STATUS OF THE WASHINGTON-OREGON-CALIFORNIA SABLEFISH STOCK IN 1988

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Abstract

The west coast sablefish stock is modeled in two stages. The first stage is a synthesis model simultaneously fit to the time series of catch biomass by trawl and fixed gear, the size and age composition of these fisheries components in 1986 and 1987, the time series of relative abundance of middle aged sablefish as measured by the northern and southern pot indexes, the recruitment information in the tri-ennial trawl surveys, and the exploitation rate information in the tag return data. In addition to estimating the time series of abundance and mortality for the sablefish, the model provides new insights on sablefish growth and of the influence the sampling process has on our perception of growth. The mean total biomass during 1988 was 94,700 mt and the age 3+ biomass was 78,600 mt. The biomass levels at the beginning of the year were 107,500 and 89,600 mt, respectively. The total F imposed by a 10,800 mt fishery in 1988 will be 0.15. Plausible, but less likely, alternative models that either emphasize the fit to the pot survey time series or de-emphasize the fit to the age composition data produce lower estimates of current stock abundance.

The second stage of the modeling process estimates the stock productivity at equilibrium and makes short-term yield forecasts utilizing a dynamic pool model and output of the synthesis model. The dynamic pool model is driven by either a Beverton-Holt stock-recruitment function or constant recruitment. Given the early age at recruitment to the fishery relative to the age at first maturity, the spawning biomass is reduced to only about 25% of the virgin level, so utilization of the B-H recruitment function seems prudent. If a 52:48 trawl:fixed gear allocation is maintained in the future, then the MSY for this stock is 8,200 mt at a mean age 3+ biomass of 67,800 mt and a F[MSY] equal to 0.13. An ABC in 1989 of 9,000 mt is indicated by applying the F[MSY] to the current stock structure. At this exploitation rateand if there are no great deviations in recruitment, the stock would be near the biomass yielding MSY in about 20 years and the ABC would then be reduced to about 8200 mt. At F = 0.15 the ABC in 1989 would be 10,400 mt and the population would reach the MSY level in about 1995.

Introduction

The fishery for sablefish, Anoplopoma fimbria, along the coasts of Washington, Oregon, and California has landed approximately 13,000 mt per year since 1981. Its landed value of approximately $11 million makes it the most valuable single species in the west coast groundfish fishery. Recent landings have been composed of 52% by trawlers and 48% by fixed gear (primarily pots and long-line). Management of the fishery includes a size limit of 22 inches total length (53 cm fork length) enacted in 1983, and an annual quota. The quota for the 1988 fishery was reduced to 10,000 mt due to concerns that the stock was in danger of being over-fished. For the first time, the 1988 quota was allocated to trawl and fixed gear according to the recent 52:48 ratio of their landings.

The annual quota for sablefish, and most other west coast groundfish species, is set on the basis of current exploitable biomass and the fishing mortality rate at maximum sustainable yield (and $F_{0.1}$). Past analyses have not been able to unambiguously estimate these two quantities because of great inadequacies in the sablefish database. Here we develop a sophisticated model with which to integrate information from diverse data sources and to make synthetic estimates of historical abundance and mortality for the west coast sablefish stock.

Assessment Philosophy and Basic Model Structure

If the sablefish database was lengthy, precise, and well-defined we could conduct a conventional assessment via cohort analysis. Alternatively, if we had one accurate, precise survey and accurate estimates of growth and natural mortality we could try stock reduction analysis, a simpler, non-age structured model. Unfortunately, the sablefish database is scanty and diverse, and none of the observations measure what we most need to know - the total fishable biomass. The measured quantities do, however, put constraints on the fishable biomass, but to make use of these data our assessment must make explicit definition of the relation between what has been measured and what we estimate to be in the population.

The assessment is a synthesis of a separable catch-at-age analysis with two types of fisheries (trawl and fixed) and 2 years of fishery data, and the following auxiliary information: recruitments in 80, 83, and 86 were observed by the tri-ennial trawl surveys, a time series of relative abundance of some middle age/size range has been observed by the pot index surveys, and the time series of fishing mortality should be consistent with the pattern of tag returns. Thus, information on the absolute level of abundance comes from the recruitment surveys and natural mortality, and and from the tag returns which set the magnitude of the exploitation rate. Estimation of the age specific pattern of availability to the tri-ennial trawl survey, to the northern and southern pot surveys, and to the fixed and trawl fisheries is most difficult because of the scarcity of age composition data and because of the high variability in the existing age composition data.

Methot (1986, 1988), following Fournier and Archibald (1982), developed a model in which the estimated sampled age composition is smeared by some estimated level of ageing error before being compared to observed age compositions. This smearing of true ages to observed ages is entirely analagous to the conversion of age to length, then conducting the goodness of fit in terms of length compositions. Because of the much greater availability of sablefish length composition data, we utilize the following strategy for its assessment. In each time period, the estimate of population numbers at age is converted to an estimate of the population length composition via an estimated growth curve and variance in length at age. Estimates of length-specific selectivity are then used to calculate the estimated length composition in each type of sample (e.g. trawl survey, pot survey, fixed and trawl fishery). Equivalent age-specific selectivities must still be calculated in order to calculate age-specific fishing mortalities. Age-specific selectivities are calculated by weighting length-specific selectivities with distributions of length at age. Because large and small fish at a given age usually have different selectivities, the mean size at age observed in a particular type of sample will be a biased estimate of the population mean size at age. The above scheme allows calculation of the magnitude of the bias and for calculation of the appropriate mean size at age. Goodness of fit to the entire sablefish database is evaluated by calculation of the log likelihood for each type of data, then summing these into an overall log likelihood. The parameters which define the length-specific selectivities and the recruitments are iteratively adjusted to maximize the overall log likelihood function.

The following sections define the sablefish database, various auxiliary inputs to the model, then define the model in more detail. The synthesis model will be used to determine the current status of the sablefish stock. Model output will be used as input to a dynamic pool model for determination of equilibrium and short-term yields under a variety of quota management strategies.

Data

Area and Time

The region to be modeled is bounded on the south by the U.S.-Mexico border and on the north by the U.S.-Canada border, and is described as the west coast (Figure 1). There is little catch and scant survey data south of Monterey Bay, and even less catch and data south of Pt. Conception. The specification of the northern boundary is important because sablefish are abundant throughout this region and the fishery operates near and on both sides of the border. Although some tagged sablefish have crossed this border, two observations suggest that the interchange is limited in this area. First, the size distribution of sablefish captured at the northernmost pot index site (Nitinat Canyon) off northern Washington is much larger than that of sablefish captured at southern sites and is more similar to the large fish found off British Columbia (Parks and Shaw, 1988). Second, the 1977 yearclass was extraordinarily abundant off Canada (McFarlane and Beamish, 1983a) and throughout Alaskan waters, but was not at all exceptional along the west coast according to the age composition in the 1983 and 1985 pot index surveys (Parks and Shaw, 1987).

The time series to be analyzed begins in 1970 and extends through 1987. Landings during the period 1956-1970 (Figure 2) averaged 3512 metric tons (mt) and the west coast stock is assumed to be in equilibrium with this catch level in 1970. Most types of survey data begin in 1979, but a precursor to the northern pot index was conducted in 1971[1/] and this observation is included in the analysis. An estimate of the 1988 landings is included to obtain a better estimate of recent trends in fishing mortality.

The model is run on an annual basis using calendar years. Recruitment is defined to occur at age 1 on January 1, although these recruits are barely available to the fixed gear fisheries and the pot surveys. Fishing mortality is implicitly assumed to be constant throughout the year. Surveys are typically conducted in July - October and are assumed here to represent the mean abundance of sablefish within the calendar year.

Catch

Landings for the period 1956 - 1987 were categorized by INPFC area and by gear type (Lynde 1986; PacFIN data series 1981-1987). The four gear types are longline, pot, trawl and miscellaneous. Shrimp trawl landings are included in trawl, set net landings are included in miscellaneous. Foreign landings were allocated to the following gear types: Japan to longline, USSR to trawl, Poland to trawl, Korea to pot, and other to miscellaneous. Landings from the Vancouver INPFC area were processed to delete the Canadian domestic landings (PMFC areas 3D and 3CCN). The PMFC area for other foreign landings in the Vancouver INPFC region is unknown, so these other foreign landings are included in the total landings for the U.S. Vancouver region. Landings from all west coast INPFC regions (Conception - U.S. Vancouver) were summed for analysis here

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[1]Shippen (1972) Progress report on sablefish (blackcod) studies by the United States National Marine Fisheries Service, 1971-1972. Int. N. Pac. Fish. Comm. Docu. Serial No. 1508.

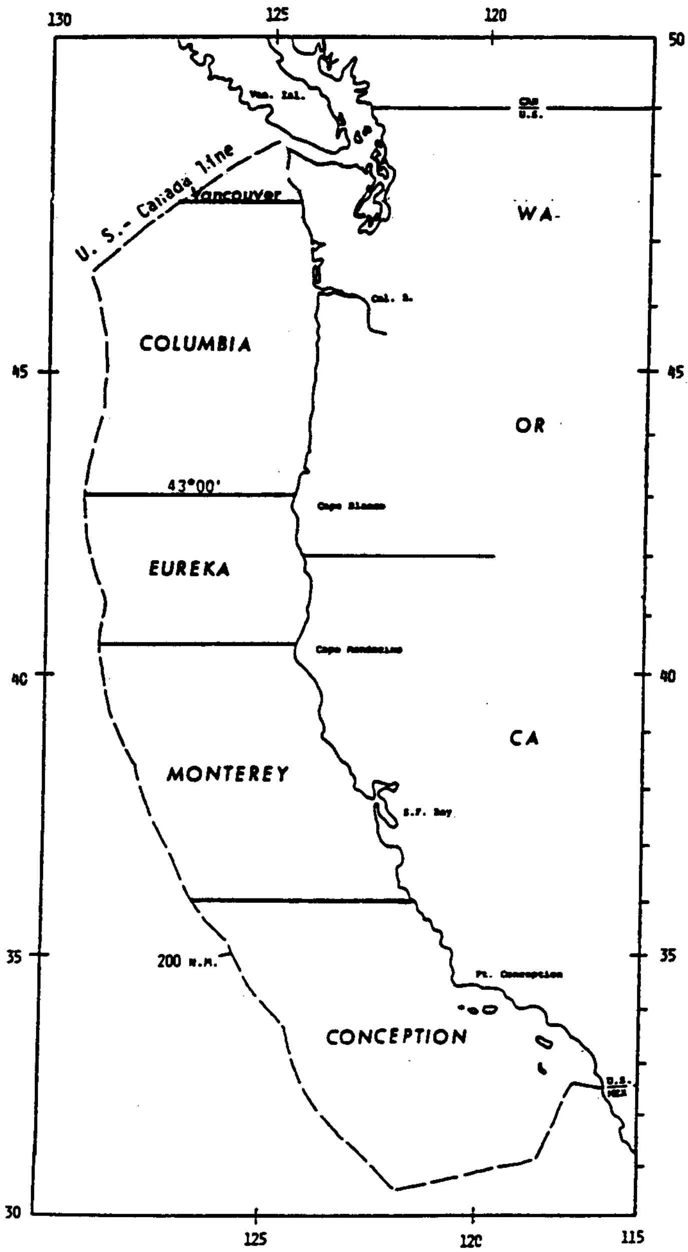


Figure 1. INPFC statistical zreas in the U.S. EEZ seaward of Washington, Oregon, and California.

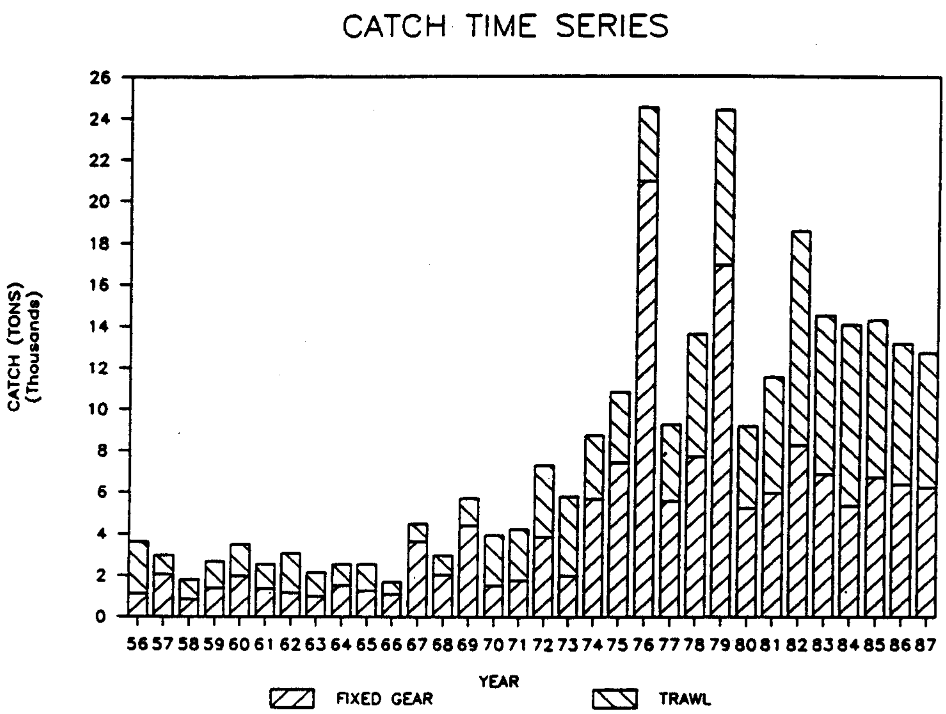


Figure 2. Sablefish catch time series showing proportion by trawl and by fixed gear.

Table 1. Landings of sablefish along the California, Oregon, Washington coast. Includes catches by foreign fishing vessels in this region and catches by non-Canadian foreign vessels throughout the Vancouver INPFC region. Catch by foreign vessels was assigned to a characteristic gear type (see text). Catch by miscellaneous gear was assigned proportionally to fixed and trawl gear categories. Catches for 1988 were estimated to allow running the model forward one year.

					- Condensed -	
Year	LLine	Pot	Trawl	Misc	Fixed	Trawl
56	1129	0	2477	7	1131	2482
57	2051	0	914	1	2051	914
58	855	0	948	0	855	948
59	1398	0	1273	1	1398	1273
60	1980	0	1510	0	1980	1510
61	1121	0	935	482	1384	1154
62	1100	0	1794	163	1162	1895
63	931	0	1053	157	1005	1136
64	1341	0	922	299	1519	1043
65	1018	0	1023	493	1264	1270
66	789	0	427	474	1097	593
67	3341	0	795	372	3641	867
68	1787	0	815	365	2038	929
69	4087	0	1186	432	4422	1283
70	1391	114	2395	41	1521	2420
71	1511	193	2395	138	1761	2475
72	3492	355	3435	37	3866	3453
73	1124	863	3791	28	1997	3809
74	2439	3240	3044	13	5687	3048
75	1736	5689	3391	8	7431	3393
76	1219	19725	3553	22	20962	3556
77	1441	4140	3662	7	5585	3665
78	1709	5753	5748	405	7691	5924
79	4187	12333	7252	601	16939	7435
80	1378	3632	3721	416	5248	3898
81	1925	3896	5437	294	5973	5579
82	1626	6494	10158	314	8259	10333
83	1003	5399	7154	963	6857	7662
84	1022	3822	7933	1296	5335	8738
85	2753	3637	7198	707	6722	7573
86	3576	2115	6024	1470	6405	6780
87	4187	2031	6463	32	6234	6479
88	0	0	0	0	4800	5200

(Table 1). The few miscellaneous landings were allocated proportionally to longline, pot and trawl gear types.

A port sampling program initiated in 1986 provides age and length composition data, by sex, for each major gear type in the west coast sablefish fishery (Appendix tables 1,2). Size compositions in the longline and pot fisheries are similar (Figure 3,4,5) and, in preliminary runs of the model, their estimated selectivity patterns were similar. Therefore, longline and pot landings, age composition, and length composition were combined into one fixed gear category.

<u>Trawl Surveys</u>

Bottom trawl surveys were conducted between Monterey Bay and Vancouver Island in the 30-200 fathom depth zone during 1980, 1983, 1986 and in the 50-250 fathom zone in 1977 (e.g. Coleman, 1986; Weinberg et al., 1984). Depth-specific trends in sablefish mean size complicate any attempt to extrapolate these nearshore surveys to an estimate of total population biomass. However, analyzing these data as estimates of age 1 recruit abundance is realistic. The size frequency distributions for each survey indicate a distinct mode at 38-39 cm FL (Figure 6); these are the age 1 fish. Age 0 fish seem to be about 26 cm and are rarely taken. When the data from all four surveys are combined and stratified by 10 fathom depth intervals (Table 2) the following patterns emerge. Where the bottom depth is less than 80 fathoms the catch is nearly 100% small (<42cm, i.e. age 1) sablefish. This size group is nearly non-existent in tows taken at depths greater than 150 fathoms. The mean catch in the 40-49 fathom zone is 48 sablefish per tow (N tows = 214), which is the greatest catch rate among all the 10 fathom intervals between 30 and 200 fathoms. The mean catch in the 30-39 fathom zone is only 2 sablefish per tow (N tows = 168). We conclude that most age 1 sablefish are found between 40 and 150 fathoms, and that a survey which covers the depth range 30-200 fathoms includes nearly 100% of the age 1 fish, and can be used as a quantitative assessment of their abundance. The 1977 survey did not work nearshore of 50 fathoms so cannot be used as a comparable survey. Calibration of the 1977 survey is not possible because the <50 fathom depth zone contained a highly variable portion of the total abundance in the other surveys.

The northern extent of the 1986 survey was the U.S.-Canada border, and the 1980 and 1983 surveys worked further north to latitude 49°15'. The 1980 and 1983 survey results were processed to delete samples taken north of the U.S.-Canada border. The southern extent of all surveys was Monterey Bay. The bottom area between Monterey Bay, the U.S.-Canada border, and the 30 and 200 fathom isobaths is approximately 11600 nm . One may consider extrapolating the survey results southward. Extrapolation to Pt. Conception would increase the area to about 12350 nm , a 6.5% increase. Extrapolation to the U.S.-Mexico border would increase the area to 14550 nm , a 25% increase. Any extrapolation requires the assumption that the density of sablefish in the 30-200 fathom depth zone is the same north and south of Monterey Bay. No extrapolation was made in the preliminary analysis and, in the final analysis, the trawl survey abundances were extrapolated to Pt. Conception.

