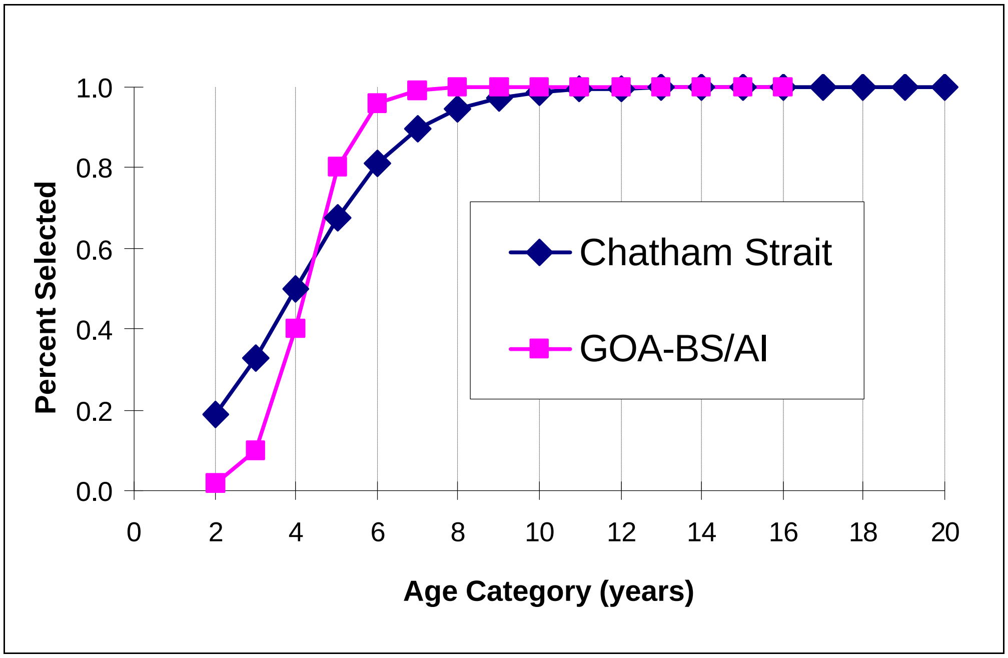

Figure 9. ASA-estimated Chatham Strait and Gulf of Alaska (GOA)/Bering Sea/Aleutian Islands (BS/AI) sablefish selectivity, 1999.

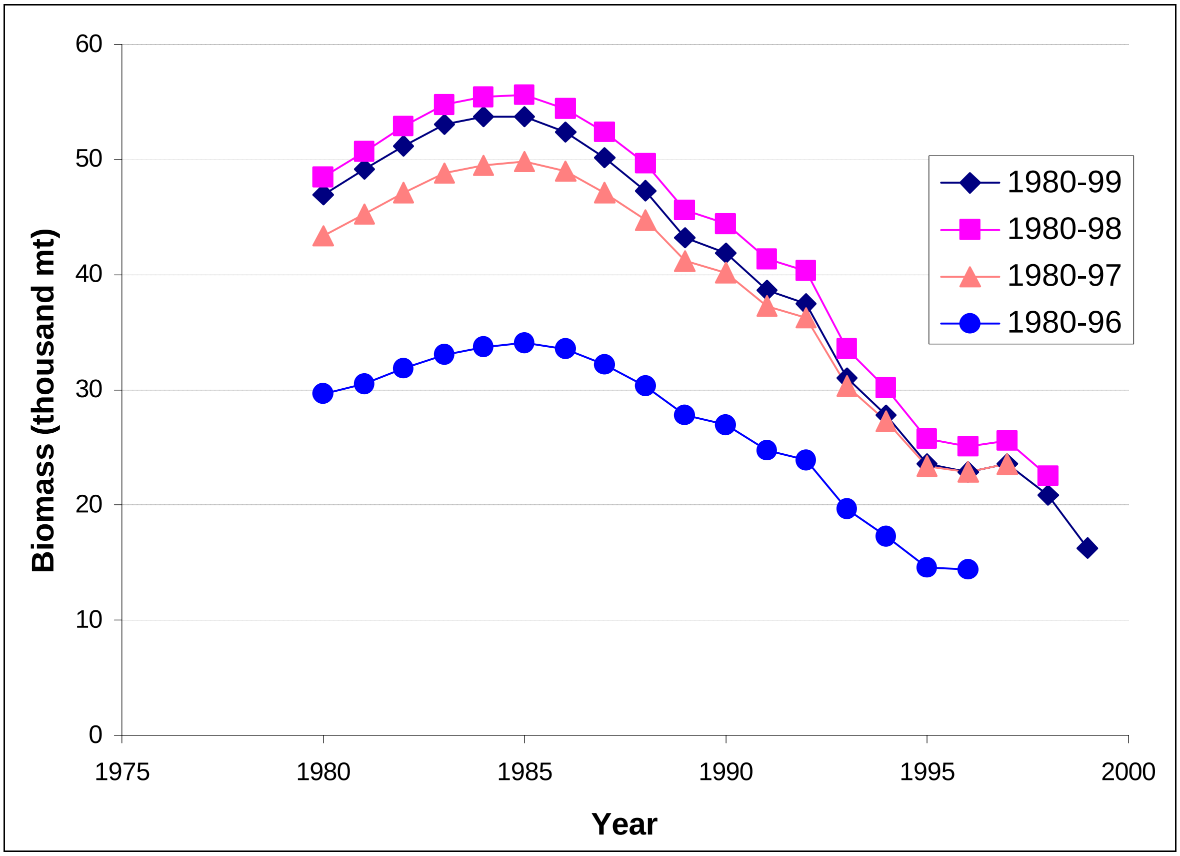

Figure 10. Chatham Strait sablefish 1999 ASA retrospective biomass estimates when tuned to varying length times series of fisheries CPUE and survey age composition.

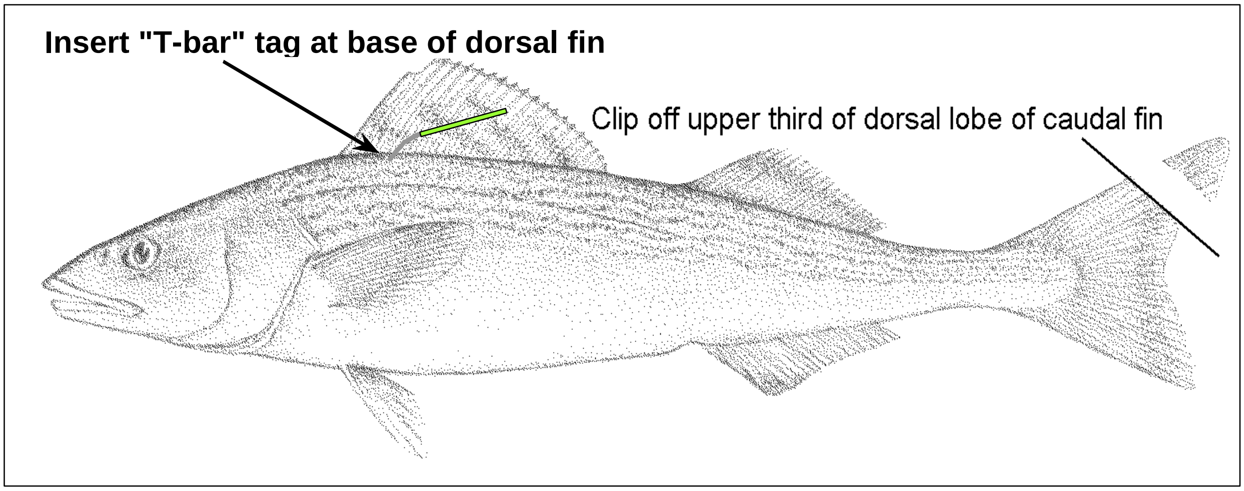

Figure 11a. Configuration and locations of marks on double-marked sablefish, 1997 and 2001. (NOTE: Upper lobe clipped)

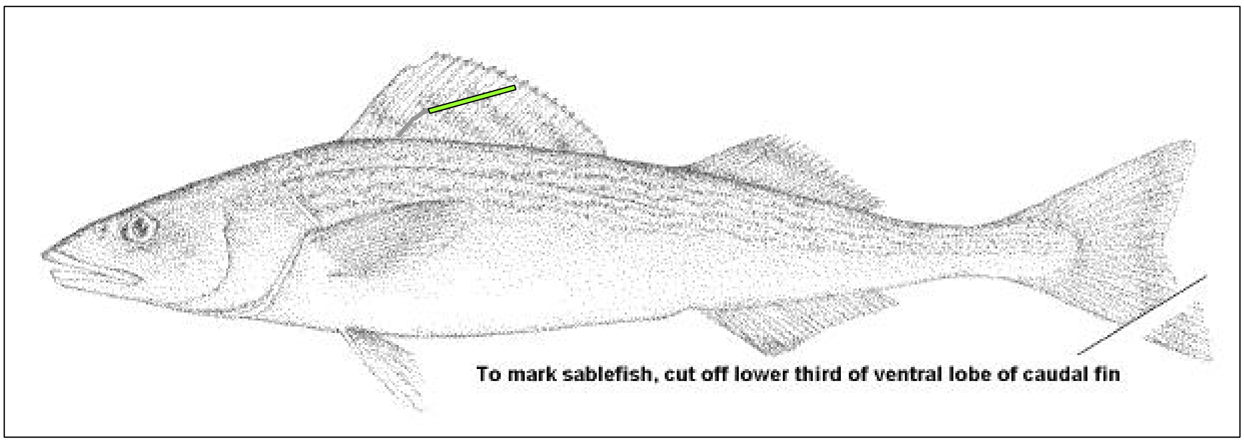

Figure 11b. Configuration and location of tail clip on marked sablefish, 1998 and 2001. (NOTE: Lower lobe clipped. In 2001, no external, T-bar tags were attached to sablefish)

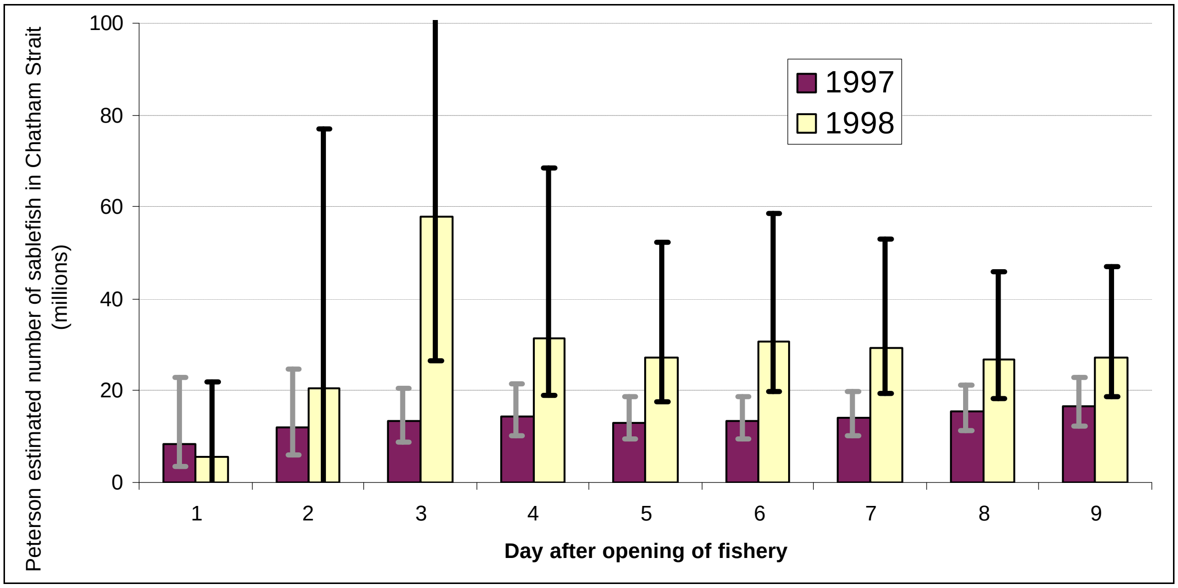

Figure 12. Comparison of running Petersen estimates (+/-95% CL), days 1–9 of port sampling following start of 1997 and 1998 fisheries.

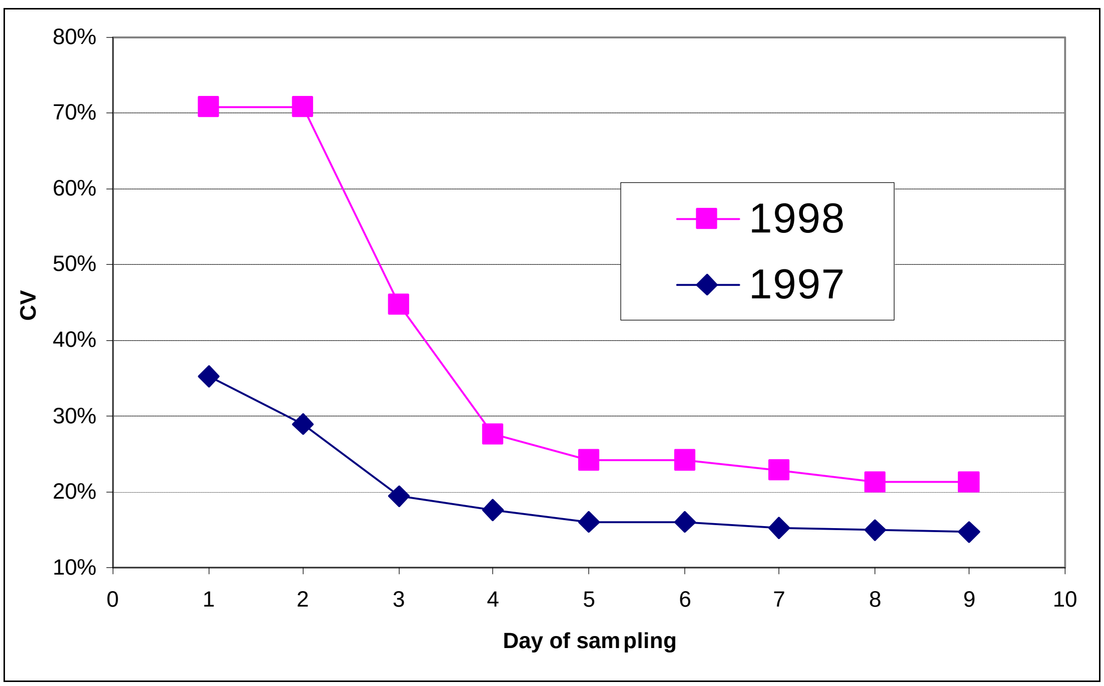

Figure 13. Coefficients of variation of 1997 and 1998 Chatham Strait abundance estimates based on cumulatively increasing data from days 1–9 of port sampling.

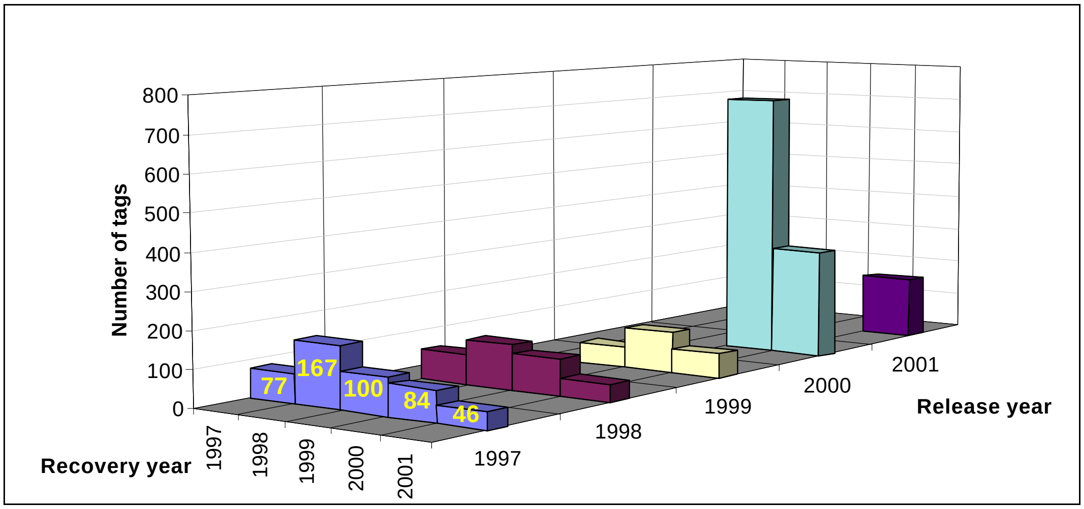

Figure 14. Numbers of tags recovered from Chatham Strait tagging, 1997–2001.

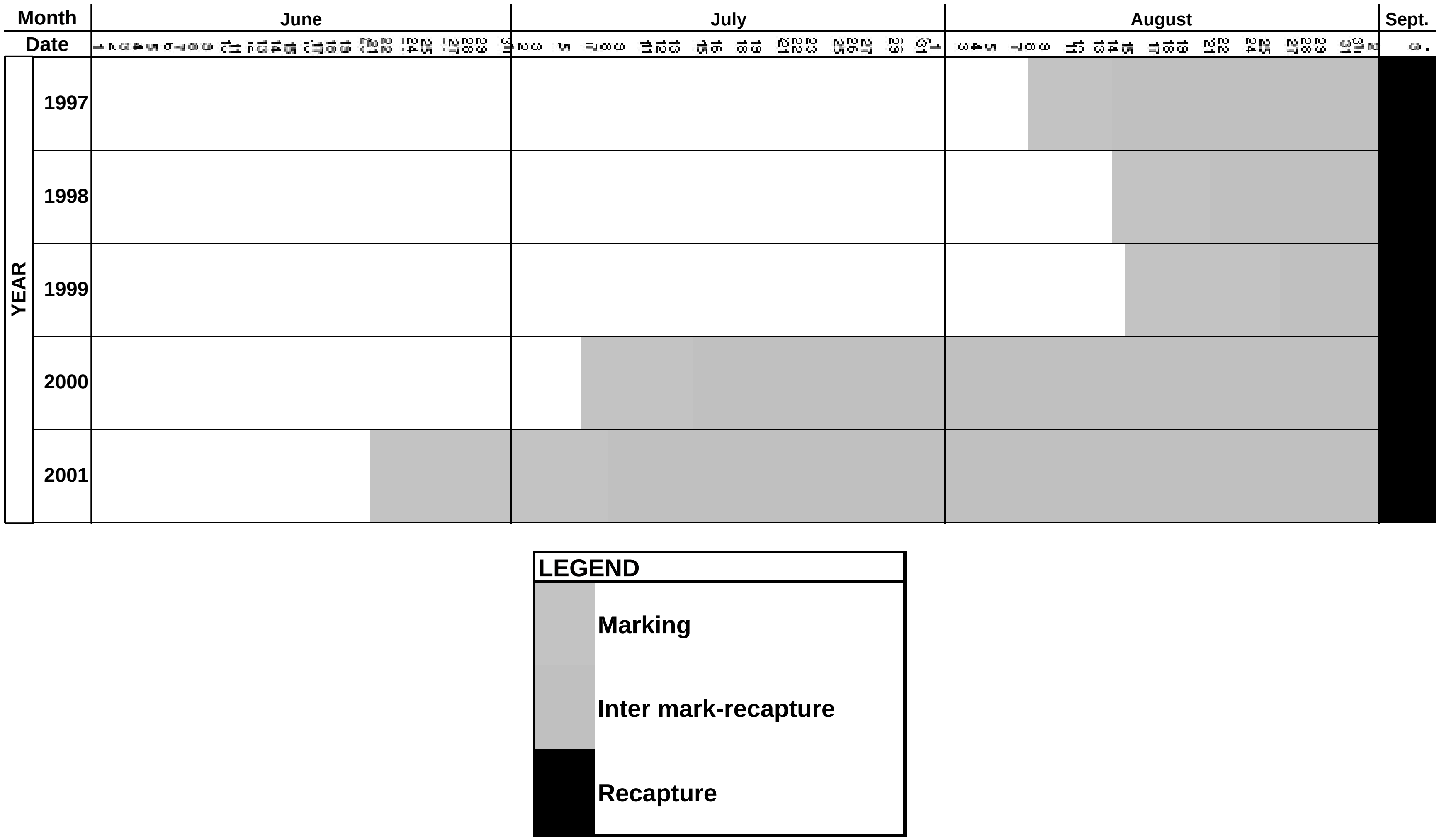

Figure 15. Chatham Strait sablefish mark-recapture chronology, 1997–2001.

