Section 6

ROCK SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 1998 SAFE:

Changes to the input data

1) 1998 fishery age composition.
2) 1998 survey age composition.
3) 1999 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 18, September 1999.
5) Estimate of retained and discarded portions of the 1998 catch.

Assessment results

1) The projected age 2+ biomass for 2000 is **2,073,600** t.
2) The projected female spawning biomass for 2000 is 675,500 t.
3) The recommended 2000 ABC is 229,500 t based on an $F_{40\%}$ (0.154) harvest level.
4) The 2000 overfishing level is 272,000 t based on an $F_{35\%}$ (0.186) harvest level.

SUMMARY

	1999 Assessment Recommendations for the 2000 harvest	1998 Assessment Recommendations for the 1999 harvest
Total biomass	**2,073,600** t	**2,320,000** t
ABC	229,500 t	308,900 t
Overfishing	272,500 t	444,100 t
F_{ABC}	$F_{0.40}$ = 0.154	$F_{0.40}$ = 0.16
$F_{overfishing}$	$F_{0.35}$ = 0.186	$F_{0.30}$ = 0.23

INTRODUCTION

The rock sole (Lepidopsetta bilineata) is distributed primarily on the eastern Bering Sea continental shelf and in lesser amounts in the Aleutian Islands region. Two species of rock sole are known to occur in the North Pacific ocean, a northern rock sole (Lenidonsetta sp. cf. bilineata) and a southern rock sole (L. bilineata) (pers. comm. Jay Orr). These species have an overlapping distribution in the Gulf of Alaska, but the northern species predominates the Bering Sea and Aleutian Islands populations where they are managed as a single stock.

Centers of abundance occur off the Kamchatka Peninsula (Shubnikov and Lisovenko 1964), British Columbia (Forrester and Thompson 1969), the central Gulf of Alaska, and in the southeastern Bering Sea (Alton and Sample 1975). Adults exhibit a benthic lifestyle and, in the eastern Bering Sea, occupy separate winter (spawning) and summertime feeding distributions on the continental shelf. Rock sole spawn during the winter-early spring period of December-March.

CATCH HISTORY

Rock sole catches increased from an average of 7,000 t annually from 1963-69 to 30,000 t between 1970 to 1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 6.1, with catch data for 1980-88 separated into catches by non-U.S. fisheries; joint venture operations and DAP catches (where available). Prior to 1987, the classification of rock sole in the "other flatfish" management category prevented reliable estimates of DAP catch. Catches since 1987 have averaged 50,540 t annually. The size composition of the 1998 catch from observer sampling, by sex and management area, are shown in Figure 6.1.

Rock sole are important as the target of a high value roe fishery occurring in February and March which accounts for the majority of the annual catch. The 1998 catch of 33,645 t, the smallest catch since 1990, was only 11% of the ABC of 3 12,000 t (40% of the TAC). The 1999 catch total is 33,249 t through September 18. During the 1999 fishing season rock sole harvesting was periodically closed in the Bering Sea and Aleutian Islands due to bycatch restrictions, as follows:

Area	Date	Bvcatch closure
BS/AI	2/26 - 3/30	First seasonal halibut cap
BS/AI	4/27 - 7/4	Second seasonal halibut cap
BS/AI	8/31 - 12/31	Annual halibut allowance

Although female rock sole are highly desirable when in spawning condition, large amounts of rock sole are discarded overboard in the various Bering Sea trawl target fisheries. Observer discard estimates applied to 'blend' estimates of observer sampling and industry reported catch provide the following estimates:

Year	Retained	Discard	% Retained
1987	14,209 t	14,701 t	49
1988	22,374 t	23,148 t	49
1989	23,544 t	24,358 t	49
1990	12,170 t	12,591 t	49
1991	25,406 t	35,181 t	42
1992	21,317 t	35,681 t	37
1993	22,589 t	45,669 t	33
1994	20,951 t	39,945 t	34
1995	21,761 t	33,108 t	40
1996	19,770 t	27,158 t	42
1997	27,743 t	39,821 t	41
1998	12,645 t	20,999 t	38

Since 1987 rock sole have been discarded in greater amounts than they have been retained. Fisheries with the highest discard rates include the rock sole roe fishery, the yellowfin sole, Pacific cod, and the bottom pollock fisheries. Since 1990, retention of rock sole has ranged from 33% in 1993 to 42% in 1996.

DATA

The data used in this assessment include estimates of total catch, trawl fishery catch-at-age, trawl survey age composition, trawl survey biomass estimates and sampling error, maturity observations from observer sampling and mean weight-at-age.

Fisher-v Catch and Catch-at-Age

Available information include fishery catch data from 1975-September 18, 1999 (Table 6.1) and fishery catch-at-age numbers from 1980-98 (Table 6.2).

Survey CPUE

Since rock sole are lightly exploited and are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries are considered an unreliable method for detecting trends in abundance. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Abundance estimates from the 1982 AFSC survey were substantially higher than from the 198 1 survey data for a number of bottom-tending species such as flatfishes. This is coincident with the change in research trawl to the 83/1 12 with better bottom tending characteristics. The increase in survey CPUE was particularly large for rock sole (6.5 to 12.3 kg/ha, Figure 6.2). Consequently, CPUE and biomass from the 1975-81 surveys are not used in the assessment model.

The CPUE trend indicates a significantly increasing population from 1982-92 when the mean CPUE more than tripled. The population leveled-off from 1994-98 when CPUE values indicated a high level of abundance. The 1999 value of 36.5 kg/ha is the lowest observed since 1992.

Absolute Abundance

Estimates of rock sole biomass are also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data. The estimates are as follows:

Year	Eastern Bering Sea (t)	Aleutian Islands (t)
1975	175,500	
1979	194,700	
1980	283,800	28,500
1981	302,400	
1982	578,800	
1983	713,000	23,300
1984	799,300	
1985	700,100	
1986	1,031,400	26,900
1987	1,269,700	
1988	1,480,100	
1989	1,138,600	
1990	1,381,300	
1991	1,588,300	31,224
1992	1,543,900	
1993	2,123,500	
1994	2,894,200	42,832
1995	2,175,040	=
1996	2,183,000	
1997	2,710,900	56,228
1998	2,168,700	
1999	1,689,100	

It should be recognized that the biomass estimates given above are point estimates from an "area-swept" bottom trawl survey. As a result they are uncertain. It is assumed that the sampling plan covers the distribution of the fish and that all fish in the path of the footrope of the trawl are captured. That is, there are no losses due to escape or gains due to gear herding effects. Due to sampling variability alone, the 95% confidence interval for the 1999 point estimate of the surveyed area is 1,347,000 t - 2,03 1,200 t.

Rock sole biomass was relatively stable through 1979, but then increased substantially in the following years to 799,300 t in 1984. In 1985 the estimate declined to 672,000 t but increased again in 1986 to over 1 million t and continued this trend through 1988. The 1989 and 1990 estimates were at a high and stable level (slightly less than the 1988 estimate) and continued to increase to the highest level estimated by the trawl survey at 2.9 million metric tons in 1994. The 1995, 1996 and 1998 estimates are near the 1993 estimate of 2.2 million metric tons and the 1997 estimate is about the level of 1994. As described in a following section, past recruitment should contribute to a stable stock biomass in the near future.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 198 1 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-S 1. Allowing the stock assessment model to tune to these early survey estimates would most likely underestimate the true pre- 1982 biomass, thus exaggerating the degree to which biomass increased during that period. The pre-1982 survey biomass estimates were omitted from the analysis.

Weight-at-age and Maturity-at-age

In conjunction with the large and steady increase in the rock sole stock size since the early 1980s, it was found that there was also a corresponding decrease in size-at-age for both sexes (Figure 6.3). This also caused a resultant decrease in weight-at-age as the population increased and expanded westward toward the shelf edge (Walters and Wilderbuer 1999). These updated values of weight-at-age (Table 6.3) were used in this assessment to model the population dynamics of the rock sole population and were compared to results obtained from the constant growth model used in past assessments.

The length-weight relationship did not change significantly over this time period as discerned from an analysis of observations made in 1975, 1976 and 1988. The following parameters have been calculated for the length (cm)-weight (g) relationship:

$$W = a * L^{**b}$$

No significant differences were found between sexes so that these parameters are for both sexes combined.

a	b
0.007610	3.11976

Maturity information available from anatomical scans collected by fishery observers during the 1993 and 1994 Bering Sea rock sole roe fishery are used in this assessment (Table 6.4). These data indicate that the age of 50% maturity occurs at 9-10 years for female rock sole.

Survey and Fishery Age composition

Rock sole otoliths have routinely been collected during the trawl surveys since 1975 to provide estimates of the population age composition (Table 6.5). Age-length keys from these surveys were applied to fishery size composition data from 1980-97 (prior to 1980 observer coverage was sparse and did not reflect the catch size composition) to provide a time-series of catch-at-age assuming that the mean length at age from the trawl survey was the same as the fishery in a given year. For the 1998 fishery age composition, the age-length key was constructed from age structures collected from the fishery.

ANALYTIC APPROACH

Model Structure

The abundance, mortality, recruitment and selectivity of rock sole were assessed with a stock assessment model using the AD Model builder software. The conceptual model is similar to that implemented in the stock synthesis program (Methot 1990, Fournier and Archibald 1982). The model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information. The model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function.

The suite of parameters estimated by the model are classified by three likelihood components:

Data Component	Distribution assumption
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 6-6). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the rock sole assessment except for the catch weight. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 6-6 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Tabie 6-7 provides a description of the variables used in Table 6-6. The model of rock sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated **Independently**

Most studies assume M = 0.20 for rock sole on the basis of the longevity of the species. In a past assessment, the stock synthesis model was used to entertain a range of M values to evaluate the fit of the observable population characteristics over a range of natural mortality values (Wilderbuer and Walters 1992). The best fit occurred at M = 0. I 8, which is the value used in this assessment. The survey catchability coefficient (q) was set equal to 1 .O.

Rock sole maturity schedules were estimated as discussed in section 6.3.4 (Table 6.4).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Total
25	4	44	73

The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery data and the entry of another year class into the observed population.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population using the population dynamics equations given in Table 6-6.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the two parameter formulation of the double logistic function, as shown in Table 6-6. The model was configured with the selectivity curve fixed asymptotically for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis was placed on the catch likelihood component.

MODEL EVALUATION

The assessment model was run using both the constant growth model used in past assessments and the annual change in weight-at-age as shown in Table 6.3 to evaluate the impact on estimates of total biomass, recruitment and selectivity. The time-varying weights-at-age model gave more variation in estimated recruitment at similar biomass levels compared to the constant weight-at-age model (Fig. 6.4). Since the model was fit to the same survey biomass and the same fishery and survey age composition estimates in both model runs, similar biomass levels were obtained. This was accomplished by increasing the year-class strengths in the model run with rock sole of reduced weight-at-age. This was particularly evident in the strength of the 1987 year class which was estimated at 40% higher than the constant growth model at age 4.

The increased recruitment variability produced periods of higher and lower rates of increase in total estimated biomass after 1985 relative to the smooth increasing trend estimated from the constant growth model (Fig. 6.4). Increased size of estimated recruitment from the time-varying weight-at-age model provided a better fit to the observed age composition data from the survey (especially when the 1999 trawl survey biomass is omitted from the model run). All stock assessment results in the following section are evaluated using the model which allows for the change in length and weight-at-age observed in the rock sole population since 1980.

MODEL RESULTS

Fishing Mortalitv and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given Table 6.8. The exploitation rate has averaged just over 2% from 1975-99, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 6.9, Fig. 6.5) indicate that rock sole are 50% selected by the fishery between the ages of 7 and 8 and are fully selected by age 12 (sexes combined).

Abundance Trend

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (300,000 - 500,000 t, Fig. 6.5 and Table 6.10). From 1982-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 6.4) and light exploitation, the estimated total biomass rapidly increased at a higher rate to over 2.7 million t by 1995. Since then, the model indicates the population biomass has declined 20% to 2.1 million t in 1999 and is projected at 2,073,600 t for 2000. The female spawning biomass is estimated to be at a high and stable level of 674,100 t (Table 6. IO). The resulting fit to all the observed fishery and survey age compositions and the model estimate of population numbers at age are shown in the Appendix.