The synthesis model separately examines the total numbers observed in the survey, the males' size composition, and the females' size composition. Total population numbers (Table 3) were taken directly from the output of the RACE

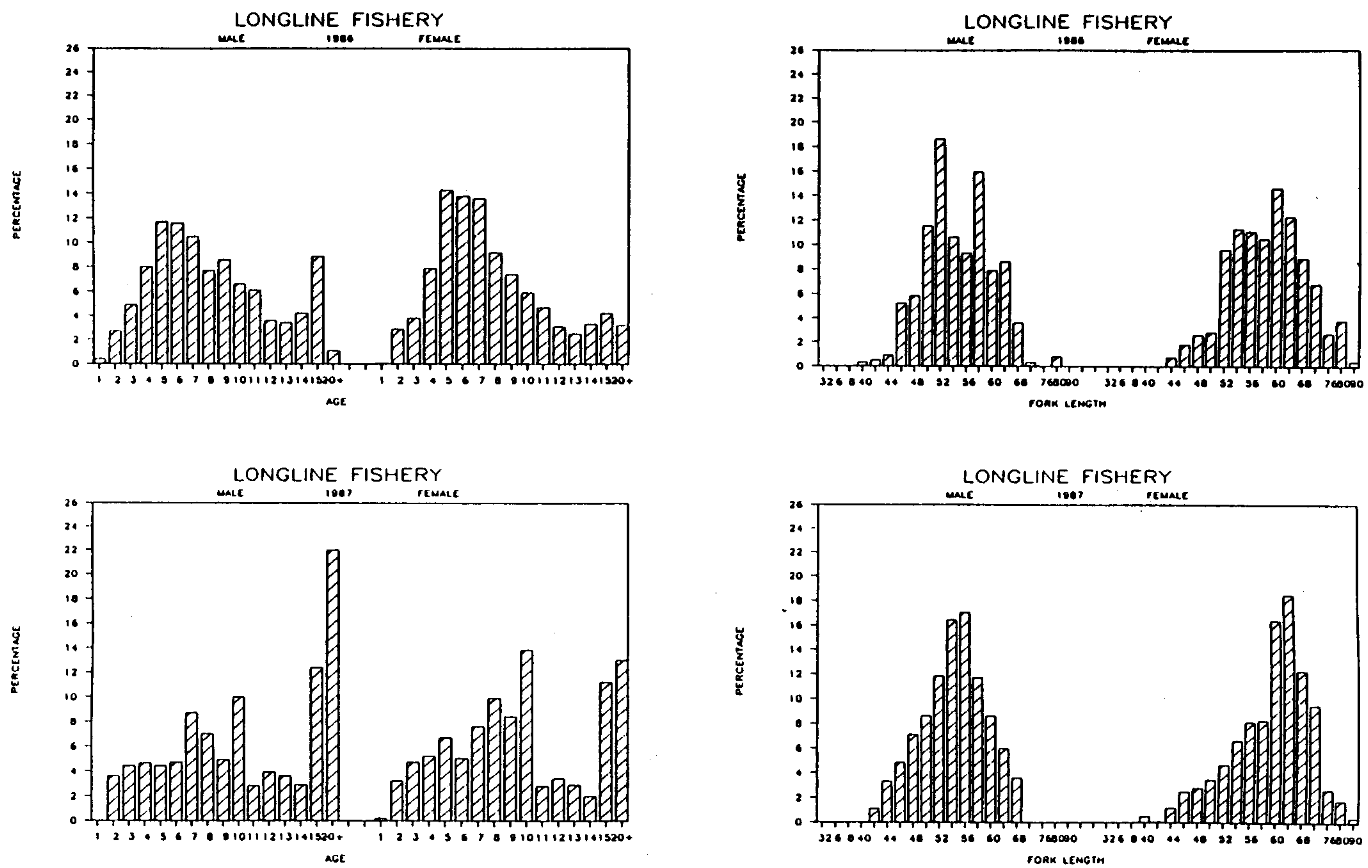


Figure 3. Size and age frequencies in the 1986 and 1987 longline fishery.

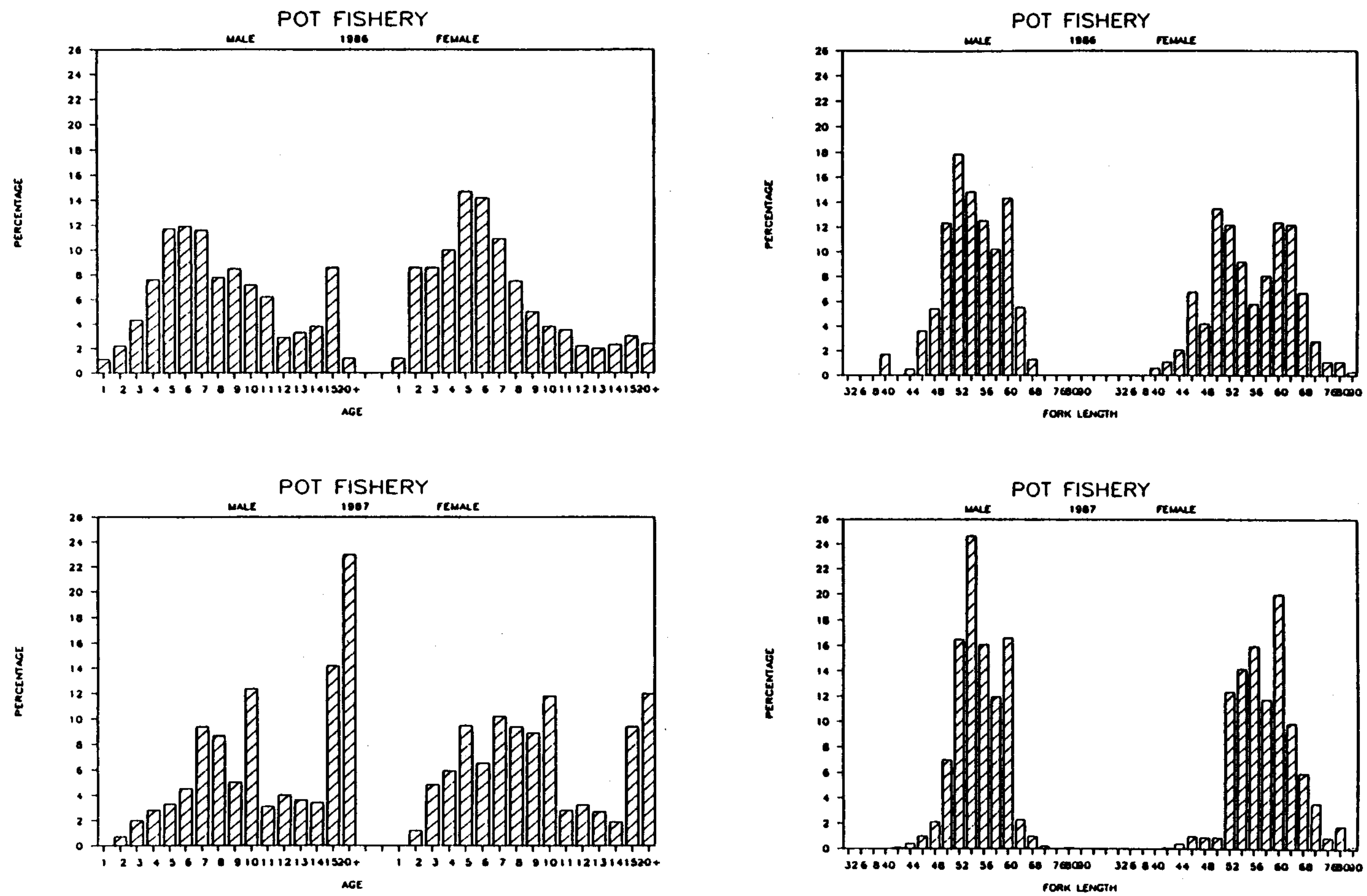


Figure 4. Size and age frequencies in the 1986 and 1987 pot fishery.

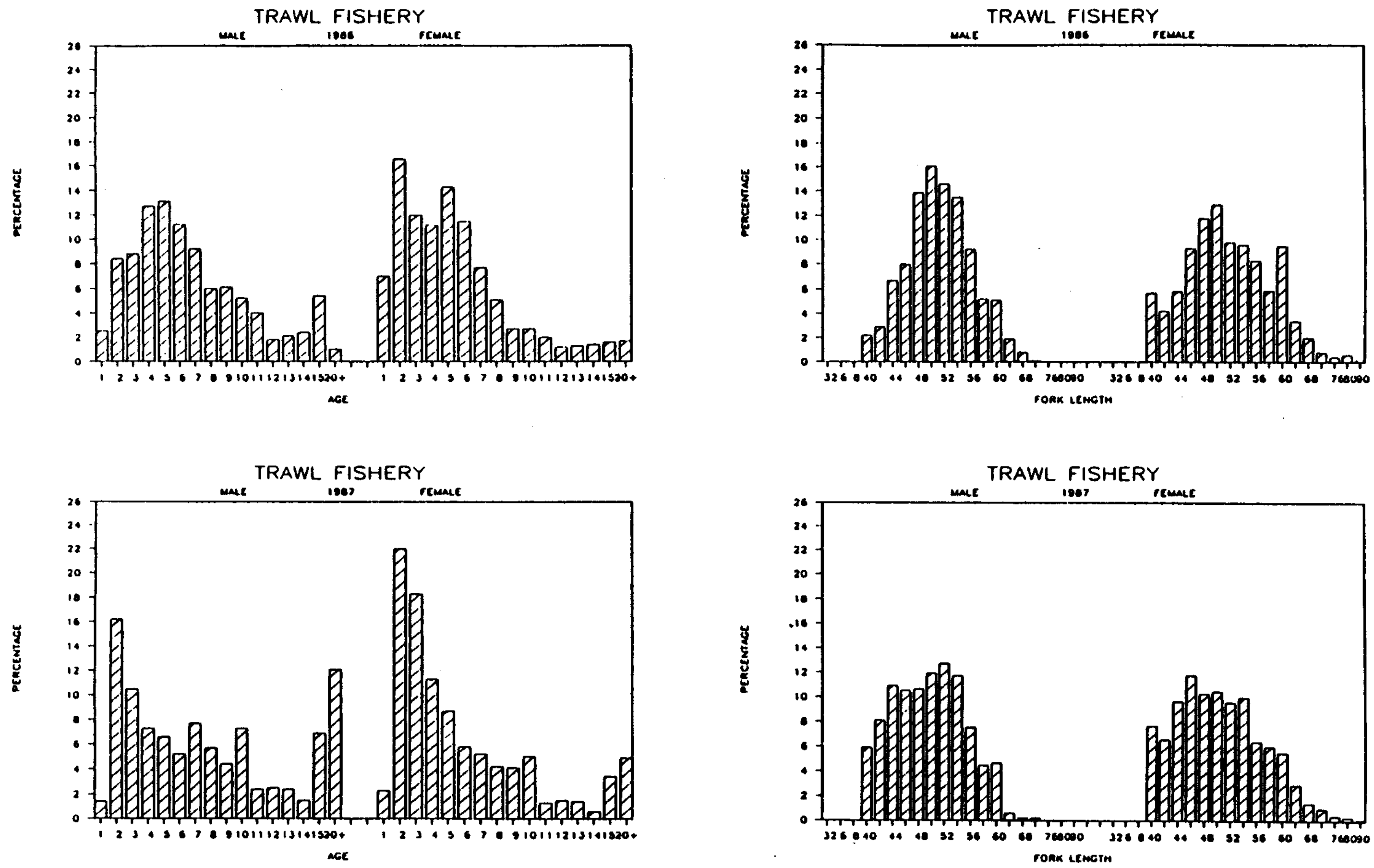


Figure 5. Size and age frequencies in the 1986 and 1987 trawl fishery.

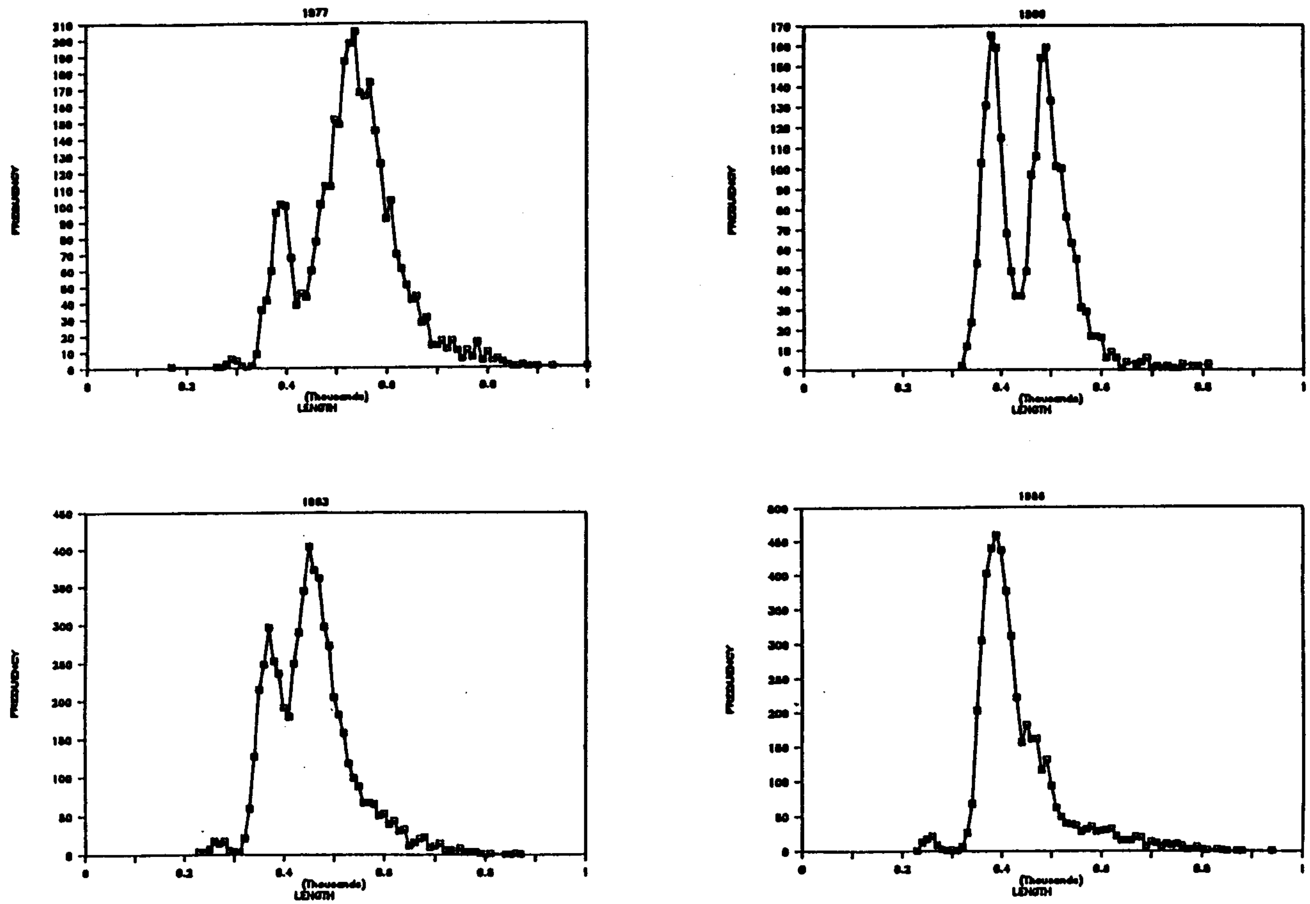


Figure 6. Unweighted size frequencies in the nearshore tri-ennial trawl surveys, sexes are combined.

Table 2. Statistics on depth distribution in trawl surveys. N is the total number of trawls in the four surveys (1977, 1980, 1983, and 1986); % zero is the percentage with no sablefish; The statistics on number of sablefish are simply based on number per tow; for the categories under % <42cm, N is the number of tows for which the number of measured sablefish was at least 5 and, for these tows, % is the percentage of the measured sablefish which were less than 42 cm fork length.

	Trawls		Number of sablefish				% <42 cm	
Depth	N	%zero	Mean	S.D.	Median	Max	N	%
30–39	168	74%	2	17	0	217	4	100%
40–	214	59	48	408	0	4473	12	88
50–	289	54	15	69	0	740	31	71
60–	312	40	25	152	1	1892	43	65
70–	262	34	27	183	2	2332	36	46
80–	184	30	26	202	3	2731	31	32
90–	136	17	27	88	5	752	30	26
100–	101	6	19	37	7	248	26	22
110–	115	18	18	50	4	468	26	18
120–	87	26	16	48	3	379	19	17
130–	53	38	16	41	3	266	13	11
140–	49	27	24	100	5	699	11	6
150–	51	12	17	30	7	172	15	12
160–	50	16	18	30	5	153	17	0
170–	55	22	25	78	6	555	18	2
180–	52	33	16	30	2	143	11	5
190–	24	21	10	10	8	40	6	1
200–	20	|	17	32	5	141	6	1
210–	21	|	11	13	5	45	6	0
220–	28	|	8	9	6	42	7	4
230–	29	17	8	10	4	38	9	4
240–	22	|	8	9	5	30	9	5
250–	7	|	18	37	7	101	2	8

Table 3. Survey observations of sablefish abundance. Trawl values are in thousands of fish. Pot values are in fish per pot. The cv for the small fish component of the trawl survey is assumed to be the same as the calculated cv for the entire size range, but these small fish cv values will have no effect on the model.

Year	Tri-ennial Trawl				N Pot		S Pot	
	<42 cm		All					
	value	cv	value	cv	value	cv	value	cv
71	—		—		10.30	.245	—	
72	—		—		—		—	
73	—		—		—		—	
74	—		—		—		—	
75	—		—		—		—	
76	—		—		—		—	
77	—		—		—		—	
78	—		—		—		—	
79	—		—		11.40	.316	—	
80	32253	.461	50158	.461	6.80	.124	—	
81	—		—		4.80	.200	—	
82	—		—		—		—	
83	16875	.368	38097	.368	10.60	.092	—	
84	—		—		—		9.80	.108
85	—		—		7.40	.193	—	
86	19267	.264	28973	.264	—		4.60	.096
87	—		—		2.80	.189	—	

BIOMASS program. Male and female size compositions could not be used directly from this output because they do not include the substantial numbers of small unsexed fish. Instead the estimated size composition for combined sexes was split into a male and female component (Figure 7) based on the estimated sex ratio within each length category.

The selectivity function which defines the relation between the true population and the population surveyed by the nearshore trawl survey should be strongly peaked at the size range which represents age 1 sablefish. It is expected that the model will be able to estimate the shape of this function from the size distribution data in these 3 surveys. The model treats the total survey numbers as a quantitative estimate of the abundance of a subset of the population; that subset being defined by the estimated selectivity function. Preliminary runs of the model disclosed an ambiguity in this definition: the model could improve the fit to the observed total survey numbers by either adjusting the estimated numbers of fish in the population, or by adjusting the selectivity function that defined the proportion of each size that contributed to the total survey numbers (subject to the constraint that at least one size category had selectivity equal to 1.0). If the model took the latter approach, it could degrade the fit to the survey size compositions. Thus, the relative emphasis placed on fitting the survey abundances and the survey size compositions became critical. We adopted the following alternative approach to alleviate this problem. A fixed subset of the trawl survey, those sablefish <42 cm, were defined to be 100% available to the survey. This size group includes nearly all of the age 1 fish and few fish of other ages. The model then includes two versions of the trawl survey numbers (Figure 8). The first, trawl survey (all), includes the entire size range, is not considered quantitative, and a size-specific selectivity function is estimated. The second, trawl survey (small), includes only the <42 cm size range, is considered quantitative, and all sizes less than 42 cm are defined to be fully available.

Pot Surveys

In the Oregon-Washington region, surveys occurred in 1979, 80, 81, 83, 85 and 1987 (Table 3, Figure 9). Each sampled the standard depths: 150, 225, 300, 375, and 450 fathoms. Extra depths sampled in later years tend to catch larger fish and have not been included in the standard index (Parks and Shaw, 1988). Only catches from the first two sets at each site were included in the index. The sampling gear was changed in 1985 from rectangular traps to conical traps. The conical traps are more efficient, and the historical catches from rectangular traps have been adjusted upwards by a measured calibration factor of 1.408 (Parks and Shaw, 1987). The gear type had no effect on the size composition of the catch. Also in 1985 the number of sites was increased from 4 to 8. The mean index was relatively unaffected (7.6 for old sites and 7.3 for new sites in 1985, 3.1 and 2.5 in 1987).

In 1971 a precursor to the northern pot index was conducted at 3 of the sites that eventually were included in the northern pot index[1/]. The gear (rectangular trap) and depths (150-450 fathoms) were identical to that used in 1979. We consider this cruise to be a valid northern pot index observation.