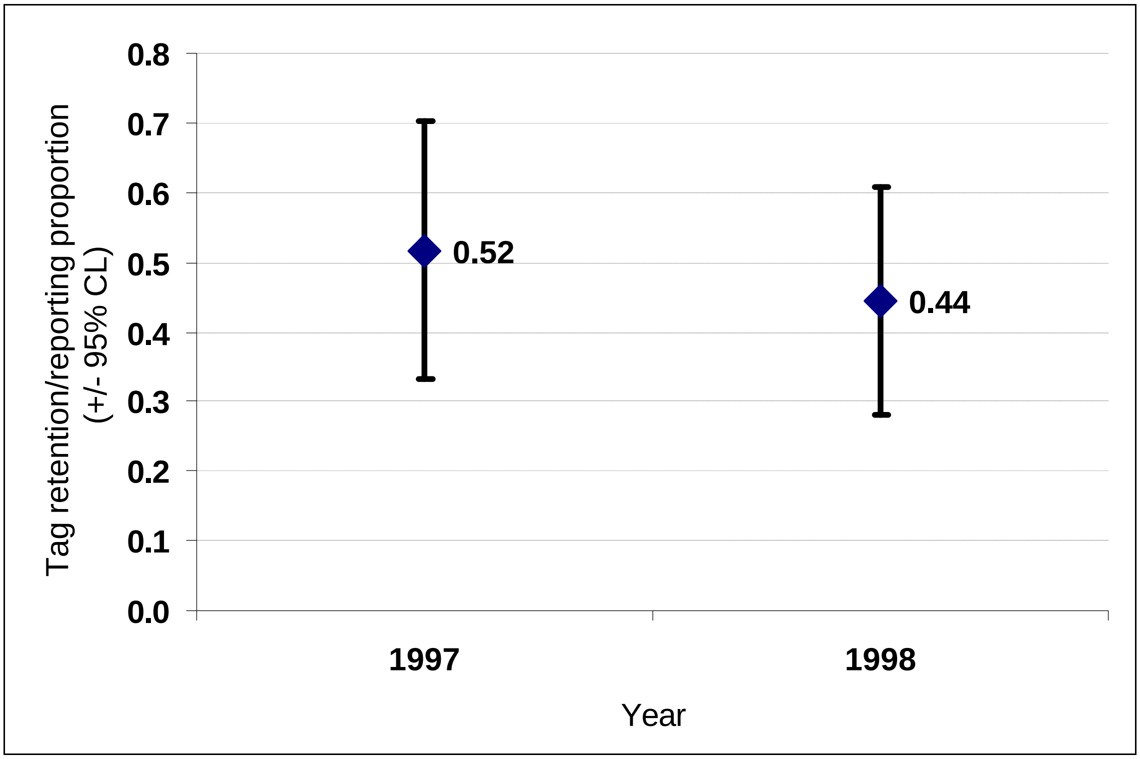

Figure 16. Chatham Strait sablefish tag retention/reporting proportions (+/- 95% confidence limits), 1997 and 1998.

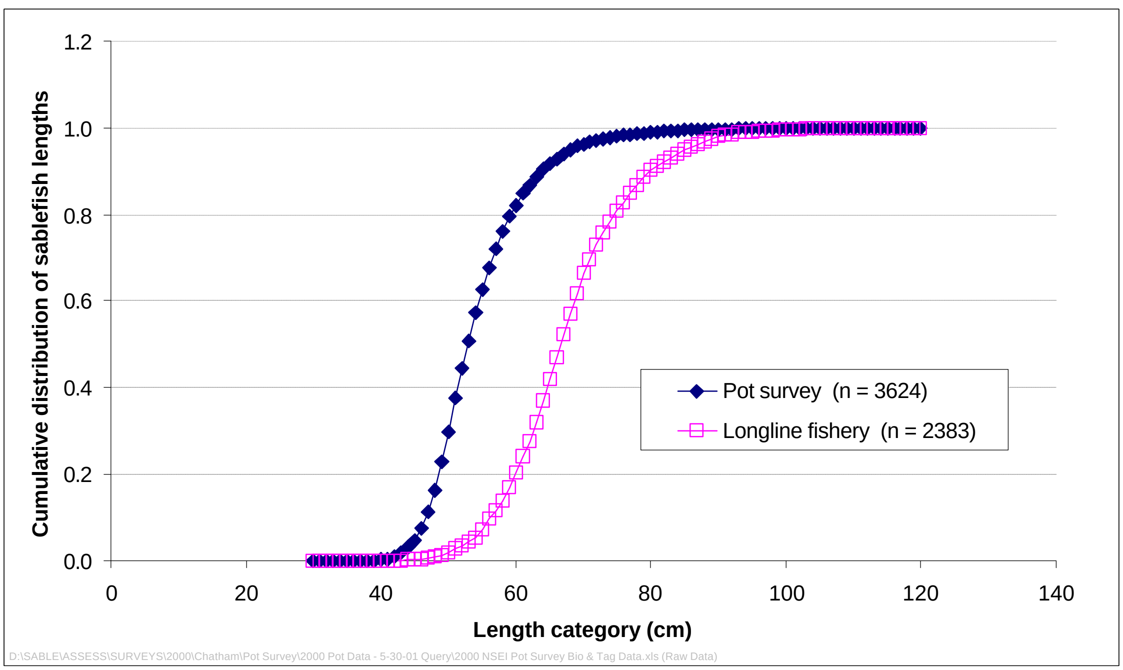

Figure 17. Cumulative length distributions of sablefish caught during the 2000 Chatham Strait pot survey and longline fishery.

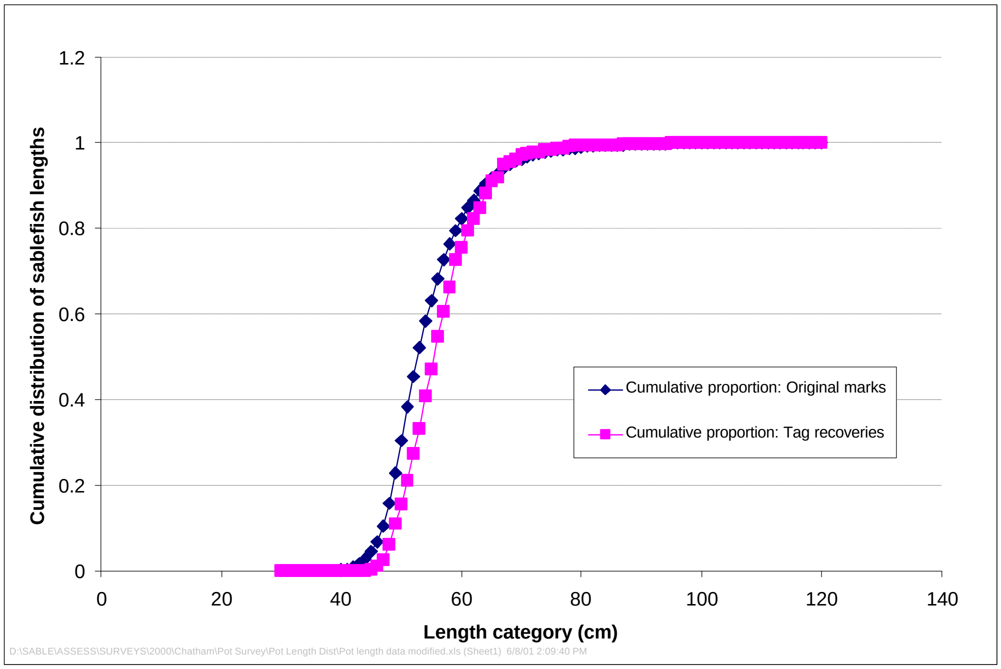

Figure 18. Cumulative lengths distributions for tagged (pots) and recaptured (longlines) sablefish in Chatham Strait, 2000.

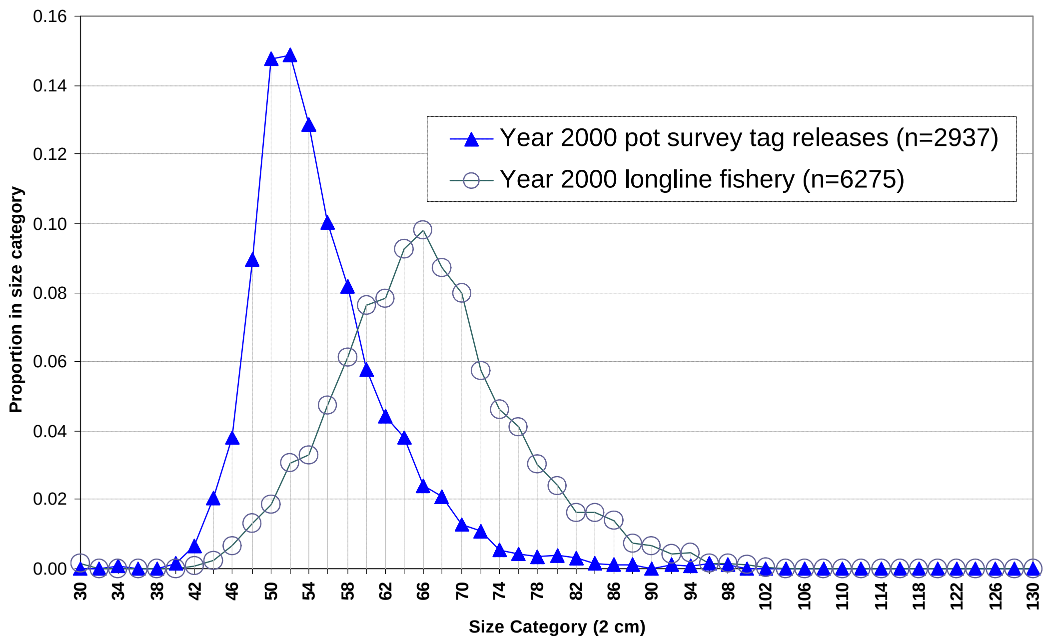

Figure 19. Size composition of Chatham Strait sablefish from the 2000 pot survey and longline fishery.

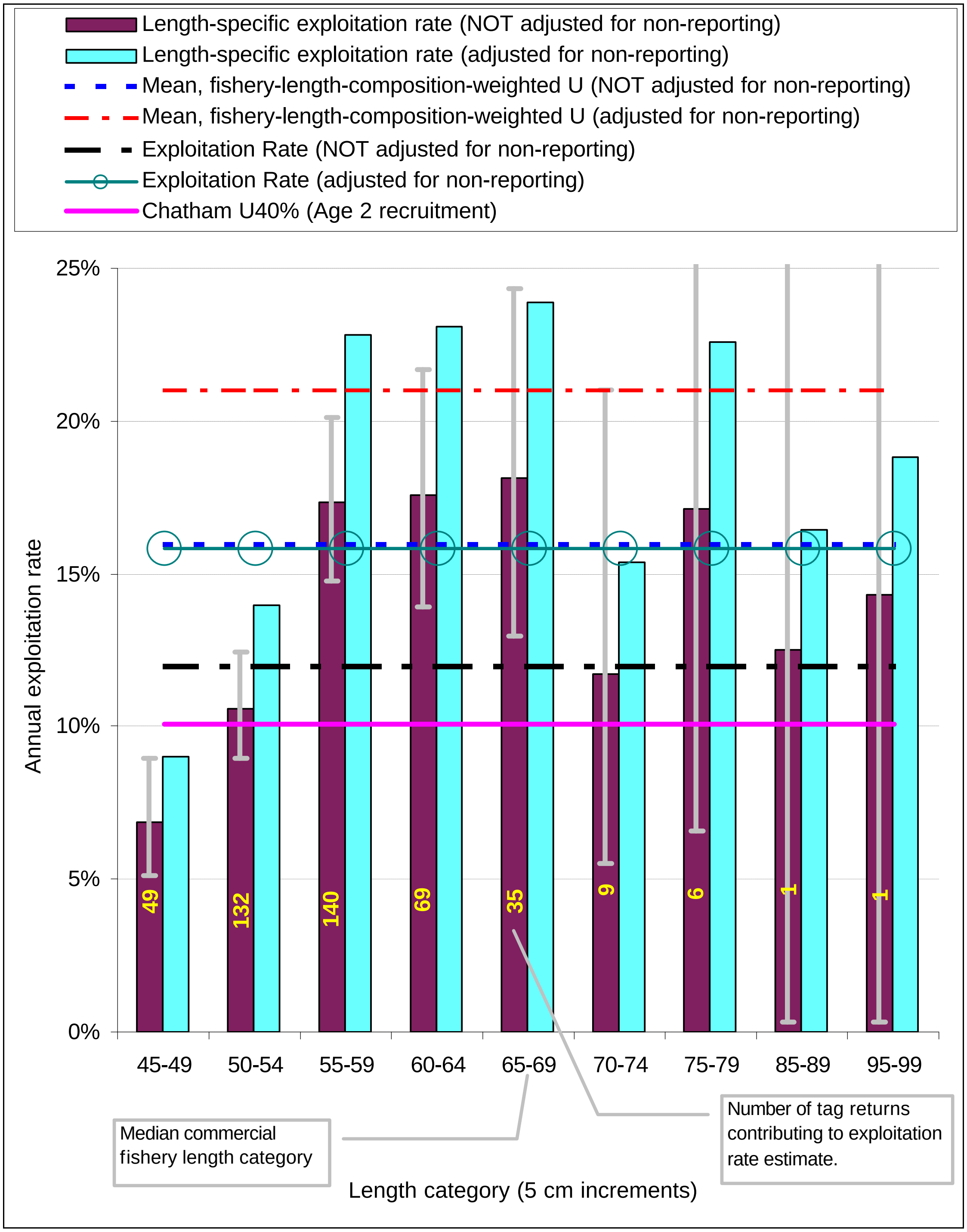

Figure 20. Estimated Chatham Strait sablefish exploitation rates based on fishery long-line recapture of pot-tagged sablefish from 2000.

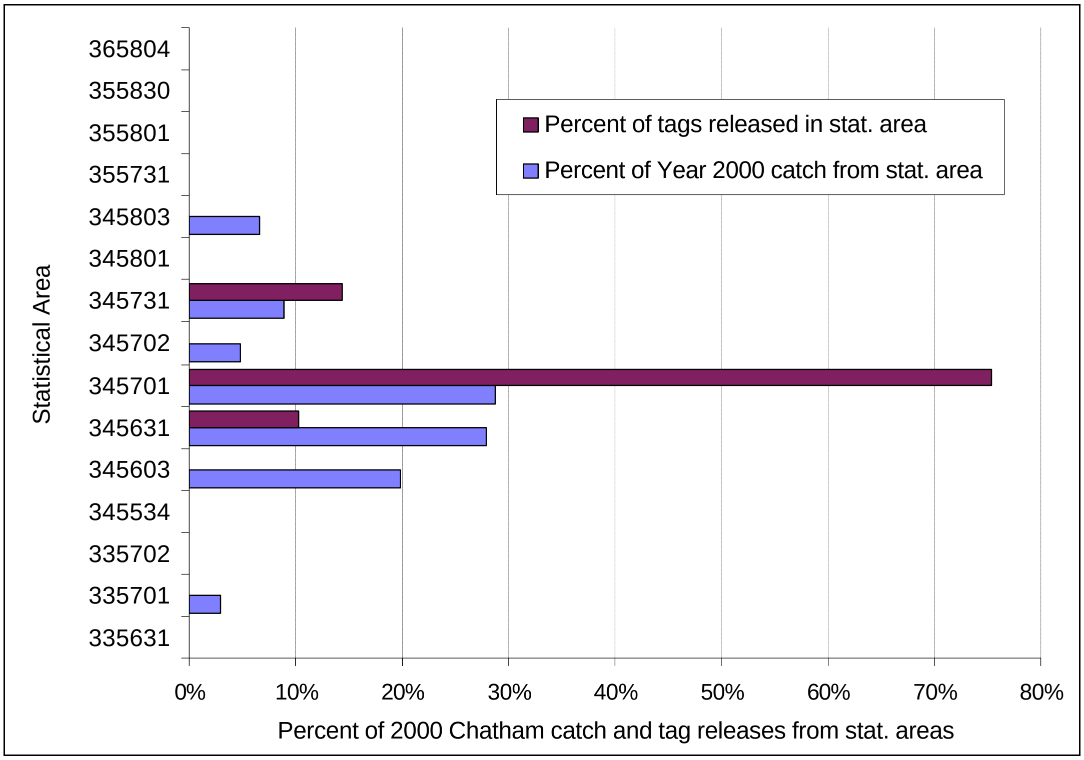

Figure 21. Percent of tagged sablefish released into, and percent of sablefish catch harvested from, Chatham Strait statistical areas, 2000.