The model estimates of survey biomass (using trawl survey age-specific selectivity applied to the total biomass, Fig. 6.5) closely match the trawl survey biomass trend since 1982. The model corresponds well with the 1993-98 survey biomass trend with the exception of the 1994 and 1997 biomass estimates which were nearly 600,000 t more than the model biomass. The 1999 survey point estimate is 200,000 t less than the model estimate. Both the trawl survey and the model indicate the same increasing biomass trend from the late 1970s to the mid 1990s and a present high level of abundance.

Total Biomass

The stock assessment model estimates of total biomass (begin year population numbers multiplied by mid-year weight at age) is used to recommend the ABC for 2000. Including the 1999 catch of 39,249 t through 18 September (including discards), the model projects the total biomass for 2000 at **2,073,600** t.

Recruitment Trends

Increases in abundance described earlier for rock sole can be attributed to the recruitment of a series of strong year classes (Fig. 6.4, Table 6.11). Rock sole ages have now been read for samples obtained in 1998 and show the continuing presence of the 1986 and 1987 year classes (Fig. 6.6). The 1990 year class also appears strong, and as 8 year old fish in 1998, comprise a significant part of the survey age composition numbers. The 1987 year class is the largest estimated during the recruitment time-series and still comprise 16% of the estimated 1998 survey age composition numbers as eleven year old fish. The 1993 year class may also be stronger than the 24 year average.

Spawner-Recruit Relationship

Model estimates of female spawning biomass and the relationship to estimated age 4 recruitment are shown in Figure 6.7. The twenty-one data points were fit with a Ricker (1958) form of spawner-recruit curve. However, estimation of MSY using these data is unreliable and is not recommended for management purposes.

ACCEPTABLE BIOLOGICAL CATCH

The reference fishing mortality rate for rock sole is determined by the amount of reliable population information available (Amendment 44 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. For the 1999 assessment, the Alaska Fisheries Science Center policy is to use only year classes spawned in 1977 or later to calculate the average equilibrium recruitment. Using the time-series of recruitment from 1978-98 from the stock assessment model results in an estimate of $B_{0.40}$ = 284,700 t. The stock assessment model estimates the 2000 level of female spawning biomass at 675,500 t(B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B>B_{0.40}$ (675,500 > 284,500), rock sole reference fishing mortality is defined in tier 3a. For the 2000 harvest: $F_{ABC} \leq F_{0.40} = 0.154$ and $F_{overfishing} = F_{0.35} = 0.186$ (full selection F values).

Acceptable biological catch is estimated for 2000 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2000 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{max}} \overline{w}_a n_a \left(\frac{Fs_a}{M + Fs_a} \right) \left(1 - e^{-M - Fs_a}\right)$$

where S, is the selectivity at age, M is natural mortality, W_a is the mean weight at age from 1998, and n, is the beginning of the year numbers at age. This results in a2000 ABC of 229,500 t for the eastern Bering Sea portion of the stock.

The stock assessment analysis must also consider harvest limits, usually described as "overfishing" fishing mortality levels with corresponding yield amounts. Previous stock assessments used $F_{0.30}$ or the fishing mortality rate which would reduce the spawning biomass per recruit to 30% of its unfished level as the harvest limit. Amendment 56 to the BS/AI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value. The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2000 Yield
$F_{0.35}$	0.186	**272,500 t**
$F_{0.40}$	0.154	229,500 t

BIOMASS PROJECTIONS

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 1999 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2000 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 1999. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2000, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to $max\ F_{ABC}$. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of $max\ F_{ABC}$, where this fraction is equal to the ratio of the F_{ABC} value for 2000 recommended in the assessment to the $max\ F_{ABC}$ for 2000. (Rationale: When F_{ABC} is set at a value below $max\ F_{ABC}$, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1994- 1998 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2000 and above its MSY level in 20 10 under this scenario, then the stock is not overfished.)

Scenario 7: In 2000 and 200 1, F is set equal to max F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2012 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 6.12 indicate that rock sole are currently not overfished and are not approaching an overfished condition.

OTHER CONSIDERATIONS

Trophic studies indicate that rock sole groundfish predators include Pacific cod, walleye pollock, skates, Pacific halibut and yellowfin sole, mostly on small rock sole ranging from 5 to 15 cm standard length. Rock sole diet includes bivalves, polychaetes, amphipods and miscellaneous crustaceans.

REFERENCES

Alton, M. S. and Terry M. Sample 1976. Rock sole (Family Pleuronectidae) p. 46 l-474. In: Demersal fish and shellfish resources in the Bering Sea in the baseline year 1975. Principal investigators Walter T. Pereyra, Jerry E. Reeves, and Richard Bakkala. U.S. Dep. Comm., Natl. Oceanic Atmos. Admin., Natl. Mar. Serv., Northwest and Alaska Fish Center, Seattle, Wa. Processed Rep., 619 p.

Foumier, D. A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish Aquat. Sci. 39:1195-1207.

Greiwank, A. and G. F. Corliss (eds) 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50:259- 277. Symposium on application of stock assessment techniques to Gadoids.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Can., (119) 300 p.

Shubnikov, D. A. and L. A. Lisovenko 1964. Data on the biology of rock sole in the southeastern Bering Sea. Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 49 (IN. Tikookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 5 1) : 209-2 14. (Transl. In Soviet Fisheries Investigations in the Northeast Pacific, Part II, p. 220-226, by Israel Program Sci. Transl., 1968, available Natl. Tech. Inf. Serv., Springfield, VA, as TT 67-5 1204).

Walters, G. E. and T. K. Wilderbuer. 1999. Decreasing length at age in a rapidly expanding population of northern rock sole in the eastern Bering Sea and its effect on management advice. Submitted to Proceedings of Fourth International Symposium on Flatfish Ecology, October 1999.

Wilderbuer, T. K., and G. E. Walters. 1992. Rock sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1993. Chapter 6. North Pacific Fishery Management Council, P. 0. Box 103 136, Anchorage Alaska 995 10.

Table 6.1--Rock sole catch from 1977 - September 18, 1999.

Year	Foreign	Joint-Venture	Domestic	Total
1977	5,319			5,319
1978	7,038			7,038
1979	5,874			5,874
1980	6,329	2,469		8,798
1981	3,480	5,541		9,021
1982	3,169	8,674		11,844
1983	4,479	9,140		13,618
1984	10,156	27,523		18,750
1985	6,671	12,079		37,678
1986	3,394	16,217		23,483
1987	776	11,136	28,910	40,046
1988		40,844	45,522	86,366
1989		21,010	47,902	68,912
1990		10,492	24,761	35,253
1991			60,587	60,587
1992			56,998	56,998
1993			63,953	63,953
1994			60,544	60,544
1995			58,870	58,870
1996			46,928	46,928
1997			67,564	67,564
1998			33,645	33,645
1999			39,245	39,249

Table &P--Estimated catch numbers at age, 1980-1998.

year/age	1	2	3	4	6	6	7	8	0	10	11	12	13	14	16	16	17	16	19	20
1980	0	161,356	1,506,280	1,287,139	3,813,559	2,191,411	2,219,119	1.627.166	1544.063	4,057,889	2.621362	1,332,479	1,050,366	1,012,583	664.060	168,764	50.377	0	0	0
1081	0	0	1.613.369	2,674,062	1,526,839	6,407,384	1,764,099	851.346	1,144,431	1,639,464	3,212,782	1,431,935	1,236,544	636,416	667,632	516.390	136,774	27.913	0	0
1982	0	267.074	1,612,930	2,305,370	2,255,614	5,008,769	8,964,406	5,568,547	2,234,882	2,404,882	2,761,468	3,209,274	2,728,298	1,492,686	126,537	352,440	132,663	0	41,463	0
1063	0	0	3,617	676,621	2,032,944	1,726,947	3,425,756	5,683,801	2.EI40.362	3,816,166	1,501,846	2,113,839	5,098,428	2,500,732	1,603,845	1.653.066	274,342	165,309	52,756	0
1984	0	0	0	2,540,068	6,888,823	5,674,313	11,672,454	9,181,803	15,210,759	9,507,960	5,396,410	5,692,916	8,549,257	6,187,093	5,603,964	4.6S6.309	1,284,859	0	070,470	0
1866	0	1,469,731	3,286,253	11,807,393	20,807,434	12,839,508	8.141321	6,531,222	4.136.716	5.EJ61.485	1,023,858	412.646	322,020	726.600	2,311,937	1,403,676	526,443	412,646	140,366	322,020
1666	0	0	0	400,105	8,076,521	17,613,373	13,113,171	7,927,508	9,156,868	2,831,253	8,829,039	1,154,853	1,139,952	076,037	350,161	001,531	946,235	29.603	0	312.026
1987	0	0	0	2,071,165	7,894,882	13,481,676	23226.066	6,993,046	5,777,861	4,501,535	2,392,157	6,468,059	993,548	267,404	351,563	101.067	672,555	343,020	84,069	716,411
1988	0	0	672,674	1,201,187	34,686,579	25,797,797	33,965,867	21,843,120	12,972,818	30,768,862	6,153,772	4.767.766	3,936,197	3,012,207	0	626,313	554,394	2,531,732	406.556	007,909
1989	0	0	0	1,495,365	10,113,391	33,265,317	16,029,266	21,433,568	10.4S4.430	10,231,446	8,696,729	5,141,958	4,105,696	5,286,247	2,925,144	1,154,317	131,172	0	0	605,214
1990	0	0	0	232,509	2,899,518	7,159,894	17,827,931	8,069,413	10,544,945	8,780,815	3,296,150	1,422,405	1,901,099	696,466	2.400306	1,135,189	253,024	266.701	102,577	1,210,412
1991	0	17.740	2,200,775	7,809,201	4,570,157	12,352,738	17,268,982	41,193,533	28,627,820	19,895,713	15,884,624	8,181,913	3,727,118	3,514,140	3,346,533	3,673,874	1,135,884	727,676	0	1,739,322
1092	0	0	160,534	1,016,593	9,166,571	9,269,954	14,680,299	35,425,697	32,599,912	14,008,313	23,123,194	11,768,362	4,634,977	5,582,649	2,532,868	223,005	6,254,634	566.603	524,142	706.446
1993	0	0	0	0	0	2,874,833	11,020,195	20,443,259	13,895,028	60,531,213	9,742,491	15,811,583	12,138,185	3,353,972	3,353,972	1,756,843	762,594	1.277.704	1,597,130	798.565
1994	0	0	0	233,760	0	2.66Q.176	16,645,048	29,410,672	28,034,637	28,730,944	27,852,271	6,482,285	9,565,929	8,189,894	3,299,168	2,636,019	746,013	116.051	1,193,669	0
1006	0	0	0	326,336	1,188,369	1,252,348	6,043,941	23,427,076	27,224,958	17,682,610	18,866,896	18,485,747	7,446,026	6,751,790	6,299,855	178,666	421,067	446,469	0	0
1996	0	0	48,548	94,666	416,726	3,980,921	3,228,430	9,102,715	27,429,515	22,064,981	14,248,783	6,238,394	7367.131	4,842,644	2,508,708	10,141,638	7,205,709	2,166,446	48,548	236,064
1997	0	9,110	126.420	1.649.142	1,549,145	3,650,123	20,447,914	4,834,055	21,812,446	55,524,413	25,705,375	21,732,179	16,669,364	12,100,188	6,794,587	3,553,803	2,036,765	1344.465	0	0
1998	0	0	0	0	271,700	336.026	1,215,152	5,109,059	4,450,470	10,219,883	31.666.021	15,829,800	6,706,877	6,525,209	2,551,910	1,161,298	1,654,521	1,144,672	112,406	238,102

Table 6-3 -Rock sole wslght-at-age (grams) by age and year determined from 1990-99 from length-at-age and length-weight relationshlps from the annual trawl survey In the eastern Bering Sea.