In the California - southern Oregon region, surveys occurred in 1984 and 1986 with 9 sites occupied in each year. The depth range is 225 - 525 fathoms. This is 75 fathoms deeper than the northern index depth range so we expect to

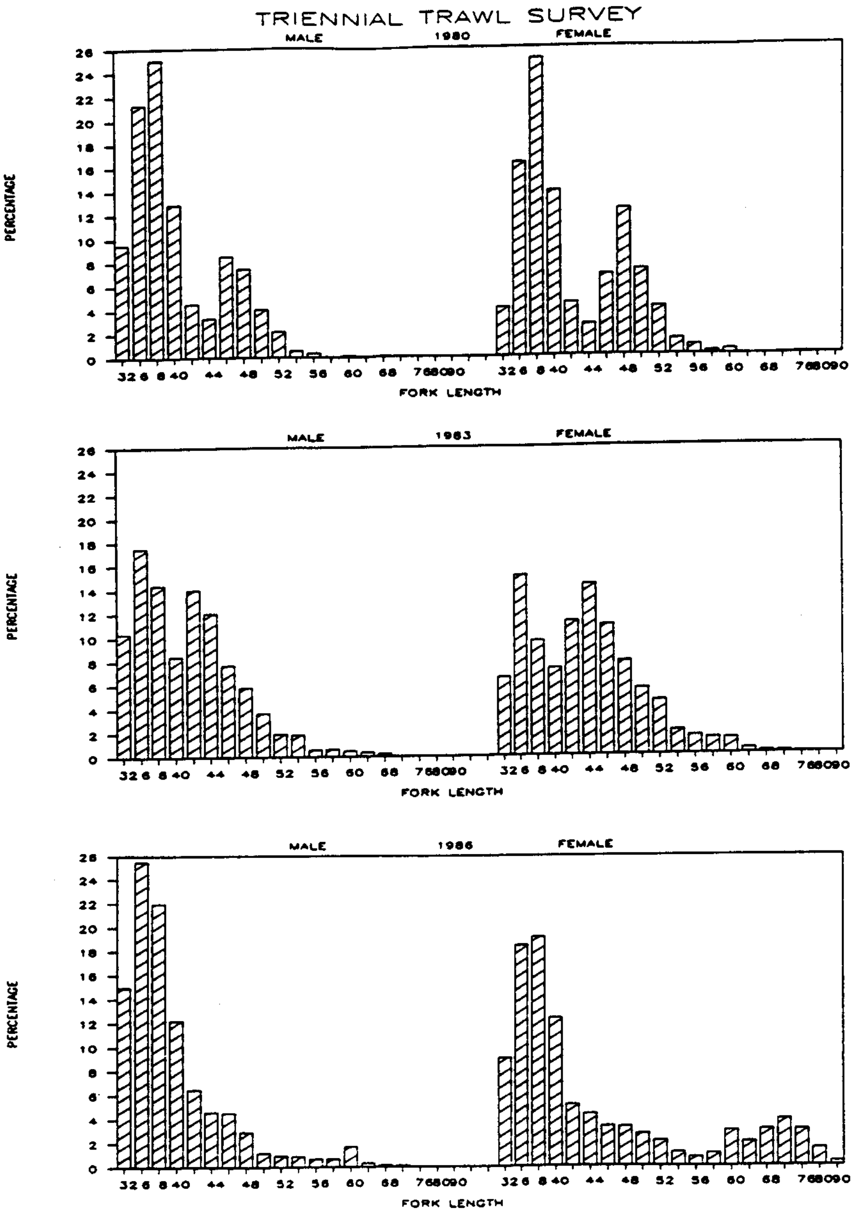


Figure 7. Condensed size frequencies in the trawl surveys by sex and weighted by catch rates. Size categories are 32-35 cm, then by 2 cm to 60 cm, by 4 cm to 80 cm, and by 10 cm to 100 cm.

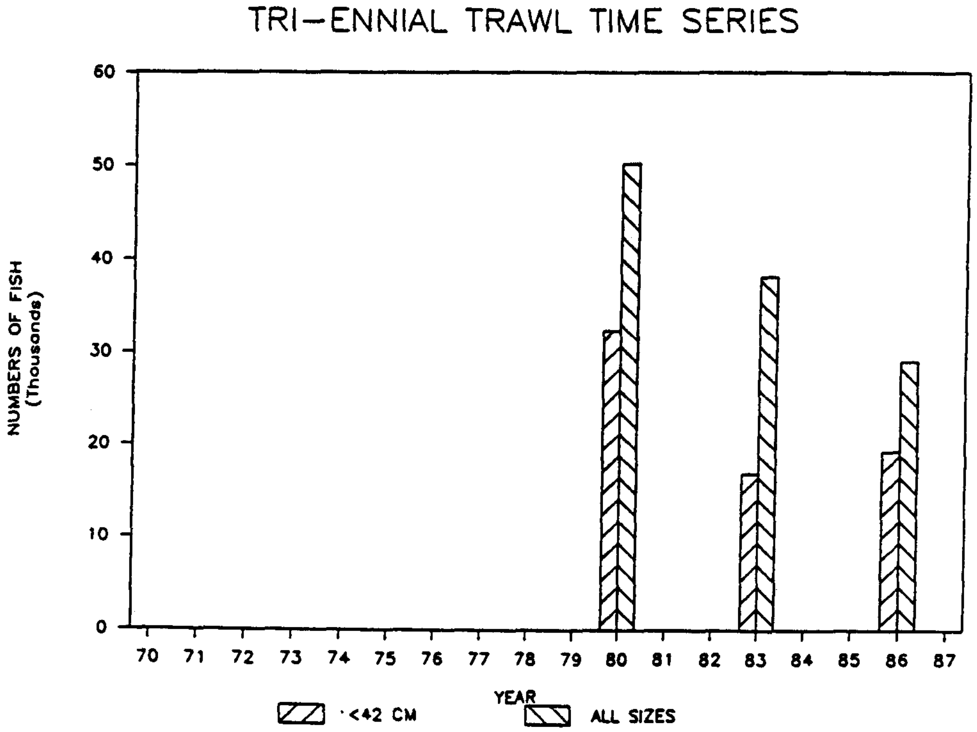


Figure 8. Trawl survey time series showing the numbers of small (<42 cm) sablefish and the numbers for the entire size range.

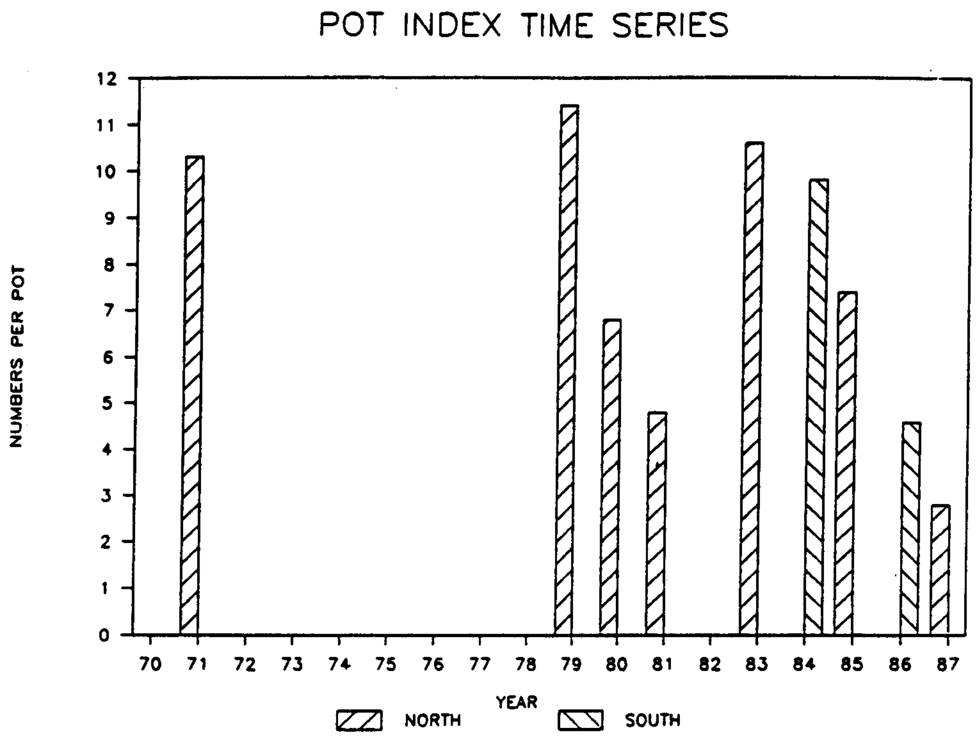


Figure 9. Northern and southern pot survey time series.

observe fewer small fish in the south index area. However, this tendency may be countered by the tendency for larger/older fish to be more common in the north. Separate selectivity functions will be estimated for the northern and southern pot surveys.

Variance estimates for recent pot index surveys have been calculated under the assumption of fixed site effects (Parks and Shaw, 1988). Because these analyses do not simultaneously analyze all survey years (thus obtaining a site effect averaged over all years), and because earlier work (Kimura and Balsiger, 1985) determined appropriate sample size on the basis of random site effects, we have recalculated the survey variances. Here we calculate a standard error for each survey from the standard deviation of the individual site values within each year (Table 3). These values are typically larger than those calculated from the fixed effect model.

All sablefish captured in the pot surveys are measured to determine the total size composition, a random sample is examined for sex, length, and age, and many are tagged and released. The size composition by sex from each random sample should be weighted by the total numbers captured at that site/depth. Alternatively, we employ the same approach as that used to process the trawl size compositions. The random sample data are pooled and used to calculate the sex ratio in each size category. These measured sex ratios are then used to split the total size composition into male and female components based on the measured sex ratio in each length category. The length composition vector for each sex (Appendix Table 2) is then scaled so that it totals to the number of fish observed for that sex in the random samples.

Age composition data is available from the random samples for the 1983 and 1985 northern pot index surveys. The age-length key for each sex in each survey was compressed into the length categories defined below, ages 15-19 were combined, and ages 20+ were combined. The revised length compositions defined above were then multiplied by the corresponding key to obtain new estimates of the sample age composition (Appendix Table 1).

Age and Length Categories

Length compositions from all surveys and fisheries were compressed into 21 categories defined by the following lower and upper bounds of fork length:

L	0	32	36	38	40	42	44	46	48	50	52	54	56	58	60	64	68	72	76	80	90
U	31	35	37	39	41	43	45	47	49	51	53	55	57	59	63	67	71	75	79	89	100

Age compositions from all surveys and fisheries were compressed into the following categories:

1 2 3 4 5 6 7 8 9 0 11 12 13 14 15-19 20+.

The lower and upper tail of each size and age distribution was further compressed so that the first non-zero value had at least 5 observed fish.

Tag Recaptures

Sablefish have been tagged and released on the west coast beginning in about 1971 with a large release of tagged fish in 1972 (Shaw, 1984). The rate at which these tags have been returned contains information on the fishing mortality rate. Here we utilize only those tag returns from fish which were greater than 52.9 cm at the time of release, because preliminary analyses (William Lenarz, SWFC Tiburon, CA) indicate a reduced return rate for tags released on smaller fish. Only returns from the west coast fishing zone, as defined above, are included (Table 4). Returns from 1976 and earlier are excluded because of the low reporting rate by the large foreign fishery in 1976. Releases from the years 1971-1976 were grouped into one aggregate release year. The model analyzes these data by examining, for each release year, the percentage of tags that were returned in each subsequent year. Thus, initial tag loss and initial tagging mortality are unimportant, even if they vary from year to year. The level of reporting also is unimportant, but it is assumed to be constant. Long term tag loss is important, and is assumed to be 0.10 per year. Sensitivity to this value will be investigated.

Other Input

Natural Mortality

The most appropriate value for natural mortality should account for emigration from the U.S. zone and from the depth strata which is fished and surveyed, because an older fish which is not vulnerable to the fishery is effectively dead. The level of natural mortality is critical because it, more than any other factor, determines whether the observed numbers of recruits in the tri-ennial surveys can supply adequate population numbers at age to support the observed fisheries. Also, the relative selectivity of older fish is nearly inextricable from the estimate of natural mortality, i.e. the reduced occurrence of larger/older fish can be due to death, migration, or gear avoidance. We can try various levels of natural mortality to see which yields the most believable estimates of selectivity. The maximum longevity of fish observed in Canada, 55 years, suggests that M is about 0.08 (Hoenig, 1983). The maximum age for fish from the 1987 port sampling program ranged from 35 to 47 among the various otolith readers, yielding M estimates of 0.10 to 0.13. Effective M, which includes emigration, for sablefish in the US west coast zone probably is in the range 0.10 - 0.20. Dynamic pool models explored by Lenarz and Methot (unpublished data) during October 1987 indicated that M = 0.1 results in an abundant current stock which is inconsistent with the decline in the survey observations and which contains a large number of older fish. At M=0.2 the population would have barely been able to support the last decade of harvests unless the level of recruitment has been greater than the approximately 20 million age 1 fish observed in the 1980, 1983, and 1986 tri-ennial trawl surveys. Natural mortality is incorporated as a parameter so that its value can be easily changed. Initial runs will use M = 0.15 and alternatives will be explored.

The abundance of predators encountered by juvenile sablefish on the continental shelf must be greater than that encountered by adults on the slope. We consider it likely that juvenile sablefish have a greater natural mortality as

Table 4. Returns of tags released in the U.S. fishery zone on fish >52.9 cm in length, and recaptured in the U.S. fishery zone.

Release year	Returns in year: 77	78	79	80	81	82	83	84	85	86	87
71 - 76	30	38	85	16	22	32	21	7	6	3	4
77											
78											
79				26	26	20	10	9	10	2	4
80					121	104	137	26	27	32	10
81						57	27	8	16	16	4
82							23	7	6	10	3
83								5	5	2	2
84											
85											
86											54

a consequence of this differential distribution. We include the possibility of extra juvenile mortality with the following formulation:

$$M_a = M1 + M2 * e^{(1-a)}$$

where: M1 is the natural mortality of older fish, set at 0.15 in most runs.

M2 is the extra juvenile mortality. This parameter was set to 0.0 for the preliminary runs, then was estimated in the final runs.

<u>Growth</u>

The growth model should be constrained by two strong observations. One is the large maximum size, L_∞, of females (about 100 cm) and the other is the mean size at age 1, L_1, in the late summer-early autumn (38.4 cm) (Table 5, Figure 6). Growth models based on fishery or pot survey samples tend to miss these two constraining points because these samples are length-selective. By undersampling the small fish they overestimate mean size at age of young fish, thus underestimate the growth rate of these young fish. By undersampling the largest fish found in deeper water, growth models fit to these data may underestimate L_∞. Various L_∞ estimates are:

author	male	female
Klein 1986	71	83
McFarlane & Beamish 1983b	66	79
Parks & Shaw 1987		
1983 pot survey	58	68
1985 pot survey	68	80
Fujiwara and Hankin 1988	~60	~80

We used these values as guidance in selecting values for L for the preliminary runs. Then in the final model runs used the model itself to find the L values which provided the best fit.

Inclusion of the constraining length at age 1 is facilitated by recasting the Von Bertalanffy growth equation in terms of L_1 instead of T_0:

$$L = L_\infty + (L_1 - L\ ) * e^{(K*(1-t))}$$

note: $T_0 = 1 + [\ln(1 - L_1/L_\infty)]/K$.

Given the above growth model and estimates of L_1 and $L\ _1$, K can be estimated from the size at any intermediate age. The pot surveys will be shown to have maximum selectivity at about age 5, so the mean size at age 5, L_5, in the pot surveys of 1983 and 1985 will be used to calculate K. Preliminary model runs indicated a small bias (explained below) in the mean size at age 5 in the pot surveys (0.4 cm for males and 0.2 cm for females). These biases were taken into account when selecting the best L_5 for the final model runs.

A normal distribution of size at age is assumed, and the coefficient of variation is assumed to increase linearly with age. Variance of the age 1 distributions was estimated from the size distributions in the trawl surveys.

Table 5. Size distributions of sablefish in neashore trawl surveys. Only sizes pertinent to definition of the size distribution at age 1 are presented. The age 1 size distribution was determined by inspection of the total size distribution. The upper tail of the age 1 distribution was assumed to be a mirror image of the better defined lower tail.

	1977		1980		1983		1986		Total
Size	All	age 1	All	age 1	All	age 1	All	age 1	age 1
23 cm					4	0	1	0	
24					4	0	13	0	
25					8	0	18	0	
26	1	0			18	0	22	0	
27	1	0			15	0	9	0	
28	3	0			18	0	3	0	
29	6	0			6	0	1	0	
30	5	0			4	0	2	0	
31	2	0			4	4	1	1	5
32	1	1	2	2	22	22	7	7	32
33	2	2	12	12	60	60	27	27	101
34	9	9	24	24	128	128	69	69	230
35	36	36	53	53	216	216	203	203	508
36	42	42	103	103	249	249	305	305	699
37	60	60	131	131	297	297	402	402	890
38	96	96	165	165	253	253	439	439	953
39	101	101	159	159	237	237	458	458	955
40	100	100	115	115	192	128	436	436	779
41	68	68	68	68	180	60	376	376	572
42	39	39	49	49	250	22	311	311	421
43	46	36	37	24	291	4	222	203	267
44	44	9	37	12	345	0	157	69	90
45	60	2	49	2	404	0	182	27	31
46	78	1	97	0	373	0	162	7	8
47	101	0	106	0	362	0	162	1	1
48	112	0	154	0	298	0	117	0	0
49	112	0	159	0	273	0	132	0	0
.									
.									
.									
Total		602		919		1680		3341	6542
mean		39.02		38.36		37.03		38.99	38.40
std.dev.		2.34		2.29		2.17		2.58	2.58

Variance of size at age 20 was estimated from size at age data in the 1986 and 1987 fisheries.

We utilize the following growth parameters (Figure 10):

	L_1	L_5	L_∞	K	T_0	coefficient of variation at age 1	coefficient of variation at age 20
Preliminary:							
MALE:	38.4	52.3	70.0	.145	-4.489	.068	.0902
FEMALE:	38.4	57.3	85.0	.130	-3.622	.068	.1452
Final:							
MALE:	38.4	52.0	64.5	.184	-3.916	.068	.0902
FEMALE:	38.4	56.2	77.5	.152	-3.505	.068	.1452

Length-Weight

The length - weight relationship used here is taken from the pot survey conducted off California and Oregon in 1986:

$$W(kg) = .00000233*L(cm)^{3.364}$$

There is no apparent difference in this relationship between males and females (Phillips and Inamura, 1954; Fujiwara and Hankin[2/]; Klein, 1986).

Maturity and Fecundity

Percentage mature is assumed to follow a logistic function of length (Figure 11). The length at 50% mature was estimated by McDevitt (1987) from data in Phillips and Inamura (1954) to be approximately 67 cm. Mason et al. (1983) estimated, from data collected off Vancouver Island in 1980, that the size at 50% mature was 58.3 cm. Parks and Shaw (1983) estimated the size to be 56.3 cm off central California. Hunter (SWFC, unpubl. data) estimated that the value was about 59 cm off central California in 1987. Here we describe percentage mature as:

$$PCTMAT_a = \frac{1.0}{(1.0 + e^{(-.2491*(L_a-58.3))})}$$

Spawner-Recruitment

Here we use the same Beverton-Holt formulation (Figure 12) that has been used in other west coast assessments:

[2/]Characteristics of blackcod captured off Eureka, California by vessels belonging to the Fishermen's Marketing Association, July 1983 - August 1984. A report submitted to the Fishermen's Marketing Assoc. by Shunji Fujiwara and David Hankin, Dec. 1984.

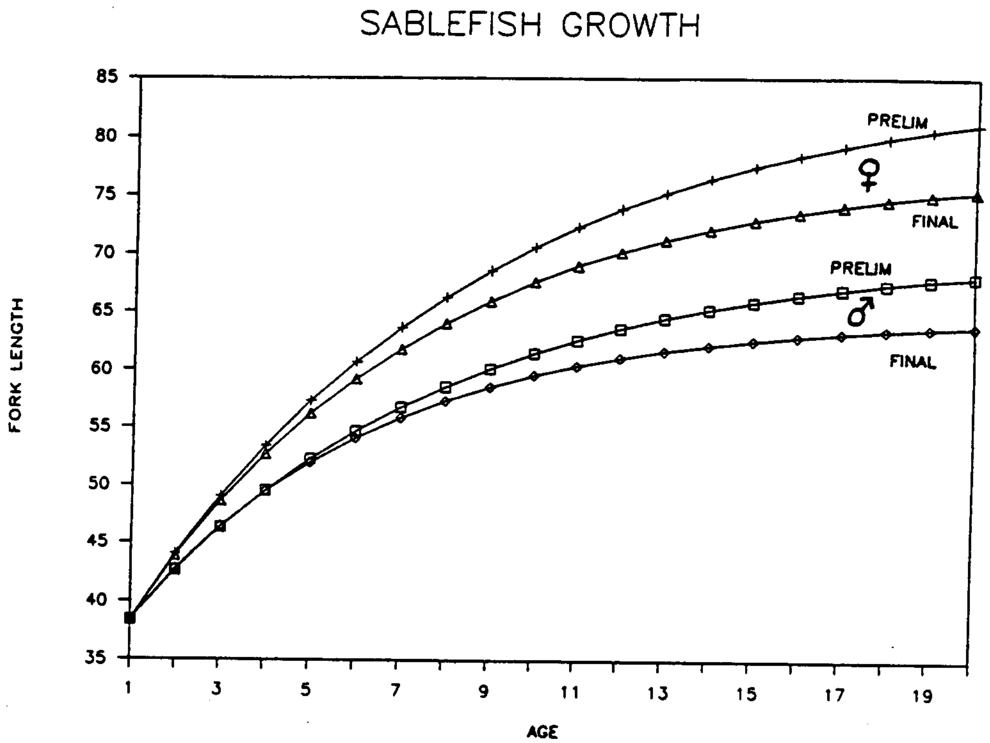


Figure 10. Growth curves for male and female sablefish using the preliminary and final parameter values.