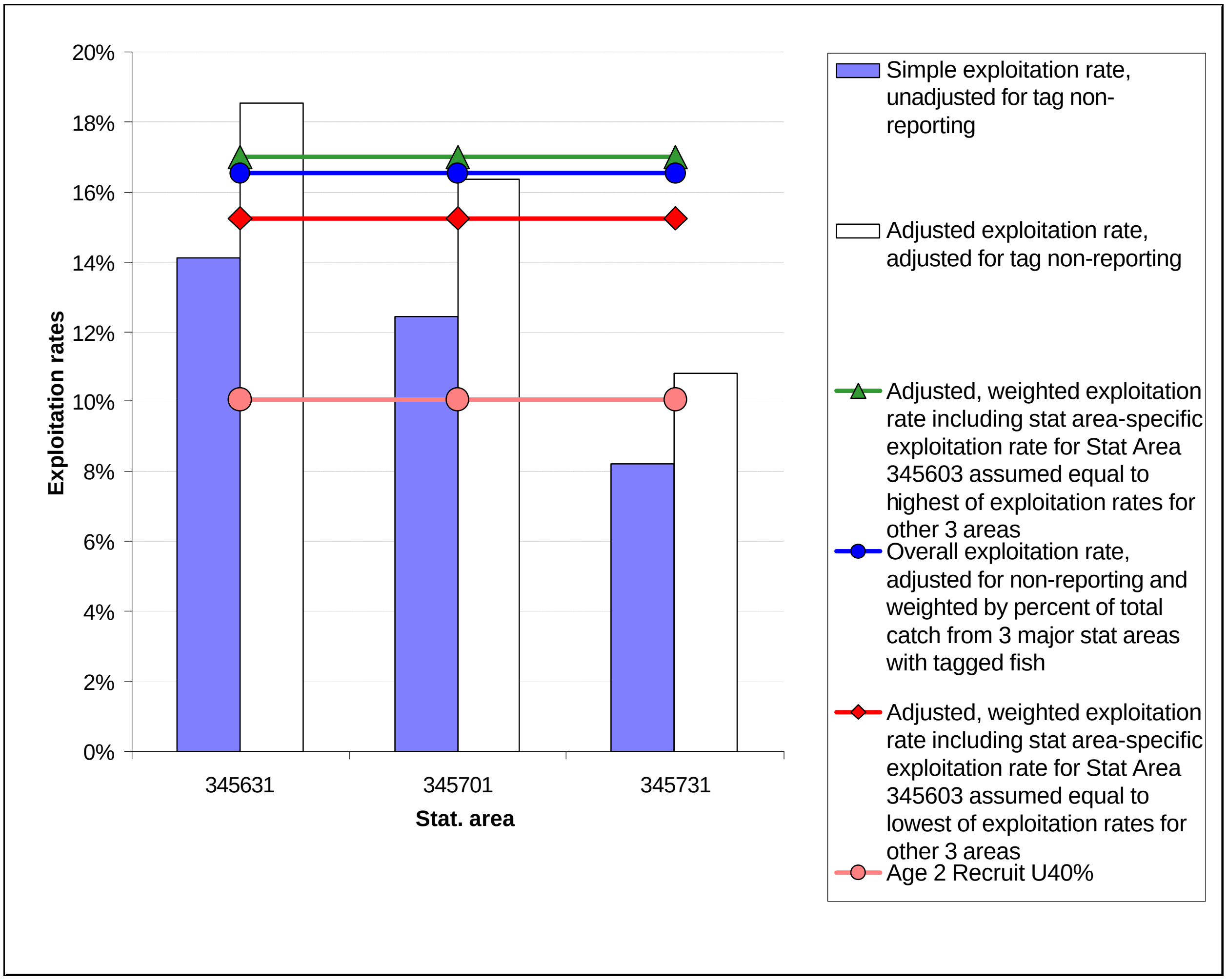

Figure 22. Statistical area-specific exploitation rates, Chatham Strait 2000.

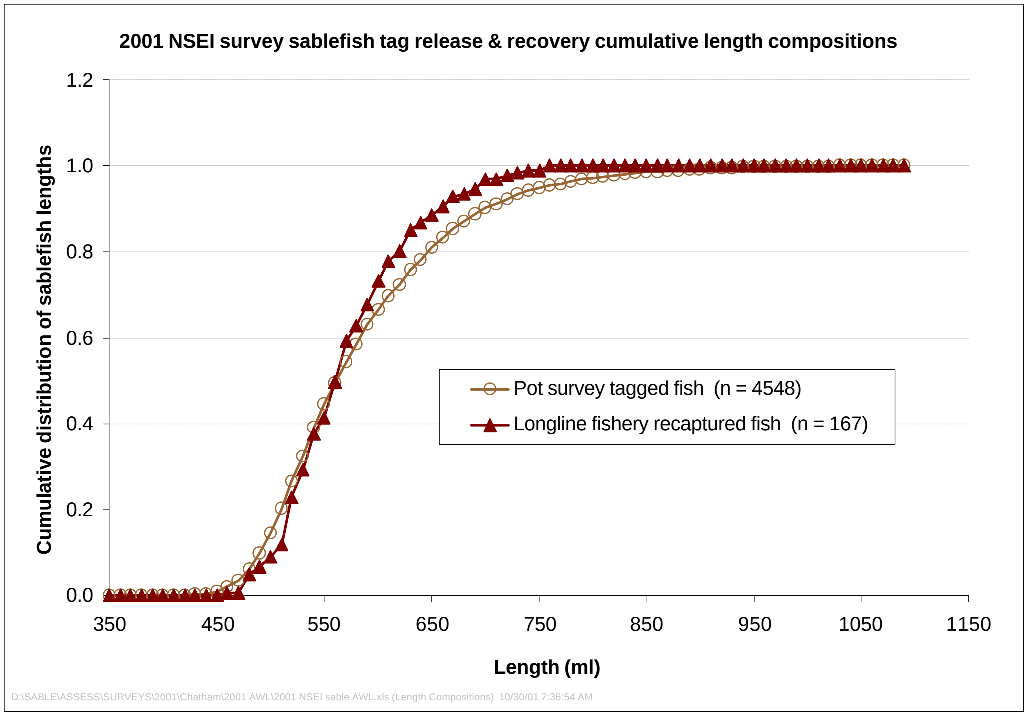

Figure 23. Cumulative lengths distributions for tagged (pots) and recaptured (longlines) sablefish in Chatham Strait, 2001.

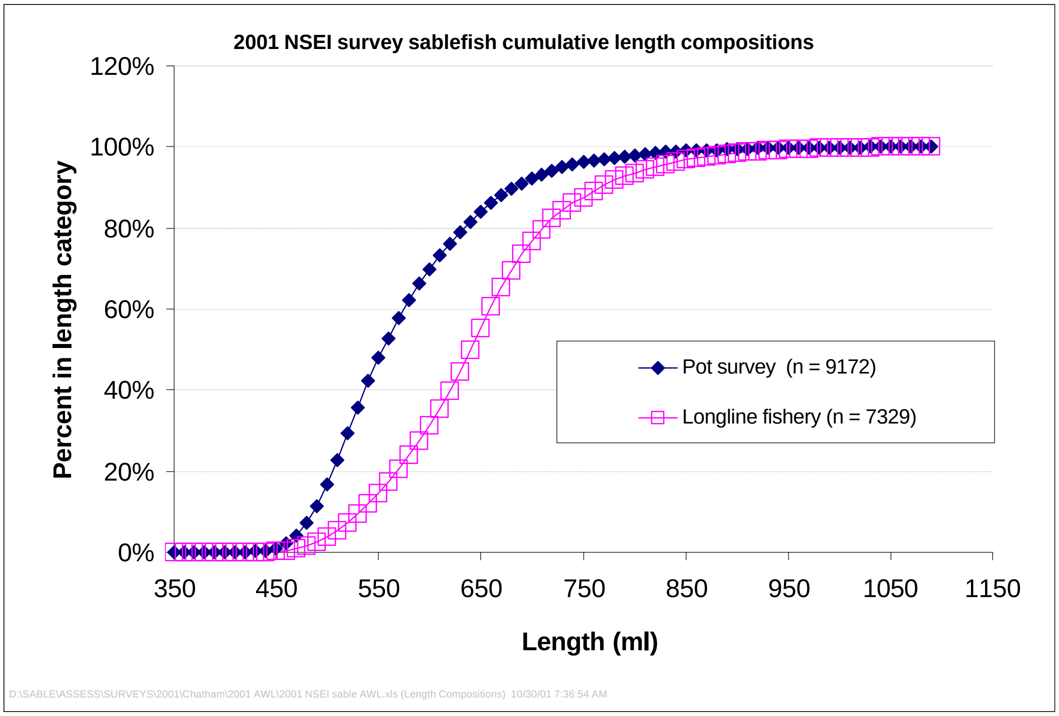

Figure 24. Cumulative length distributions of sablefish caught during pot survey and longline fishery. Chatham Strait, 2001.

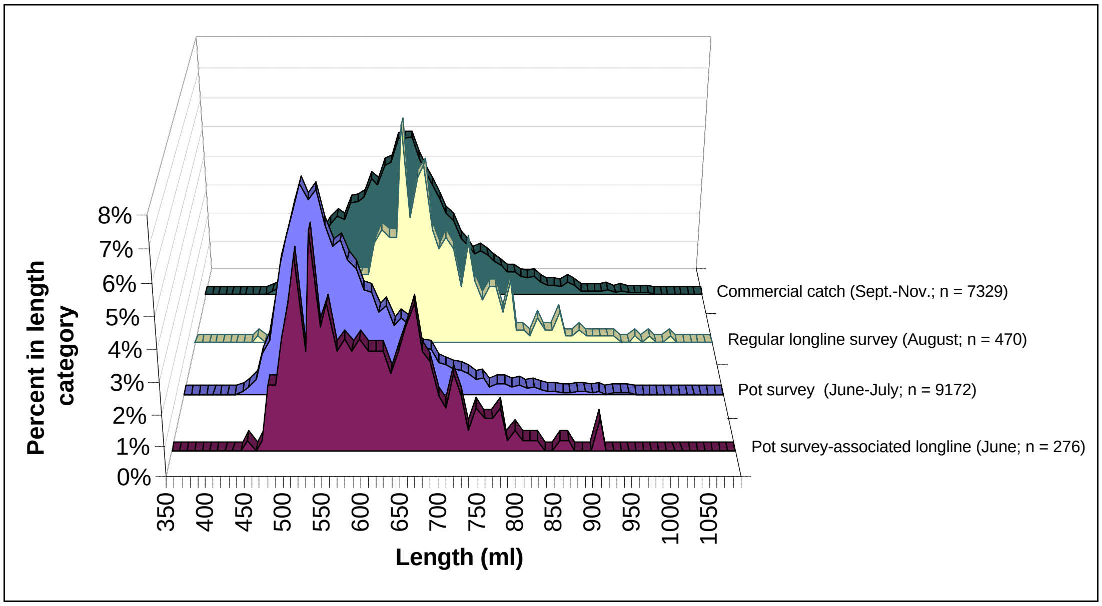

Figure 25. Length distributions of Chatham Strait sablefish caught with pots and longlines, June–November, 2001.

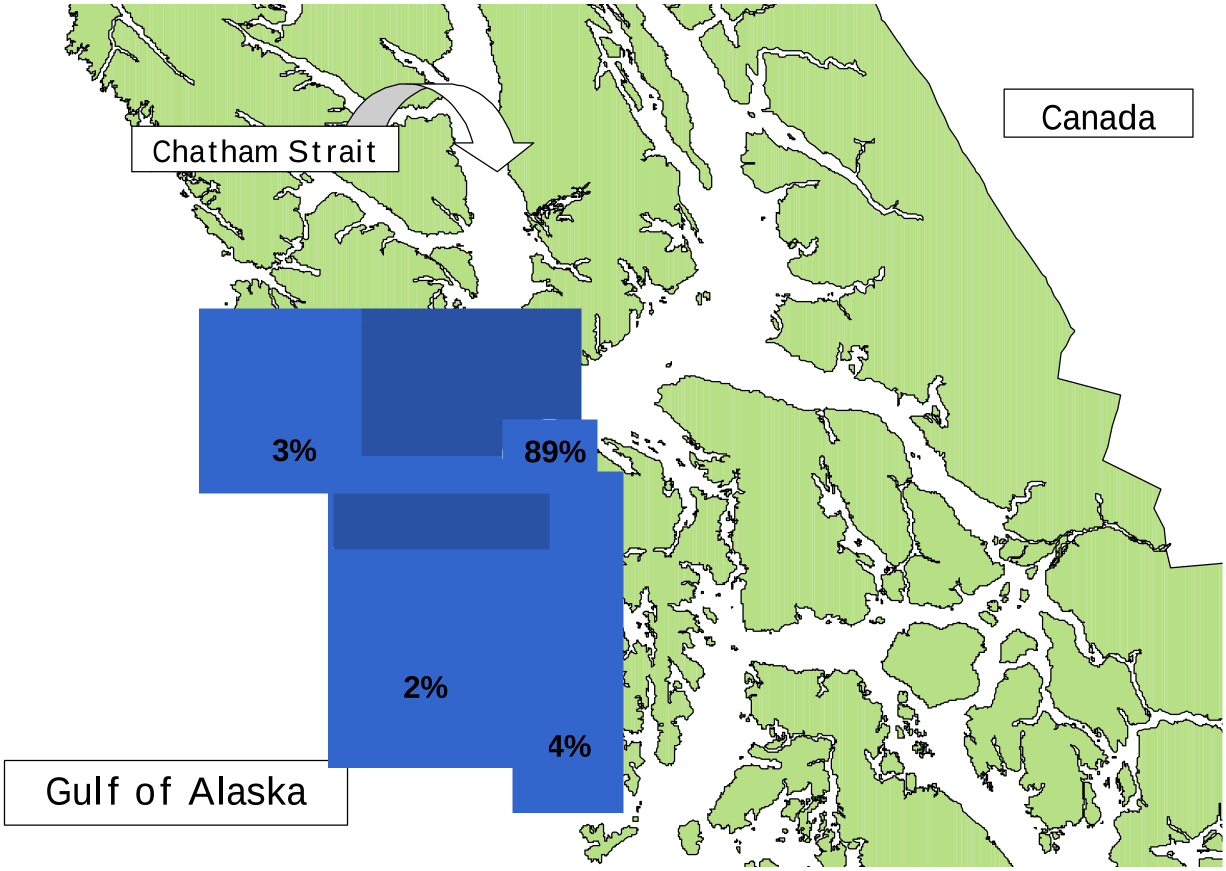

Figure 26. Distribution of tag returns from sablefish tagged in Chatham Strait. (e.g. Of sablefish tagged and released in Chatham Strait, 89% were recaptured in Chatham Strait)

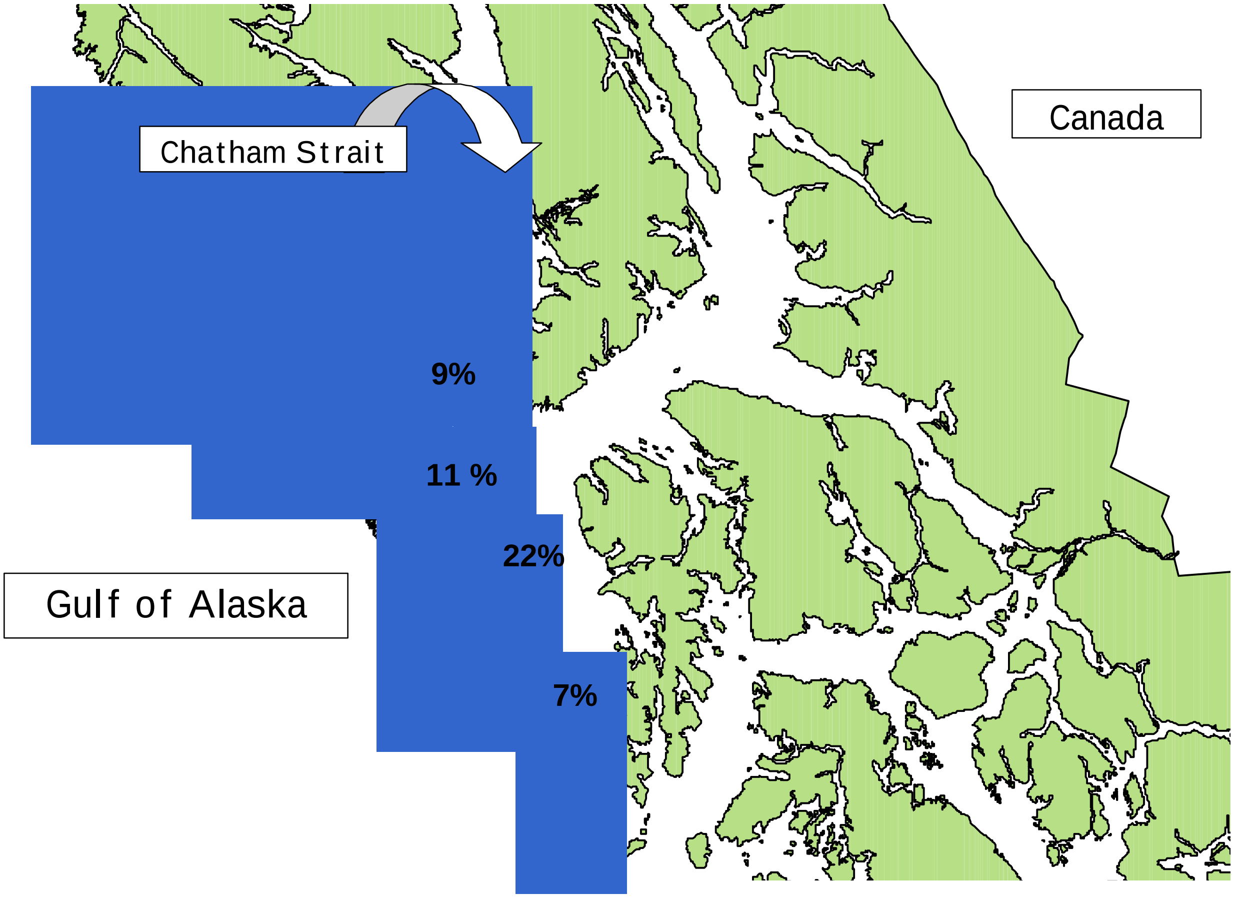

Figure 27. Distribution of tag returns in Chatham from sablefish tagged in waters proximate to Chatham Strait. (e.g. Of sablefish tagged and released off Cape Ommaney, 22% were recaptured in Chatham Strait)

APPENDICES

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Appendix A. History of fishery and management.