year/age	1	2	2	4	6	6	7	6	9	10	11	12	12	14	16	16	17	16	19	20
1980	0	6	31	76	136	202	274	344	409	471	522	572	613	646	677	702	727	745	764	777
1681	0	6	21	76	125	202	274	244	409	471	522	572	612	646	677	702	727	745	764	777
1982	0	16	56	67	106	164	215	271	336	395	466	415	522	544	725	763	742	742	742	742
1962	0	17	35	109	160	105	261	206	257	369	400	406	513	531	588	655	625	946	665	665
1984	0	19	30	64	141	167	246	206	265	424	460	450	406	628	466	588	727	727	727	727
1966	0	16	22	54	113	197	264	325	363	469	466	660	556	477	654	595	556	604	705	807
1966	0	19	32	46	110	198	307	246	263	431	475	463	541	602	616	603	652	705	705	795
1987	0	15	36	74	120	212	321	447	450	421	498	522	543	612	468	662	701	746	696	698
1988	0	17	20	55	127	202	202	400	416	620	524	565	506	615	611	679	643	659	654	654
1989	0	16	27	58	106	184	246	372	420	616	521	516	611	605	594	566	702	702	682	702
1990	0	9	17	41	63	151	242	246	409	473	524	550	526	609	648	755	755	743	743	743
1991	0	12	17	36	77	126	198	296	345	422	402	541	602	611	690	751	761	696	622	666
1992	0	10	16	39	64	105	166	230	220	282	420	466	627	527	566	696	700	700	700	700
1993	0	9	24	26	66	114	164	220	314	200	406	547	565	564	609	661	661	661	739	730
1994	0	12	26	50	70	111	176	233	202	376	407	464	512	574	528	600	701	700	644	644
1995	0	12	26	42	79	122	172	236	260	418	442	500	720	706	672	622	822	752	762	700
1996	0	6	24	55	60	125	160	250	271	227	416	454	434	551	514	610	705	659	770	722
1997	0	6	23	49	86	120	176	223	259	316	363	362	443	513	577	529	546	695	695	695
1998	0	6	22	40	86	120	178	222	250	216	262	382	442	513	677	620	546	605	605	695

Table 6-4.--Mean length-at-age (cm) and proportion mature for female Bering Sea rock sole from observer anatomical scans during the 1993-94 fishing seasons.

Age	Length-at-age	Proportion mature
1	4.0	0
2	8.2	0.006
3	14.3	0.003
4	19.4	0.012
5	23.6	0.039
6	27.1	0.098
7	30.1	0.198
8	32.6	0.330
9	34.6	0.470
10	36.4	0.590
11	37.8	0.680
12	39.0	0.746
13	40.0	0.795
14	40.8	0.830
15	41.5	0.856
16	42.1	0.875
17	42.6	0.889
18	43.0	0.900
19	43.4	0.908
20	43.7	0.915

Table 6.5--Trawl survey estimates of population number at age, 1982-98.

year	1	2	3	4	6	6	7	8	9	10
1982	0	225916871	253410032	491261081	536301753	528695360	530339164	245459913	83476246	73536597
1983	0	70146087	887990146	562979049	632739066	312630782	312630782	353935077	161656464	135683244
1984	0	155455109	468530441	1068307206	666421763	367203155	588044675	258081463	323467873	128174686
1986	0	164996671	412930092	1128940284	1127616790	523221249	320728665	247052192	141172681	157936937
1986	0	117330678	596380276	1299148471	1384256606	1214038136	532547525	287551346	278606589	53497925
1987	0	64442126	751624053	1073834685	1148515280	901587506	1030471759	268609237	268809237	171644916
1988	0	335346670	1104051960	1467749194	1931078410	974449382	922608351	504640037	308996106	68421321
1989	0	130635572	868884259	989480719	1136194518	1304345945	748977281	557378442	414014275	128625794
1990	0	2985011041	4732599323	2496554689	1352171235	1849897012	490007007	669882997	457443250	190730576
1991	0	26889987	167793518	3633375028	2308238475	1336045748	973417525	847572387	508328312	354947827
1992	0	8717815	244098829	657710734	2945652934	2283098989	887906948	1056792947	505633289	300280306
1993	0	45456620	994850590	1384478759	1250706421	3957323432	2180618983	1019527041	958485295	540284394
1994	0	43414950	507798502	2183503189	1356356528	1385164035	4533134237	2239840881	1075275477	348200349
1995	0	0	139718785	850148391	1845692845	847648539	727172766	2228283677	1255342489	507827746
1996	0	38289799	955910314	434702415	687397292	1832136719	539349335	901337711	2132582623	1269781869
1997	0	4207952	572689014	1528289628	552308822	903690557	2858218730	523298535	948287850	2040952394
1998	0	1661532	233739495	653884618	762747096	532122974	833812210	1607399936	494998115	525199924

year	11	12	13	14	16	16	17	18	19	20
1982	61944674	108982876	61944674	24512888	5962589	7950119	7950119	0	993765	0
1983	53054654	72282518	98631807	51830368	35963222	24212882	4272858	2138429	712143	0
1984	52395733	57158982	64953368	38539010	51096865	22950197	8660452	0	2165113	3031158
1986	35734335	16440782	7058634	16764268	'44116463	36616664	8382128	6382128	2205823	2205823
1986	201833080	21277584	21277584	21277584	0	21277584	21277584	0	0	10942757
1987	75282858	215007842	31919932	10840732	10840732	0	0	0	0	0
1988	163623255	88291758	69861366	57511144	0	6480129	11340226	58321160	23490467	8100161
1989	92449790	93789642	68332453	81061047	26127114	24117336	2009778	2009778	16748150	14736372
1990	83735375	94589980	24810481	59924893	1550655	0	10854586	0	37215722	0
1991	229102688	150583927	70989585	55931173	33343584	13982793	0	44099578	.0	0
1992	298343013	185011414	130787230	91052738	46628369	25164800	12592400	0	10655108	0
1993	161046310	149357485	146769943	97407042	48054141	10390084	0	0	5195042	10390084
1994	663904023	295365289	167494542	190424436	89897342	54971010	13514972	10629753	28852188	18096484
1996	462197823	392829178	111380505	134446852	92164361	3233182	8756480	1924501	2213176	10026651
1996	368987906	190796495	230727427	69085751	97479323	85346782	31537428	10874975	1384088	8759298
1997	783448244	677844056	373046092	280806836	118733786	124919814	55027058	28772318	0	13894632
1998	1426269570	922756102	304441149	107739974	133701414	45778672	29422965	8039392	11223996	16892237

Table 6-6.–Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t - N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_t, = R_t = R_\gamma e^{\tau_t}, \ \tau_t - N(0,\delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year t for age a fish
$N_{t+1,a+1} = N_{t,a}e^{-z_{t,a}}$	Numbers of fish in year t+l at age a
$N_{t+1,A} = N_{t,A-1}e^{-z_{t,A-1}} + N_{t,A}e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a}W_{t,a}\phi_a$	-- Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year t at age a
$F_{t,a} = s_a\mu^F \exp^{\varepsilon^F{}_t}, \ \varepsilon^F{}_t - N(o, \sigma^2{}_F)$	Fishing mortality
$s_a = \frac{1}{1+\left(e^{-\alpha+\beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch
$P_{t,a} = {}^{C_{t,a}}/_{C_t}$	Proportion at age in catch
$\widehat{SurB}_t = q\sum N_{t,a}W_{t,a}v_a$	Survey biomass

$$L = \sum m_t p_{t,a} \ln \frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5)\sum \left(\frac{\ln surB_t \big/ \ln \hat{surB}_t}{\sigma_t} \right)^2 - \ln \sigma_t$$ Total log likelihood

Table 6-7.–Variables used in the population dynamics model.

Variables

R_t	Age 1 recruitment in year t
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year t
$N_{t,a}$	Number of fish in year t at age a
$C_{t,a}$	Catch numbers of fish in year t at age a
$P_{t,a}$	Proportion of the numbers of age a fish in the catch in year t
C_t	Total catch numbers in year t
$W_{t,a}$	Mean body weight (kg) of fish age a in year t
ϕ_a	Proportion mature at age a
$F_{t,a}$	Instantaneous annual fishing mortality of age a fish in year t
M	Instantaneous natural mortality, assumed constant for all years and ages
$Z_{t,a}$	Instantaneous annual total mortality for all ages and years
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
$\varepsilon^F{}_t$	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation

Table 6.8--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.095	0.043
1976	0.069	0.033
1977	0.032	0.017
1978	0.037	0.020
1979	0.028	0.015
1980	0.040	0.020
1981	0.038	0.018
1982	0.054	0.021
1983	0.052	0.019
1984	0.131	0.048
1985	0.054	0.020
1986	0.056	0.020
1987	0.045	0.017
1988	0.091	0.035
1989	0.054	0.022
1990	0.025	0.012
1991	0.056	0.029
1992	0.051	0.027
1993	0.047	0.026
1994	0.040	0.024
1995	0.030	0.020
1996	0.028	0.019
1997	0.041	0.029
1998	0.020	0.015

Table 6.9. --Model estimates of rock sole age-specific fishery and survey selectiviiies.

Age	Fishery (1980-98)	Survey (1982-98)
1	0.002	0.011
2	0.005	0.065
3	0.013	0.296
4	0.033	0.718
5	0.062	0.939
6	0.169	0.990
7	0.376	0.998
8	0.610	1
9	0.803	1
10	0.913	1
11	0.965	1
12	0.986	1
13	0.995	1
14	0.995	1
15	0.995	1
16	0.995	1
17	0.995	1
16	0.995	1
19	0.995	1
20	0.995	1

Table 6-10.--Model estimates of rock sole age 2+ total biomass and female spawning biomass from the 1996 and 1999 assessments.

	1999 Assessment		1996 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1976	282,242	47,625	264215	31,552
1976	298,897	53,374	287,404	39,928
1977	319,108	60,892	312,780	49,590
1976	352,181	69,990	349,263	60,455
1979	391,947	77,708	390,417	69,828
1960	442,328	84,907	440,074	78,255
1961	500,901	91,559	495,214	85,653
1962	553,631	85,911	568,771	94,565
1963	711,179	98,550	663,973	105,240
1964	787,738	111,835	790,942	118,308
1965	936,173	128,339	923,858	127,741
1966	1,167,060	153,177	1,110,687	148,011
1967	1,582,480	201,779	1,315,107	175,150
1966	1,808,380	248,548	1,527,704	211,321
1969	1,998,710	291,316	1,723,448	246,623
1990	2,024,330	345,117	1,970,388	294,322
1991	2,111,390	391,514	2,226,676	353,609
1992	2,100,890	409,204	2399,347	407,423
1993	2,420,800	503,151	2,527,430	466,018
1994	2,468,880	544,523	2,588,019	525,052
1995	2,713,790	686,750	2592,146	582,442
1996	2,480,520	650,550	2553,891	628,661
1997	2,317,210	658,507	2,493,050	658,930
1998	2,236,630	673,227	2,390,585	662,969
1999	2,132,210	674,117	2,320,068	663,338

Table 6.11--Estimated age 4 recruitment of rock sole (thousands of fish) from the 1998 and 1999 assessments.