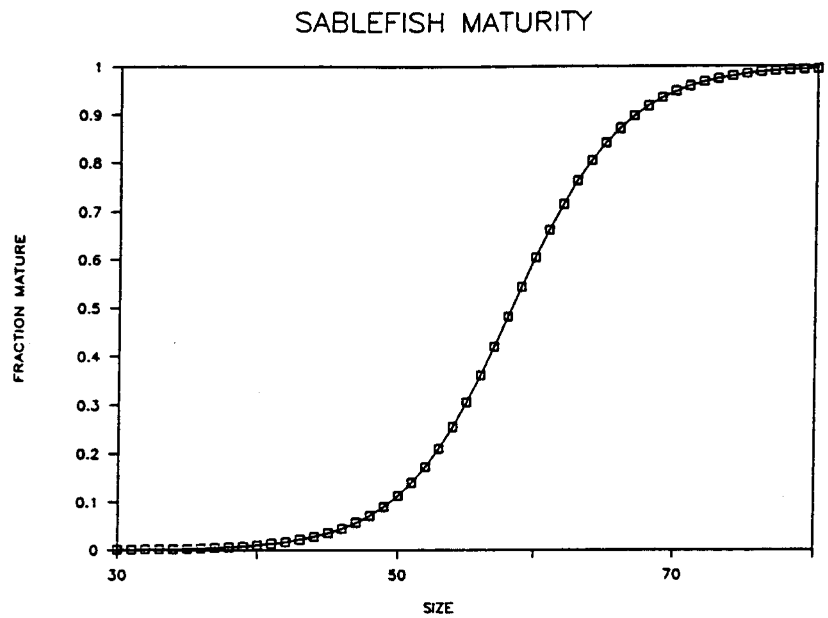


Figure 11. Percentage mature for female sablefish.

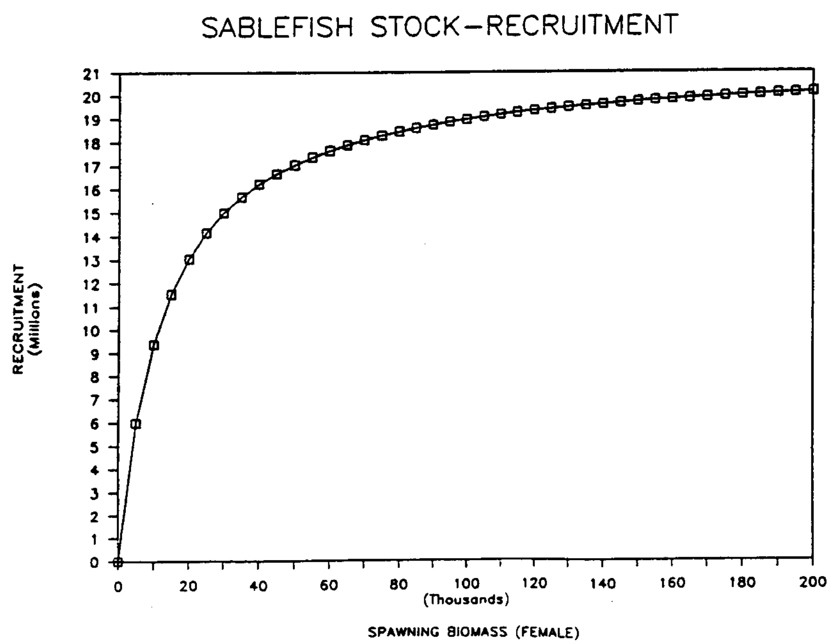


Figure 12. Spawner-recruitment relationship with DD=0.889.

$$RECRUIT = VR * \frac{SPB / VSPB}{(1 - DD*(1-(SPB/VSPB)))}$$

The density-dependence factor (DD) is set at 0.889 so that recruitment is 90% of virgin recruitment (VR) when spawning biomass (SPB) is 50% of virgin spawning biomass (VSPB). Spawning biomass is calculated from female numbers at age, weight at age and percentage mature at age. Virgin spawning biomass is calculated from the virgin age-structure which is calculated from the parameters which define virgin recruitment and natural mortality.

Ageing Error

Annuli in the otoliths of sablefish are difficult to interpret unambiguously, even by the break-and-burn technique. Agreement among readers is low relative to the agreement attained for otoliths of other species. Here we assume that the assigned ages are unbiased estimates of true age, but that there is substantial variability in the assigned ages. The impact of this variability is to diminish the apparent importance of abundant year classes and, especially, to enhance the apparent abundance of poor year classes. In early versions of the model, we specified the level of ageing error as a linear function of true age. When the parameters of this function were fit within the sablefish synthesis model, the estimated level of ageing error was similar to that estimated from the agreement between readers. In the final model runs we specified the standard deviation of observed age from the non-linear reader agreement function (Figure 13) fit to the 1986 fishery samples:

$$std.dev._a = \frac{A}{.223*A + 4.345}$$

We assume a normal distribution of assigned age for each true age, and generate a transition matrix, A'@A, which defines the distribution of observed age at each true age.

Trawl Discard

Discard of sablefish may occur because of poor market conditions, small size, or closed seasons. Here we attempt to incorporate one of these factors - discard in the trawl fishery due to small size. We assume that all small fish die after being captured in a trawl and discarded, and that small fish discarded from a pot or longline will survive. Inaccuracies in these two assumptions will tend to cancel each other. Length-specific data on trawl discards were obtained from two sources. Fujiwara and Hankin[2/] obtained data from the Eureka trawl fishery in 1983 and 1984. They found that the smallest size captured was 36 cm, the smallest size retained was 40 cm, and 100% retention occurred at 46 cm. A logistic function fit to their data indicates 50% retention at 42.8 cm and a slope of 1.092 (Figure 14). Pikitch (unpublished data) placed observers on board domestic fishing vessels to document levels of by-catch in 1986 and 1987. Information collected by these observers can also be used to calculate the length-specific fraction retained for sablefish. The smallest observed sablefish was 27 cm, the smallest retained sablefish was 35 cm, and an asymptote of 89.5% retained occurred at 48 cm. Less than 100%

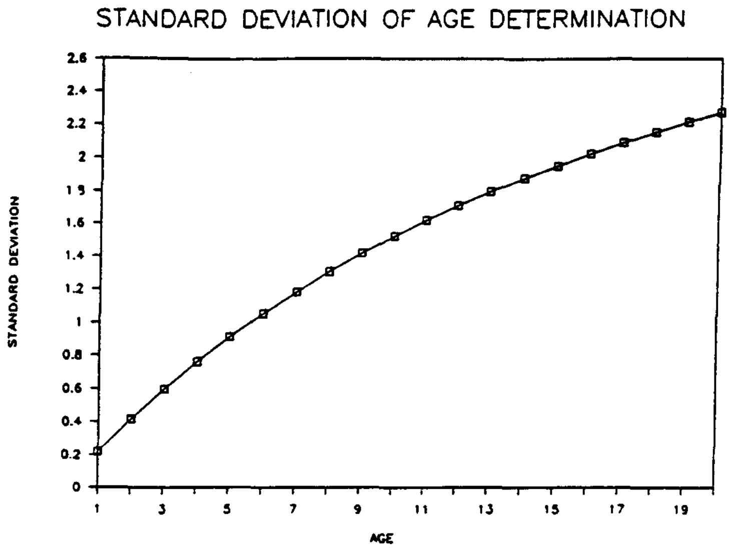


Figure 13. Ageing error calculated from reader agreement.

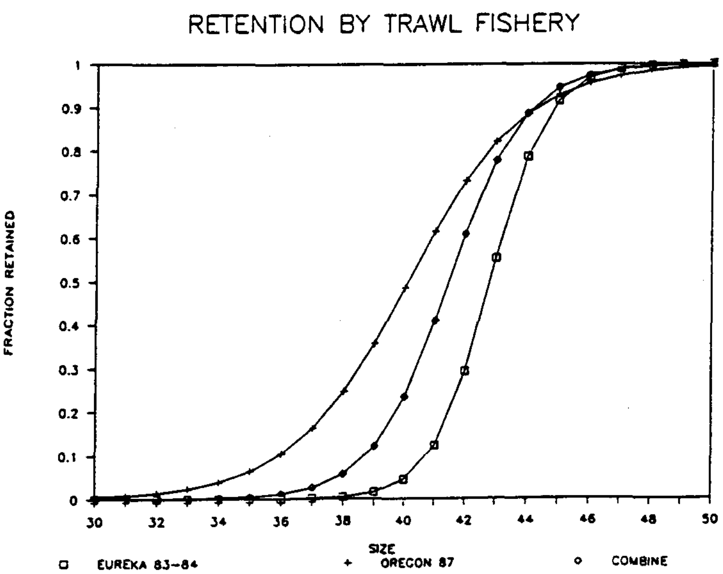


Figure 14. Retention of small fish by the trawl fishery. The 1984 data are from Fujiwara and Hankin (1984) and the 1987 data are from Pikitch (pers.comm).

retention of the larger fish is due primarily to discards which occurred after the close of the season in 1987. The values of percentage retained were divided by 0.895 to estimate the level of discard due solely to small size. A logistic function fit to these adjusted values indicates 50% retention at 40.1 cm with a slope of 0.526. Both retention functions will be investigated in the model and final model runs will utilize the average of the two functions.

Model

Subscripts

y = year
t = type of fishery or survey
a = true age
a' = category of observed age, sensitive to ageing error
l = category of length
s = sex

Vulnerability, Catchability, Availability

We note our use of the terms vulnerability, availability, selectivity, and catchability. Vulnerability means that fraction of the stock that has some positive probability of being captured. If some fish were not vulnerable, then infinite effort could not catch them. Vulnerability may be age-specific, and if vulnerability is less than 1.0 for some age, then that age fails to meet the assumption of homogeneity. Catchability is the fraction of the vulnerable stock that is captured by one unit of effort. Instead of defining catchability as being age-specific, we define catchability relative to the most available age and introduce an age-specific availability which modifies catchability for the other ages. Therefore, availability is 1.0 for at least one age and less than or equal to 1.0 for all other ages. We treat selectivity as synonomous with availability, or at least indistinguishable for it. Availability (selectivity) is an amalgam of gear avoidance, mesh retention, targeting behavior by fishermen, and geographic heterogeneity in the distribution of fishermen relative to that of each age group. For simplicity, we define that all ages are fully vulnerable to the fisheries and to the surveys, but that some ages have much lower availability (selectivity) than other ages. The consequence of this definition is that if effort was infinite, then an entire age group could be captured as long as it had non-zero availability. The distinction between vulnerability and availability is a trivial issue, however, at low levels of fishing mortality.

Model definition

The basic equations which define the dynamics of a homogeneous population follow:

Recruitment at age 1 is:

$$N_{y1} = R_y$$

where: R is recruitment
N is numbers at age

Numbers at age are:

$$N_{ya} = N_{y-1,a-1} * e^{-Z_{y-1,a-1}}$$

and for the maximum, accumulator age:

$$N_{ya} = N_{y-1,a-1} * e^{-Z_{y-1,a-1}} + N_{y-1,a} * e^{-Z_{y-1,a}}$$

where: Z is total mortality

$$Z_{ya} = M_{ya} + \Sigma_t [F_{yat}]$$

where: M is natural mortality
F is fishing mortality

Catch at age for the Tth fishery is:

$$C_{yat} = F_{yat} * N_{ya} * (1 - e^{-Z_{ya}}) / Z_{ya}$$

$$= F_{yat} * \bar{N}_{ya}$$

Catch biomass for the Tth fishery is:

$$CB_{yt} = \Sigma_a [C_{yat} * W_{yat}]$$

where: W is body weight

Numbers at age available to the Tth type of survey, conducted near the middle of the year are equal to:

$$S_{yat} = Q_t * VA_{yat} * \bar{N}_{ya}$$

where: VA is selectivity at age

Q is a scaling factor (catchability coefficient) defined as the ratio of the sum of the observed survey abundances to the sum of the estimated survey abundances.

The expected value for the Tth type of survey is:

$$SB_{yt} = Q_t * \Sigma_a [S_{yat} * W_{yat}] \quad \text{if measured in biomass}$$

$$SN_{yt} = Q_t * \Sigma_a [S_{yat}] \quad \text{if measured in numbers}$$

Here we make the following simplifications to reduce the number of parameters and to impose a well-defined pattern on the solution. Basically we assume that availability and natural mortality vary with age, but are invariant over time.

$VA_{yat} = VA_{at}$

where: VA_{at} = 1.0 for at least 1 age, and is $\leq$ 1.0 in all other ages

$M_{ya} = M_a$

$F_{yat} = E_{yt} * VA_{at}$

E is the fishing mortality rate for the most available age. E should be proportional to fishery effort by a catchability coefficient, Q.

The above equations are sufficient to describe the dynamics of a fished population. One needs only supply estimates of the vectors of recruitment, R; full fishing mortality, E; and selectivity, VA, to calculate the full time series of F, Z, C, and N. Because of the scarcity of age composition data for sablefish, we cannot directly utilize these estimates of numbers at age to determine how well the model's estimates match observations from the surveys and fisheries. We also cannot directly estimate the age-specific selectivity vectors. Instead, the model is cast primarily in terms of size composition for estimation of the selectivity vectors and for determining goodness-of-fit. Because of sex-specific differences in growth, we introduce an additional subscript, s, for sex.

Expected numbers at length in the population:

$$POPLEN_{yls} = \Sigma_a [\bar{N}_{yas} * L@A_{als}]$$

where: L@A is the distribution of length at age calculated from the growth curve and the linear increase in CV length at age

Expected numbers at length in the sample of type T:

$$SAMPLEN_{ytls} = VL_{tls} * POPLEN_{yls}$$

where: L is size-specific selectivity

Expected abundance index of type T:

$$SN_{yt} = Q_t * \{\Sigma_l \Sigma_s [SAMPLEN_{ytls}]\}$$

Note that this length-based definition replaces the age-based definition above.

Calculation of fishing mortality requires conversion of length-specific selectivity into age-specific selectivity:

$$VA_{tas} = \frac{\Sigma_l [VL_{tls} * L@A_{als}]}{\Sigma_l L@A_{als}}$$

$$= \frac{\Sigma_l [VL_{tls} * L@A_{als}]}{1.0}$$

Because of low precision in age determination, C is not the best estimate of the expected age composition for the fishery samples. Instead, C must be smeared by the estimated error in age determination:

$$SAMPAGE_{yta's} = \Sigma_a \, [C_{ytas} * A'@A_{aa's}]$$

Where A'@A is the ageing error matrix defined above.

Also, the observed weight at age for each type of survey or fishery depends on the pattern of length-specific selectivity. Especially, the fisheries tend to select only the larger individuals of the younger ages. These adjusted weights at age are needed to calculate the expected catch biomass:

$$W@A_{tas} = \frac{\Sigma_l \, [\, W_l * VL_{tls} * L@A_{als} \,]}{_l \, [\, VL_{tls} * L@A_{als} \,]} = \frac{\Sigma_l \, [\, W_l * VL_{tls} * L@A_{als} \,]}{VA_{tas}}$$

Selectivity

Size-specific selectivity by each fishery and each type of survey is defined by a 3 parameter function of length:

$$VL_{tls} = \frac{(L - P1_t)}{\left\{ 1 + \left[\frac{(L-P1_t)}{(P2_t - P1_t)} \right] \wedge P3_{ts} \right\}}$$

P1 defines the length at first availability. P2 influences the rate at which selectivity increases. P3 influences the peakedness of the function. The function is scaled so that the length with maximum selectivity has a selectivity value of 1.0. Selectivity at lengths less than P1 and greater than 30 cm were given a small positive value by first calculating the selectivity at a length 5% greater than P1 then defining selectivity to increase linearly from 0.0 at 30 cm to this calculated value at 1.05 * P1.

Initially, we assumed that males and females have the same length-specific selectivity and different age-specific selectivities because of their different sizes at age. However, a better fit was consistently obtained if the males had a larger value for the P3 parameter, thus decreasing their selectivity at larger sizes and old ages. A single parameter was used to mimic this pattern:

$$P3_{ts} = P3_t + P4 * (2-s)$$

where: s=1 for males and s=2 for females.

Parameters of the selectivity function for each of the types of samples were estimated by the model.

Likelihoods

With the above equations we can calculate the goodness-of-fit between the model and the diverse data available for sablefish. We define this goodness-of-fit in terms of log likelihood, L. This puts the fit to each type of data on the same probabilistic basis so that they can more easily be combined into an overall assessment of the total goodness-of-fit.

For each type of survey abundance we assume a lognormal error, and we approximate the lognormal standard error of each survey estimate by the coefficient of variation calculated for that survey. The lognormal deviation of a given observation is:

$$DEV_{yt} = \log(OSN_{yt}/SN_{yt})$$

The log likelihood of this deviation is (ignoring a constant):

$$L_{yt} = - [DEV_{yt} / se_{yt}]^2 - \log[se_{yt}]$$

where: OSN is the observed survey value
se is the survey's coefficient of variation

For each survey and fishery age or length composition, we assume a multinomial error structure to define the log likelihood of that sample:

$$L_{yt} = K * \Sigma_a [p_{yat} * \log(p'_{yat})]$$

where: K is the minimum of 400 and the actual number of fish in the yt sample. This maximum of 400 on K follows Fournier and Archibald (1982) and Methot (1986) and prevents large samples from dominating the result.

p_{yat} is the observed proportion at age in the yt sample

p'_{yat} is the estimated proportion at age in the yt sample. It is calculated from the C_{ytas} for fishery samples and the S_{ytas} for survey samples and the ageing error matrix, A'@A, which defines the distribution of age assignments. It is the SAMPAGE from above converted to proportions.

Similarly for size compositions:

$$L_{yt} = K * \Sigma_l [p_{ylt} * \log(p'_{ylt})]$$

Where the p'_{ylt} are calculated from the SAMPLEN.

This multinomial error structure is also used to measure the fit to the proportion of tags returned in each year.

An extra component to the overall likelihood function is defined to force the mean of the trawl survey (small) fish to be estimated correctly. This component is calculated from the ratio of the sum of the observed abundances to the sum of the expected abundances, Q_t:

$$L_t = \frac{1.0}{1.0 + abs(\log(Q_t))} - 1.0$$

Outline of model calculations

a. Recalculate the length at age matrix, L@A, for each sex if estimated growth parameters or variance have changed.
b. Recalculate the ageing error matrix, A'@A, if estimated ageing error parameters have changed.
c. Recalculate the length-specific selectivities, VL, if any of the pertinent parameters have changed.

i. then recalculate the equivalent age-specific selectivities, VA, as the mean of the VL weighted by the distribution of length at age, L@A.

ii. recalculate the expected mean body weight at age for each sample type, W@A, from the population length at age distribution, L@A, the body weight at length equation, and the length specific selectivities, VL.

d. Use the current estimate of natural mortality and virgin recruitment to calculate the virgin age composition and virgin spawning biomass for use in the stock-recruitment relationship. Then assume knife-edge recruitment to the fishery and iteratively calculate the fishing mortality which produces an equilibrium yield of 3512 mt. This equilibrium state is the starting point in 1970.

For each subsequent year

Note that all of below occurs for each sex.

a. Graduate the survivors from last year into the next age category; except accumulate in the age 20+ category.

b. Get the age 1 yearclass abundance in one of two ways:

i. Use the stock-recruitment relationship and last year's spawning biomass.

ii. Use the mean recruitment level multiplied by a recruitment factor for that year. These recruitment factors are parameters to be estimated by the model. Recruitment factors are used only for years which are followed by an adequate amount of age and length data. We will estimate recruitments for the 1977 through 1985 yearclasses. Earlier and later yearclasses will be calculated from the stock-recruitment relationship.

c. Assume that age-specific fishing mortality by each type of fishery is the product of a type,age,sex-specific selectivity, VA(tas), and effort, E(yt). Calculate age,sex-specific total mortality, Z(as), as the sum of natural mortality and each of the type, age, sex-specific fishing mortalities.

d. For each age and sex, calculate the mean population numbers and surviving numbers.

e. For each type of fishery, use the mean population numbers, weight at age for that type, fishing mortality, and fraction retained by the trawl fishery to calculate the total retained catch biomass and the total discarded biomass.

f. For each type of fishery, compare the estimated total catch biomass to the observed total catch biomass. If the ratio differs from 1.0, then use the ratio to adjust the estimated effort for that type of fishery and redo above steps c-e until the observed and estimated catch biomasses are within 0.1% of each other.

g. If there was a pot survey or tri-ennial survey in that year, then use the mean numbers at length and the length-specific selectivities to calculate the sample catch you would expect from a survey of that type. These estimated abundances will be adjusted by the recalculated Q before comparison to the observed survey values.

h. If there was an age composition observation in that year, then use the mean numbers at age and the age-specific selectivities for that type of observation to calculate an expected sampled age composition. Then use the A'@A key to convert this expected sampled age composition to an expected observed age composition. Pool for ages 10+ because of the low precision in the age determinations and because recruitments prior to 1977 are not individually estimated. Calculate the log likelihood of the observed age composition and sum with log likelihoods for this type of data in other years.

i. If there was a length composition observation in that year, then use the length at age key to convert the mean numbers at age in the population to the length composition of the population. Then use the type, length-specific selectivities to calculate an expection for the sampled, observed length composition. Calculate the log likelihood of the observed length composition and sum with log likelihoods for this type of data in other years.

j. Calculate the total fishing mortality for ages 5+, weighted by the abundance at each age and sex. This mortality will be used to calculate the expected number of tags returned in this year.

k. Calculate spawning biomass of females from the numbers at age at the beginning of the year (when spawning occurs), weight at age, and fraction mature.

l. Goto step 2.a. for the next year.