History of Fishery

It is not known when sablefish were first commercially harvested in the internal waters of Southeast Alaska. However, the first landing records for sablefish from this area were for 59,000 pounds in 1906 (Bergmann 1975). Prior to the 1940s, sablefish were primarily landed as incidental catch in the halibut fishery but there is a report of a directed blackcod trip in NSEI in 1913 (Bergmann 1975). Halibut longline gear was modified in the late 1940s to specifically target sablefish. At that time sablefish was valued for both its flesh and oil. Fish oil was utilized in manufacturing vitamins. Harvest levels fluctuated widely until the 1970s due to price and increased opportunities in other fisheries. Reported harvest has ranged from 26,984 pounds in 1912 to 6.5 million pounds (round) in 1947. Recent high harvest was in 1997 when 4.75 million pounds (round weight) was landed (Table 1). The accuracy of catch data prior to 1985 is questionable, especially in earlier years given limited information on landing records and fishtickets.

The history of management action is listed in Table A2. Season limitations were first imposed in 1945 with the season extending from mid March until the end of November. An industry recommended harvest limit of 1 million dressed pounds was implemented in 1973. ADF&G recommended a reduction in quota to 850,000 dressed pounds in 1979 and then moved to a guideline harvest range of 500,000 to 900,000 pounds in 1980, based on historic catches (Figure A1, Table A2). Seasons were shortened as effort escalated in the 1970s and 1980s (Bracken 1983).

Fleet effort and efficiency continued to increase dramatically and the season was reduced to five days in the NSEI area by 1984 (Table A2). In 1985, a limited entry program was implemented for the fishing fleets in the NSEI and the guideline harvest range (GHR) objective was raised to 500,000 to 1.5 million pounds dressed weight. However, the overall operating efficiency of the NSEI longline fleet increased seven fold after the limited entry program was in place. For example, the average number of hooks set per vessel per day increased from 4,791 in 1984 to 28,514 in 1993. In order to stay within harvest objectives, the department continued to reduce the number of fishing days. The number of fishing days went from 76 in 1980 to one in 1987 (Table A2). A one-day opening continued until 1993. In that year, the fleet harvested 3,640,000 dressed pounds, 2,140,000 pounds over the upper bounds of the 1,500,000 pounds GHR (Figure A1). In an effort to improve management, the Board of Fish adopted a shared quota system for the NSEI fishery beginning in 1994, to be evaluated in 1997. This plan was recommended by a working group of industry representatives and state fisheries managers after extensive negotiations to come to terms. Under the shared quota system each permit holder was given an “equal” share of the annual quota and an extended season. The upper end of the GHR was increased to 3 million dressed pounds (4.76 million pounds round weight) at the time this system was implemented. The share quota system was made “permanent” in 1997 based on fleet and department recommendations with a quota of 4.8 million round pounds and a season set for September 1 through November 15 (Table A2). The GHR was set at 1.59–4.8 million round pounds. Individual shares have ranged from 38,889 round pounds to 19,600 round pounds. Annual quota shares vary based on total annual quota and number of legal participants.

Fleet size

Prior to limited entry (from 1975 to 1984) the fleet size ranged from a low of 46 permits in 1982 to a high of 125 permits in 1976 (Table A1). The limited entry system was implemented by the Commercial Fishery Entry Commission (CFEC) in 1985 with the guideline that there would eventually be about 73 permanent permit holders (AS 16.43.270). As is typical of limited entry programs the annual fleet size increased dramatically initially, from 86 in 1984 to a high of 166 permit holders fishing in 1987 (Table A1). The Commercial Fishery Entry Commission has completed work on 124 of the 167 applications received and 43 cases remain to be decided. There were 115 permit holders in 2001.

Catch Per Unit of Effort

Fishery catch per unit of effort information is collected through skipper interview and voluntary logbook programs (prior to 1997) and through mandatory logbook program beginning in 1997. Fishery CPUE in this document is expressed as total round pounds/total hooks. CPUE is affected by hooks spacing and NMFS uses the following formula for CPUE standardization for commercial catch data (Sigler et al. 2001):

$$n_s = n_u * 2.2 * (1\text{-}\exp(-0.57 \text{ hook spacing})),$$

where n_s is the number of standardized hooks, n_u is the number of unstandardized hooks and hook spacing is expressed in meters and standard hook spacing is 1 m. We have converted fishery CPUE using this formula. Circle hooks (which dramatically increase CPUE) first appeared in the Chatham fishery in 1983. CPUE for j-hook data has been converted (IPHC reference).

Catch per unit of effort was low in the early 1980s increasing dramatically with the recruitment of very strong year classes (Figure A2). It has ranged from 0.4 in 1980 to 1.6 in 1993. Beginning in 1994 the fishery CPUE declined dramatically to 1.0. The declining fishery CPUE experienced between 1993 and 1994 was not unexpected because of the change in management from derby style to share quota. However, the continued decline in fishery CPUE since 1994 is of concern. Effort increased as CPUE declined, with 52% more hooks fished in 1998 than were fished in 1997 (Figure A3). CPUE continued to decline until 2000 when it leveled off at 0.5, the second lowest fishery CPUE since 1980.

Recent Management Action

The fishery quota was lowered 35% in 1998 from 4.8 million pounds round to 3.12 million pounds round. This decision was based on the poor fishery performance over the prior 5 years and acknowledgement of the general decline in sablefish abundance coastwide (Sigler et al. 1997). The quota was again lowered by 35% in 2001 to 2.184 million pounds based on fishery CPUE and a mark-recapture-based estimate of exploitation rate that suggested the exploitation rate for the 2000 fishery was higher than warranted.

Bycatch

The primary landed bycatch in the NSEI sablefish fishery is thornyhead rockfish followed by shortraker and rougheye rockfish. Other bycatch species landed include redbanded rockfish and arrowtooth flounder. Skates, dover sole, and pacific sleeper sharks are also taken as bycatch but are not usually landed. New regulations, implemented in summer of 2000, require full retention of all rockfish.

2001 Fishery Summary

The 2001 quota was set at 2.184 million round pounds, a 30% reduction from the 2000 and 1999 quotas. The number of allowable interim use and permanent permits was 111 in 2001 which is the same as in 2000 and represents a gradual reduction from the 122 allowed to fish in 1994–1997. The per quota share declined this year from 28,600 round pounds in 2000 to 19,600 round pounds, a decrease of 50% from the initiation of the quota-share system in 1994.

Eighty-seven individual vessels made at least one landing during the 2001 fishery compared with 94 vessels in 2000, a 7.5% reduction. Forty-one of the vessels (or 47%) that fished this year have participated in the fishery for each of the past 5 years with only 5 new vessels participating in 2001 that had not participated in any of the years 1994–2000.

The total directed commercial harvest from NSEI in 2001 was 2,142,617 round pounds or 98% of the quota. Of this years harvest, 11,930 round pounds (0.5% of 2001 GHL) were landed as overages compared with 10,830 rounds pounds (0.35% of 2000 GHL) of overage landed in 2000.

Due primarily to the decrease in the quota share, the 111 permits made a total of 296 landings in 2001, which was a 20% decrease in the total number of landings when compared with 372 in 2000. The maximum number of landings per permit in 2001 decreased to 8 from 9 in 2000, and the average number of landings per permit in 2001 was 2.7 down 20% from 3.4 in 2000. In 2001 20 permits finished their quota-share in one landing and 43 made only 2 landings compared with 10 and 30 respectively in 2000.

For 2001 the total bycatch of all species was approximately 11% of the total 2001 sablefish harvest compared with almost 15% bycatch landed in 2000. The primary bycatch species was thornyhead rockfish comprising 7%. Other major species that make up the landed bycatch of the NSEI sablefish fishery are rougheye (1.32%), shortraker (01.65%), and redbanded (0.20%) rockfish as well as pacific cod (0.20%). The reason for the decrease in percent of bycatch is unclear as there is a full retention policy in place for all rockfish (*Sebastes*) species.

Preliminary review of the 2001 fishery data indicates that fleet performance was comparable to the 2000 fishery. Twenty-five percent of the catch was landed by September 4, 50% by September 16, and 90% by October 26. Despite a notable increase in CPUEs both overall and for a majority of the sets in the 2001 NSEI longline survey over the 2000 survey the fishery CPUEs for 2001 were relatively flat. Mandatory logbooks required since 1997 provide effort data by set for each landing. In both 2001 and 2000 valid logbook data is available for 99% of the harvest and 98% in 1999. The overall CPUE for the 2001 fishery from landings with valid logbooks (all landings that had complete information) was 0.52 rounds pounds/hook compared to 0.51 in 2000 and 0.52 in 1999 (Figure 3).

Table A1. Fleet size and catch reported on fishtickets for NSEI sablefish.

Year	Number of Permits in Directed Fishery	Total Poundage Reported Removed From NSEI	Total All Permits From Fleet
1969		400,521	
1970		421,344	
1971		315,692	
1972		1,089,150	
1973		977,995	
1974		815,731	
1975		984,179	110
1976		970,313	125
1977		559,031	95
1978		788,523	80
1979		1,190,356	110
1980		881,469	65
1981		710,147	53
1982		804,004	46
1983		1,165,871	68
1984		1,329,072	86
1985	105	3,084,914	
1986	138	4,179,554	
1987	158	3,950,758	
1988	149	4,258,691	
1989	151	3,788,690	
1990	121	3,345,485	
1991	127	3,988,220	
1992	115	4,324,343	
1993	120	5,833,463	
1994	121	4,743,147	
1995	121	4,595,532	
1996	121	4,733,102	
1997	122	4,804,458	
1998	116	4,767,943	
1999	112	3,102,600	
2000	111	3,171,242	
2001	111	2,260,053	

Prior to 1985 the following applies:

All data FT above this point (with the exception of the spreadsheet data) was entered with no dress code but may have been converted to round before being entered.

Also the above data is on all sorts of gear codes, B permits, C permits, M and a few S. Mostly longline and no pot.

The above NSEI is defined as area 109-00 thru 112-99, 114-00 thru 115-99.

Table A2. NSEI harvest objectives, management actions, survey design changes, and dock-side data, 1945–2001 seasons.

YEAR	Guideline Harvest Range	Harvest Objective (round weight)	Per Share Quota (round weight)	Season	Dates Fishery Open	Management Actions	NSEI Survey Design Changes	Dock-Side Data
1867	no quota				year round	Federal management of Alaskan fisheries began with the purchase of the Alaskan Territory.		
1871	"				"	US Commission of Fish and Fisheries established.		
1903	"				"	US Bureau of Fisheries established.		
1906	"				"	An Act for the Preservation and Regulation of the Fisheries of Alaska enacted.		First landing records available
1932-1944	"				"			Vessel logs maintained
1945-1946	"			03/16-11/30	03/16-11/30			"
1947-1958	"			05/01-11/30	05/01-11/30		Alaska Department of Fishery first tagged in March, October, and November 1951; tagged 989. Again in 1952; tagged 2,909.	"
1959	"			"	"	Alaska Statehood. Fisheries management transferred to the state. BOF maintained regulations already in place in 1959.		"
1960	"			"	"			Vessel logbook program discontinued. No monitoring of fishery performance 1960-1978.
1961-1962	"							
1963-1969	"			08/15-10/15	08/15-10/15			
1970-1971	"			09/15-11/15	09/15-11/15	1970 pot gear first allowed.		
1972	"			09/01-11/15	09/01-11/15	Incidental catch allowance was reduced to 20% in 1972.		
1973	1,000,000 dr			"	EO	Quota requested by industry. Fishery closed by Emergency Order.		
1974-1975	"			"	09/01-11/15			
1976	"			"	"	Magnuson Fisheries Conservation and Management Act (MFCMA).		
1977	"			"	"			

-continued-

Table A.2. (page 2 of 5)

YEAR	Guideline Harvest Range	Harvest Objective (round weight)	Per Share Quota (round weight)	Season	Dates Fishery Open	Management Actions	NSEI Survey Design Changes	Dock-Side Data
1978	"			"	"	Voluntary agreement by Japanese North Pacific Longline-Gillnet Association to voluntarily withdraw from the area east of Yakutat Bay. Sablefish became prohibited species in US fisheries for other species.		1978 NMFS and ALFA introduce cooperative voluntary logbook program.
1979	850,000 dr			"	EO	Southeast Groundfish Project established. Quota reduced by department recommendation to account for portion of previous quota that came from outside waters. Season closed by Emergency Order. Closure to foreign fishing enforced by Federal Regulation.	Released 37 tagged sablefish on ADFG crab survey. 07/20/79-07/19/79	
1980	500,000-900,000 dr			"	09/01-11/15	GHR by department recommendation based on annual harvest from previous 10 years and allowing two standard deviations from mean to determine range. Registration 72 hours prior to fishing instituted for all vessels in NSEI by phone, in person, by radio. Difficult to enforce. Repealed in 1985.	No ADFG sablefish survey.	Voluntary skipper interviews for trips
1981	"			"	09/01-10/10	Fishery closed by Emergency Order.	Non-standardized survey. Sablefish pot survey w/ *R/V Stellar* included tagging, stomach content study and subsample from lengths and weights. 05/20/81-05/29/81.	"
1982	300,00-900,000 dr			"	09/01-09/15	Lower end of GHR reduced. Pot gear no longer allowed in NSEI. Fishery restricted to longline only. Fishery closed by EO.	No ADFG sablefish survey.	"
1983	"			"	09/01-09/07 & 10/10-10/14	Fishery openings set by EO.	"	"
1984	"			"	01/01-03/03 & 09/01-09/05	Groundfish management within the intrusion areas beyond the three-mile territorial limit was formally conveyed to the state through an amendment to the MFCMA.(01/01-03/03 open period represents landings in this intrusion area during federal opening). Fishery openings set by EO.	"	"

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Table A.2. (page 3 of 5)

YEAR	Guideline Harvest Range	Harvest Objective (round weight)	Per Share Quota (round weight)	Season	Dates Fishery Open	Management Actions	NSEI Survey Design Changes	Dock-Side Data
1985	500-1,500,000 dr			"	09/04-09/05 & 10/04-10/06	Limited Entry program adopted for this fishery. First year Chatham specific CFEC permits were issued (ie C61A). Vessel operators who could demonstrate landing during a regular season prior to December 31, 1984 were eligible to apply for permits. Registration requirement was repealed. GHR increased. Groundfish went from 5 digit salmon statistical areas to current 6 digit groundfish statistical areas. Mgt area boundaries remained the same. Regulation initiated to require unloading sablefish prior to fishing sablefish in NSEI and unloading after NSEI prior to fishing another area. Fishery openings set by EO.	Non-standardized survey. Commercial vessel released 538 tags. 12/20/85, 1 day.	"
1986	"			"	09/09-09/11	No gear in water 72 hour prior and 24 hr after rule in regulation. Fishery set by EO.	Non-standardized survey. Commercial vessel w/ conventional gear released 3,126 tags. 1/20/86-02/04/86.	"
1987	"			"	09/15-09/16	Begin 24 hour opening by EO.	No ADFG survey.	"
1988	"			"	09/19-09/20		Begin annual longline surveys using a commercial vessel, snap gear, approx 2 weeks, 1000 hooks per station, 1 hour soak, herring for bait, 3-meters spacing, vessel's gear, 24 stations in 3 major statistical areas, tagged sablefish every third station. Subsample 10% for AWL. 08/14/88-08/26/88.	"
1989	"			"	09/22-09/23	NSEI management area 1st described in Regulations, previously described as the northern sablefish area. Bait regulations instituted, includes sablefish as bait, up to 2,000 pounds allowed annually, more with a permit.	2nd year annual survey. Decreased hooks to 500 per station. No tagging. Increased stations to 44 in same survey area. 08/07/89-08/25/89. Cooperative survey including tagging with NMFS on Townsend Cromwell.	"
1990	"			"	09/12-09/13		3rd year annual survey. Vessel's gear include swivel hooks and beads. Set 40 stations. 08/26/90-09/10/90.	"

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Table A.2. (page 4 of 5)

YEAR	Guideline Harvest Range	Harvest Objective (round weight)	Per Share Quota (round weight)	Season	Dates Fishery Open	Management Actions	NSEI Survey Design Changes	Dock-Side Data
1991	"			"	09/16-09/17	Changed statarea line between Frederick Sound and Chatham Strait.	4th year annual survey. Began using weight of 2.26kg every 100 hooks. Used ADFG vessel *R/VStellar* and ADFG standardized snap gear. 08/13/91-08/30/91.	"
1992	"			"	09/17-09/18		5th year annual survey. Used commercial vessel and both commercial gear and ADFG gear. 08/17/92-08/31/92.	"
1993	"			"	09/25-09/26		6th year annual survey. First year using ADFG vessel *R/VMedeia* with ADFG gear. Decreased survey to 38 stations. 08/23/93-09/08/93.	"
1994	1,000,000-3,000,000 dr	4,761,905	38,889	"	09/22-10/22	First year of 3 year trial quota-share system. Regulations specify a single 30 day during 09/01-11/15 season. GHR increased and capped at 3,000,000 dr pounds. Annual harvest limit to be set within the GHR based on survey information and is to be divided equally among all eligible permit holders. Written registration required prior to 1 week before season opens. Allow retention of tagged sablefish. Sablefish taken for use as bait must be "mutilated". Sablefish taken as bait must be reported on ADFG fishtickets.	7th year of annual survey. No change from 1993. 08/23/94-09/05/94.	"
1995	"	"	"	"	09/13-10/13	In person written registration required prior to fishing. Applied .63 conversion to dressed wt for vessels landing in round.	8th year of annual survey. Only set 30 stations with ADFG snap gear, one hour soak, and herring. Set 30 sets right next to these sets using 3-hour soak (6 of these sets using conventional gear), and squid. 08/23/95-09/08/95.	"
1996	"	"	"	"	09/08-11/08	Season extended to 60 days.	9th year of annual survey. Same design as 1993-1994. 08/17/96-08/31/96. In addition, the *F/V Ida June* made 16 conventional sets independent of the survey during the same time period to assess using commercial vessels and conventional gear and squid for future surveys.	"

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Table A.2. (page 5 of 5)