Year class	1999 Assessment	1998 Assessment
1871	182,753	195.662
1972	148,625	154,789
1973	195,419	206,073
1974	262,781	274,466
1975	662,975	661,580
1976	392,222	359,976
1977	572,917	549,702
1978	652,630	597,644
1979	831,541	742,590
1980	1,622,920	1,442,633
1981	1,653,100	1,434,865
1982	1,470,820	1,244,174
1983	2,646,730	2,162,821
1984	2,053,810	1,594,411
1985	2,039,310	1,520,825
1986	3,140,470	2,209,218
1987	4,941,370	3400,757
1988	1,732,850	1,238,353
1999	1,018,540	707,009
1990	2,394,940	1,756,862
1991	986,266	702,831
1992	584,713	411,738
1983	1352,630	1,235,507
1984	898,299	581,957
1995	604,257	946,302

Table 6.12–Projections of rock sole female spawning biomass (1 ,000s t), future catch (1,000s t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biimass	catch	F
1999	651.678	39.2481	0.08
2000	639.805	226.089	0.15
2001	562.489	195.848	0.15
2002	478.158	165.025	0.15
2003	402.374	136.813	0.15
2004	349.327	121.253	0.15
2005	311.952	110.07	0.15
2006	278.508	101.29	0.15
2007	25o.504	93.6442	0.14
2008	255.412	91.9524	0.14
2009	252.605	91.0965	0.14
2010	253.702	92.1402	0.14
2011	257.935	94.6746	0.14
2012	262.297	88.9532	0.14

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
1999	651.678	39.2465	0.08
2000	647.667	116.933	0.08
2001	610.766	108.446	0.08
2002	555.505	97.4756	0.08
2003	497.835	86.9457	0.08
2004	457.401	79.8588	0.06
2005	428.285	75.3059	0.08
2006	394.427	70.7383	0.08
2007	374.572	68.7807	0.08
2008	368.016	68.8632	0.08
2009	380.948	68.6384	0.08
2010	358.566	68.8858	0.08
2011	361.814	69.7791	0.08
2012	366.101	70.6757	0.08

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
1999	651.678	39.247	0.08
2000	653.381	32.530	0.02
2001	646.620	31.715	0.02
2002	620.006	29.802	0.02
2003	582.359	27.680	0.02
2004	558.845	26.644	0.02
2005	543.851	25.869	0.02
2006	515.711	24.938	0.02
2007	499.809	24.573	0.02
2008	498.367	24.844	0.02
2009	462.630	24.872	0.02
2010	491.530	25.033	0.02
2oii	498.187	25.467	0.02
2012	505.737	25.889	0.02

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
1999	651.68	0	0
2000	655.52	0	0
2001	663.33	0	0
2002	645.98	0	0
2003	617.59	0	0
2004	802.58	0	0
2005	595.35	0	0
2006	571.44	0	0
2007	558.97	0	0
2008	561.53	0	0
2009	557.74	0	0
2010	558.40	0	0
2011	567.76	0	0
2012	577.79	0	0

Table **6.12--continued.**

Scenario 6
Determination of whether rock sole are currently **overfished** **B35=234.17**

Year	Female spawning biomass	catch	F
1999	651.678	39.2481	0.08
2000	636.763	266.162	0.18
2001	544.094	225.998	0.18
2002	450.147	165.582	0.18
2003	369.478	152.563	0.18
2004	313.853	130.786	0.18
2005	275.527	117.221	0.18
2006	244.325	98.3367	0.16
2007	231.02	91.3199	0.15
2008	229.361	922285	0.15
2009	229.345	93.6045	0.15
2010	232065	962323	0.15
2011	236.856	99.7957	0.16
2012	241.211	102.728	0.16

Scenario 7
Determination of whether rock **sole** are approaching an **overfished condition** **B35=234.17**

Year	Female spawning biomass	catch	F
1999	651.678	392484	0.08
2000	639.916	226.091	0.15
2001	562.501	195.862	0.15
2002	476.913	195.818	0.18
2003	389.671	160.526	0.18
2004	330.37	137.373	0.18
2005	290.164	123.391	0.18
2006	257.168	107.54	0.17
2007	241.181	98.6964	0.16
2008	237.91	98.108	0.16
2009	235.887	97.8632	0.15
2010	236.551	99.0272	0.15
2011	240.109	101.681	0.16
2012	243.683	104.177	0.16

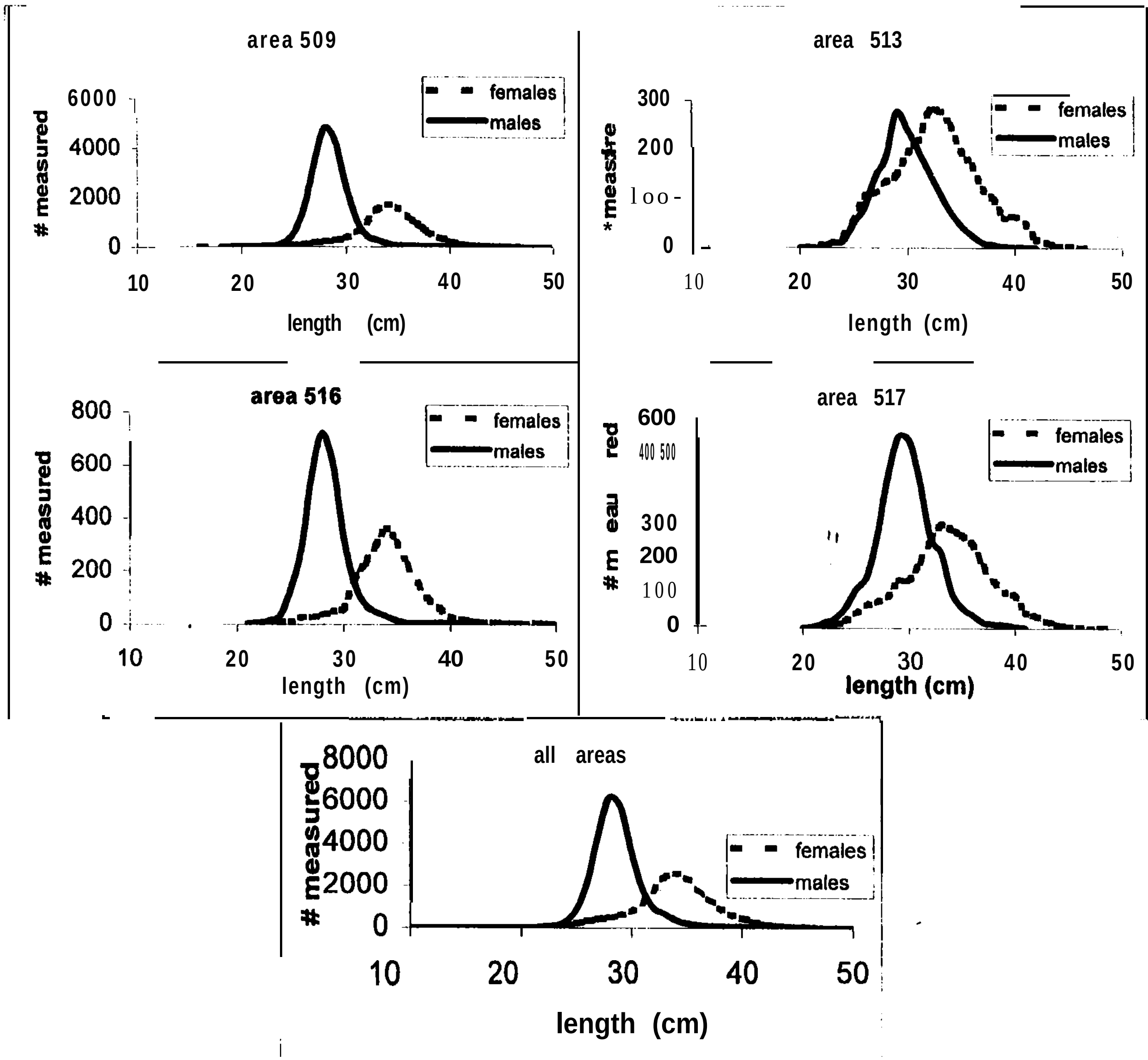

Figure 6.1--Observer estimates of rock sole size composition, by area and sex, from the 1998 Bering sea fishery.

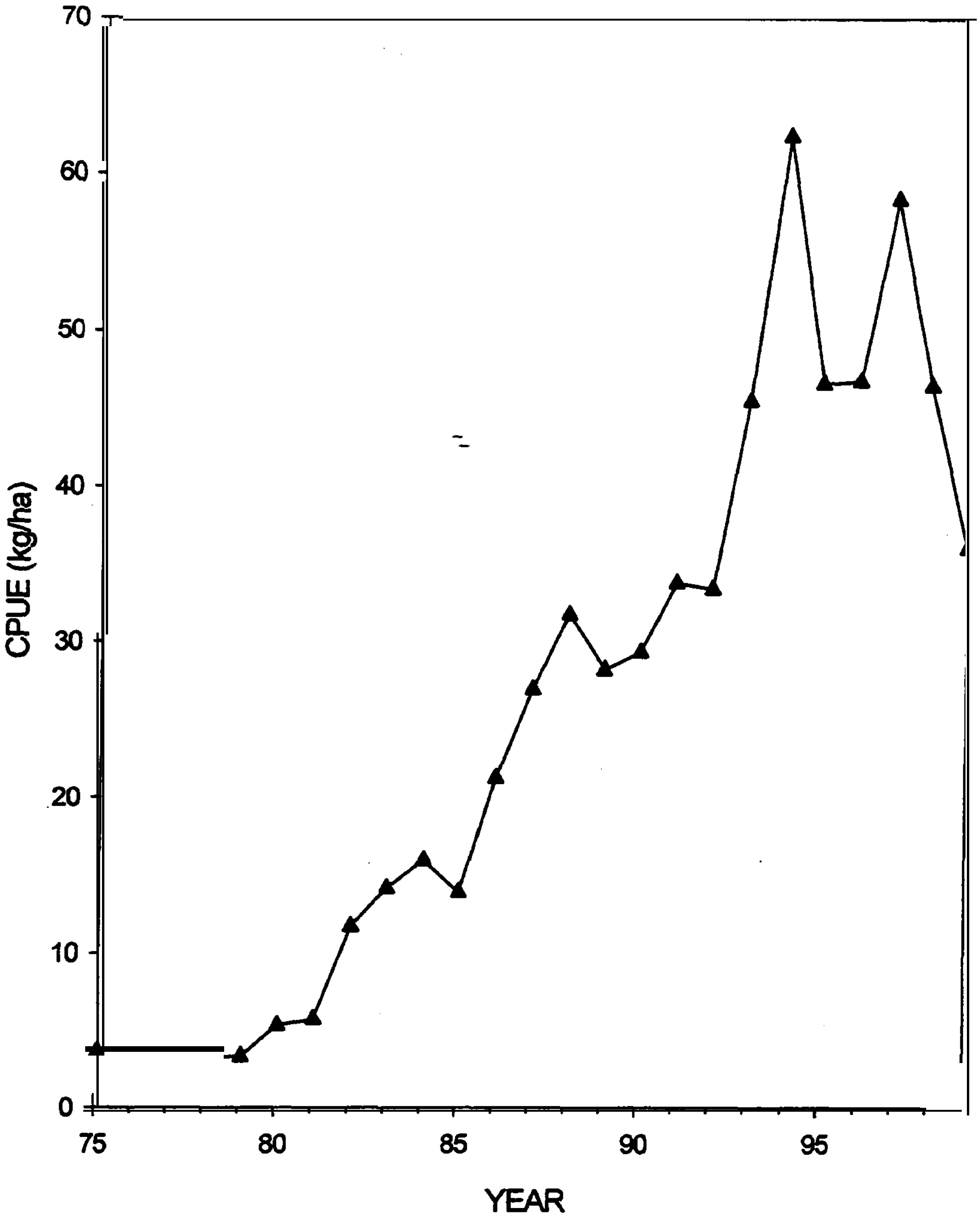

Figure 6.2– Relative abundance (catch per unit effort, CPUE) for rock sole from Alaska Fisheries Science Center bottom trawl surveys.