3. For each type of survey, recalculate Q before calculating the deviations between the individual observed and estimated survey abundances. Q is fixed at 1.0 for the survey that is defined as fully quantitative, the abundance of 32-41cm sablefish in the tri-ennial trawl surveys.

4. For each year in which tags were released, calculate the expected percentage returned in each subsequent year from the time series of age 5+ mortalities. The following FORTRAN statements accomplish this task:

```
      TAGSOUT=1.0
      RELRET=0.0
      LIKE(Y,T)=0.0

      DO 800 Y1 = Y+1,LYR
        Z = F5(Y1) + NATMORT + TAGLOSS
        ERETURN(Y1) = TAGSOUT * F5(Y1)/Z * (1.0-EXP(-Z))
        RELRET = RELRET + ERETURN(Y1)
800     TAGSOUT = TAGSOUT * EXP(-Z)
        DO 810 Y1 = Y+1,LYR
          ERETURN(Y1) = ERETURN(Y1)/RELRET
810       LIKE(Y,T) = LIKE(Y,T)+ORETURN(Y,Y1)*ALOG(ERETURN(Y1))
```

where Y is the release year, LYR is the last year for which there are returns from this release, ORETURN is the observed number of returns in year Y1 from release year Y, F5 is the fishing mortality for ages 5+ combining both gear types and weighting F at age by the abundance at that age, ERETURN/RELRET is the expected percentage of these returns that should occur in year Y1. TAGSOUT is proportional to the effective initial number of tags and its value does not matter.

5. Calculate the likelihood component for the mean trawl survey (small) from the Q for this type of survey.

6. Calculate the likelihood for the stock-recruitment relationship from the log(estimated/expected) for 1977 - 1985, the years with individual recruitment estimates. Use a standard error value of 0.40 for calculation of the log likelihood.

Total log likelihood

The log likelihoods for each type of data are multiplied by their assigned emphasis factor then summed to provide the current value for the overall log-likelihood. The emphasis factors for each component were set equal to 1.0 with the following exceptions. Goodness-of-fit to a stock-recruitment relationship was calculated, but assigned an emphasis of 0.001 so that it would not affect the parameter estimates. The importance of the trawl survey (small) is solely to set the mean level of recruitment for the survey years. Therefore, the likelihood of the deviations in individual years is given a nil emphasis of 0.001, and the fit to the size composition which contributes to this subset of the trawl survey is not even calculated. Instead, the emphasis on the fit to the mean of the trawl survey (small) is started at a high (100) value, then reduced within the run as the fit to the mean stays at a good level (>-0.02). Although the age and length compositions each have an emphasis of 1.0, they have already been deemphasized by scaling each individual sample so that the total number of fish measured (or aged) is a maximum of 400 in each sample. Note that the total number of fish measured (aged) acts as a multiplier on the log likelihood for that sample. Because the multinomial error model ignores process error, it is unreasonable to allow a sample with a large sample size to be given extremely high emphasis.

Parameter Estimation

The parameters which maximize the above overall log likelihood are found by an iterative procedure that utilizes numerical estimates of the first derivatives and Hessian matrix of mixed partial derivatives. In this adaptation of the Gauss-Newton procedure, the amount by which to change the parameters is calculated by inverting the Hessian matrix and post-multiplying by the first derivatives. The procedure works well and generally converges in fewer iterations than the number of parameters (26). However, this numerical, brute-force approach is time-consuming. On a 20 Mhz micro-computer with math co-processor, evaluation of the likelihood function takes about 1 second. But a very large number of evaluations are necessary to calculate all the derivatives so, even with numerous short-cuts, the total run time is 15 min to 1 hour.

Results

The configuration of the model included the parameters and coefficients listed in Tables 6 and 7. Evaluation of the model's ability to match the sablefish database proceeded in several stages. Most of these stages occurred in the preliminary scenario, then a small subset were evaluated in the final scenario. The differences between the two scenarios are as follows: (1) extra juvenile mortality - none in the preliminary scenario, estimated in the final scenario; (2) area expansion of the trawl survey - none in the preliminary and 6.5% expansion to Pt. Conception in the final runs; (3) size at age 5 - revised downwards in final runs due to bias detected in preliminary runs and because the L_5 used in the preliminary runs was based on the growth curves fit to the 1983 and 1985 pot survey data rather than the observed mean size at age 5 in these two surveys; (4) maximum size - best values were estimated in the first stage of the final scenario to be less than the values used in the preliminary scenario. The expected impact of the differences between the two scenarios is that juvenile mortality will decrease estimated population biomass, area expansion will increase biomass, and decreased growth and decreased maximum size will decrease biomass.

Preliminary scenario

Incomplete models

The first set of runs in the preliminary scenario was designed to gradually relax the assumptions made in past analyses. The first run was designed to mimic stock reduction analysis, albeit in a cumbersome age-structured manner (Table 8). All recruitments were taken from the stock-recruitment relationship, only the fit to the mean abundance in the 3 tri-ennial surveys was considered, the fixed gear selectivity was set nearly at knife-edge at age 3, trawl selectivity was set so that the peak occurred at 44-45 cm and gradually declined for larger fish, and the only parameter estimated was the level of virgin recruitment. Hence we are calculating the virgin recruitment level that would produce the mean of the 3 observed recruitments and be consistent with the observed time series of fishery removals. The resultant estimate of age 3+ biomass in 1988 is 127,000 mt, down from 240,000 mt in 1970. The fit of this simple model to the individual surveys and to the age and length compositions is poor. When the survey selectivities and, especially, the fishery selectivities are estimated, there are large improvements to the fit to these data but little change in the estimated abundance. Fitting the individual recruitments during 1977 - 1985 results in a smaller improvement to the overall likelihood function and a decrease in the level of abundance. The improved fit obtained by estimating individual recruitments is due to the model's ability to match the scant information on variation in year class strength. Because the improvement is small, it seems that either variation in recruitment has not been great or that the various types of data are not consistent in indicating which years had good recruitments. When individual recruitments are estimated, the model is now able to estimate that the mean recruitment during the period 1977 - 1985 was less than the mean of the recruitments observed in 1980, 1983, and 1986. This causes mean biomass to be lower and to decline more rapidly, thus improving the fit to the declining pot index.

Table 6. Constants in the sablefish synthesis model.

	Preliminary	Final
Male growth:		
Length at age 1	38.4	38.4
Length at age 5	52.3	52.0
Asymptotic length	70.0	64.5
c.v. length at age 1	0.068	0.068
c.v. length at age 20	0.0902	0.0902
Female growth:		
Length at age 1	38.4	38.4
Length at age 5	57.3	56.2
Asymptotic length	85.0	77.5
c.v. length at age 1	0.068	0.068
c.v. length at age 20	0.1452	0.1452
Length-Weight power function		
intercept	2.3319E-6	2.3319E-6
slope	3.3639	3.3639
Maturity-Length logistic function		
slope	0.2491	0.2491
Length at 50% maturity	58.3	58.3
Trawl fishery logistic retention function		
slope	0.809	0.809
Length at 50% retention	41.4	41.4
Asymptotic retention	1.00	1.00
Trawl survey are multiplier	1.000	1.065
Long-term tag loss rate	0.100	0.100
Stock-recruitment density dependence	0.889	0.889
Ageing error saturation function		
parameter 1	0.223	0.223
parameter 2	4.345	4.345
Catch multiplier	1.000	1.000

Table 7. Parameters estimated by numerical calculation of derivatives to the overall log likelihood, except natural mortality, trawl fishery P1, and trawl survey P1 were fixed at the indicated values and were not changed within a run and recruitment multipliers expressed as negative values are simply calculated from the spawner-recruitment curve and are not individually estimated. Recruitments are expressed as multiples of the mean recruitment.

	Initial value	Final value
Nat mort	0.15	0.15
Juve mort	0.04	0.012
Male effect	1.50	1.717
Fixed P1	45.0	44.4
P2	65.0	67.2
P3	4.0	2.154
Trawl P1	36.0	36.0
P2	50.0	57.6
P3	4.0	4.215
Trawl Surv P1	24.0	24.0
P2	38.0	38.3
P3	3.0	3.354
N pot P1	45.0	43.8
P2	55.0	54.2
P3	2.5	2.144
S pot P1	45.0	42.9
P2	55.0	53.4
P3	2.5	2.499
Virgin Recr.	9500.	9522.
Mean Recr.	9500.	9560.
Recr 69	-1.0	-0.971
Recr 70	-1.0	-0.971
Recr 71	-1.0	-0.971
Recr 72	-1.0	-0.971
Recr 73	-1.0	-0.968
Recr 74	-1.0	-0.966
Recr 75	-1.0	-0.962
Recr 76	-1.0	-0.955
Recr 77	1.5	1.598
Recr 78	0.5	0.217
Recr 79	1.5	1.763
Recr 80	1.5	1.345
Recr 81	1.0	0.819
Recr 82	1.0	0.838
Recr 83	0.5	0.650
Recr 84	0.5	0.499
Recr 85	1.5	1.266
Recr 86	-1.0	-0.841
Recr 87	-1.0	-0.827

Table 8. Summary of synthesis model runs. The values displayed are estimated virgin recruitment, estimated mean recruitment for the 1977 - 1985 year classes, biomass for ages 3+ in 1970 and 1988 (values are mean within year, not beginning of year), fishing mortality for ages 5+ which is used to calculate expected tag returns, the overall log likelihood calculated using the standard emphasis factors, and for the northern pot index the log likelihood of the time series and the expected survey value for 1987.

	Recruitment		Age 3+ Biomass		Age 5+ F in	Total	Northern Pot	
Title	Virgin	Mean	1970	1988	1988	Like	Like	E(87)
Incomplete models								
SRA MIMIC	10969	N/A	240	127	0.073	-3293	-34	6.3
FIT SURVEY	11470	N/A	253	120	0.065	-2672	-33	6.0
FIT SURVEY & FISH	10817	N/A	236	124	0.085	-1341	-35	6.6
FIT SURVEY & RECR	7136	10234	141	54	0.149	-2601	-18	5.8
Preliminary "best" model								
NULL START	8987	9080	189	86	0.122	-1196	-21	5.6
GOOD START (LOW VR)	9688	9286	207	95	0.111	-1196	-20	5.4
GOOD START (HIGH VR)	9825	9284	210	95	0.111	-1195	-19	5.3
No forcing on mean trawl survey small fish								
GOOD START	8913	7955	187	68	0.155	-1192	-18	4.8
GOOD START (LOW VR)	8463	7253	175	54	0.192	-1192	-17	4.4
GOOD START (HIGH VR)	9478	8752	201	84	0.126	-1192	-19	5.2

Table 8 continued.

Title	Recruitment Virgin	Recruitment Mean	Age 3+ Biomass 1970	Age 3+ Biomass 1988	Age 5+ F in 1988	Total Like	Northern Pot Like	Northern Pot E(87)
Emphasis runs								
STOCK-RECR 10x	9887	9370	212	101	0.104	-1212	-23	5.8
STOCK-RECR 0.1X	9493	9185	202	92	0.114	-1199	-19	5.5
TAG RETURN 100x	12429	11348	277	141	0.077	-2064	-40	6.5
TAG RETURN 10x	9497	9168	202	94	0.111	-1206	-23	5.8
TAG RETURN 0.1x	9864	9298	211	95	0.111	-1195	-19	5.3
TRL SURV 10x ALL	10774	10320	235	111	0.096	-1255	-15	4.7
TRL SURV 0.1x ALL	9330	8702	198	85	0.123	-1207	-20	5.5
TRL SURV 10x ABUND	9893	9216	212	94	0.112	-1195	-19	5.2
TRL SURV 0.1x ABUND	9604	9195	205	92	0.114	-1193	-20	5.4
POT SURV 10X ALL	5924	7699	109	49	0.227	-1441	-27	6.4
POT SURV 0.1X ALL	19796	12447	466	235	0.046	-1394	-23	3.7
POT SURV 0.1X ABUND	9482	9248	201	93	0.113	-1194	-21	5.6
POT SURV 5X ABUND	9630	8577	205	80	0.118	-1213	-12	4.6
POT SURV 10X ABUND	8841	7757	185	58	0.174	-1265	-6	4.1
POT SURV 25X ABUND	8817	7610	184	52	0.189	-1390	3	3.7
FISHERY 10X	22205	13315	528	272	0.040	-1452	-28	3.6
FISHERY 0.1X	6408	8027	121	57	0.186	-1318	-26	6.4
AGE COMP 10X	8957	8174	188	89	0.116	-1603	-27	6.0
AGE COMP 0.1X	7754	8986	157	67	0.157	-1338	-22	5.9
LEN COMP 10X	7480	9408	149	71	0.150	-1386	-27	6.5
LEN COMP 0.1X	9592	8056	204	91	0.113	-1579	-19	5.3

Title	Recruitment Virgin	Recruitment Mean	Age 3+ Biomass 1970	Age 3+ Biomass 1988	Age 5+ F in 1988	Total Like	Northern Pot Like	Northern Pot E(87)
Sensitivity to biological and other constants								
BIOLOGY - SET-UP	9528	9122	202	91	0.116	-1193	-20	5.4
LARGE MALES 75	9404	8953	205	91	0.118	-1228	-20	5.4
SMALL MALES 65	9606	9228	198	91	0.116	-1176	-20	5.5
FAST MALES L5=54.3	10232	9592	231	110	0.092	-1275	-19	5.3
SLOW MALES L5=50.3	9021	8619	180	72	0.148	-1159	-21	5.3
LARGE FEMALE 90	9451	9117	209	94	0.114	-1218	-20	5.4
SMALL FEMALE 80	9531	9068	194	85	0.120	-1177	-20	5.4
FAST FEMALE L5=59.3	9695	9484	221	108	0.098	-1240	-20	5.6
SLOW FEMALE L5=55.3	9232	8556	180	71	0.147	-1181	-20	5.1
NATURAL MORT=.175	11068	9204	180	66	0.155	-1222	-19	4.7
NATURAL MORT=.125	7678	8734	219	113	0.096	-1177	-22	6.1
NATURAL MORT=.100	6419	8604	263	155	0.073	-1177	-25	6.7
EXTRA JUVEMORT=.05	9902	9302	193	79	0.132	-1195	-19	5.1
EXTRA JUVEMORT=.15	11401	10393	189	74	0.141	-1199	-19	5.0
LOWER AGE ERROR	10121	9347	218	101	0.104	-1209	-23	5.5
HIGHER AGE ERROR	9472	8932	201	87	0.120	-1190	-21	5.3
CATCH MULT = 1.05	9708	9247	207	88	0.126	-1193	-19	5.3
CATCH MULT = 1.20	10279	9400	221	77	0.163	-1189	-18	4.8
MAX TWL RETAIN=.95	9559	9162	203	88	0.123	-1193	-19	5.3
MAX TWL RETAIN=.90	9618	9220	205	85	0.130	-1192	-19	5.2
TAGLOSS=.15 (10x)	11730	9731	259	123	0.109	-1222	-22	5.4
TAGLOSS=.05 (10x)	8077	8687	165	77	0.173	-1211	-25	6.2
TWL RECR SIZE=38	9394	8875	199	87	0.121	-1203	-20	5.3
TWL RECR SIZE=34	9549	9280	203	91	0.115	-1194	-19	5.4
TRL RECR SIZE=26	9548	9176	203	91	0.115	-1194	-20	5.4
TRL RECR SIZE=22	9512	9134	202	91	0.116	-1194	-20	5.4

Table 8 continued.

Title	Recruitment Virgin	Recruitment Mean	Age 3+ Biomass 1970	Age 3+ Biomass 1988	Age 5+ F in 1988	Total Like	Northern Pot Like	Northern Pot E(87)
FOLLOWING RUNS USE NO FORCING ON THE MEAN TRI-SMALL								
START 9300 7000	9402	9083	199	90	0.116	-1198	-20	5.5
START 8000 7000	9302	8255	197	76	0.137	-1193	-18	4.9
START 10000 7000	9358	8982	198	88	0.119	-1198	-20	5.4
START 11000 9000	9485	9365	201	95	0.110	-1215	-21	5.7
START 8000 6000	9000	8227	189	73	0.140	-1192	-18	5.0
STOCK-RECR 10x	9771	9234	209	99	0.107	-1216	-23	5.8
STOCK-RECR 0.1X	9618	9158	205	94	0.113	-1196	-20	5.5
TAG RETURN 10x	9359	8570	198	86	0.121	-1210	-22	5.6
TAG RETURN 0.1x	9486	8986	201	89	0.118	-1198	-20	5.3
TRI SURV 10x ALL	9460	8060	201	65	0.162	-1270	-14	3.7
TRI SURV 0.1x ALL	9642	9157	205	96	0.109	-1211	-21	5.7
TRI SURV 10x AB	9293	8562	196	81	0.129	-1199	-18	5.1
TRI SURV 0.1x AB	9084	8741	191	82	0.127	-1198	-20	5.4
POT SURV 10x ALL	5906	6108	108	25	0.431	-1446	3	4.5
POT SURV 0.1X ALL	18158	14117	424	241	0.045	-1378	-22	4.2
POT SURV 25x AB	7918	6595	161	33	0.289	-1386	1	3.3
POT SURV 10x AB	8198	6789	168	40	0.247	-1260	-6	3.6
POT SURV 5x AB	8397	7116	173	49	0.208	-1217	-11	4.0
POT SURV 0.1X AB	10009	10706	215	121	0.087	-1200	-25	6.3
FISHERY 10x	43783	31344	1079	765	0.015	-1417	-26	4.6
FISHERY 0.1x	6170	6345	116	31	0.334	-1333	-19	4.7
AGE COMP 10x	12140	16493	270	244	0.043	-1607	-39	8.4
AGE COMP 0.1x	7455	7455	149	42	0.245	-1346	-16	4.7
LEN COMP 10x	6507	7887	124	43	0.241	-1444	-23	5.7
LEN COMP 0.1x	9259	8170	196	91	0.111	-1596	-21	5.6

Table 8 continued.

Title	Recruitment Virgin	Recruitment Mean	Age 3+ Biomass 1970	Age 3+ Biomass 1988	Age 5+ F in 1988	Total Like	Northern Pot Like	Northern Pot E(87)
FOLLOWING RUNS DELETE ONE SURVEY OR FISHERY SAMPLE								
NULL, NO DELETIONS	9596	8893	204	87	0.121	-1195	-19	5.2
DEL 71 N POT SURV	12512	9567	279	127	0.085	-1089	-20	5.0
DEL 79 N POT SURV	9844	9867	211	102	0.104	-1095	-21	4.9
DEL 80 TRAWL SURV	9651	8825	206	89	0.117	-1112	-18	5.4
DEL 80 N POT SURV	9856	9586	211	100	0.106	-1187	-20	5.6
DEL 81 N POT SURV	9632	8785	205	88	0.120	-1145	-13	5.7
DEL 83 TRAWL SURV	9400	9002	199	89	0.118	-1149	-21	5.5
DEL 83 N POT SURV	10722	9916	233	116	0.092	-1097	-9	5.3
DEL 84 S POT SURV	9486	9301	201	96	0.110	-1170	-22	5.7
DEL 85 N POT SURV	11224	10337	246	120	0.089	-960	-18	4.8
DEL 86 FIXED FISH	9081	8931	191	90	0.115	-1146	-21	5.7
DEL 86 TRAWL FISH	8620	8975	179	83	0.126	-1120	-21	5.8
DEL 86 TRAWL SURV	9437	9654	200	101	0.104	-1119	-23	6.1
DEL 86 S POT SURV	9541	9350	203	96	0.109	-1154	-22	5.7
DEL 87 FIXED FISH	8438	9122	174	83	0.127	-1046	-24	6.1
DEL 87 TRAWL FISH	8250	9099	176	83	0.126	-1048	-22	6.1
DEL 87 N POT SURV	9307	9511	197	95	0.110	-1172	-7	6.1

Table 8. continued.