YEAR	Guideline Harvest Range	Harvest Objective (round weight)	Per Share Quota (round weight)	Season	Dates Fishery Open	Management Actions	NSEI Survey Design Changes	Dock-Side Data
1997	1,590,000-4,800,000 rnd	4,800,000	39,300	"	09/01-11/15	BOF decision to make permanent the quota share system after first 3 years of trial system. Initiated sablefish management based on round weight (.63 conversion to be used from Eastern cut to round weights). Instituted confidential logbooks requirement for each trip (to be attached to fishtickets at time of landing). Season set in regulation as entire period Sept 1- November 15.	10th year of annual survey however with major changes. Used 3 commercial vessels fishing concurrently, approx 1 week duration, vessel's conventional gear, *illex* squid as bait, approx 1100 hooks per set, 3-11 hour soak time, approx 2 meter spacing. Increased area of survey by adding 7 stations on the south in 345603. Began tagging, tagging a portion of the stations. Sampled approx 5% for AWL. 08/07/97-08/13/97.	Mandatory logbooks required
1998	"	"	41,700	"	"		11th year of annual survey. No changes from 1997. 08/13/98-08/19/98.	"
1999	"	3,120,000	28,000	"	"	Harvest Objective decreased 35%.	12th year of annual survey. Used only 2 instead of 3 vessels this year to complete survey. Tagged. Did not use tentacles on squid. 08/15/99-08/23/99.	"
2000	"	"	28,600	"	"	EYAK was deleted from 72-24 hr rule. Full retention of all rockfish (not including thornyheads) in inside waters in effect July 5th. CFEC review of optimum number of permits (re) confirmed 73 as optimum number.	13th year of annual survey. Returned to 3 vessels. Began using ADFG standardized gear. Did not tag . 08/16/00-08/23/00. First year of marking (tagging) with commercial pot vessel in 3 statistical areas.	Fishery lengths "
2001	"	2,184,000	19,600	"	"	Sablefish harvest objective was decreased 30% from year 2000 to 2,184,000 for 2001 with notification of indications showing further cut necessary to 1,700,000 for 2002. Public meetings were held in Petersburg, Sitka and Juneau.	14th year of annual survey. No changes from 2000 except for timing. 08/08/01-08/13/01. Second year of marking (both tags and only clips) with commercial pot vessel in 4 statistical areas.	" "

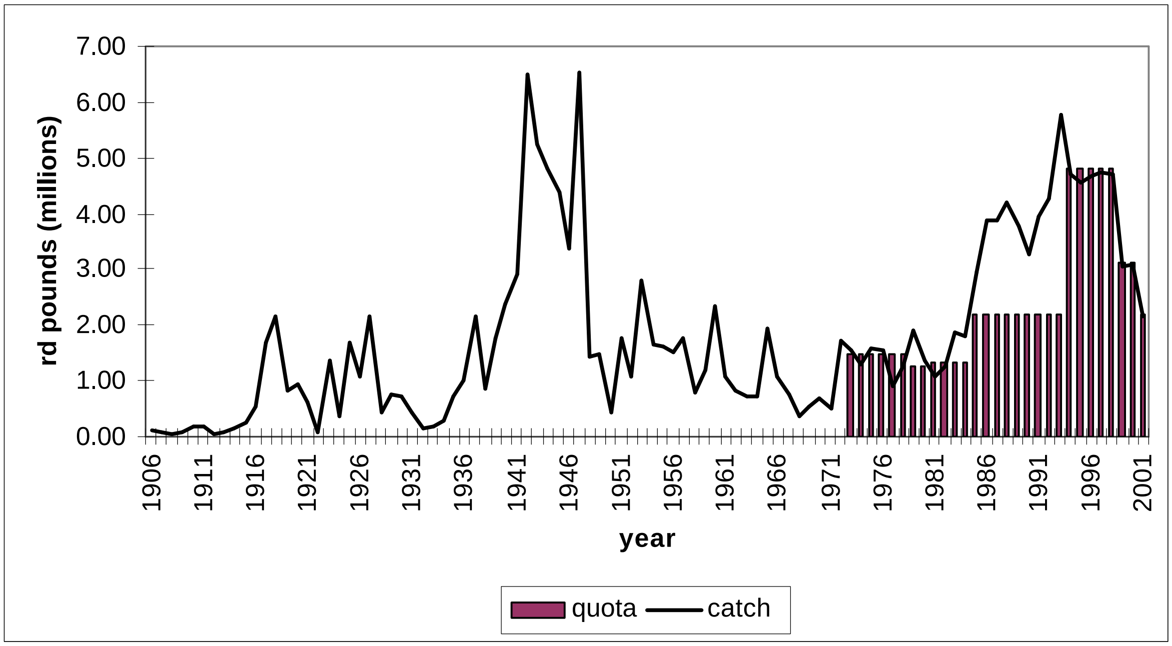


Figure A1. Sablefish catch and quota for NSEI fishery.

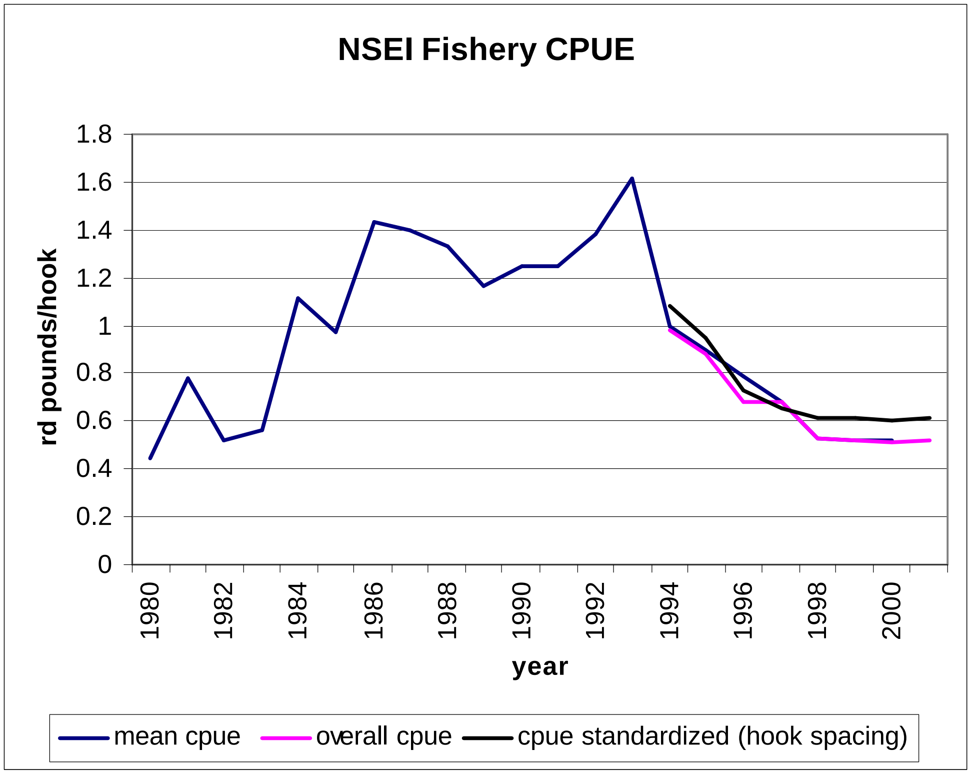


Figure A2. Sablefish catch per unit effort (rd pounds/hook) by year for NSEI fishery.

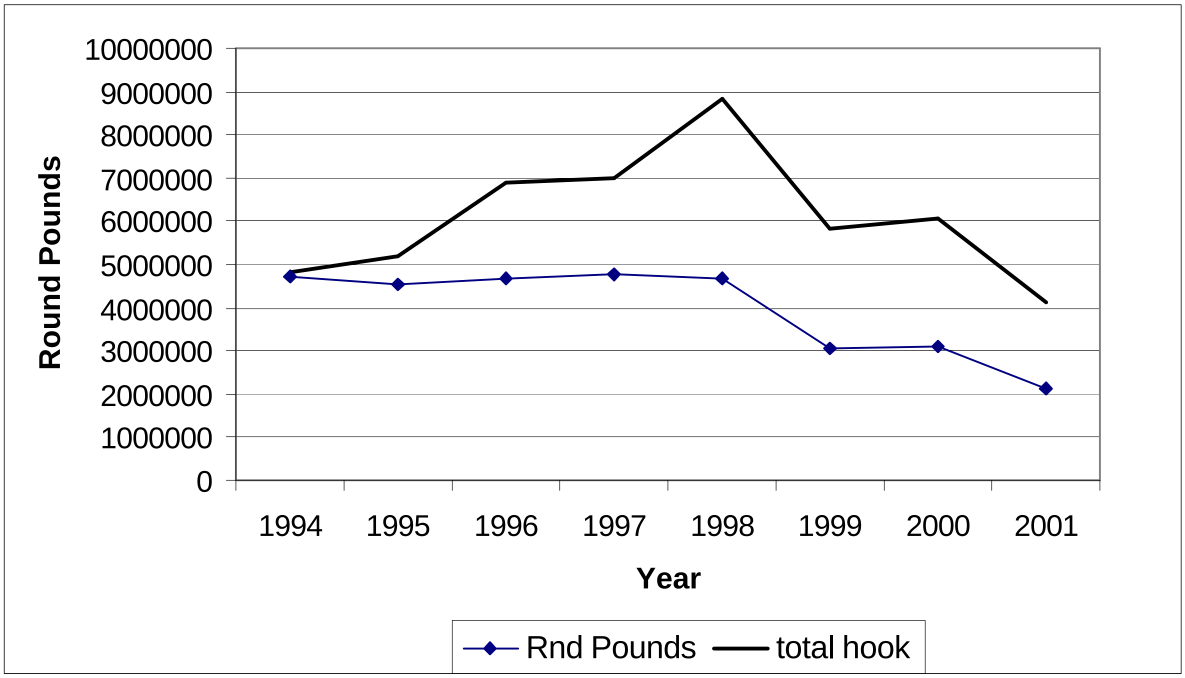


Figure A3. Round pounds caught and total hooks set in the NSEI sablefish fishery, 1994–2001.

Appendix B. NSEI sablefish survey specifications by year, 1985–2001.

Year	Start	End	Vessels	Gear	Hooks per set	Hook spacing	Hook size	Gangion length	Bait	Soak Time	Skate Wts	Fish tagged[a]	Sets made
1985	12/20	12/20	*F/V Prowler*	Conv.	2150	0.76 m	13 C	NA	Herring	2.5 hr	NA	538 t	2
1986	1/20	2/4	*F/V Martina*	Conv.								3126 t	19
1988	8/14	8/26	*F/V Betty*	Snap	1000	3 m	13 C	NA	Herring	1 hr	No	1298 t	24
1989	8/7	8/25	*F/V Carrie*	Snap	500	3 m	13 C	NA	Herring	1 hr	No	None	44
1990	8/26	9/10	*F/V Isis*	Snap	500	3 m	13 C	NA	Herring	1 hr	No	None	40
1991	8/13	8/30	*R/V Stellar*	Snap	500	3 m	13 C	0.375 m	Herring	1 hr	2.3 kg	None	40
1992	8/17	8/31	*F/V Charles T*	Snap	500	3 m	13 C	0.375 m	Herring	1 hr	2.3 kg	None	40
1993	8/23	9/8	*R/V Medeia*	Snap	500	3 m	13 C	0.375 m	Herring	1 hr	2.3 kg	None	38
1994	8/23	9/5	*R/V Medeia*	Snap	500	3 m	13 C	0.375 m	Herring	1 hr	2.3 kg	None	38
1995	8/23	9/8	*R/V Medeia*	Snap Conv[b] Snap	500	3 m	13 C	0.375 m	Herring Squid Squid	1 hr 3 hr 3 hr	2.3 kg	None	30 6 24
1996	8/17 8/19	8/31 8/23	*R/V Medeia* *F/V Ida June*	Snap Conv	500 750	3 m 1 m	13 C 13C	0.375 m 0.2 m	Herring Squid	1 hr 3-7 hr	2.3 kg 1.0 kg	None None	38 16
1997	8/7	8/13	*F/V Ida June* *F/V Charles T* *F/V Kruzof*	Conv	923-1217	2 m	13 C	0.2-0.3 m	Squid	3-11 hr	1-3.2 kg	5579 tu	45
1998	8/13	8/19	*F/V Ida June* *F/V Charles T* *F/V Ocean Cape*	Conv	831-1267	2 m	13 C	0.2-0.3 m	Squid	3-11 hr	1-3.2 kg	4998 tl	45
1999	8/13	8/19	*F/V Ida June* *F/V Charles T*	Conv	1002-1129	2 m	13 C	0.2-0.3 m	Squid	3-11 hr	1.4 kg	3568 t	45
2000	8/16 7/06	8/26 7/13	*F/V Ida June* *F/V Charles T* *F/V Spirit* *F/V Ocean Cape*	NMFS Conv Pot	1125 20 pots	2 m	13 C cones	0.375 m	Squid Squid	3-11 hr 10-46 hr	3.2 kg	 5768 tu	45
2001	8/16 6/21	8/26 7/07	*F/V Ida June* *F/V Charles T* *F/V Sylvia* *F/V Miss Conception*	NMFS Conv Pot	1125 35 pots	2 m 50 fm or 100 fm	13 C 5' & 6' conical	0.375 m	Squid Fish/sq.	3-11 hr 8-24 hr	3.2 kg	 4552 tu 4624 l	45

[a] Notation on tags: t=t-bar tag, u=upper fin clip, l=lower fin clip.

[b] In 1995 30 sets were made side-by-side to compare 1-hour and 3-hours soaks, 6 of these sets were done using conventional gear but due to operational problems the rest of the comparison sets were snap-on gear.

Appendix C. Age structured analyses, 1995 and 1998.

1995

Although the time series of longline survey data was relatively short (8 years), in 1995 for the first time we incorporated the survey and fishery CPUE and age and length composition data into an age-structured model to attempt to estimate abundance of Chatham Strait sablefish. The model was provided by Mike Sigler (National Marine Fisheries Service) and used the quasi-Newton algorithm in Microsoft EXCEL Solver to estimate the parameters needed for final estimation of sablefish abundance. The model uses maximum likelihood to estimate parameters. Multinomial error structure was assumed for age and length data and log-normal error for catch data. A weighting factor (λ) is included in the likelihood function that varies the relative influence of abundance indices and the age and length components of the likelihood (Sigler 1999). Like Sigler, we used a value of λ=1. Further details of the model are provided by Sigler (1999).

Model estimates included numbers of age-2 recruits for the years 1980 through 1995, the numbers of sablefish at ages 3 through 16+ for 1980 and two parameters which defined a logistic longline gear selectivity function. These estimates, along with an assumed or empirical estimate of natural mortality, and an estimate of age-2 recruitment for 1995 (mean of model-estimated, 1980–1994 age-2 recruits) were used to attempt to forecast Chatham Strait sablefish abundance in 1996. Full input data used in the estimation of these parameters included an independent estimate of natural mortality, annual age and length composition data from 1988 through 1995, 1980–1995 fishery CPUE, 1988–1995 survey CPUE, mean annual weights-at-age from the 1988 through 1995 surveys, and annual reported harvest.

When tuned to both fishery and survey CPUE, and age and length composition, the model yielded the estimated CPUEs depicted in Figure C1. Qualitatively, the ASA-estimates of fishery and survey CPUE displayed very marginal or poor fits to the observed survey and fishery CPUEs. There was a somewhat better fit of the ASA-estimated to observed age compositions (Figure C2). The estimated 1995 Chatham exploitable biomass from this modeling effort was 244,432 mt. This biomass estimate was unrealistically high.

For further model evaluation we used the two methods of validating the ASA model used by Sigler (1999). The first method was to vary the starting values of age-2 recruitment (the starting point for the model) to see if the model converged to the same estimates. Using this approach, and varying the initial starting points by as much as a factor of 100, the model converged to the results, which yielded the 244,432-mt estimate for 1995.

The second method of validation used Monte Carlo simulation (Kimura 1989). For this method the estimated parameters from the initial fitting process (i.e., the process yielding the 244,432 tonne estimate) were designated the “actual” estimates. From these parameters the “exact” data were calculated. Many new data sets were then simulated based on an assumed log-normal error structure (CV=0.1) for the expected abundance indices and multinomial error (n=200) for the expected age and length data (Sigler 1999). Finally, the model parameters for the simulated data were estimated. If the parameter estimates from the simulated data were close to the “actual” estimates, then the model would be validated to some extent. This second method, based on 25 Monte Carlo simulations, did not tend to support the initial model results as the simulated parameter estimates differed substantially from the “actual” estimates.

The poor model performance may have been due partly to the relatively short (8 year) time series of survey CPUE and length and age data. Eight years may have been too short a time period and the data too variable to provide stable, accurate estimates of the population parameters. Sablefish, particularly older sablefish, are difficult to age. This aging difficulty, coupled with limited sample sizes, may have contributed to high variability in estimates of age compositions and also compromised performance of the model. For the period 1988 through 1995, what appeared initially to be larger age cohorts in some years did not always consistently appear as larger age classes in subsequent years. For example, in 1989, 8-year-old fish appeared to predominate, comprising over 13% of the age composition. However, in 1990, 9-year-old fish comprised only 9.3% of the sample. Conversely, 11-year-old fish that comprised 9.3% of the sample in 1989 increased to 12.4% of the population as 12-year olds in 1990 (Figure C3). This apparent inconsistency in age compositions from year to year, may be at least partly attributable to small sample sizes. Sablefish movement to or from Chatham Strait, particularly size-specific movement as tag return data suggest occurs (see “Sablefish Stock Structure,” p. 27), could also contribute to inconsistencies in inter-year age class modes in graphs of annual age compositions. For example a mode represented by 9-year-old fish one year that would show up as a mode of 10-year-old fish the subsequent year might be masked by a large influx of 11-year old or older fish from outside waters.

Sablefish movement might also introduce inconsistencies in CPUE data. If sufficient numbers of fish were immigrating into Chatham over the course of the 6 years represented in the data, the ASA model might tend to overestimate the population since the catchability coefficient might tend to be underestimated.

It is also possible that the survey and fishery CPUE data may simply not reflect sufficiently any changes in relative abundance of Chatham sablefish and/or may have been so variable that changes in relative abundance were masked.

As Sigler’s (1993) research suggests, 1-hour soak times may be too short to provide a sufficiently accurate measure of relative abundance. However, the general similarity in trends and magnitudes of the survey and fishery CPUEs suggest that both measures were responding similarly to the same population phenomenon, whether a change in abundance, catchability, or both. In particular, a similar spike in 1993 fishery and survey CPUEs (Figure C1) indicates that the spike was probably not merely a survey-specific phenomenon that might otherwise have been attributable to insufficient (1-hour) soak time or some other anomaly specific to the survey. The suggested presence of a slight stand-out recruitment reflected in the 1993 age composition (Figure C3) is somewhat consistent with an increase in abundance suggested by the spike in the 1993 CPUE (Figure C1). However the rapid decline in CPUE after 1993 seems somewhat implausible assuming that the 1993 spike reflected an increase in relative abundance of a magnitude indicated by the increase in CPUE, assuming there was a linear relationship between CPUE and abundance.

The poor performance of the ASA model, based on the limited 1989–1995 data, prompted us to begin exploring supplementary approaches for estimating abundance of Chatham sablefish, while planning to continue the annual surveys to provide data for additional modeling in the future (see Mark/Recapture section).

1998

With an additional three years of data, we again conducted ASA in 1998. We estimated the numbers of age-2 recruits for the years 1980 through 1998, the numbers of sablefish at ages 3 through 16+ for 1980, and two parameters defining a logistic longline gear selectivity function. These estimates, an estimate of natural mortality, and an estimate of age-2 recruitment for 1999 were used to forecast Chatham Strait sablefish abundance in 1999. Input data included an estimate of natural mortality, annual age and length composition data from 1988 through 1998, 1980–1998 fishery CPUE, 1988–1998 survey CPUE, mean annual weights-at-age, and annual catch.