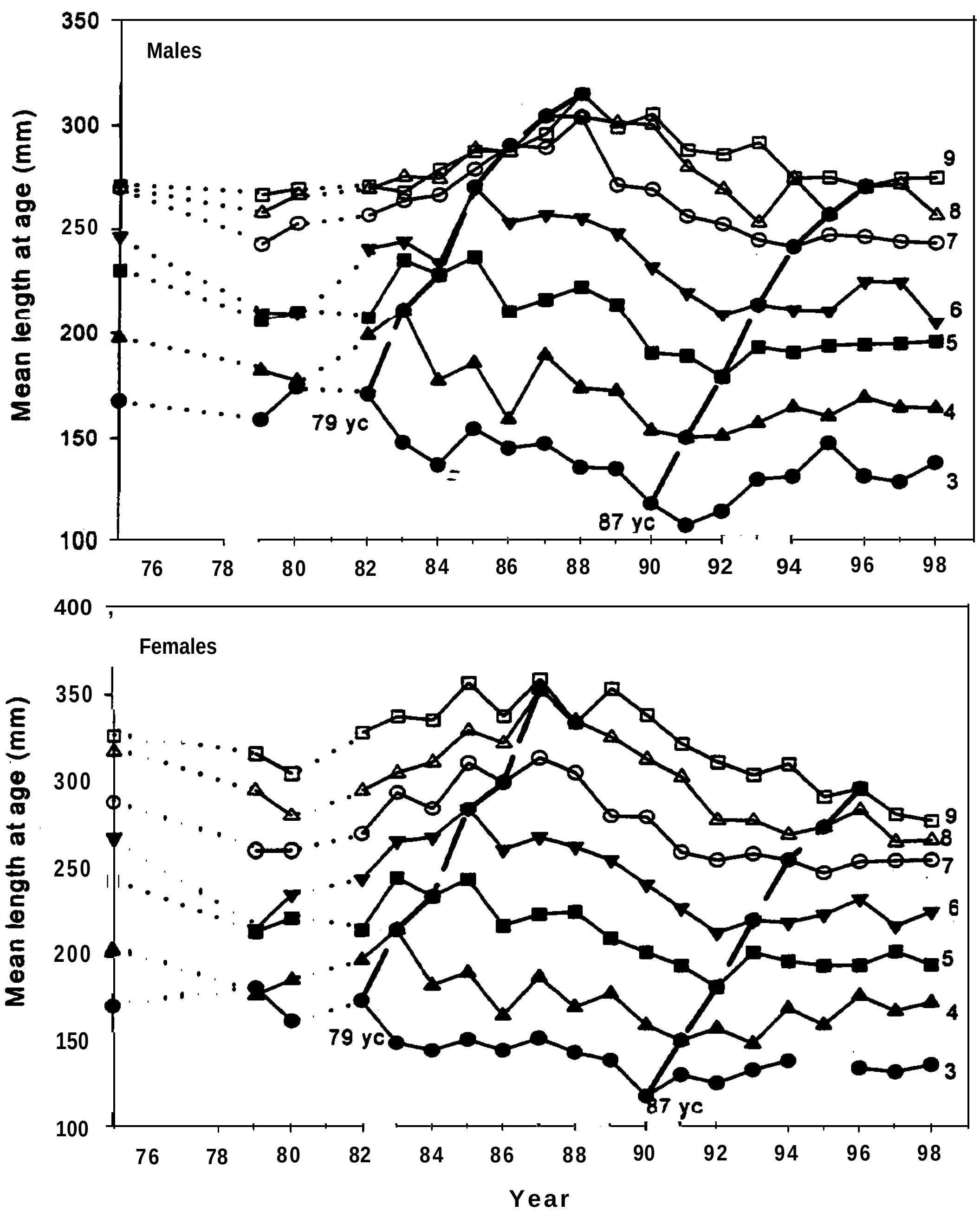

Figure 6.3– Mean length-at-age of male and female rock sole, ages 3-9, based on survey age samples collected in 1975 and 1979-98.

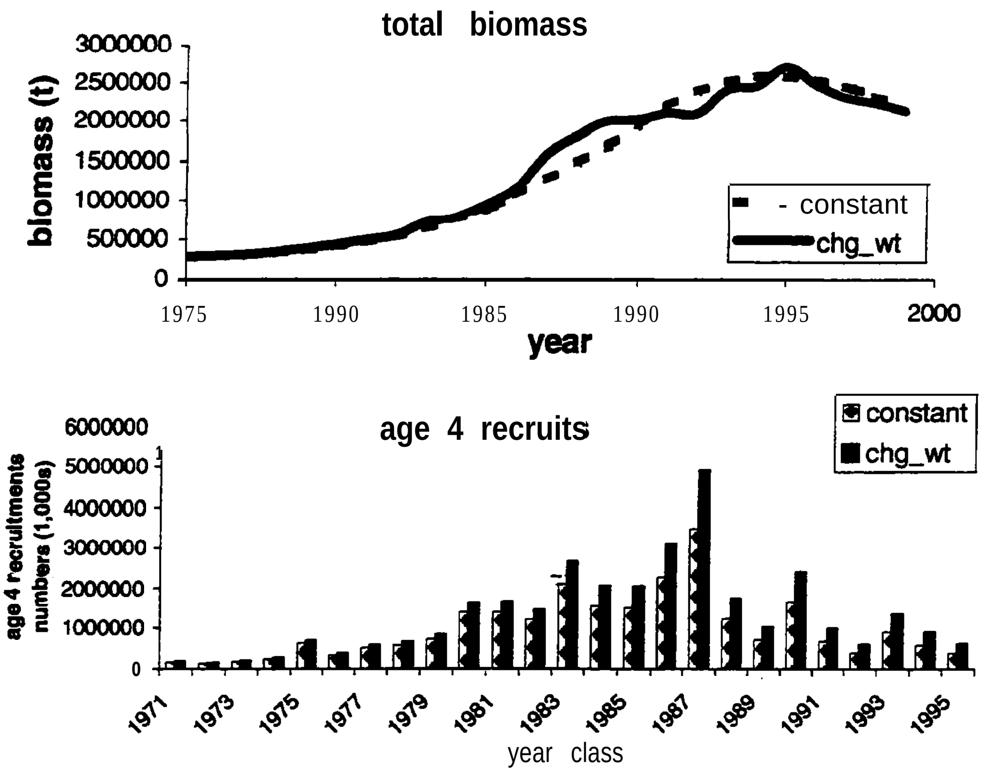

Figure **6.4--Comparison** of the stock assessment model **results** for estimates of total biomass and age 4 recruitment from the constant growth and changing weight-at-age models.

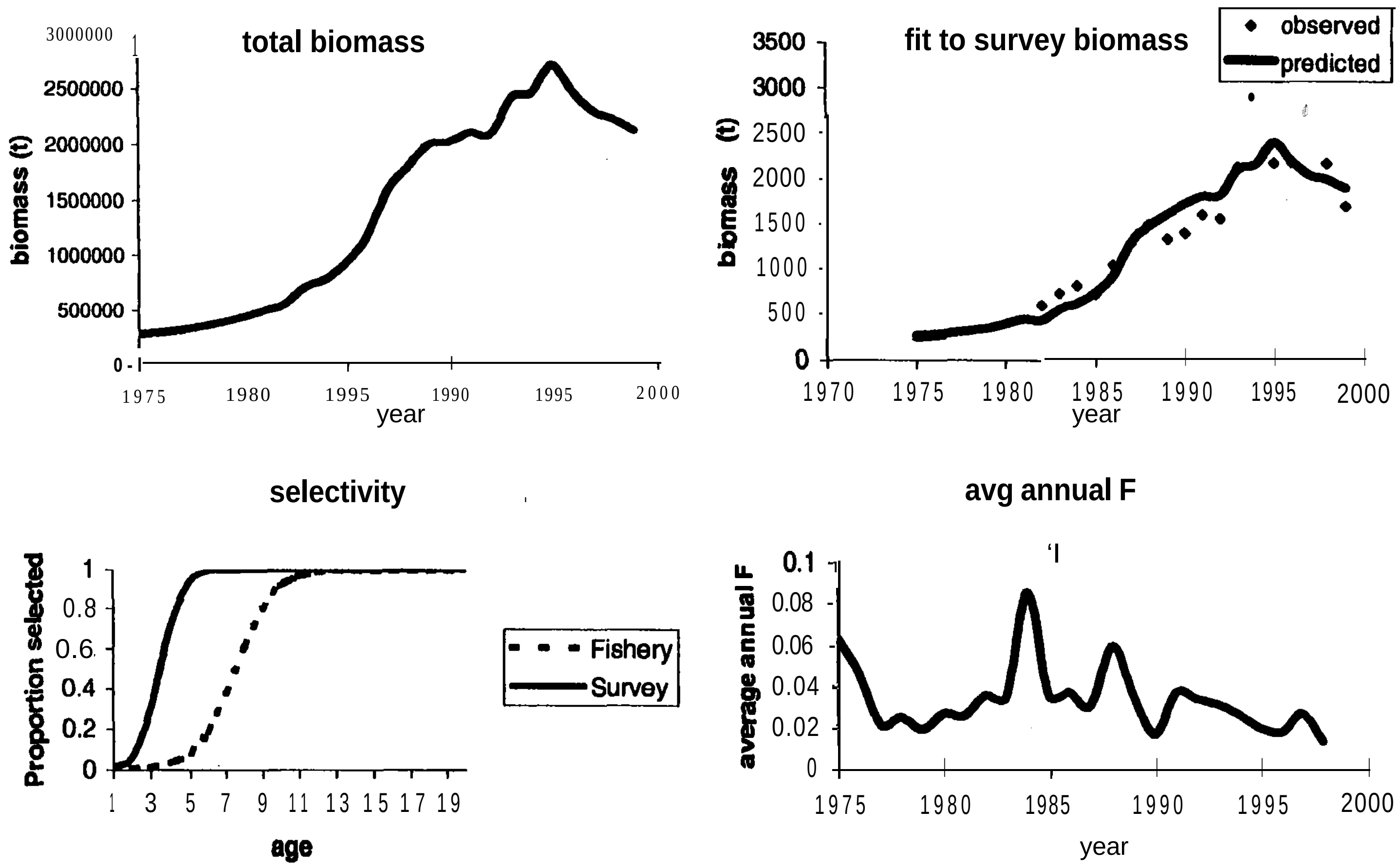

Figure 6.5--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (bottom left panel) and average annual fishing mortality rate (bottom right panel) from the model run using changing weight-at-age.

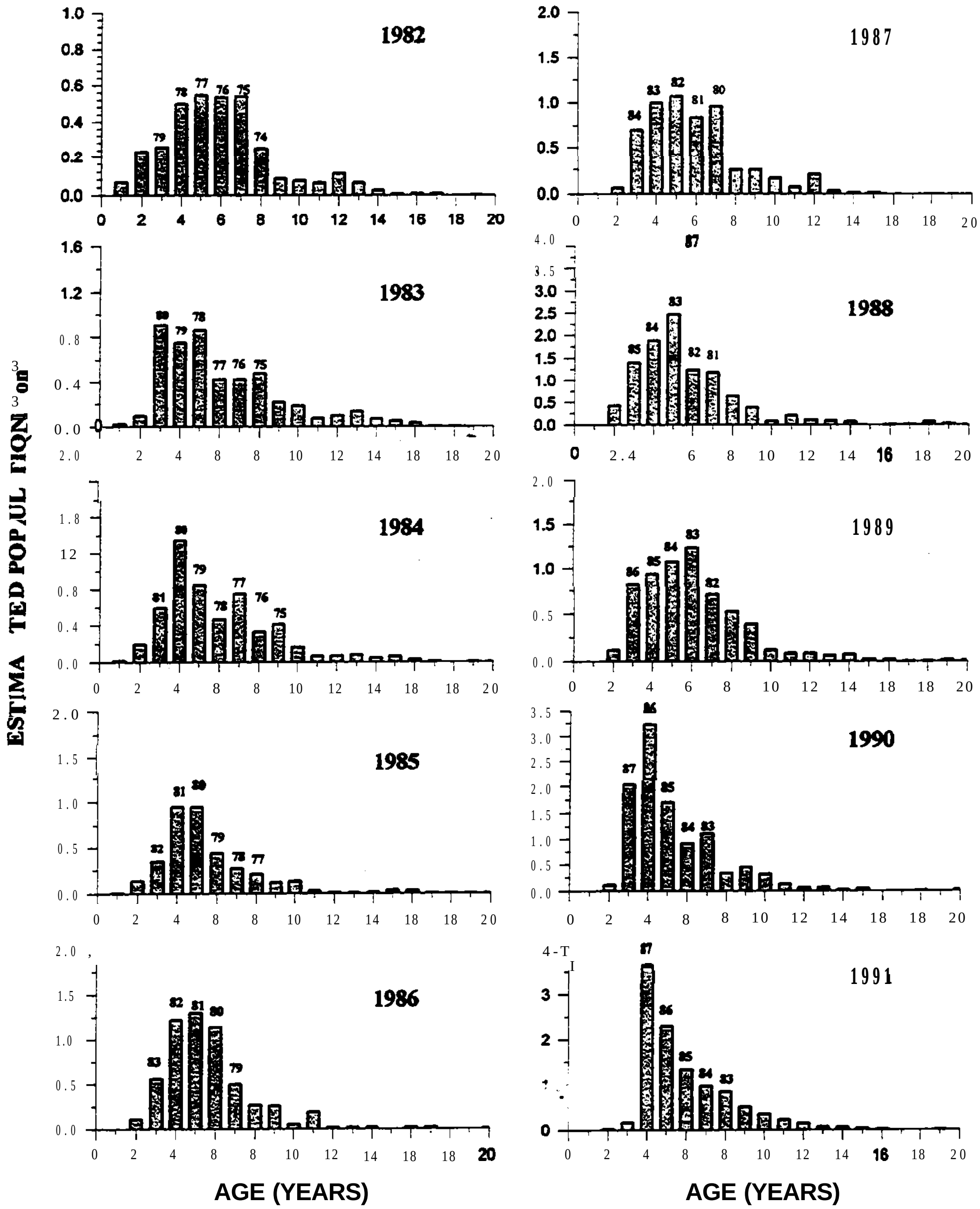

Figure 6.6–Age composition of rock sole as shown by data collected on Alaska Fisheries Science Center demersal trawl surveys.