The following set of final runs have these characteristics:

1. increase survey abundances by 6.5% for the Conception expansion
2. include extra natural mortality on juveniles
3. change L5 values to 52.0 for males, 56.4 for females

Title	Recruitment		Age 3+ Biomass		Age 5+ F in	Total	Northern Pot	
	Virgin	Mean	1970	1988	1988	Like	Like	E(87)
Find best L values								
M 65 F 76	9910	9710	176	76	0.132	-1142	-20.4	5.36
M 65 F 78	10133	9789	179	80	0.127	-1141	-20.5	5.42
M 65 F 80	9853	9671	177	74	0.136	-1145	-19.7	5.32
M 65 F 82	9977	9695	180	79	0.13	-1151	-20.3	5.42
M 62 F 79	10223	9735	177	79	0.128	-1153	-20.4	5.43
M 64 F 79	9922	9751	176	76	0.133	-1141	-20.7	5.4
M 66 F 79	10113	9521	178	77	0.132	-1146	-20.2	5.35
M 68 F 79	9651	9609	177	74	0.137	-1156	-20.2	5.36
Select best L as M 64.5, F 77.5								
Final Runs. THE FIRST OF THESE IS SELECTED AS THE BEST FINAL RUN								
virg-recr=8000	9522	9560	176	79	0.126	-1143	-20.2	5.54
virg-recr=11000	10249	9913	175	79	0.128	-1153	-20.7	5.5
pot abund 10x	9716	8369	163	48	0.199	-1224	-7.3	4.03
age comp 0.1x	8947	9998	145	65	0.156	-1247	-22.7	5.84
natmort = .17	11861	10143	176	68	0.144	-1170	-19	4.87
natmort = .13	8426	9436	175	85	0.119	-1128	-22.3	5.97
natmort = .11	7267	9405	175	91	0.114	-1095	-23.9	6.44

Preliminary best model

The model is able to converge on approximately the same "best" point from a range of starting points (Table 8): initial selectivities are knife-edge and initial recruitments are from stock-recruitment relationship (null start), good starting values but a low initial guess for virgin recruitment (good low start), or good starting values and a high initial guess for virgin recruitment (good high start). The end result is sensitive to the starting virgin recruitment level when run without the extra likelihood component which forces a near perfect fit to the mean of the trawl survey (small). Without this forcing, the estimated recruitment levels are lower which causes a more rapid decline in biomass and a better fit to the pot index surveys. Note that the overall likelihood is the same for these three different levels of virgin recruitment. The patterns of estimated selectivity in this model largely match our prior expectations (Table 9): smaller fish are more available to the trawl fishery than to the fixed gear fishery, maximum availability to the trawl survey (all) occurs for the size range of the age 1 fish then trails off rapidly throughout the size range of the age 2 and 3 fish, the size range of the age 1 and age 2 fish is barely available to the pot index, peak availability to the pot index occurs for the size range of ages 4-6, availability to the southern pot index is displaced slightly towards smaller fish relative to the northern pot index.

Varying Emphasis

The level of emphasis placed on each type of data can influence the nature of the final solution if the various types of data are not completely consistent with each other. If all of the components of the overall log likelihood function are correctly specified, then placing equal emphasis on each type should achieve the best compromise solution among the various types of data. However, we have already noted that the multinomial model used to specify the error structure for the age and length compositions will tend to overestimate confidence in these samples. Certainly other simplifications in the model will distort the correctness of the likelihood definitions. Here we will explore the sensitivity of the overall result to variation in the emphasis placed on each type of data. In each of the following runs the emphasis on some likelihood component is changed. To facilitate comparison of results, we also calculate the overall likelihood with the original, standard emphasis factors. These likelihoods are presented in Table 8.

1. Stock-recruitment. The basic model largely ignored the fit to this function, the emphasis was only 0.001. Raising the emphasis to 1.0 degraded the overall likelihood by only about 5 units. Raising the emphasis to 10.0 tended to reduce the variation in the estimated recruitments as they were pulled closer to the stock-recruitment relationship. This degraded the fit and raised the ending biomass, similar to the above models in which the all recruitments were taken directly from the stock-recruitment relationship.

2. Tag return. Reducing this emphasis to 0.1 had no effect on the model. Increasing the emphasis to 10.0 slightly degraded the fit but did not substantially change the estimated stock abundance. However, increasing the emphasis to 100.0 caused a large increase in estimated abundance and a great degradation in the overall likelihood.

Table 9. Size specific selectivities in preliminary model. The trawl survey (small) selectivities are fixed at the indicated values and are not estimated. The trawl fishery retention fractions are calculated from a logistic function and are not estimated in the model.

Length	Fishery Fixed	Fishery Trawl	Trawl Survey small	Trawl Survey all	N. Pot	S. Pot	Trawl retain
			Male Selectivities				
32.0- 36.0	.003	.005	1.000	.971	.005	.005	.007
36.0- 38.0	.005	.073	1.000	1.000	.009	.009	.036
38.0- 40.0	.006	.209	1.000	.852	.012	.011	.152
40.0- 42.0	.007	.349	1.000	.661	.014	.013	.431
42.0- 44.0	.009	.488	.000	.484	.017	.078	.755
44.0- 46.0	.066	.626	.000	.347	.143	.302	.934
46.0- 48.0	.220	.758	.000	.248	.456	.616	.986
48.0- 50.0	.414	.877	.000	.179	.796	.878	.997
50.0- 52.0	.602	.965	.000	.131	1.000	1.000	.999
52.0- 54.0	.774	1.000	.000	.097	.986	.926	1.000
54.0- 56.0	.910	.964	.000	.073	.807	.723	1.000
56.0- 58.0	.989	.859	.000	.056	.591	.509	1.000
58.0- 60.0	1.000	.710	.000	.044	.416	.345	1.000
60.0- 64.0	.888	.491	.000	.031	.259	.206	1.000
64.0- 68.0	.670	.271	.000	.020	.138	.103	1.000
68.0- 72.0	.462	.146	.000	.014	.080	.056	1.000
72.0- 76.0	.312	.081	.000	.010	.050	.033	1.000
76.0- 80.0	.214	.047	.000	.007	.033	.021	1.000
80.0- 90.0	.128	.023	.000	.004	.020	.012	1.000
90.0-100.0	.080	.011	.000	.003	.012	.007	1.000
			Female Selectivities				
32.0- 36.0	.003	.005	1.000	.963	.006	.005	.007
36.0- 38.0	.005	.079	1.000	1.000	.010	.010	.036
38.0- 40.0	.007	.227	1.000	.924	.013	.012	.152
40.0- 42.0	.008	.378	1.000	.818	.016	.015	.431
42.0- 44.0	.010	.527	.000	.705	.019	.087	.755
44.0- 46.0	.074	.671	.000	.599	.155	.333	.934
46.0- 48.0	.246	.802	.000	.506	.474	.657	.986
48.0- 50.0	.454	.909	.000	.427	.782	.893	.997
50.0- 52.0	.640	.979	.000	.362	.955	1.000	.999
52.0- 54.0	.792	1.000	.000	.308	1.000	.987	1.000
54.0- 56.0	.903	.970	.000	.264	.962	.898	1.000
56.0- 58.0	.971	.897	.000	.228	.884	.782	1.000
58.0- 60.0	1.000	.796	.000	.198	.795	.667	1.000
60.0- 64.0	.981	.633	.000	.163	.672	.526	1.000
64.0- 68.0	.908	.442	.000	.127	.536	.383	1.000
68.0- 72.0	.808	.302	.000	.101	.435	.286	1.000
72.0- 76.0	.708	.208	.000	.082	.359	.220	1.000
76.0- 80.0	.617	.146	.000	.067	.303	.174	1.000
80.0- 90.0	.497	.090	.000	.050	.237	.126	1.000
90.0-100.0	.418	.057	.000	.040	.197	.097	1.000

3. Tri-ennial trawl survey. Tenfold increase or decrease in the emphasis on just the abundance estimates had no effect on the model. Apparently these observations are highly consistent with other data in the model. Increasing or decreasing the emphasis on survey abundance and length composition by tenfold caused a degradation in the overall likelihood, but a different effect on estimated abundance. High emphasis on all trawl survey data caused higher estimated abundance and, unexpectedly, an improved fit to the pot index abundance.

4. Pot surveys. Increasing the emphasis on all pot survey abundance, length composition and age composition data produced a poor overall fit and an unreasonable result with a very low level of virgin recruitment. This may be due to an improved fit to the 1971 northern pot index size composition because, note below, that deletion of the 1971 northern pot index data caused a high estimate of virgin recruitment. Conversely, reducing the emphasis on all pot index data also produced a poor overall fit, but with a very high level of estimated abundance. A very consistent, monotonic result occurred when the change in emphasis was only on the abundance aspect of the pot index survey. Higher emphasis on the abundance in the pot index caused a much improved fit to this type of data, a degraded overall fit, and a decrease in the estimate of current biomass.

5. All fishery data. The overall result was highly sensitive to the emphasis placed on the fishery age and size composition data. Primarily because the great abundance of older fish in the fisheries is at odds with the declining pot index and the lack of older fish in the 1983 and 1985 pot index surveys. Note that the break-and-burn technology for reading sablefish otoliths is still evolving. A change in ageing criteria occurred between the time the 1986 port samples were read and the 1987 port samples were read. The magnitude of the change is not known and it is likely that only older fish are affected. Some otoliths previously read by the old criteria are being re-read so that a calibration can be developed.

6. All age composition or all size composition data. The estimated biomass was not overly sensitive to the emphasis placed on all the age composition data or on all the size composition data. But the overall fit to the model is substantially degraded if the emphasis on all age composition or all size composition is changed. We see no reason for setting these emphasis factors at anything other than 1.0.

Model Sensitivity to Constants

In the next stage of the preliminary runs we investigated the model's sensitivity to various fixed coefficients.

1. Growth. Faster and slower growth and maximum size was investigated for each sex (Table 8). Better fits and substantially lower biomasses were obtained at slower growth or smaller maximum size for each sex. On the basis of this result we reexamined the information available on size at age 5 and made small adjustments for the final scenario and we decided to use the model to determine which values for maximum size gave the best fit.

2. Natural mortality. A better fit and substantially higher biomass was obtained at lower levels of natural mortality. Most of the improved fit was due to a better match to the high frequency of old fish in the 1987 fishery samples. The fit to the pot index surveys was degraded at lower levels of natural mortality because with more old fish in the population the estimated pot index cannot change nearly as rapidly as the observations changed. At low levels of natural mortality an unexpected result occurs. Estimated virgin recruitment is substantially less than the estimated mean level of recruitment during 1977-1985. This occurs because virgin recruitment and natural mortality determine the relative abundance of older fish at the end of the time series, when most of the data wre collected. With lower M, virgin recruitment also must be lower otherwise there will be too many old fish in the population. Although a better overall fit is obtained at lower levels of natural mortality, the poor fit to the pot index and the low estimate for virgin recruitment suggest that the natural mortality equal to 0.15 is more realistic for the WOC portion of the sablefish population.

Introducing additional natural mortality on juveniles had an insignificant effect on the fit and lowered the estimated current biomass. The major impact was on the estimated level of recruitment. This occurs because the recruitment values are referenced to the beginning of the year, but the recruitment measurements (i.e. the trawl survey (small)) are referenced to the mean abundance within the year. The extra natural mortality on juveniles has a large impact on the ratio of initial numbers to mean numbers so at higher levels of juvenile mortality the estimated initial numbers must be increased to maintain a good match with the observed mean numbers.

3. Ageing error. Changing the level of ageing error had only a small effect on estimated biomasses or the goodness of fit.

4. Catch multiplier. Increasing all of the catch biomasses (trawl and fixed) by 5 or 20% had the expected effect of decreasing the estimated current biomass because mean recruitment is fixed by the 3 observed recruitments. This decrease in recent levels of biomass improves the fit to the pot index and, slightly, to the overall likelihood. If there is evidence that historical landings were underreported by more than 5%, then this factor should be incorporated in the analysis.

5. Trawl discard. In 1987 there is evidence that about 10.5% of large sablefish were discarded by the trawl fishery, presumably most of this occurred at the end of the year after the sablefish quota had been reached. If we assume that similar levels of discard occurred historically, then the model estimates a small reduction in the current biomass. In next year's version of the sablefish model we should make provisions for yearly changes in the amount of sablefish discarded after the close of the season.

6. Tag loss. Increasing or decreasing the long term level of tag loss causes a degradation in the overall likelihood. Note that these runs used a 10x emphasis on the tag return data, so the default for comparison is the emphasis run called TAG RETURN 10x. Estimated biomass is positively correlated with the level of tag loss for the following reason: if tag loss is lower than the default value of 0.1 then, in order for the model to maintain a good match to the observed pattern of tag returns, it must decrease estimated biomass thus

increasing estimated fishing mortality thus increasing the rate at which tags are removed from the tagged population.

7. First availability. The model has difficulty in estimating the size at which sablefish first become available to the trawl fishery. This occurs because the retention goes to zero for the small fish so one cannot tell the difference between not catching any small fish and catching and discarding many small fish. In fact, the model prefers the latter scenario because it allows it to kill off many small fish, driving the biomass down and achieving a better fit to the declining pot index. We found it necessary to fix the size at first availability at a reasonable value (36 cm). Table 8 indicates that any value in the range 34 - 38 cm would have the same result. The model also had difficulty with estimating the size at first availability to the tri-ennial trawl survey probably because the model ignored fish less than 32 cm and the first category, 32-35 cm, was 4 cm wide. We found that values in the range 22-26 cm gave the best shape to the availability function for larger sizes and all runs were done with this availability parameter set at 24 cm.

Model Sensitivity to Data

The influence of individual surveys and fishery samples was investigated by deleting one survey or fishery sample then running the model without that observation. Note that in Table 8 the reported likelihoods cannot be readily compared because the likelihoods are total likelihoods and are not likelihoods per observation. When a deletion was made, all types of data (abundance, size composition, and age composition) were deleted at the same time. Among these 16 runs, the mean age 3+ biomass in 1988 was 97,000 mt (s = 13,000). The minimum was 83,000 mt which occurred when the 86 trawl fishery samples, or the 87 trawl fishery, or the 87 fixed gear fishery samples were deleted. The maximum was 127,000 mt which occurred with deletion of the 1971 northern pot survey, and large biomasses also resulted from deletion of the 1983 or 1985 northern pot surveys. These results reinforce a conclusion reached earlier. The relative abundance of old fish in the 1986 and 1987 fishery samples is at odds with the scarcity of old fish in the 1983 and 1985 pot index samples and with the large recent decline in the pot index.

Final Scenario

Final Model Configuration

The "final" set of runs was made with the following changes to the "preliminary" scenario. Abundances in the trawl surveys was increased by 6.5% to extrapolate to Pt. Conception. Extra juvenile natural mortality was incorporated as a parameter to be estimated and was given an initial value of 0.04, so that age 1 fish had a natural mortality of 0.19 and this rate declined exponentially to 0.15 for the older fish. Size at age 5 was adjusted to better fit the observed sizes at age 5 in the 1983 and 1985 pot index surveys. The best values for maximum size were estimated in the first set of the final scenario.

We investigated values of male maximum size in the range 62 - 68 cm (Table 8). The best fit occurred at 64 cm and we selected 64.5 cm by a crude quadratic interpolation as the value to use in the final runs. In comparing the L = 64 to the L = 68 runs, the greatest parameter change was the parameter which decreased the availability of larger males. With a smaller L , the large males are estimated to be more available. The change in likelihood for those components with substantial change was as follows: fixed gear age comp +7, trawl age comp +16, north pot survey age comp -12, fixed gear size comp +3, trawl size comp +5, trawl survey size comp +3, north pot survey size comp -3, south pot survey size comp -3, overall +14. For females, we investigated values in the range 76- 82 cm with 77.5 cm being selected as providing the best fit. At L = 78, relative to L = 82, the larger females were estimated to have higher availability to all surveys and fisheries. The change in likelihood was as follows: fixed gear age comp +2, trawl age comp +7, north pot survey age comp -7, fixed gear size comp +6, trawl size comp +1, trawl survey size comp -5, north pot survey size comp +4, south pot survey size comp +3, overall +10.

Seven final runs were made after incorporating the above changes to male and female maximum size. These runs were selected to produce an estimate of the most likely status of the west coast sablefish stock and to bracket a range of plausible alternatives. Results are summarized in Tables 10-14 and Figures 15-16. Because the extra juvenile mortality parameter was included in the set of parameters to be estimated, we tried two different starting values of virgin recruitment, 8,000 and 11,000 (Runs 1 and 2). The higher value produced a higher ending estimate for virgin recruitment (10,249 vs. 9,522) and for juvenile mortality (.042 vs. .012) and a worse fit (-1153 vs. -1143). Beginning age 3+ biomasses (174,880 vs. 175,601) and ending age 3+ biomasses (78,524 vs. 78,621) were nearly identical. The run with the starting value of 8,000 was selected as the best run to be examined in more detail below, and the following runs used a starting value of 9,500 (which was the final value from run 1) for virgin recruitment.

Increasing the emphasis on the pot index survey's abundance index (Run 3) certainly increases the goodness of fit to these observations, but degrades the fit to several types of size and age composition, especially the size composition in the northern pot index itself. This occurs for two reasons. First, the model, in an attempt to better match the fluctuations in the pot index, estimates that a narrower size range is available to the pot index thus degrading the fit to the size composition. Conversely, with a broader size (hence age) range available to the survey, the estimated survey index cannot change rapidly enough to go down to 4.8 in 1981, up to 10.6 in 1983, then decline yearly to 2.8 in 1987. Secondly, the changes in rcruitment necessary to match the index are not obvious in the size/age composition data. Overall, the fit to the northern pot index size composition in run 1 (Figure 17) was reasonably good.

Decreasing the emphasis on all age composition data causes a large degradation in the fit to the fishery age composition data (Run 4), and an improvement in the fit to all length composition data, especially the northern pot survey length composition. The fit to the pot index abundance observations is slightly degraded because, as mentioned above, a tight fit to these observations is somewhat at odds with a tight fit to the corresponding size compositions.

Natural mortality levels from 0.11 to 0.17 (Runs 5,6,7) were evaluated. Lower levels of natural mortality produce higher estimates of juvenile natural mortality, lower estimates of virgin recruitment, nearly identical starting

Table 10. Parameter values for the final runs. Pot 10x had an emphasis of 10.0 on the abundances in the northern and southern pot index. Age 0.1x had an emphasis of 0.1 on all types of age composition. Recruitments indicated as negative values were simply taken from the stock-recruitment relationship and were not individually estimated as parameters of the model. Recruitments for the year classes 1977 - 1985 were estimated as ratios to the estimated mean recruitment. Three parameters, natural mortality, trawl fishery P1, and trawl survey P1 were fixed at the indicated values and were not changed within a run.