For model runs that included data up through 1998, we expressed CPUE as number of sablefish per 2,000 hooks. This alternative expression of CPUE (i.e. rather than number of sablefish per hook) was used to scale the CPUEs to levels more similar to the RPNs used as relative abundance input data for the sablefish stock assessment for the Gulf of Alaska and Bering Sea/Aleutian Islands (Sigler et al. 1998).

We ran the model with variations of the full input data ("base conditions"), or aspects of the modeling process, to try to improve the performance of the model or investigate response of the model to changes in input data or the modeling process. A synopsis of run variations is provided in Table C1.

The "base conditions," or full data set, included survey data from 1988 through 1998 for length and age composition, and CPUE , and fishery CPUE from 1980 through 1998. The assumed natural mortality for the base conditions was M=0.10.

Forecasts of 1999 biomass ranged from 8.94 to 37.23 metric tons. Applying a Chatham Strait-specific $F_{40\%}$ exploitation rate (0.101) to these biomass estimates yielded 1999 harvest quotas which ranged from 1.98 to 8.27 million round pounds (Figure C4). These quotas would have represented changes of -59% to +72% compared to the 1998 quota of 4.8 million pounds.

Plots of modeled versus observed values show marginal goodness-of-fit of modeled fishery and survey CPUEs, and age and length compositions to the observed values for these variables under most analysis conditions (Figures C5–C7).

In addition to evaluating the models based on goodness-of-fit of ASA-estimates to observed data, we examined gear selectivity functions to determine the plausibility of selectivity functions associated with various candidate models and analysis conditions. Graphs of the selectivity functions associated with each candidate model or set of analysis conditions are shown in Table C1 along with rationale for each set of analysis conditions.

Among the alternative model conditions, we deemed the "base conditions," which include all available data, most appropriate as the basis for management.

As discussed with the 1995 ASA results, although both fishery and survey CPUE data for 1993 seemed anomalously high, age compositions do suggest the possibility of a standout recruitment in 1993 (Figure C3). This may have contributed, to some extent, to the higher CPUEs observed in 1993. Assuming that CPUE varies as a linear function of abundance, as tacitly assumed for the ASA model, the high 1993 CPUEs suggest abundance close to that observed in the mid-1980s, when sablefish abundance appeared to peak (Figure C5) as a result of strong year classes in the late 1970s. As discussed in association with the 1995 ASA results, if abundance was truly as high as 1993 CPUEs might seem to indicate, the sharp decline in CPUE (and perhaps, therefore, abundance) immediately after 1993 still seems difficult to explain. If the abundance was as high as in the mid-1980s, it seems the greater abundance should have persisted longer than is suggested by the post-1993 survey and fishery CPUEs.

An alternative explanation for the high 1993 CPUE might have been a marked, but brief, increase in the catchability of both fishery and survey longline gear. This increased catchability may have resulted from, for example, a short-lived reduction in availability of natural food, making baited long-line hooks more attractive to sablefish. A similar, difficult-to-explain and short-lived increase in 1993 sablefish trap survey CPUE occurred in southern British Columbia, Canada (M. Saunders DFO personal communication).

We conducted model runs in which we either did not tune the model to the 1993 fishery and survey CPUEs or we estimated a unique, 1993-specific catchability coefficient for the fishery and survey. Our intent was to try to either remove the influence of the 1993 CPUEs, or account for what seemed to be inordinately high CPUEs.

An expanded (i.e. ages 2-20+, as opposed to 2-16+ under “base conditions”) age composition run was conducted to try to improve the fit of the model to the data. Often, collapsing data into broader categories, as done with some of the older age categories for most of these analyses, can result in a loss of information. However, the collapsing was maintained for most runs because of the increased uncertainty in aging older sablefish.

The rationale for excluding pre-1988 data (i.e. fishery CPUE) from some of the runs was to reduce the possible influence of changes which may have occurred over time in natural mortality, gear selectivity, or catchability. In addition, the potential adverse influence on the model of movement of sablefish into and out of Chatham Strait over time may possibly be reduced by shortening the time series of data to which the model is tuned.

A model run which assumed natural mortality (M) of 0.12 was conducted primarily to evaluate the influence of a slightly higher assumed mortality, rather than to try to improve the fit of the model.

Gear selectivity for the Chatham Strait sablefish longline fishery and survey might be similar to the IFQ fisheries in the GOA and Bering Sea survey, since the gear used in these fisheries and surveys are somewhat similar. For that reason we ran a model using a fixed selectivity function very similar to that estimated for the IFQ fisheries (Sigler et al. 1998).

In addition to examining resultant selectivity functions and goodness-of-fit graphics for each model, we again conducted Monte Carlo simulations as a form of model validation (Sigler 1999 and Kimura 1989). Results of one simulation are shown in Figure C8. Although results of the Monte Carlo simulation improved compared to the 1995 run, some consistent, though often small, discrepancies remained between “true” and simulated results.

Based on results, the analyses conditions which seemed most appropriate were the base conditions; that is, with all available data included. This run resulted in a forecast 1999 exploitable biomass of 10,620 metric tons. Applying an $F_{40\%}$ exploitation rate (= 0.101) to this biomass yielded a candidate 1999 quota of 2.35 million round pounds (Figure C4). This quota was 51% of the 1998 quota of 4.8 million pounds. The primary rationale for choosing this model run as the preferred run was the lack of any particularly compelling reason to use conditions other than the base conditions, with data from all years treated the same.

The possible exceptions to this conclusion were the model runs which either omitted the 1993 CPUEs or estimated a unique catchability coefficient for 1993. As discussed previously, the inordinately high 1993 CPUEs are difficult to reconcile without assuming that catchability may have temporarily changed during 1993. The selectivity functions which result from runs which treat 1993 uniquely (either by not tuning the model to the 1993 CPUE, or estimating a unique catchability coefficient only for 1993) are more similar in shape and scale to the selectivity function estimated for sablefish in the GOA and BS/AI. (Sigler et al. 1998; see Table C1). In addition, Monte Carlo simulations suggest more consistent results from runs in which 1993 CPUEs are treated uniquely, but otherwise all available data are used. For these two conditions, 1999 exploitable biomass estimates were 16,920 and 17,400 metric tons. The associated 1999 quotas would be 3.75 and 3.86 million round pounds. These would have been 22% and 19% reductions in the quota, relative to the 1998 quota of 4.8 million pounds.

The 1998 ASA modeling produced better results than the 1995 modeling, including somewhat better agreement between observed and estimated data, and some plausible estimates of abundance. However, we had concerns about the adequacy of our CPUE and age and length data as the sole or primary bases for estimating abundance, via ASA modeling. Among concerns was our shift from 1 to 3+-hour soaks in 1997, unaccompanied by a strong, clearly-definable relationship between 1 and 3+-hour CPUEs that could have provided an effectively uninterrupted time series of CPUE. In addition, we switched from herring to squid bait, and from snap-on to fixed gear. Also the spike in CPUE in 1993 raised questions about substantial reliance on CPUE data as an indicator of relative abundance. In addition, as discussed for the 1995 modeling, inter-year inconsistencies in age composition modes persisted during the 1996–1998 period. In particular, there was a pronounced discontinuity in age class modes between 1996 and 1997. In 1996 there was a single age composition mode centered around 7-year old fish (Figure C3). In 1997 a second mode suddenly appeared, centered around 22-year-old fish, in addition to the expected mode centered around 8-year old fish.

Despite these concerns, given the ASA-based estimate of biomass that resulted in a candidate quota of 2.35 million pounds and the downward trajectory of survey and fishery CPUEs, we reduced the 4.8 million pound quota which had been in effect since 1994, to 3.12 million pounds for 1999.

Concerns about ASA model performance, the underlying data, and our increasing reluctance to rely solely on ASA, or any other single method, prompted investigations of alternative approaches for estimating abundance of sablefish in the NSEI management area. An alternative approach could produce additional data to be used in the ASA modeling, or independent estimates to supplement information provided by ASA modeling. (See Mark-Recapture Section, p. 14)

Table C1.   Synopsis of ASA results and analysis conditions

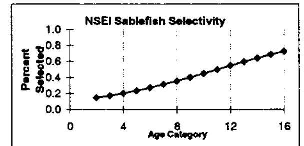
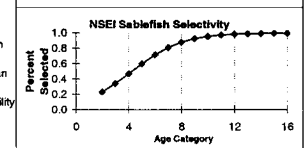
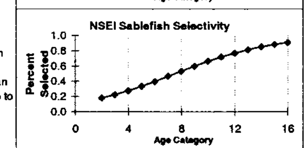
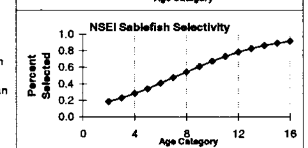
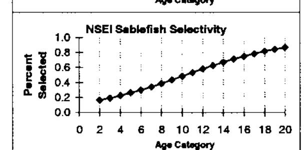
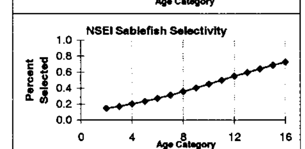
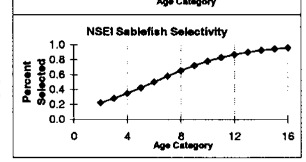
Run Date & Time	Exploitable Biomass (k mt)	Quota (round lbs.)	% change from '98	Assumed M	Tuned to.... Survey CPUE	Fishery CPUE	Age Composition	Length Composition	Transition Matrix	Analysis Conditions	Rationale for conditions	Selectivity
4/19/99 - 2:58 PM	23.29	4,795,500								**1998 Quota**		
4/6/99 - 11:28 A.M.	10.62	2,358,512	-51%	0.1	'88-'98	'80-'98	'88-'98	'88-'98	Chatham	**BASE CONDITIONS; All data included**	Assume that including all available data will yield the most information on the population.	
4/20/99 - 10:00 A.M.	37.23	8,266,270	72%	0.1	'88-'92, '94-'98	'88-'92, '94-'98	'88-'98	'88-'98	Chatham	**Not tuned to '93 CPUE ; First fishery CPUE year = 1988**	Survey and fishery CPUE for 1993 seem inordinately high; perhaps temporary, marked change in catchability rather than actual change in abundance; another alternative to estimating unique catchability for '93.	
4/6/99 - 3:56 P.M.	16.92	3,757,560	-22%	0.1	'88-'92, '94-'98	'80-'92, '94-'98	'88-'98	'88-'98	Chatham	**Not tuned to '93 CPUE ; First fishery CPUE year = 1980**	Survey and fishery CPUE for 1993 seem inordinately high; perhaps temporary, marked change in catchability rather than actual change in abundance; alternative to estimating unique catchability for '93.	
4/7/99 - 11:20 A.M.	17.4	3,864,616	-19%	0.1	'88-'98	'80-'98	'88-'98	'88-'98	Chatham	**Unique catchability for '93**	Survey and fishery CPUE for 1993 seem inordinately high; perhaps temporary, marked change in catchability rather than actual change in abundance	
4/6/99 - 11:28 A.M.	16.51	3,666,715	-24%	0.1	'88-'98	'80-'98	'88-'98	'88-'98	Chatham	**Age comps: 2-20+ by 1 year increments**	Sensitivity of model to change in age structure may be reduced unnecessarily by collapsing age categories	
4/5/99 - 9:41 A.M.	9.2	2,043,618	-57%	0.1	'88-'98	'80-'98	'88-'98	-	Chatham	**Not tuned to length**	Length a surrogate for age through the length-age transition matrix. If sufficient age data available, length not as useful.	
4/19/99 - 2:58 P.M.	23.29	5,172,586.00	8%	0.1	'88-'98	'88-'98	'88-'98	'88-'98	Chatham	**1988-1998 data only**	Reduce influence of possible changes in natural mortality and selectivity over time	

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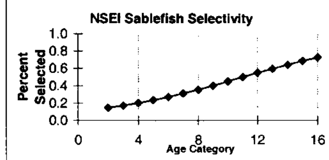
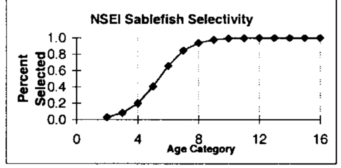
Table C1. (page 2 of 2)

Tuned to.... Run Date & Time | Exploitable Biomass (k mt) | Quota (round lbs.) | % change from '98 | Assumed M | Survey CPUE | Fishery CPUE | Age Composition | Length Composition | Transition Matrix | Analysis Conditions | Rationale for conditions | Selectivity

Run Date & Time	Exploitable Biomass (k mt)	Quota (round lbs.)	% change from '98	Assumed M	Tuned to.... Survey CPUE	Fishery CPUE	Age Composition	Length Composition	Transition Matrix	Analysis Conditions	Rationale for conditions	Selectivity
4/7/99 - 1:24 P.M.	8.94	1,984,603	**-59%**	**0.12**	'88-'98	'80-'98	'88-'98	'88-'98	Chatham	**ALL DATA INCLUDED; Assumed M = 0.12**	Test ASA response to higher-than-assumed natural mortality	
4/19/99 - 10:59 AM	29.241	6,493,498	35%	0.1	'88-'98	'80-'98	'88-'98	'88-'98	Chatham	**GOA SAFE selectivity**	Chatham fishing gear and methods essentially same as in GOA	

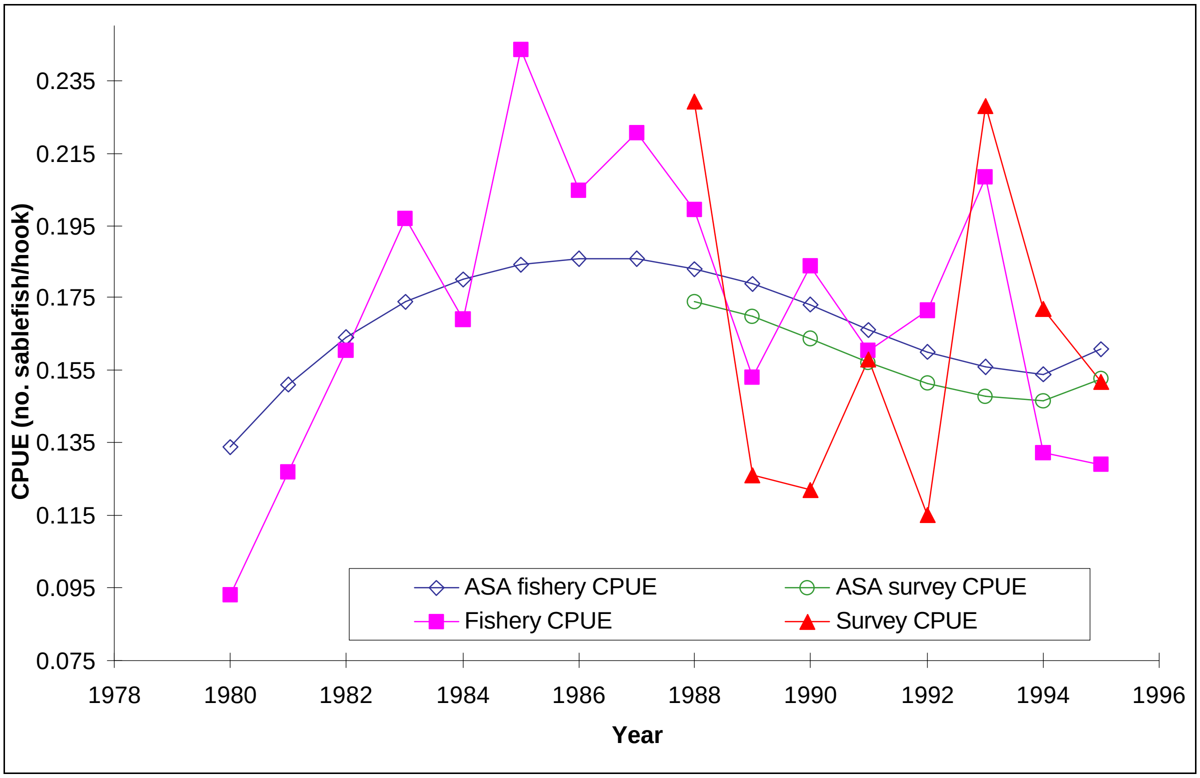


Figure C1. Goodness of fit of ASA-estimated CPUEs to observed Chatham fishery and survey CPUE, 1995 model run.

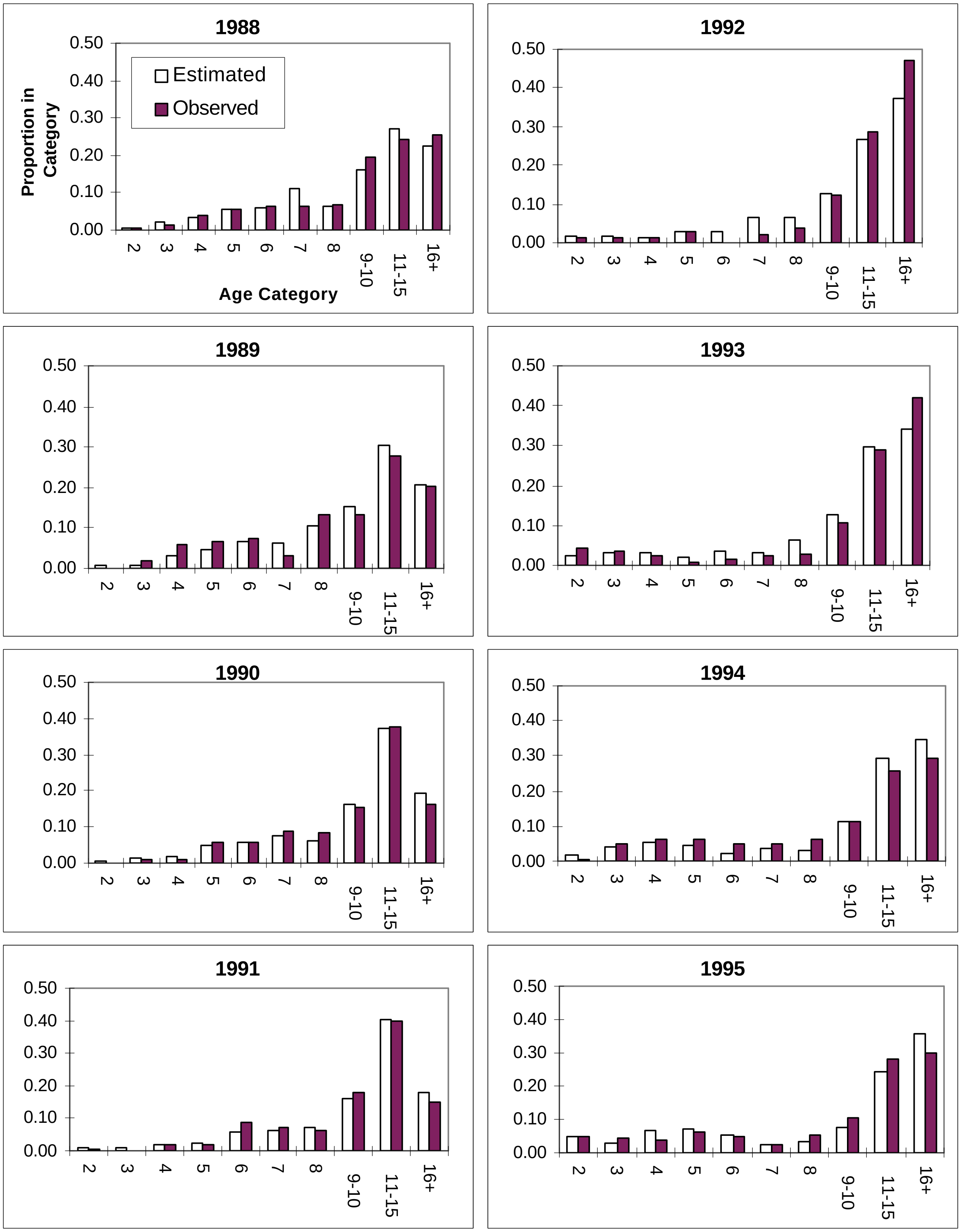


Figure C2. Goodness of fit of 1995 ASA-estimated survey age composition to observed Chatham Strait age compositions.