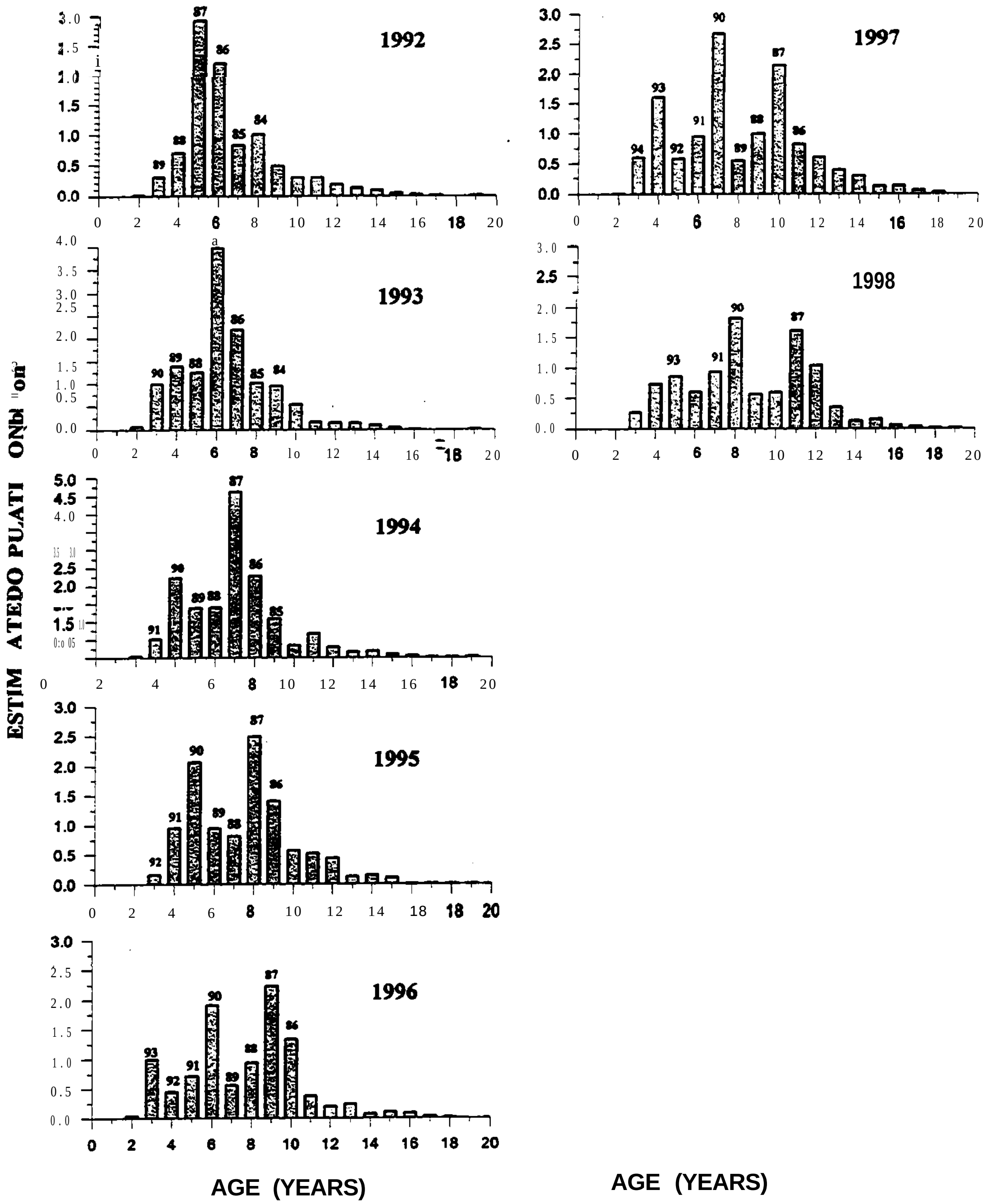

Figure 6.6 (continued)

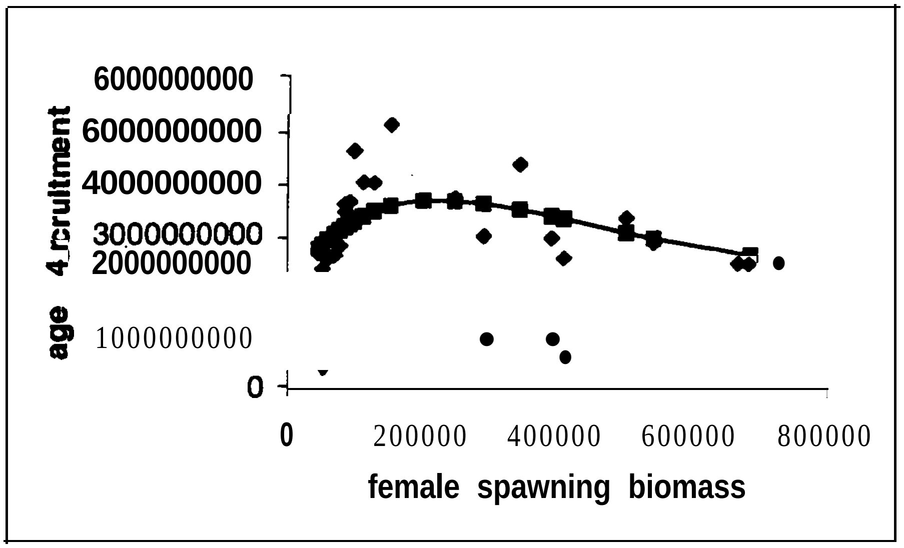

Figure 6.7--Ricker (1958) model fit to twenty-one age 4 recruitment and female spawning biomass estimates from the model results.

Appendix

1) Observed fishery trawl locations, by quarter, for the 1997 fishing season where rock sole comprised **20% or more** of the catch.

2) **Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey** age compositions (survey and fishery observations are the solid lines).

3) Table of the assessment model estimates of population numbers at age and total biomass, 1975- 99.

4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-95.