Parameter	Start Virgin Rec 8000	Start Virgin Rec 11000	Pot 10x	Age 0.1x	Natural Mortality M=.17	Natural Mortality M=.13	Natural Mortality M=.11
Nat mort	0.15	0.15	0.15	0.15	0.17	0.13	0.11
Juve mort	0.012	0.042	0.044	0.05	0.028	0.050	0.101
Male effect	1.717	1.379	1.421	1.525	1.430	1.423	1.537
Fixed P1	44.4	44.8	44.6	44.9	44.6	44.8	44.9
P2	67.2	66.4	61.5	67.5	66.9	64.8	64.2
P3	2.154	2.289	2.106	1.893	2.193	2.214	2.216
Trawl P1	36	36	36	36	36	36	36
P2	57.6	58.1	56.3	58.0	57.8	57.9	58.0
P3	4.215	4.566	5.103	4.794	4.359	4.567	4.682
Twl Svy P1	24	24	24	24	24	24	24
P2	38.3	38.1	39.4	38.7	38.1	38.5	39.0
P3	3.354	3.407	3.594	3.175	3.37	3.475	3.46
N pot P1	43.8	44.6	44.7	44.7	44.6	44.7	44.7
P2	54.2	53.3	53.3	53.9	53.4	53.2	53.4
P3	2.144	2.078	2.156	1.788	1.962	2.158	2.262
S pot P1	42.9	44.6	43.0	43.1	43.0	44.4	43.2
P2	53.4	51.9	52.5	53.6	53.2	52.1	53.1
P3	2.499	2.175	2.695	2.157	2.465	2.292	2.595
Virgin Recr.	9522	10249	9716	8947	11861	8426	7267
Mean Recr.	9560	9913	8369	9998	10143	9436	9405
Recr 69	-9283	-9952	-9415	-8628	-11593	-8153	-6997
Recr 70	-9283	-9952	-9415	-8628	-11593	-8153	-6997
Recr 71	-9283	-9952	-9415	-8628	-11593	-8153	-6997
Recr 72	-9283	-9952	-9415	-8628	-11593	-8153	-6997
Recr 73	-9254	-9923	-9382	-8598	-11553	-8125	-6979
Recr 74	-9235	-9903	-9365	-8578	-11532	-8115	-6960
Recr 75	-9197	-9863	-9323	-8528	-11482	-8077	-6932
Recr 76	-9130	-9794	-9248	-8458	-11411	-8021	-6875
Recr 77	15277	15018	12570	15156	17618	14872	14888
Recr 78	2075	3668	1306	940	2069	2076	1307
Recr 79	16854	16525	24521	15386	18389	16806	16563
Recr 80	12858	13303	10352	15126	14169	10682	10816
Recr 81	7830	7930	5892	7638	8145	8436	8088
Recr 82	8011	8396	7122	8338	8540	7662	7703
Recr 83	6214	6532	2820	10587	6258	6351	6555
Recr 84	4770	5402	3088	1320	4950	5162	4957
Recr 85	12103	12440	7791	15766	11198	12909	14004
Recr 86	-8049	-8624	-7867	-7138	-9980	-7077	-6048
Recr 87	-7906	-8465	-7574	-7018	-9737	-6983	-5991

Table 11. Likelihood values for the final runs. Where Svy indicates a survey and Fish indicates a fishery, Twl indicates trawl, Sml indicates the <42 cm component of the tri-ennial trawl survey. Twl Svy Sml Q indicates the extra component for forcing the mean deviation to be near zero. The total likelihood is the sum of the individual components weighted by the indicated emphasis factors, except using the alternate factors in the Pot 10x and the Age 0.1x runs. The standard total likelihood is computed after a run using the standard emphasis factors and zero emphasis on Twl Svy Sm Q.

		Start Virgin Rec		Pot	Age	Natural Mortality		
Type	Emphasis	8000	11000	10x	0.1x	M=.17	M=.13	M=.11
				Survey Abundance				
Twl Svy Sml	0.001	2.83	2.73	0.93	1.68	3.05	2.59	2.22
Twl Svy All	1	2.57	2.51	2.28	1.63	2.96	2.21	1.76
N Pot Svy	1(10)	-20.2	-20.7	-7.3	-22.7	-19.0	-22.3	-23.9
S Pot Svy	1(10)	-10.1	-10.4	0.0	-13.9	-7.5	-12.1	-13.8
				Age Composition				
Fix Fish	1(0.1)	-82.7	-83.1	-83.2	-138.6	-85.8	-80.9	-78.1
Twl Fish	1(0.1)	-138.7	-132.9	-160.2	-281.1	-144.4	-124.7	-119.0
N Pot Svy	1(0.1)	-135.6	-136.4	-130.4	-119.5	-139.2	-133.5	-132.8
				Size Composition				
Fix Fish	1	-66.0	-63.8	-57.7	-51.8	-62.8	-62.5	-63.5
Twl Fish	1	-48.4	-47.5	-33.2	-31.7	-44.6	-49.3	-52.3
Twl Svy	1	-191.0	-193.2	-206.8	-190.4	-190.3	-190.4	-187.7
N Pot Svy	1	-345.2	-342.7	-433.0	-282.5	-366.4	-328.6	-314.7
S Pot Svy	1	-38.1	-55.2	-37.5	-41.0	-41.0	-57.5	-42.8
				Other				
Twl Svy Sm Q	vary	-0.008	0.000	-0.013	-0.003	-0.003	-0.004	-0.010
Stock-Recr	0.001	-13.9	-4.6	-36.4	-51.6	-18.6	-13.0	-24.6
Tag Return	1	-69.7	-69.5	-77.2	-75.0	-71.7	-68.6	-67.8
Total		-1143.2	-1152.8	-1291.8	-761.5	-1169.9	-1128.3	-1095.2
Std. Total		-1143.1	-1152.8	-1224.3	-1246.6	-1169.7	-1128.2	-1094.8

Table 12. Estimates of the northern pot index for the 7 final runs: 1 = start virgin 8000, 2 = start virgin 11000, 3 = 10x pot emphasis, 4 = 0.1x age comp emphasis, 5 = natural mortality 0.17, 6 = natural mortality .13, 7 = natural mortality .11.

Final Run:		1	2	3	4	5	6	7
	Northern Pot Index							
Year	Obs	estimated						
70		10.6	10.5	11.6	11.0	11.0	10.2	9.8
71	10.3	10.5	10.4	11.5	10.9	10.9	10.1	9.8
72		10.3	10.3	11.3	10.7	10.8	9.9	9.6
73		10.1	10.1	11.1	10.5	10.5	9.8	9.4
74		9.9	9.9	10.8	10.3	10.3	9.6	9.2
75		9.6	9.7	10.5	9.9	10.0	9.3	9.0
76		9.0	9.1	9.7	9.1	9.4	8.7	8.3
77		8.5	8.6	9.1	8.6	8.9	8.2	7.9
78		8.3	8.5	8.9	8.3	8.8	8.1	7.7
79	11.4	8.0	8.1	8.2	7.8	8.4	7.7	7.4
80	6.8	7.8	7.9	7.8	7.6	8.1	7.7	7.5
81	4.8	7.7	7.8	7.9	7.4	7.9	7.7	7.6
82		7.9	7.9	8.7	7.6	7.9	8.0	8.0
83	10.6	7.9	7.8	8.4	7.7	7.7	8.0	8.1
84		7.4	7.4	7.5	7.4	7.1	7.6	7.8
85	7.4	6.7	6.7	6.2	6.9	6.3	7.0	7.3
86		6.0	5.9	4.9	6.4	5.4	6.3	6.7
87	2.8	5.5	5.5	4.0	5.8	4.9	6.0	6.4
88		5.7	5.6	3.9	6.1	4.9	6.2	6.8

Table 13. Estimates of the biomass at ages 3+ (mean within year) for the 7 final runs: 1 = start virgin 8000, 2 = start virgin 11000, 3 = 10x pot emphasis, 4 = 0.1x age comp emphasis, 5 = natural mortality 0.17, 6 = natural mortality .13, 7 = natural mortality .11.

Run:	1	2	3	4	5	6	7
Year	Biomass at Ages 3+						
70	175601	174880	162954	145019	175585	174899	174895
71	174976	174245	162198	144398	174991	174210	174155
72	172376	171957	159724	142136	172428	171835	171702
73	169049	168974	156495	139180	169187	168716	168460
74	165159	165441	152680	135673	165423	165008	164591
75	159302	159931	146843	130234	159762	159240	158580
76	146491	147420	133862	117857	147275	146295	145218
77	135798	137013	122966	107687	137057	135307	133669
78	130481	131993	117570	102703	132262	129697	127462
79	118499	120226	105235	91057	120875	117273	114344
80	117462	117973	99852	90491	120029	116570	114065
81	106553	108703	88188	79737	107373	106936	104653
82	109895	110655	99999	81788	109630	111215	109214
83	107402	107799	94316	82501	106011	107129	106180
84	100987	100883	85237	77027	97724	102507	102225
85	94512	94272	76898	72176	89715	96736	97607
86	86159	85861	63900	70171	79608	89641	91878
87	76962	77091	52198	58620	69142	81948	85046
88	78621	78524	47829	65094	67906	85474	90624

Table 14. Estimates of the fishing mortality for ages 5+ (weighted by numbers at age) for the 7 final runs: 1 = start virgin 8000, 2 = start virgin 11000, 3 = 10x pot emphasis, 4 = 0.1x age comp emphasis, 5 = natural mortality 0.17, 6 = natural mortality .13, 7 = natural mortality .11.

Run:	1	2	3	4	5	6	7
Year	------ Fishing Mortality at ages 5+ ----------						
70	0.023	0.023	0.025	0.028	0.023	0.023	0.024
71	0.025	0.025	0.027	0.030	0.024	0.025	0.026
72	0.043	0.043	0.047	0.052	0.043	0.044	0.045
73	0.035	0.035	0.038	0.042	0.035	0.036	0.037
74	0.053	0.053	0.058	0.064	0.053	0.054	0.055
75	0.068	0.068	0.075	0.083	0.068	0.069	0.071
76	0.166	0.167	0.187	0.206	0.166	0.170	0.172
77	0.068	0.068	0.076	0.086	0.067	0.070	0.072
78	0.104	0.104	0.116	0.132	0.102	0.107	0.110
79	0.202	0.202	0.232	0.261	0.199	0.207	0.214
80	0.081	0.080	0.094	0.106	0.079	0.082	0.085
81	0.102	0.102	0.117	0.134	0.101	0.103	0.106
82	0.168	0.168	0.187	0.221	0.168	0.171	0.175
83	0.135	0.136	0.147	0.178	0.137	0.136	0.138
84	0.138	0.139	0.167	0.177	0.142	0.138	0.140
85	0.151	0.153	0.194	0.193	0.160	0.150	0.150
86	0.153	0.154	0.211	0.192	0.165	0.149	0.147
87	0.157	0.159	0.238	0.196	0.175	0.150	0.146
88	0.126	0.128	0.199	0.156	0.144	0.119	0.114

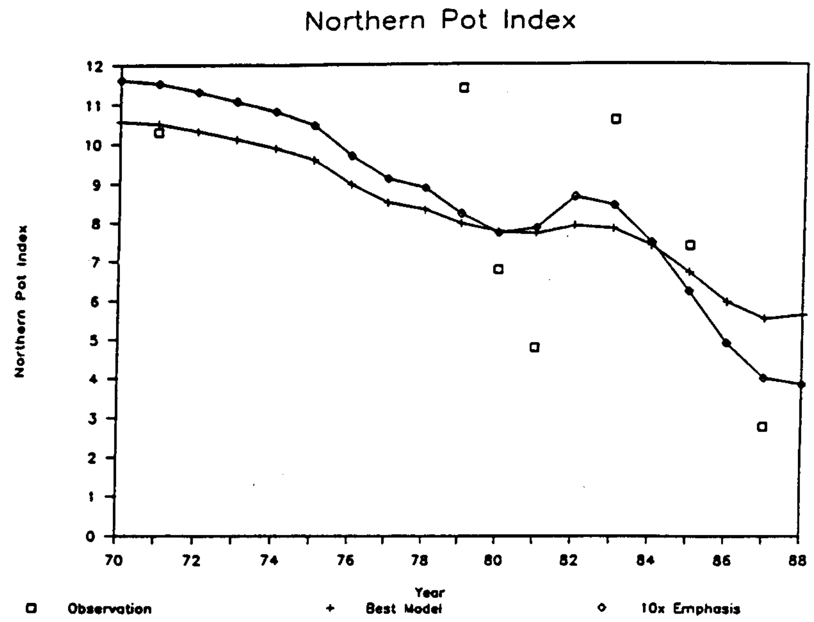


Figure 15. Northern pot index: observed and estimated.

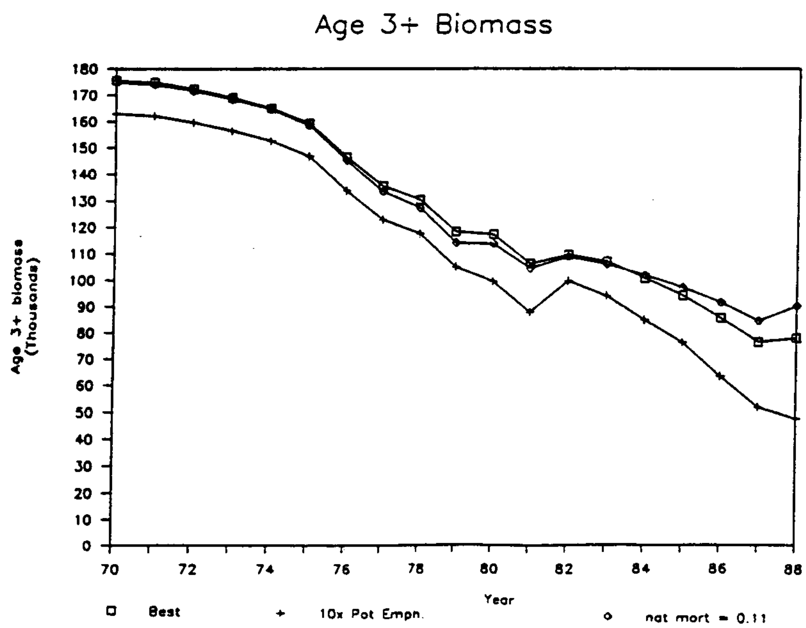


Figure 16. Biomass at age 3+ in final runs.

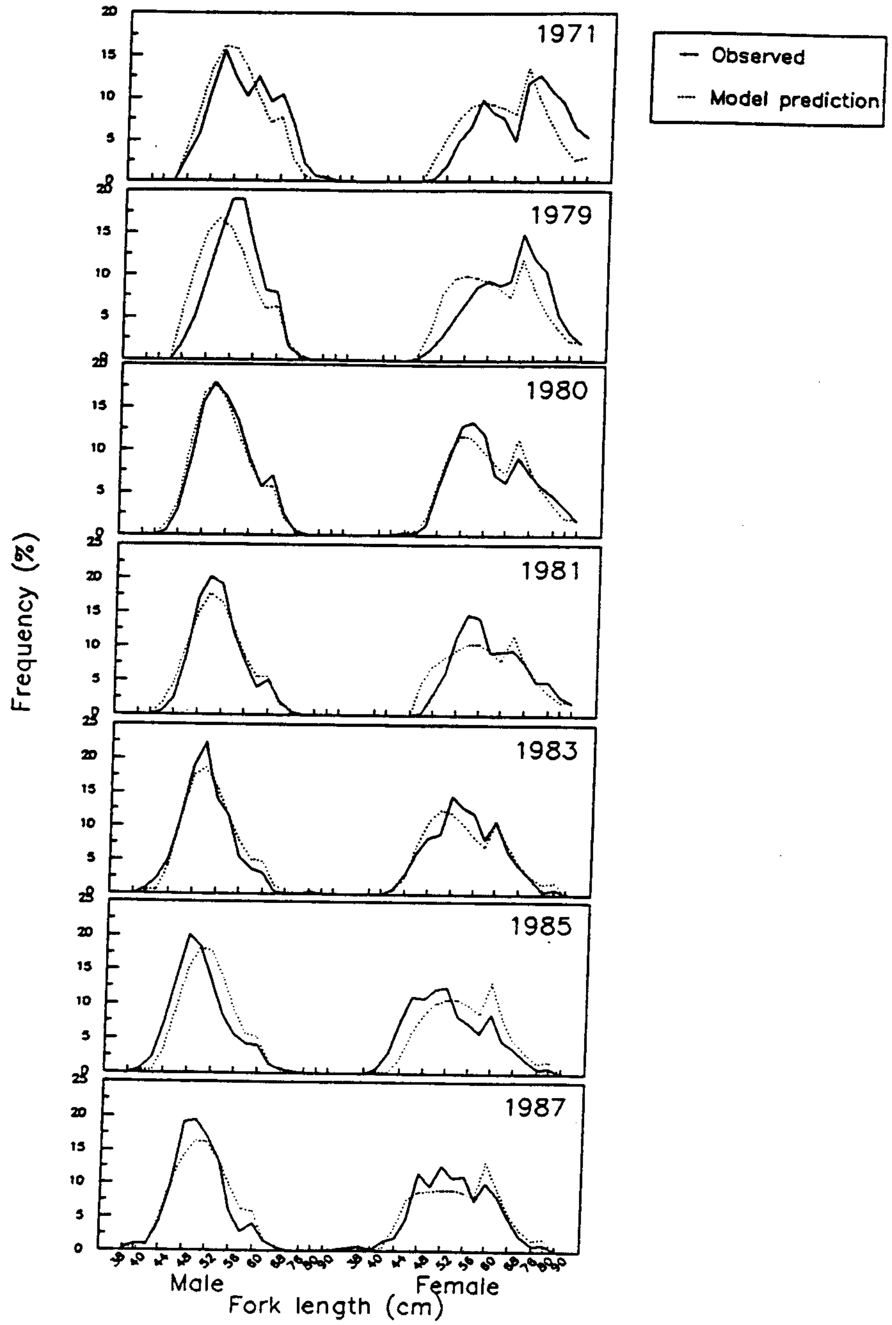


Figure 17. Time series of observed and estimated size composition in the northern pot survey. Estimated composition is from final run 1. Note variable width of size categories.

biomass levels, higher ending biomass levels, and better overall fits to the model. However, lower natural mortality seems unrealistic because of further degradation in the fit to the pot index and because of the low estimate of virgin recruitment relative to mean 1977-1985 recruitment.

The following detailed description of the model's ability to fit the data is based only on run 1 above.

Final Selectivities

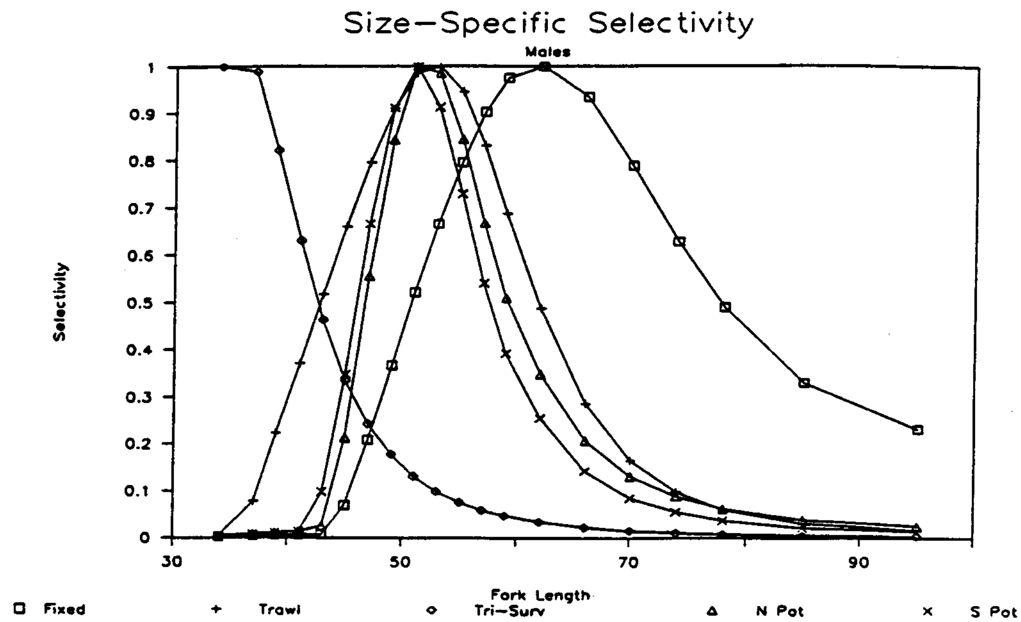
The estimated selectivity patterns are described in Figures 18-19 and Table 15. Selectivity by the tri-ennial surveys is maximum at the size mode of the age 1 fish. Selectivity is similar for the two pot surveys and the trawl fishery with maximum selectivity occurring for ages 4-6. Large, old fish are most selected by the fixed gear fishery. Note that for the older fish, the two sexes are more similar in age-specific selectivity than in size-specific selectivity, especially for sizes greater than L . This is sensible for the following reason. Most of the decline in selectivity for larger older fish must be due to offshore movement, out of the range of most surveys and fisheries. The older males must tend to move offshore with similar aged females rather than remain in mid-depths with similar sized females. Because most of the pattern occurred for fish larger than L , we should in the future examine model sensitivity to the variance in size at age.