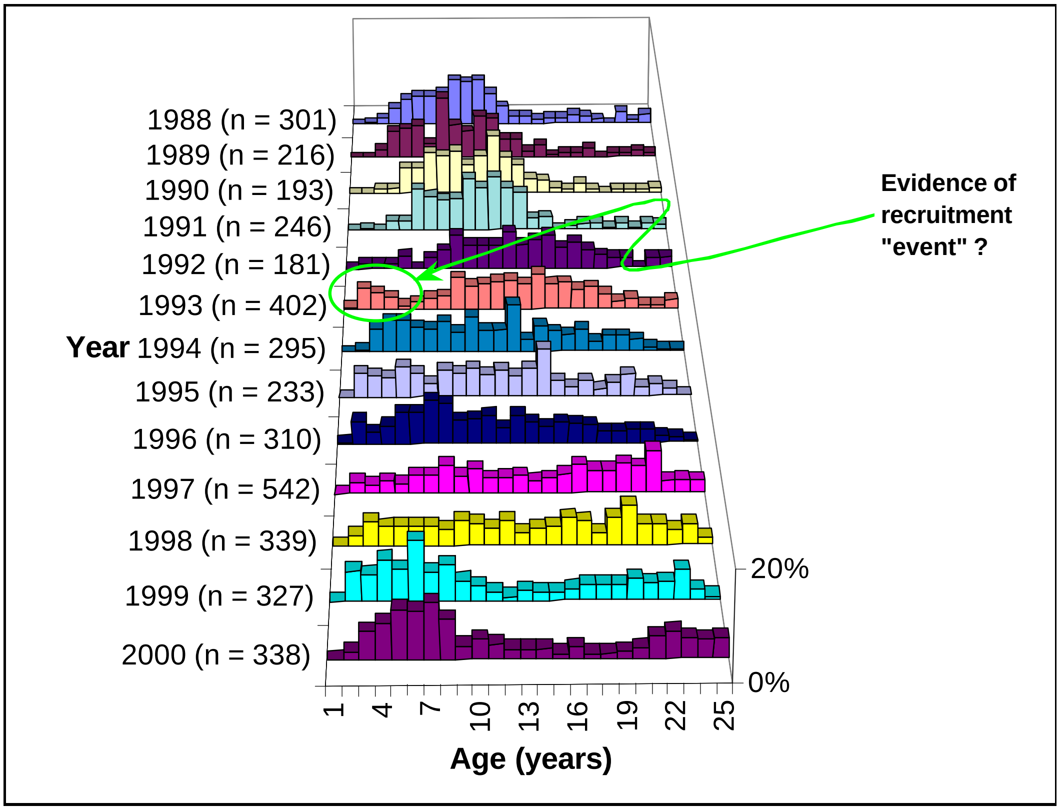


Figure C3. Age compositions of Chatham Strait sablefish, 1988–2000, ages 1 to 25. Numbers in parentheses next to year are sample sizes for biological sampling.

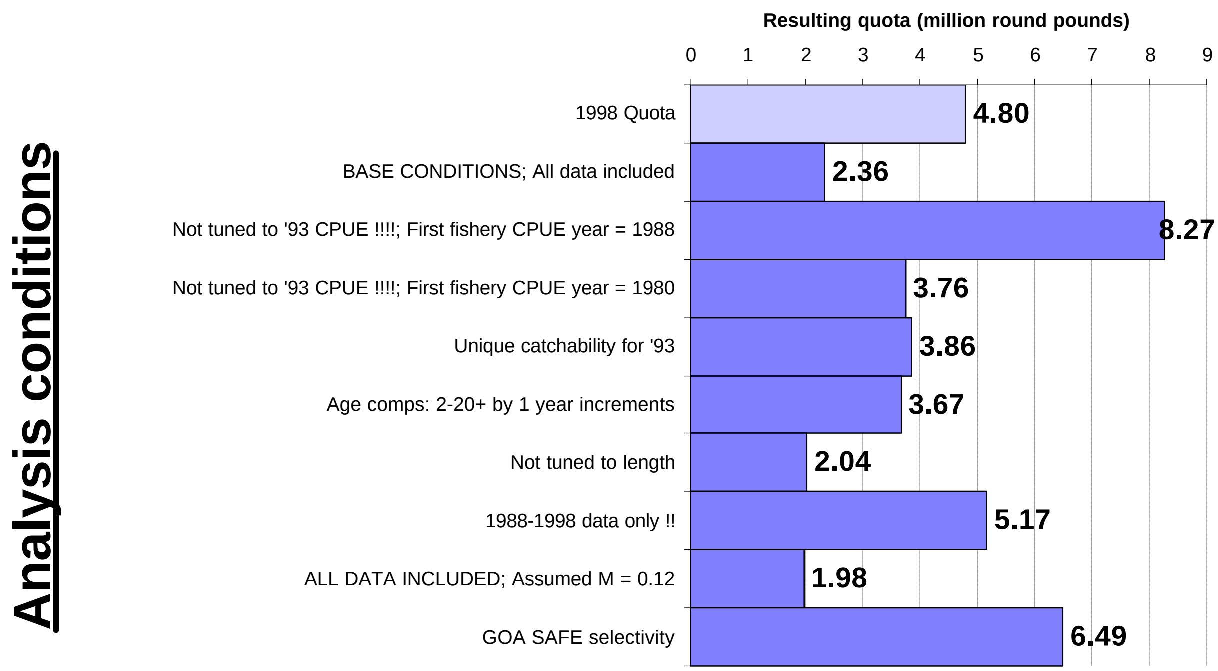


Figure C4. Candidate 1999 Chatham Strait sablefish quotas resulting from 1998 ASA runs based on different analysis conditions.

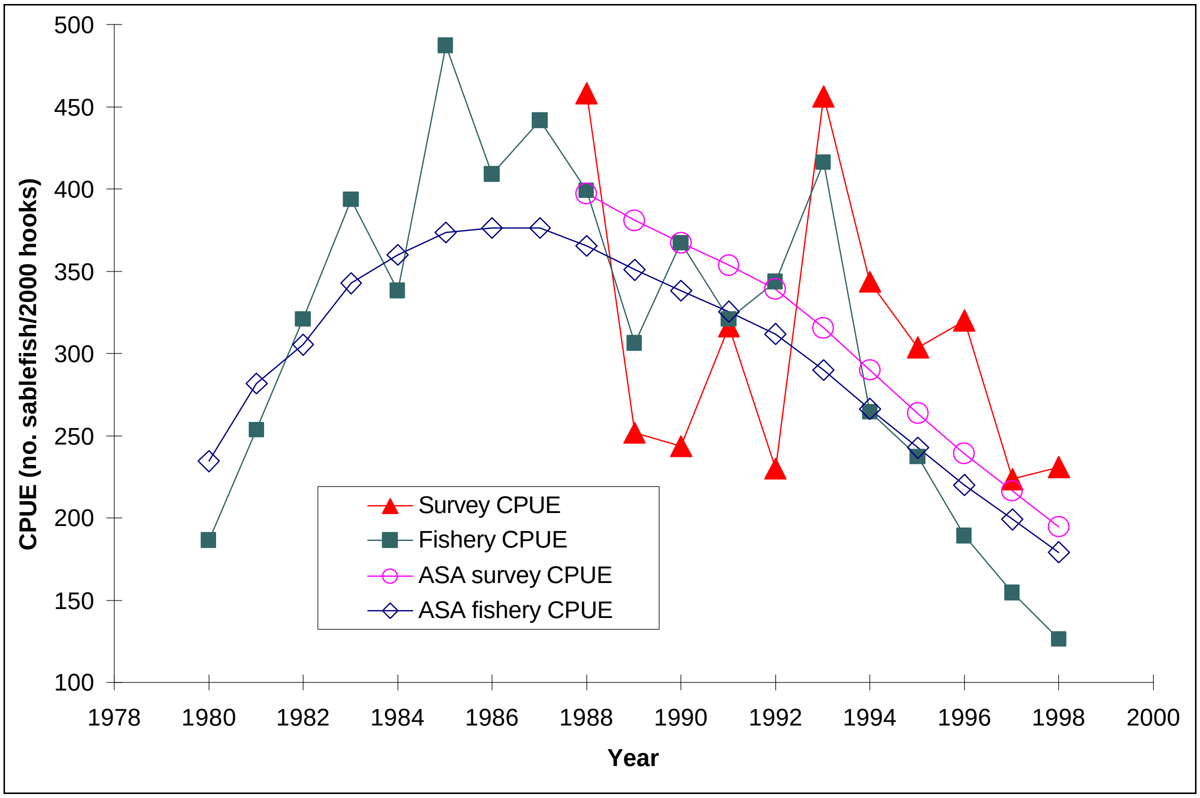


Figure C5. Goodness of fit of ASA-estimated CPUE to observed Chatham Strait fishery and survey CPUE, 1998.

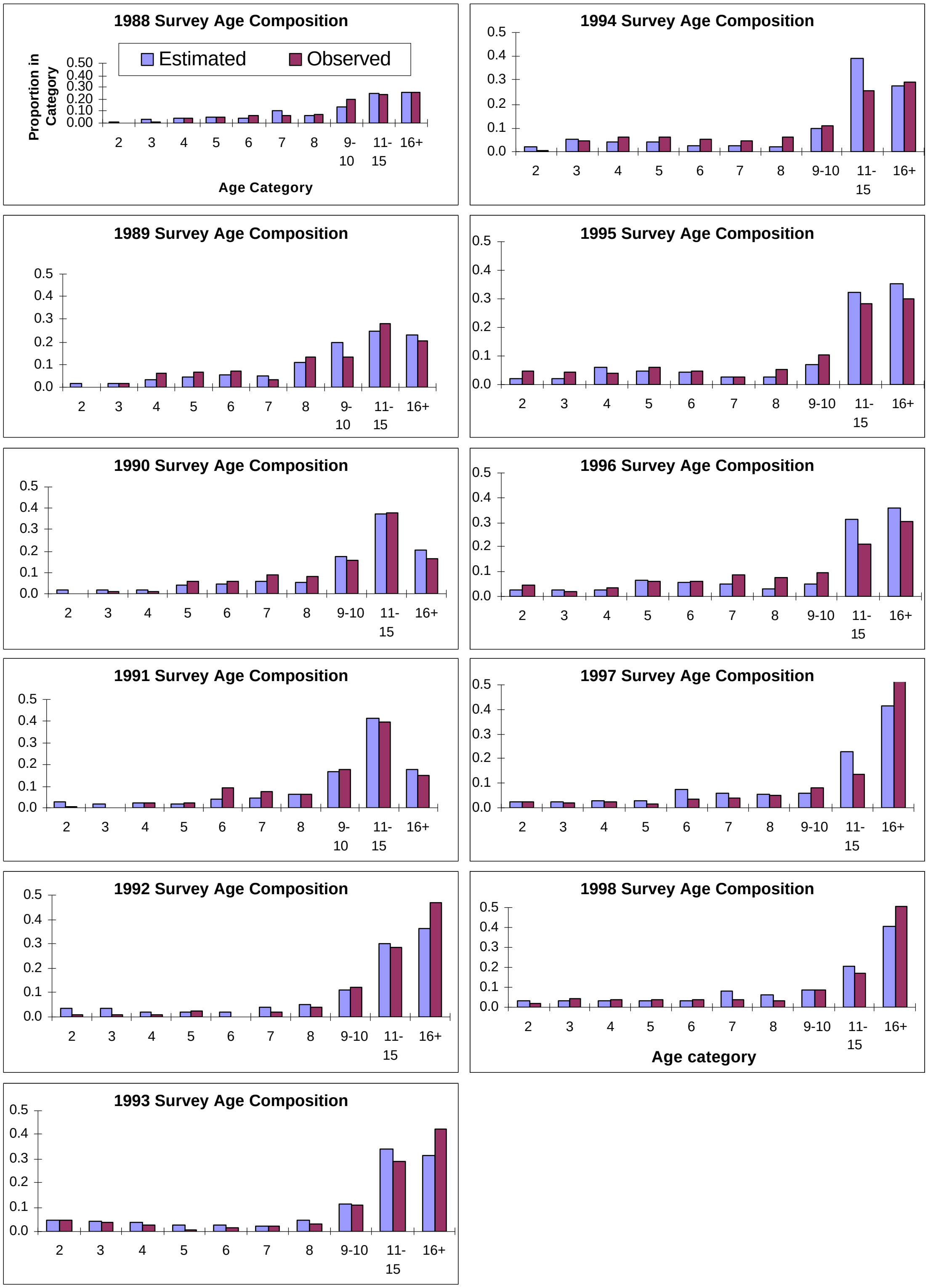


Figure C6. Goodness of fit of 1998 ASA-estimated, versus observed age compositions.

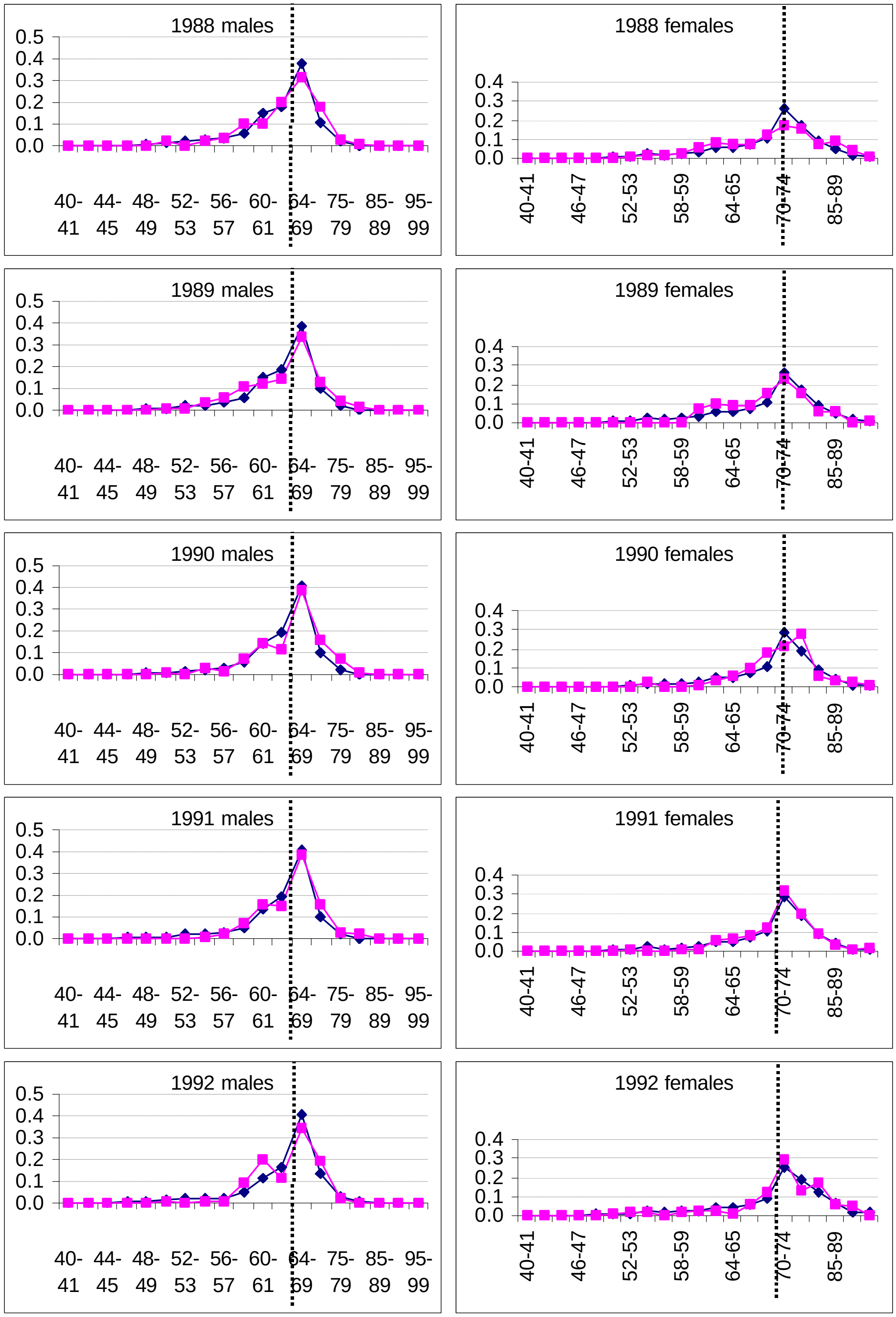


Figure C7. Goodness of fit of 1998 ASA-estimated versus observed Chatham Strait sablefish length compositions.