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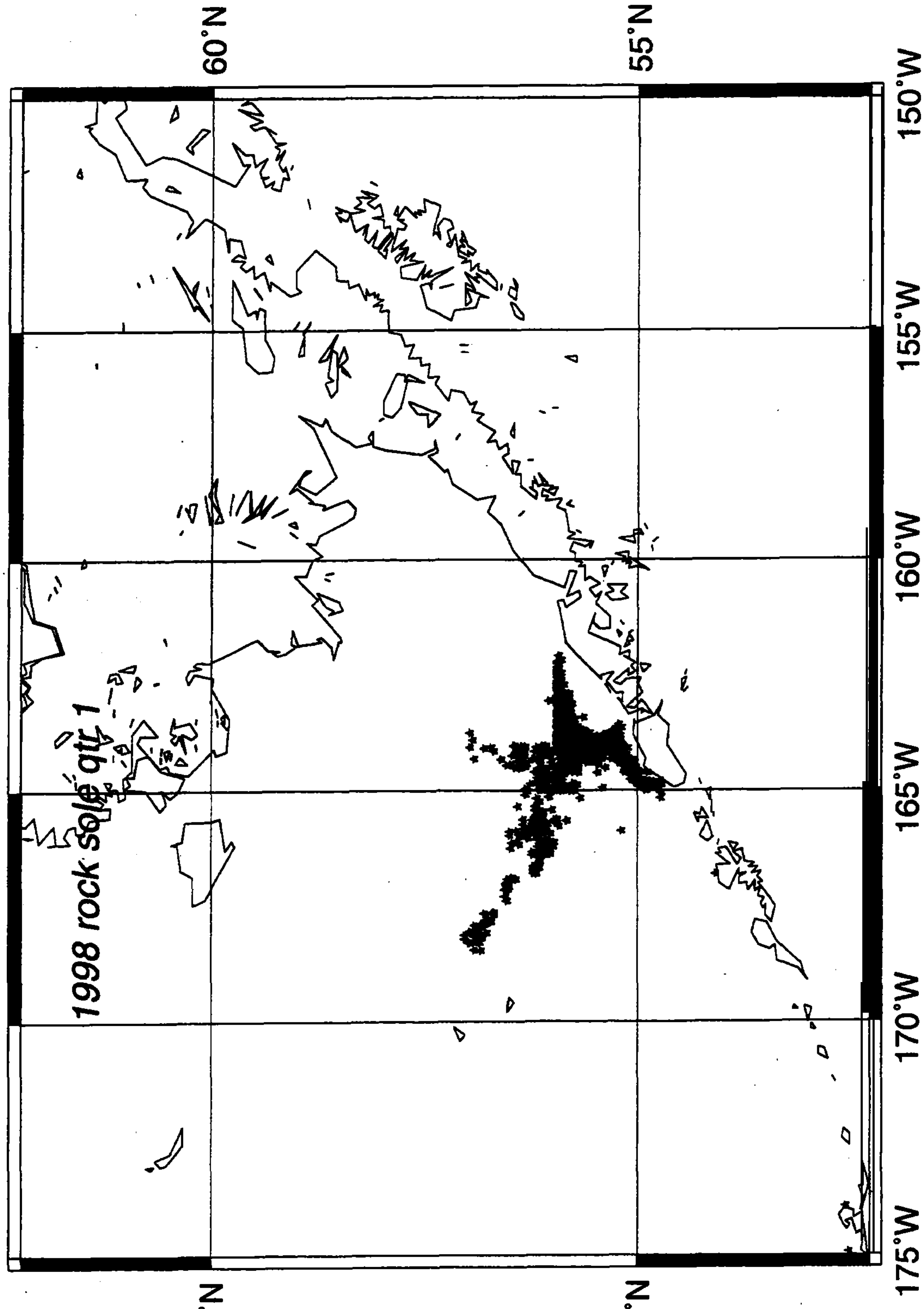
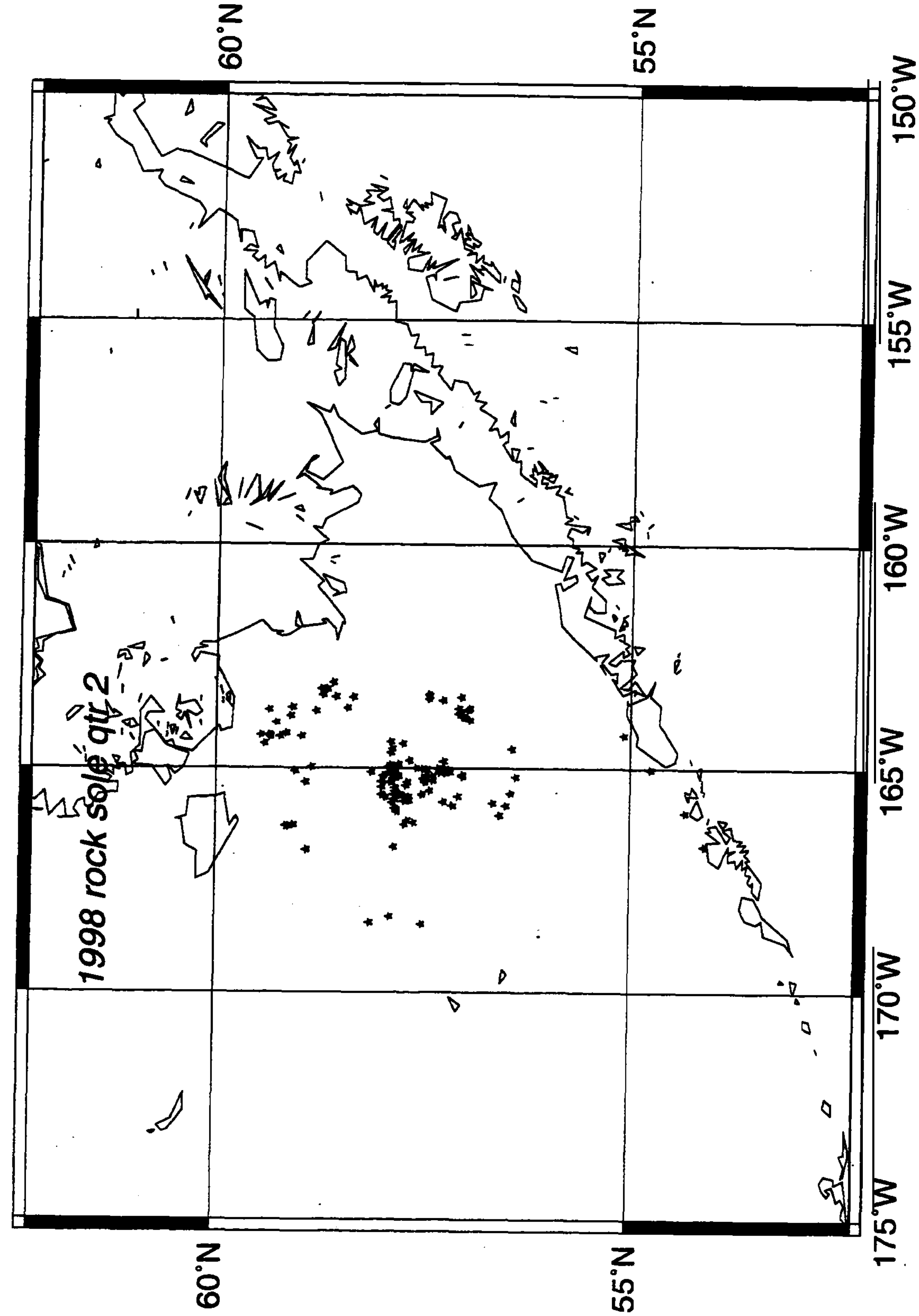
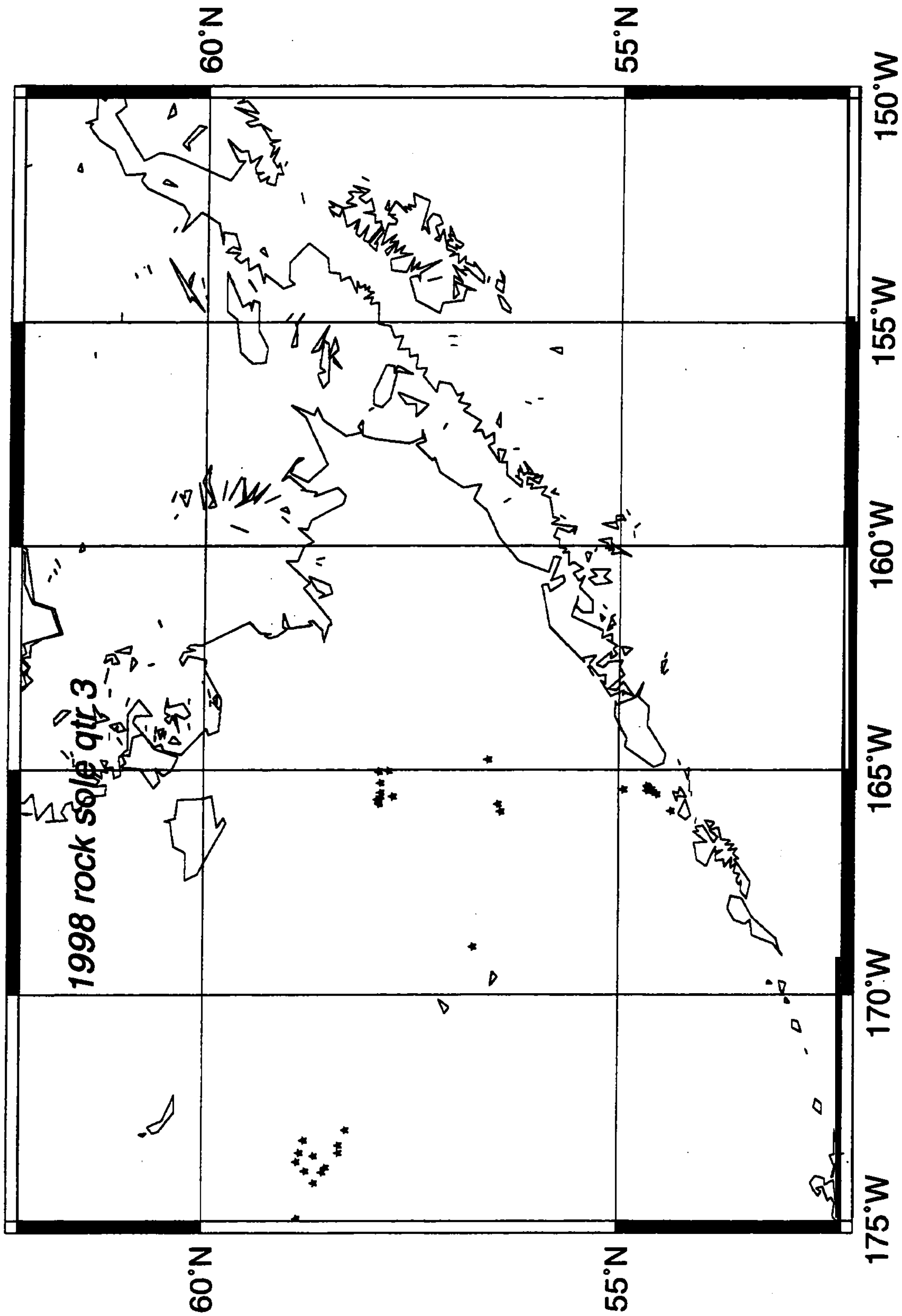
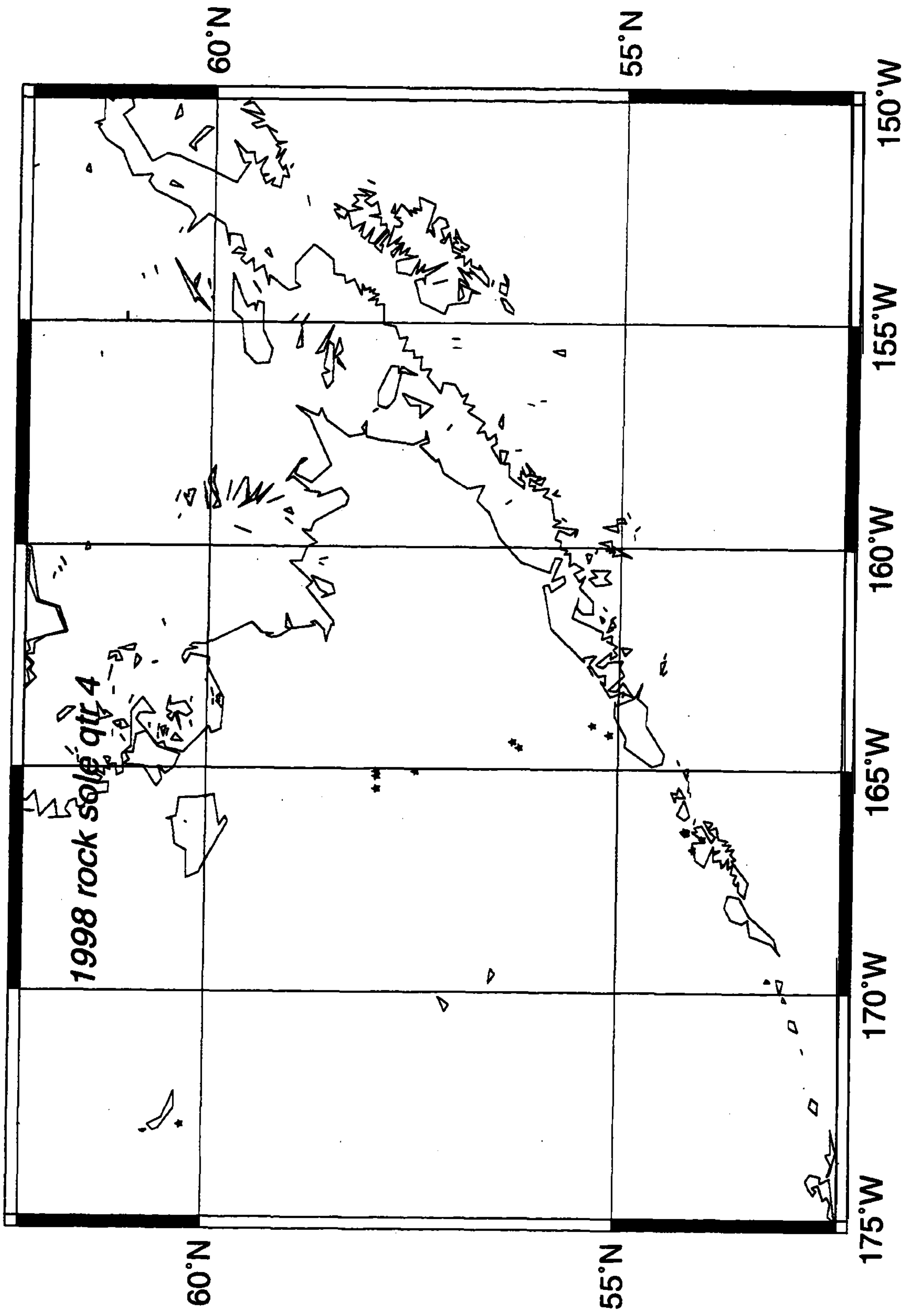

1998 rock sole qtr 1
60°N
55°N
150°W
155°W
160°W
165°W
170°W
175°W


1998 rock sole qtr 2
60°N
55°N
60°N
55°N
150°W
155°W
160°W
165°W
170°W
175°W


1998 rock sole qtr 3
60°N
55°N
150°W
155°W
160°W
165°W
170°W
175°W
60°N
55°N


1998 rock sole qtr 4
60°N
55°N
150°W
155°W
160°W
165°W
170°W
175°W

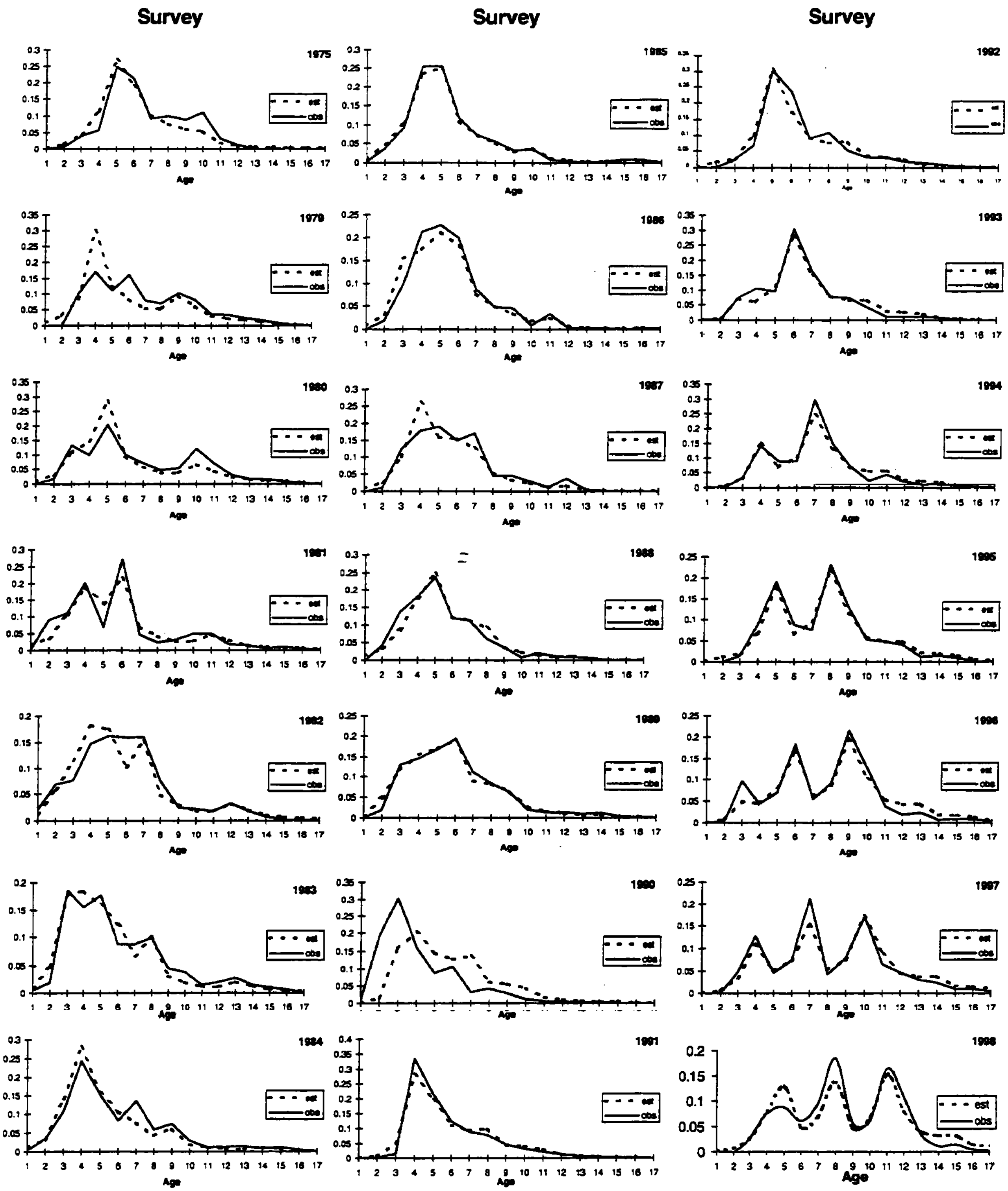


Figure **2.--AD** Mode4 fit to the **observed** survey age composition data.

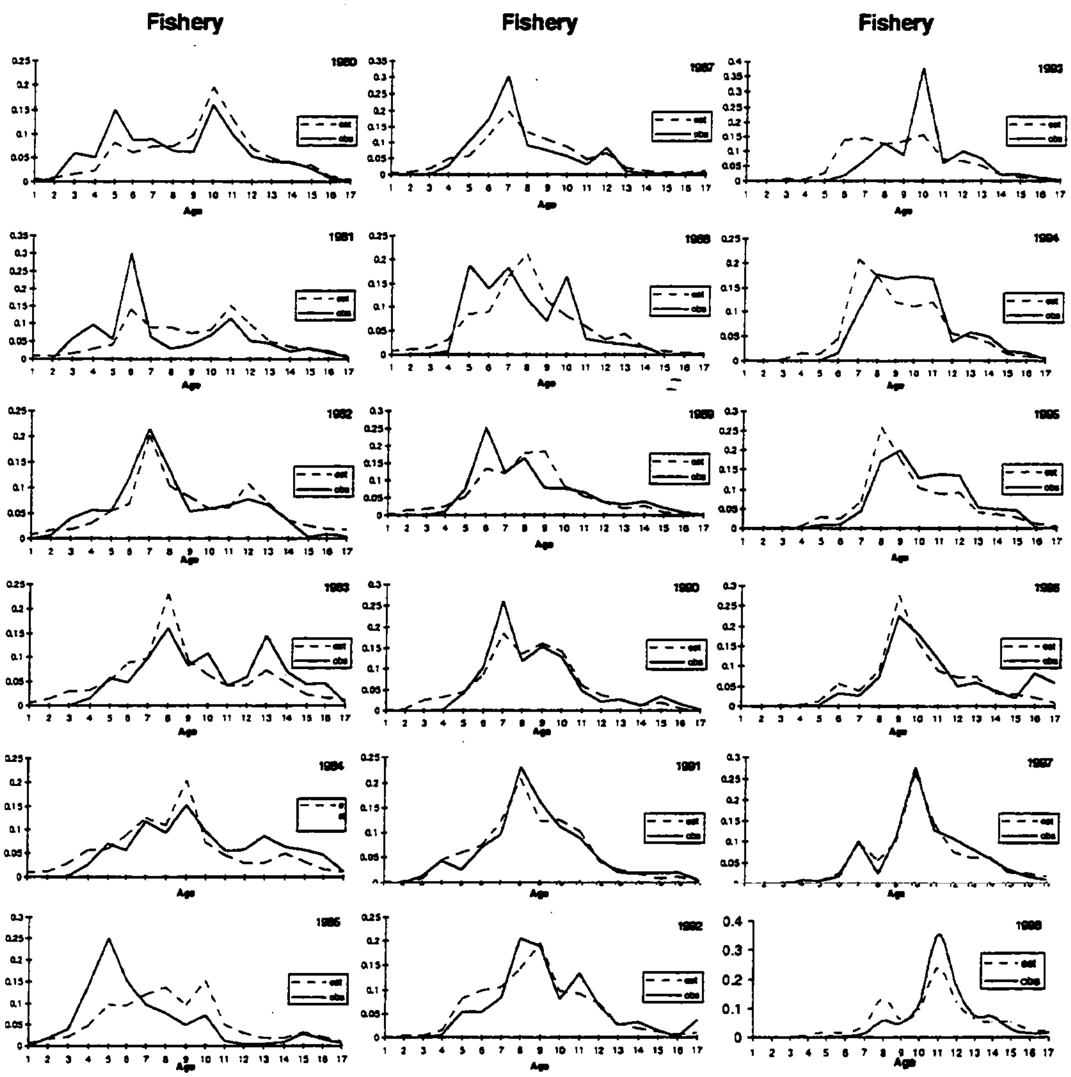


Figure 3.–AD Model fit to the observed fishery age composition data

Rock sole population numbers at age estimated from the stock assessment model (thousands of fish).

	1	2	3	4	5	5	7	5	9	10	11	12	13	14	15	16	17	15	19	20
1975	461.355	250.491	175.150	152.753	332,353	221,555	115,513	86,905	58,250	62,423	20,203	10,796	5.550	5.312	6,095	5.001	5,995	5,991	5,957	5,985
1976	1,172,910	375,942	234.172	145.525	152,153	276,444	152.013	85.742	55,454	53,550	47,790	16.392	5,205	6.052	4,795	4.530	4.655	4.554	4,551	9,095
1977	555,305	979.654	314.737	195.419	123.566	125.375	227.051	145.115	78,567	64,107	42,000	37.336	12,007	6,399	3,938	3,735	3,510	3.664	3,651	10,639
1975	883.565	548,158	515.055	252.751	153,055	103.182	104.925	157,414	121,334	52.413	43,898	34.025	30,220	Q.715	6,175	3,157	3.026	2.821	2,575	11.453
1979	1.120.770	521,727	467,773	552,976	218,222	136,755	56,554	66,426	153,038	98,375	50,396	36.378	27,401	24,325	7,022	4,169	2,655	2.435	2,352	11,559
1980	1,428,320	936,092	555,256	352,222	659,830	152,553	112,605	70,727	70,951	124,863	50.070	40,959	28.736	22,251	19,756	5.362	3.355	2,053	1,875	11,286
1051	2,787,820	1,192,940	751,731	672,817	315,534	474,455	161,445	52,521	67,556	67,395	100,536	54.364	32.592	23,055	17.552	15,859	5,099	2,717	1.572	10.565
1952	2,842,660	2,328,410	996,235	552.530	477,932	256.478	393,485	124,588	76,745	45.707	45,300	51.022	51.770	25.461	15.651	14.355	12.754	4,101	2.155	9,914
1983	2,527,660	2,374,140	1,944,320	531.541	544.149	397.447	210,515	322,102	100.503	60,505	37,145	35,724	64,191	40,997	20,817	14.581	11.375	10,100	3,247	9,552
1984	4547.650	2,111,070	1,982,520	1,622,920	5Q3.360	462.551	325.715	179.751	250,655	50.735	45,250	28.602	29.132	60,589	32,605	15,509	11,549	9,020	5.008	10.173
1955	3,527,830	3,797,450	1,762,140	1,653,100	1,349,680	672.842	355,500	251.351	135.545	195,975	59,843	35.532	21,561	21,366	37,329	23,841	12,151	5,543	5.515	13,334
1986	3,504,830	2,946,380	3.171.030	1,470,820	1,378,300	1,122,350	473.705	301,545	211,245	110,891	165,505	47.445	28.138	17,146	16,912	28,645	15.572	9,642	5,752	15,791
1987	5,395,850	2,927,160	2,460,320	2,646,730	1,226,250	1,145,990	927,663	357,456	243,694	155.727	88,029	123.332	37,512	22,237	13.549	13.355	23.350	14,913	7,520	17.523
1988	8,486,090	4,506,590	2,444,400	2,053,810	2,207,380	1,020,430	949,041	751,707	314,753	196,259	135,201	70,373	98,500	29,948	17.763	10.517	10,570	15.542	11,906	20,312
1989	2,976,480	7,086,910	3,762,480	2,039,310	1.710.310	1,830,070	537,564	755,121	601,991	244,451	150,904	103,474	63,756	76,151	22,565	13,660	5,266	5,144	141229	24,591
1990	1,749,580	2,465,900	5,917,860	3,140,470	1,700,310	1,422,250	1,513,140	685,798	619,198	451,626	194,392	119,565	81,952	42,556	69.617	18,095	10,727	5,535	5,447	30,731
1991	4,113,810	1,461,300	2,076,130	4,941,370	2,620,920	1.417.270	1.152.300	1,251,860	654,037	605.755	393,002	155.448	87,475	55.740	34.550	45,475	14.735	5.737	6,324	30.281
1992	1,693,900	3,435,760	1.220.230	1,732,850	4.11Q.640	2,179,080	1,171,310	885,566	1.010.370	460,328	402,108	310.925	125,207	76,991	62,720	27.375	38,288	11,541	6,901	25.122
1993	1,004,070	1,414,720	2,869,040	1,018,540	1,444,940	3,426,590	1,802,660	959,719	782,751	610,017	358,989	319,707	246,941	99,398	51,121	41.553	21,733	30,395	9,241	27.503
1994	2,322,510	535.591	1,181,390	2,394,940	548,414	1,202,230	2,836,710	1,479,150	775,524	629,469	547.857	255,453	264,577	196,788	79,211	45,707	33,353	17.319	24,222	20.521
1955	1,542,630	1,939,770	700.305	885.255	1,997,760	707.155	996,662	2.334.130	1,205,790	530.041	505.859	620.519	230.055	204.514	157,980	63,590	38,102	25,775	13,903	43,144
1996	1,037,460	1,288,430	1,619,980	554.713	822,962	1,664,500	657..21	822,992	1,813,720	982,831	611.512	411,207	422.160	1a5,431	155.507	125,015	51,529	31,555	21.597	45,225
1997	1,018,250	866,512	1,076,040	1,352,630	457.042	-855.533	1,383,060	459453	675,902	1,563,340	500,428	415,233	334,218	343,032	161,491	134,732	104,025	41,572	25,747	55,1W
1998	1,692,770	560,443	723,521	898,299	1,128,270	406,194	655,447	1,137,560	395.452	646,355	1,257,870	542.573	333,908	255.020	275.055	121,455	105,045	53.421	33.578	54,910
1999	2,048,750	1,413,860	710,276	604,257	749.514	940,836	337,982	471,156	938,445	324.854	447,910	1,030,230	525.141	273.314	219,384	225,150	88,440	55.430	55.253	50.615

Total catch (t) of rock sole due to Alaska Fisheries Science Center research activii in the Bering Sea and Aleutian Islands, 1977-95.

Year	Research Catch	Proportion of Commercial catch
1977	10	0.00195
1978	14	0.00202
1979	13	0.00228
1980	20	0.00227
1981	12	0.00137
1982	26	0.00219
1983	59	0.00435
1964	63	0.00167
1985	34	0.00179
1986	53	0.00227
1987	52	0.00199
1988	82	0.00129
1989	83	0.00187
1990	88	0.00356
1991	97	0.00160
1992	46	0.00080
1993	75	0.00117
1994	113	0.00195
1995	99	0.00180