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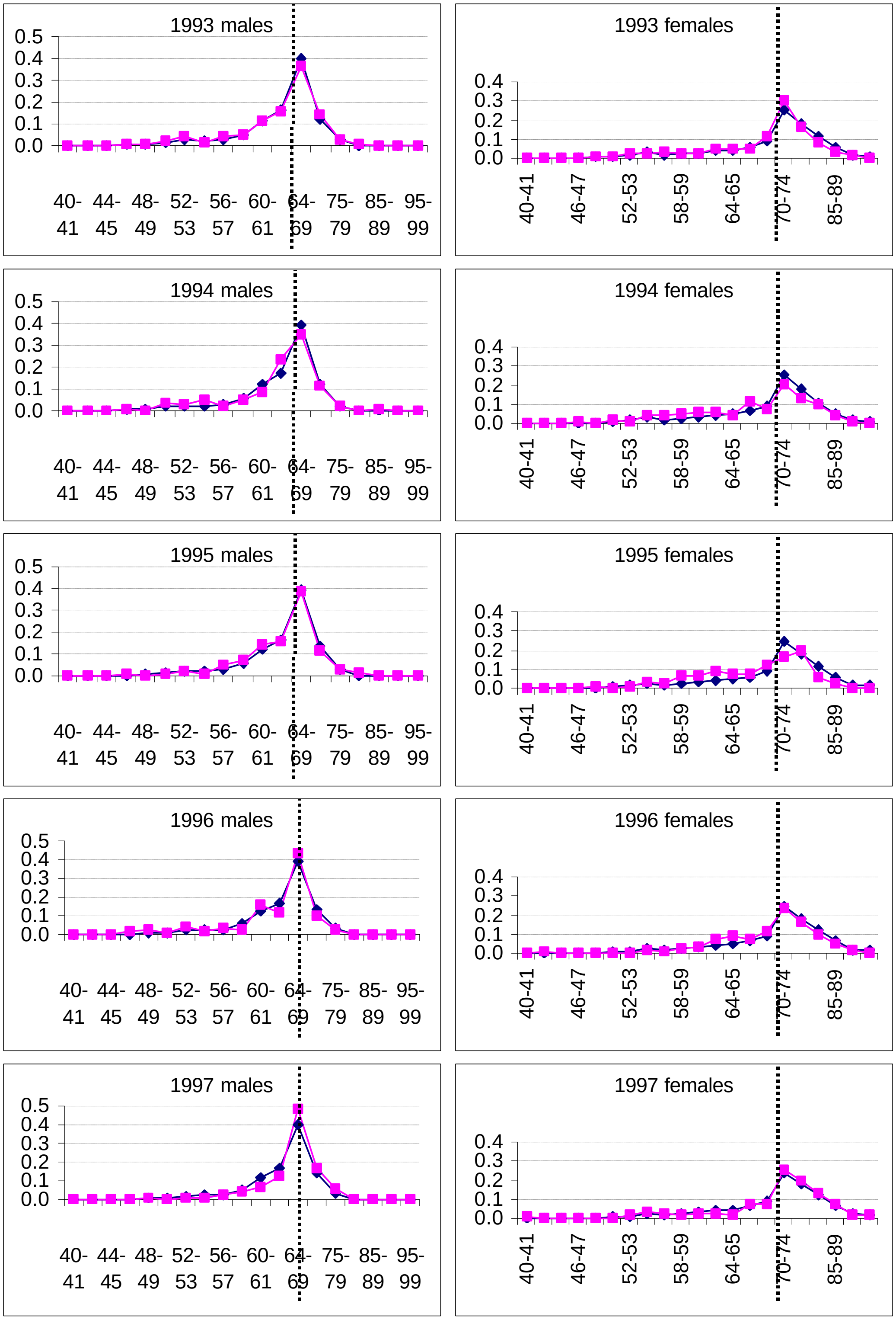

Figure C7. (page 2 of 3)

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Figure C7. (page 3 of 3)

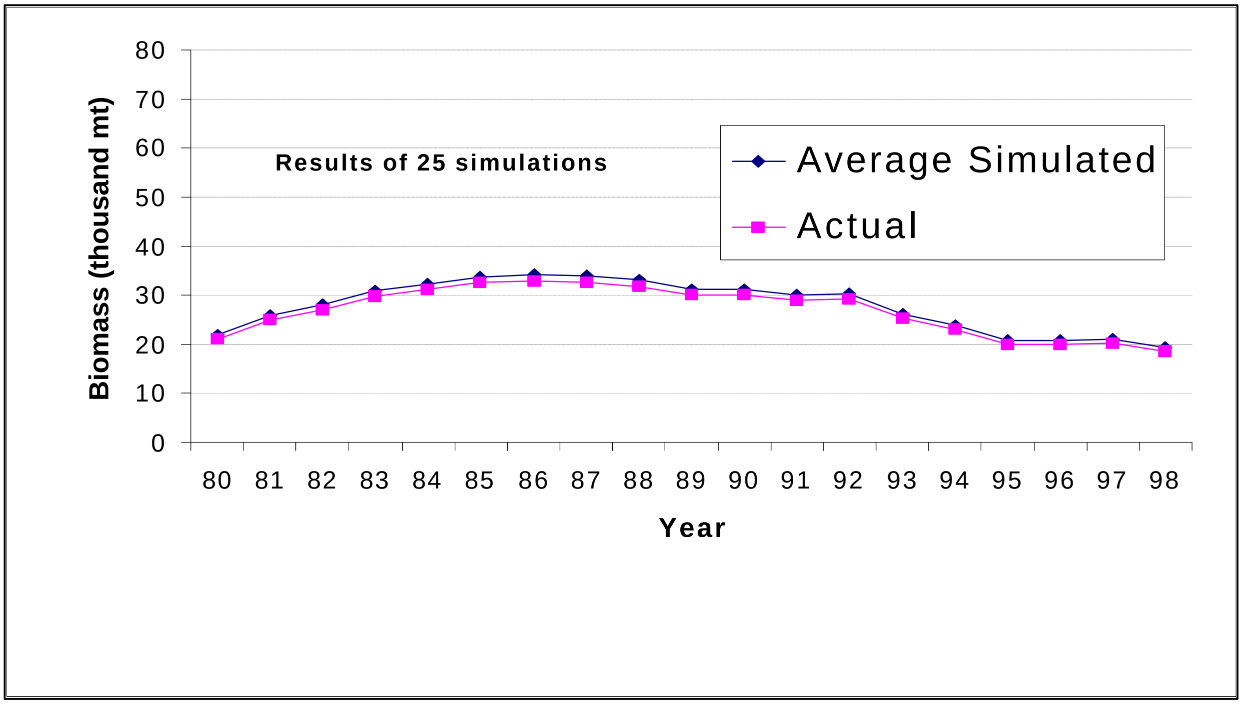

Figure C8. Comparison of "actual" 1998 ASA biomass estimate versus average simulated.

Appendix D. Peterson abundance estimation tests of assumptions, 1997.

Closure.

It is often difficult to test definitively for violation of the closure assumption. Skalski and Robson (1982) describe statistical tests which may help address the assumption of closure. These tests can be applied in mark-recapture studies with multiple removal opportunities, as characterized the 1997 Chatham Strait sablefish mark-recapture survey. Valid application of the mark-removal estimator advanced by Skalski and Robson (1982) assumes: 1) that marked and unmarked animals have equal probability of capture during the removal period, and 2) that the probability of capture is constant during removal periods. Skalski and Robson (1982) prescribe tests for both of these assumptions. While neither test is a direct test of the closure assumption, one or both of these tests in combination may help determine the likelihood of whether, or the extent to which, closure was achieved.

We applied a test for equal capture probabilities for marked and unmarked sablefish. This test was applied first using only data from fish port sampled from individual vessels and then to data for both individual vessels and tenders. This test was applied separately to the individual vessel landings, since we believed that landings from individual vessels on particular days would be more consistent with the concept of discrete, individual removal periods than might fish landed from tenders. Landings from tenders might more likely be comprised of fish caught from multiple vessels over a more extended period of days than would landings from individual vessels. The test was also applied to the combined vessel + tender data to include all of the mark-recapture data.

Results of the individual vessel test indicated no statistically significant difference in capture probabilities between marked and unmarked sablefish [Q = 0.99, P(X12 > 0.99) = 0.32]. Similarly, there was no statistically significant difference in marked versus unmarked capture probabilities when this test was applied to the combined individual vessel + tender mark-recapture data. [Q = 1.7; P(X12 > 1.7) = 0.19]. While the power of these tests is unknown, a finding of no significant difference in marked versus unmarked capture probabilities may provide some supporting evidence of closure.

As indicated by Skalski and Robson (1982): “When marked and unmarked individuals have equal probability of capture, the proportion of marked and unmarked in each of k removal samples should remain constant outside of sampling error.” Therefore if there had been a substantial influx of unmarked fish into the Chatham Strait study area, from immigration and/or recruitment, or loss of only marked or unmarked fish from the study area, through emigration and/or natural mortality, the capture probabilities of marked and unmarked sablefish theoretically would have changed. If both marked and unmarked sablefish had been lost from the study area, due to emigration and/or natural mortality, but at the same rate, there would not be a change in the capture probabilities of marked and unmarked sablefish. The tests of equal capture probabilities indicated no significant differences in marked versus unmarked capture probabilities, which tends to support the assumption of closure, or that if there was loss from the study area, it occurred at the same rate for both marked and unmarked individuals. As indicated previously, some limited violation of the closure assumption can occur without biasing the abundance estimates from a Petersen estimator. Specifically, if only loss (i.e. emigration and/or mortality) occurs and the loss rate is equal for marked and unmarked sablefish, then N^ estimates population abundance at the time of the marking sample. If recruitment only occurs, N^ estimates the population at the time of the recapture sample (Seber 1982, Skalski and Robson 1992). If both losses from, and gains to, the population occur simultaneously the Petersen estimate is not valid.

Logically, and from tag recovery data, we know that complete closure of the Chatham Strait sablefish population was not achieved. For example, in 1997, two external tags from fish marked in Chatham Strait were recovered in the IFQ sablefish fishery from the Central Southeast Outside (CSEO) management areas and one tag was recovered in Frederick Sound (Figure 1). Both of the CSEO tags were recovered from fish landed after cessation, on 9/10/97, of port sampling for tail-clipped fish. One of these tags, (No. 97-3246) was recovered from a fish landed on 9/18/97, and the other (No. 97-0132) was recovered from a fish landed on 11/12/97. Although these two tagged fish were recovered after port sampling to check for tail clips was completed, it is unknown when these fish left Chatham Strait and therefore effectively contributed to the violation of a strict closure assumption. These two fish were tagged on 8/8/97 and 8/7/97, having been at large a minimum of 29 and 65 days, respectively. The tag recovered in Frederick Sound was from a fish landed on 9/4/97, well within the 9/2/97 to 9/10/97 port sampling period. This fish had been tagged on 8/9/97 and so had been at large a minimum of 26 days.

Examination of data from external tag returns indicated that movement of tagged sablefish out of Chatham Strait was minimal. Only three of 76 tags were recovered outside of Chatham Strait and two of these were recovered well after formal completion of the recapture (i.e. port sampling) phase. Consequently violation of the closure assumption was perhaps not sufficient to preclude useful application of the Petersen estimator.

However, recaptures of tagged fish were probably influenced to some unknown, but perhaps substantial, degree by relative fishing effort in various areas. While no direct indication of actual effort (e.g. logbook data on hooks fished) was available for all relevant areas at the time of this writing, an indirect indication of effort is provided by examining catch data from areas within Chatham Strait and in the Eastern Gulf of Alaska (EGOA). During the period from 8/7 to 12/12/97 the vast majority of sablefish catch from Chatham Strait and the CSEO was caught in Chatham Strait. Two tags were recovered from the CSEO area, despite the minor fishing effort in that area, relative to Chatham Strait. This suggests the possibility of substantial emigration from Chatham Strait. Again, for valid application of the Petersen estimator, this would only be problematic if the loss rate from Chatham was different for marked and unmarked sablefish or if there was substantial recruitment and/or immigration occurring simultaneously with loss of sablefish from Chatham. We have no direct way of determining the amount of immigration and/or recruitment that may have occurred during the recapture period, since no sablefish were tagged outside of Chatham Strait immediately prior to the recapture period, and no length data, which might help to address the question of recruitment, were collected during the recapture phase.

However, CPUE may provide some useful information about the extent of immigration and/or recruitment into Chatham Strait during the recapture period. Assuming that CPUE provides some indication of abundance, a substantial influx of sablefish into Chatham Strait from immigration and/or recruitment might be expected to produce an increase in CPUE, unless that increase was met or exceeded by exploitation in the fishery. During the first 3 days of the Chatham fishery, there was a slight increase CPUE from a low of 0.75 sablefish/hook on 9/2/97 to a high of 0.9 sablefish/hook on 9/3/97. Thereafter, the CPUE declined daily to a low of about 0.55 sablefish/hook on 9/7/97, followed by modest daily increases back to about 0.63 on 9/10/97, the last day of port sampling. To the extent that CPUE may reflect abundance, this pattern of changing CPUE does not suggest a substantial increase in the population during the recapture phase. A test of constant capture probability (Skalski and Robson 1982) throughout the port sampling period also suggests that there was no substantial change in the abundance during the port sampling period. That is, there was no statistically significant change in the overall capture probability during the sampling period. Assuming that CPUE is proportional to abundance, a finding of constant capture probabilities tends to suggest no substantial change in the population that may have arisen from large, closure-violating changes in the population.

Equal Capture Probabilities of Marked and Unmarked Fish

The previous test of equal capture probabilities of marked and unmarked sablefish was used to address the closure assumption. The finding of no statistically significant (α = 0.05) differences in capture probabilities between marked and unmarked sablefish also suggests that the equal capture probability assumption is satisfied.

Mixing

This assumption is a supporting condition for the equal capture probability assumption. To the extent that marked and unmarked sablefish do not mix, and to the extent that the fishery does not overlap areas in Chatham Strait where fish were marked, the capture probabilities for marked and unmarked fish would not be equal and any estimate would be biased. The test of equal capture probabilities for marked and unmarked sablefish, referred to previously, suggests that there was sufficient mixing of marked and unmarked sablefish to render the capture probabilities statistically indistinguishable. In addition, the median distance between release and recapture points for tagged sablefish was almost 9 km. Given the release locations of marked fish, the median release-recapture, and the median movement range of 8.9 km, there appears to be sufficient overlap of these ranges and coverage of the principle Chatham Strait fishing locations to indicate that adequate mixing of marked and unmarked fish probably occurred.

Tag Reporting/Retention

Tail clips, in combination with the use of port samplers whose primary responsibility was to check sablefish catch for those tail clips, were used to minimize or alleviate problems associated with the loss and/or non-reporting of the marks. One approach for evaluating the potential non-reporting of tail clips would be to double sample a portion of the catch, however this approach was not used. This approach was not intentionally used. Although some fish were inadvertently double counted in Petersburg, this double-counting was not done in an organized way intended to ascertain the incidence of non-reporting of tail clips. However, clipped fish were also marked with an external tag. Any return of external tags from a landing which exceed the numbers of tail clipped fish noted by port samplers from that landing would provide an indication of non-reporting (i.e. non-observation) of tail clips. This method of checking for possible non-reporting of tail clips could be used for those landings for which the entire load of fish was scrutinized for tail clips. One goal of the port sampling was to conduct 100% sampling of as many landings as possible. This method of determining or estimating the degree of non-observation of tail clips by port samplers is crude at best, since the estimated non-reporting/loss rate of external tags was low, only about 47%. Tail-clipped fish might have been missed by port samplers whose external tags were either lost, or not returned by fishers or processing line workers.

Among tags returned during the port sampling period (9/2 – 9/10/97), there was only one instance where a tag was returned with no tail-clipped fish noted for that landing. In all other cases, the number of tail-clipped fish observed by port samplers in a landing equaled or exceeded the number of external tags returned from that landing. Based on the single instance of a tag recovery without at least equivalent number of tail-marks, the estimated incidence of tail-clip recovery or observation is 0.16. Observation of recovered tail clipped fish by port samplers who also had participated in the tail clip marking process indicated essentially no change in the appearance of the tail clips. This observation indicates that loss of detectability of marks by healing, regrowth, or necrosis of the clipped section of the tails was extremely unlikely and therefore that loss of marks was not a serious concern.

Appendix E. Estimates of tag retention/reporting.

The estimates of tag retention/reporting are contrasted with Lenarz and Shaw's (1996, p. 298, Table 3) estimates of sablefish tag *retention* rates of 0.97 and 0.93 (anterior and posterior dorsal fin tag sites; retention rates given here are the complement of the shedding rates actually reported by Lenarz and Shaw). Lenarz and Shaw's estimates of tag retention, although substantially higher than ours, are not completely comparable to our estimates because of fundamental differences in marking and sampling approaches. Lenarz and Shaw conducted a traditional double-tagging experiment, wherein each fish was tagged with two identical tags, one each at the anterior and posterior ends of the dorsal fin. Recovery of tags was presumably made by one person. There was a reward for each tag and each tag attached to a fish was probably equally visible to the finder. So, presumably any tags retained on a fish would be observed, whether one or both tags were present, and turned in at the same time.

In contrast to Lenarz and Shaw's study, different people observed the two different marks given each sablefish in our study. A port sampler observed the tail clip of any marked sablefish in a load, whereas either a fisher or processing line worker was most likely to find, and turn in, any tag which had been retained and discovered on a fish. In addition, the only opportunity to observe one of the marks, the tail clip, in our study was during the relatively brief port sampling periods. Recovery data from external tags from fish in landings which had not been 100% observed by port samplers could not be used in our estimates of tag retention/reporting rates. This contributed to the relatively low sample size, and attendantly higher-than-desirable variance in the estimates.

A case can be made that the inherently greater detectability of the tail clip compared to the external tag may also have tended to reduce our estimates of tag retention/reporting compared to Lenarz and Shaw. Our tail clips may have been inherently more detectable than tags since the focus of the port samplers was specifically to look for tail clips. In contrast, the principle focus of fishers was catching fish and the principle focus of the processing line workers was processing the fish. Observation and recovery of tags was incidental to their primary tasks. In addition detectability of tags may have been further reduced, relative to the tail clips, because at many times during the catching and processing of fish, each fish may have been lying on its side opposite the side which held the tag. In contrast, the tail clip could probably be detected more readily, regardless of which side the fish was lying on.

Because of the differences in the mark detection process and in the detectability of the marks, Lenarz and Shaw's estimates may more aptly be considered pure estimates of tag retention rates, whereas our estimates must be classified as tag retention/reporting rates. Tag shedding versus reporting are indistinguishable in our data, because failure to return a tag associated with a tail clip observed by one of our port samplers could have been due to either the loss of the tag prior to the fish being caught and processed, or to the failure of fishers or processing workers to find, or if found, turn in, the tag.

An assumption could be made that the external tags in our study may have experienced a pure tag retention rate similar to that reported by Lenarz and Shaw. If that was the case, then a substantial part of the combined tag retention/reporting rate in our study may be contributed by reporting rate. This might suggest that there is rather substantial non-reporting of tagged fish, due to non-detection of the tags, or retention of the tags by fishers and processing line workers. This non-reporting may be higher during the early stages of the Chatham sablefish fishery, when our port sampling occurred, because of the, perhaps greater, pre-occupation of fishers and processing line workers with their primary tasks.