The interaction between these selectivity patterns and the normal distribution of size at age produces sample estimates of mean size at age that are biased relative to the population mean size at age (Figure 20). The tri-ennial trawl survey is relatively unbiased for the age 1 fish, the trawl fishery and pot surveys are good estimators for mean size at age 5, and the fixed gear fishery should do a good job for the age 10+ fish. A sense of the accuracy of the assumptions which lead to this result can be obtained by examining Figure 21. In 1986, the mean size of young female sablefish was overestimated in both trawl and fixed gear samples, the mean size of older female sablefish was underestimated by the predicted amount in the trawl samples, and the mean size of older female sablefish was correctly estimated by the fixed gear samples.

Deviations in Model Fit

Patterns of deviations in the fit to the diverse data are presented in Tables 16-19. An excellent fit is obtained for the tri-ennial trawl surveys (Table 16). The standard deviation of the log(observed/expected), SD, was only 0.117 for the small fish component and 0.145 for the entire size range. The model is able to obtain a good fit to these observations because each observation is composed primarily of one yearclass. Therefore, the model need adjust only one parameter (one estimated recruitment) to get a good fit to each survey. Note that for the trawl survey (small), the model is only attempting to force Q to be near 1.0 and it gives nil emphasis to year to year variations in this component.

The model is less able to fit fluctuations in the pot indexes because at least 5 ages contribute strongly to this index. The model is not able to track the two fold decline from 79 to 81, the two fold increase from 81 to 83, then the



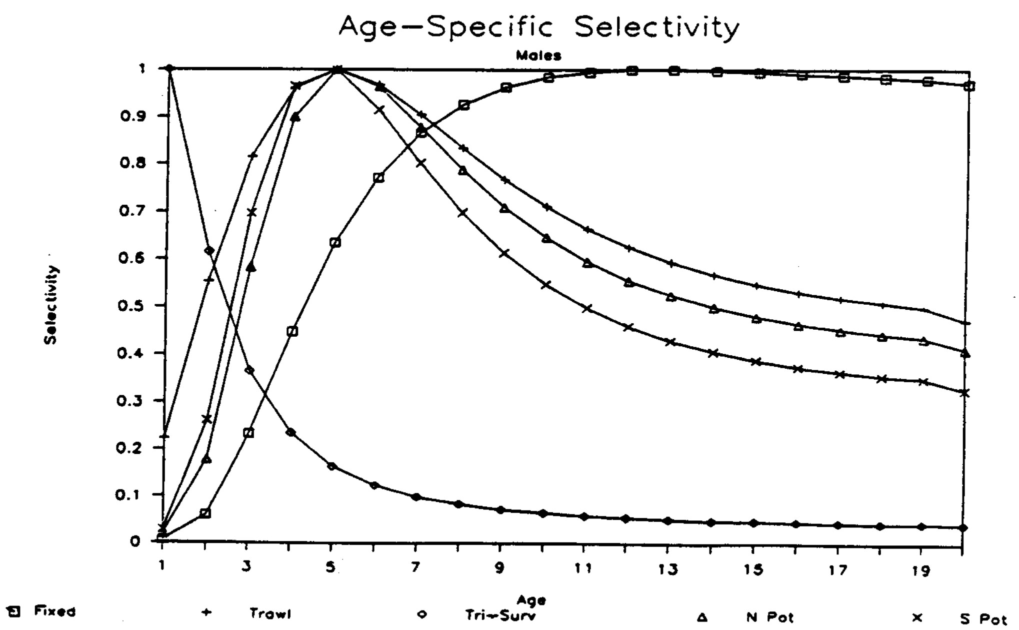
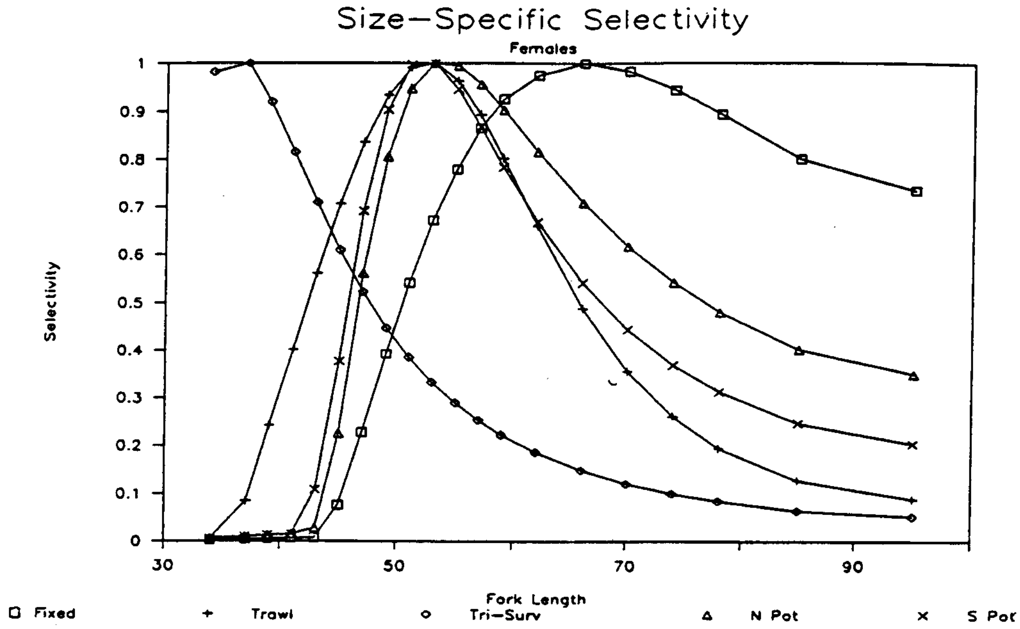


Figure 18. Size and age specific selectivity for male sablefish in the final run 1.



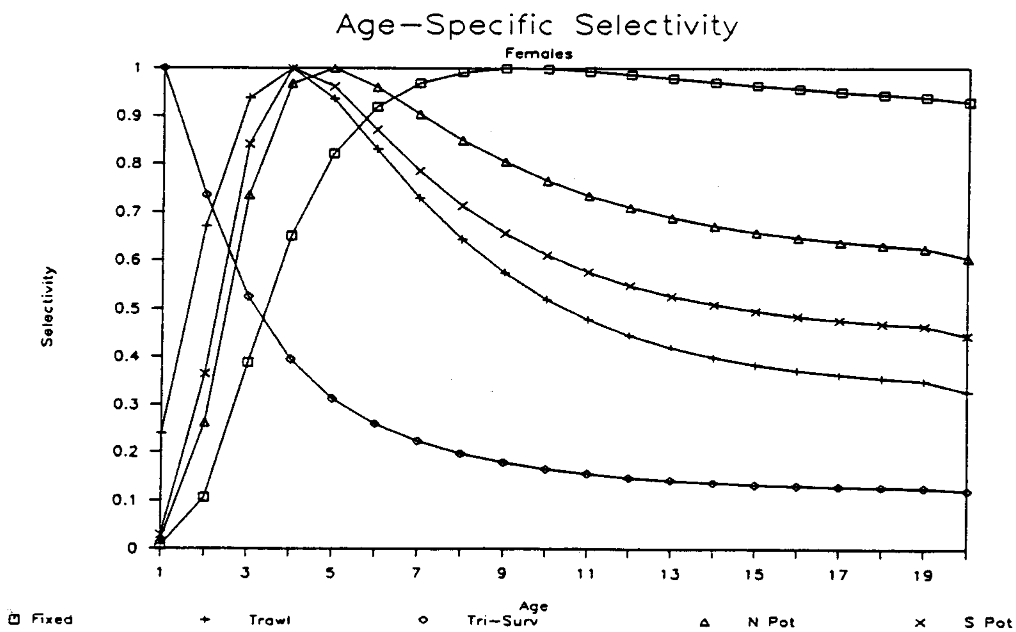


Figure 19. Size and age specific selectivity for female sablefish in the final run 1.

Table 15. Size- and age-specific selectivities in the final model. Age-specific selectivities calculated from size-specific selectivity and the distribution of size at age. Trawl retention is the same function of size for both sexes, but differs with age because of different size at age for the two sexes.

	Male					Female					Trawl
Length	Fixed	Trawl	Twl Svy	N Pot	S Pot	Fixed	Trawl	Twl Svy	N Pot	S Pot	Retain
32-36	.002	.005	1.000	.005	.005	.002	.005	.982	.006	.006	.007
36-38	.004	.078	.989	.009	.009	.004	.085	1.000	.010	.010	.036
38-40	.005	.222	.821	.011	.012	.005	.243	.920	.013	.013	.152
40-42	.006	.369	.629	.014	.014	.007	.403	.817	.015	.016	.431
42-44	.007	.516	.461	.026	.097	.008	.561	.710	.028	.109	.755
44-46	.069	.660	.333	.212	.346	.076	.708	.610	.226	.378	.934
46-48	.208	.796	.241	.555	.666	.228	.837	.523	.562	.692	.986
48-50	.366	.910	.177	.843	.911	.393	.935	.448	.807	.904	.997
50-52	.520	.985	.131	1.000	1.000	.542	.991	.386	.947	.998	.999
52-54	.666	1.000	.099	.985	.913	.673	1.000	.333	1.000	1.000	1.000
54-56	.796	.945	.076	.845	.729	.780	.964	.290	.995	.946	1.000
56-58	.903	.832	.059	.668	.541	.865	.894	.254	.957	.868	1.000
58-60	.976	.688	.047	.509	.391	.926	.803	.223	.903	.784	1.000
60-64	1.000	.487	.034	.347	.254	.976	.660	.187	.817	.669	1.000
64-68	.934	.284	.023	.207	.142	1.000	.488	.149	.709	.541	1.000
68-72	.788	.164	.016	.131	.085	.983	.356	.121	.617	.443	1.000
72-76	.628	.097	.011	.088	.055	.944	.261	.100	.542	.369	1.000
76-80	.489	.060	.008	.062	.037	.893	.195	.084	.480	.313	1.000
80-90	.329	.032	.005	.039	.022	.801	.128	.064	.402	.247	1.000
90-100	.231	.017	.004	.026	.014	.736	.089	.052	.351	.205	1.000

	Male						Female					
Age	Fixed	Trawl	Twl Svy	N Pot	S Pot	Trawl retain	Fixed	Trawl	Twl Svy	N Pot	S Pot	Trawl retain
1	.006	.223	1.000	.019	.028	.384	.007	.239	1.000	.018	.028	.383
2	.060	.554	.616	.179	.261	.767	.106	.670	.736	.262	.365	.834
3	.233	.815	.366	.584	.697	.935	.388	.938	.526	.736	.842	.969
4	.448	.961	.235	.900	.965	.982	.651	1.000	.395	.968	1.000	.993
5	.634	1.000	.164	1.000	1.000	.994	.822	.936	.313	1.000	.961	.998
6	.772	.968	.124	.964	.915	.998	.919	.832	.260	.960	.872	.999
7	.867	.905	.099	.878	.802	.999	.969	.730	.224	.904	.786	1.000
8	.927	.834	.083	.788	.699	.999	.992	.645	.198	.850	.714	1.000
9	.964	.768	.072	.710	.614	1.000	1.000	.576	.180	.805	.657	1.000
10	.985	.712	.065	.647	.549	1.000	.999	.521	.166	.766	.612	1.000
11	.995	.664	.059	.596	.499	1.000	.994	.479	.156	.735	.577	1.000
12	1.000	.626	.055	.556	.460	1.000	.987	.446	.148	.710	.549	1.000
13	1.000	.594	.052	.525	.430	1.000	.979	.420	.142	.689	.527	1.000
14	.998	.569	.049	.501	.408	1.000	.971	.400	.137	.672	.510	1.000
15	.995	.549	.048	.481	.390	1.000	.964	.385	.133	.659	.497	1.000
16	.991	.532	.046	.466	.376	1.000	.957	.373	.131	.648	.486	1.000
17	.987	.519	.045	.454	.365	1.000	.950	.364	.129	.639	.478	1.000
18	.983	.509	.044	.445	.357	1.000	.944	.357	.128	.632	.471	1.000
19	.979	.500	.044	.437	.351	1.000	.939	.351	.127	.626	.466	1.000
20	.971	.474	.042	.414	.329	1.000	.929	.329	.121	.607	.446	1.000

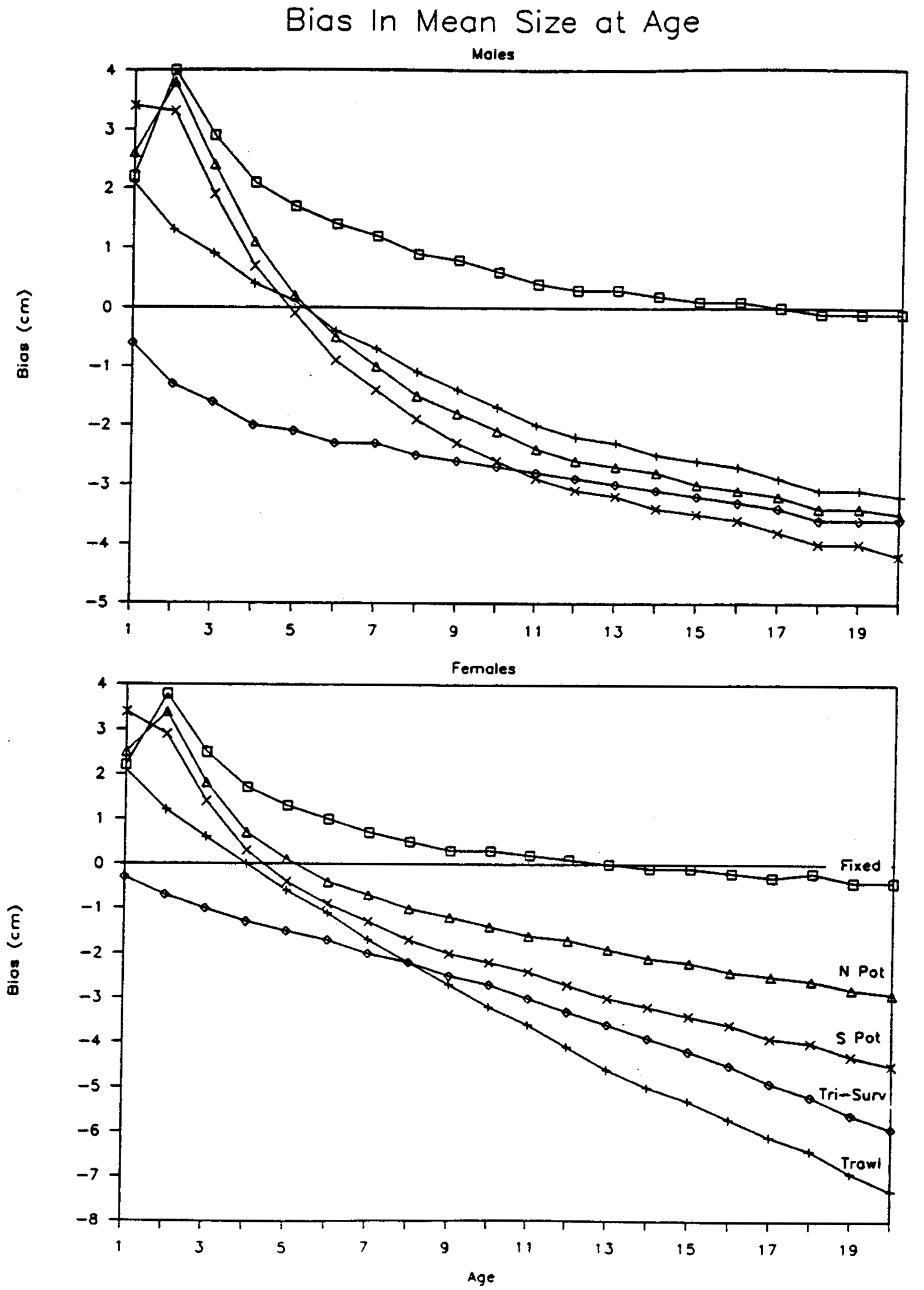


Figure 20. Calculated bias in mean size at age for each type of sampler.

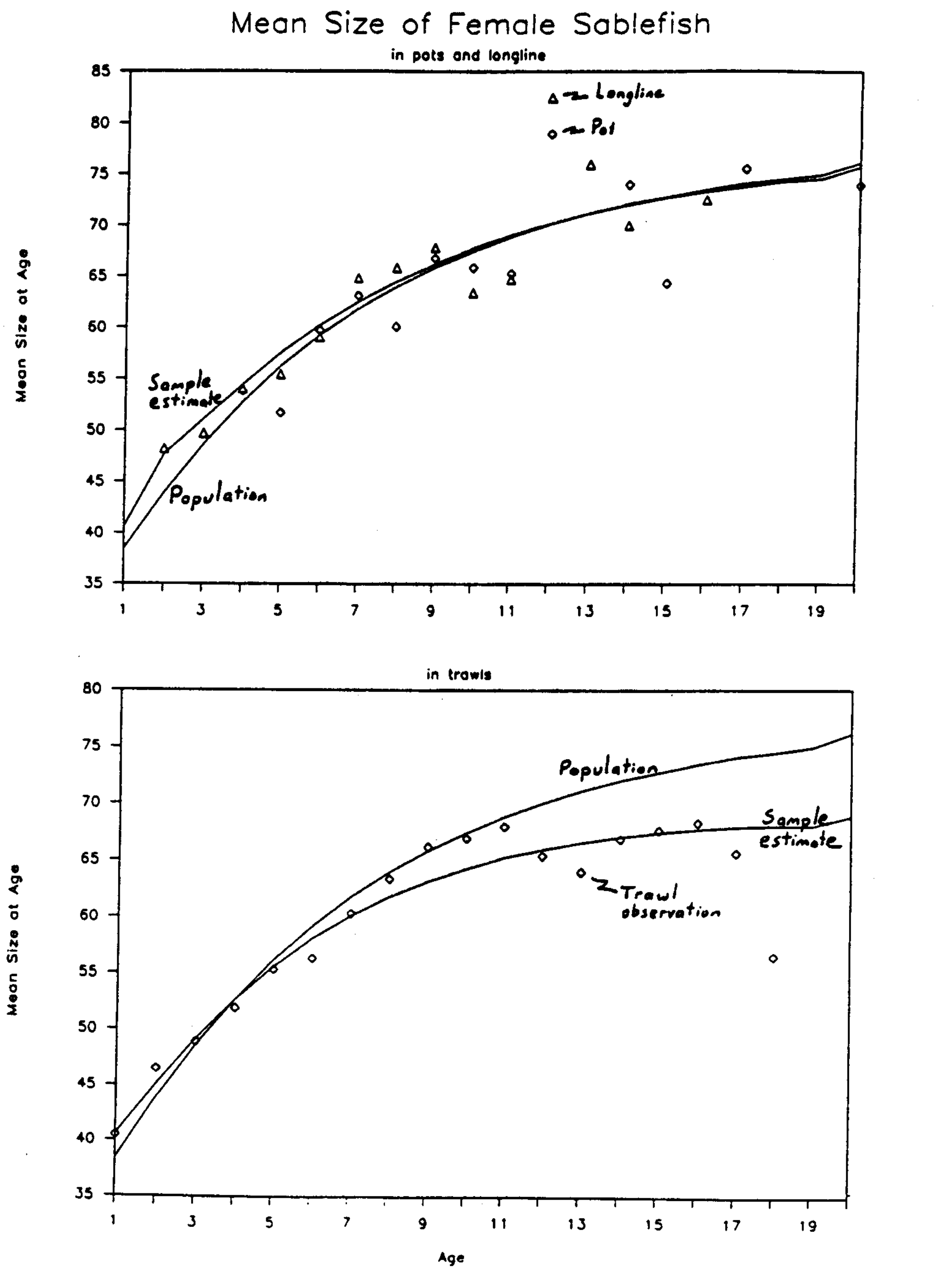


Figure 21. Estimated and cbserved mean size at age for female sablefish in the 1986 fishery.

Table 16. Results of the final model run including: observed and estimated values for each type of survey; mean biomass within each year, fishing mortality for the age at selectivity = 1.0; and estimated biomass discarded by the trawl fishery. Q is the ratio of the mean observed to the mean estimated. MN is the mean of the log(observed/estimated). SD is the standard deviation of the log(observed/estimated).

	Trawl Survey < 42 cm		Trawl Survey all sizes		N Pot		S Pot		Biomass		F at Full - Selection-		Trawl
Year	Obs	Est	Obs	Est	Obs	Est	Obs	Est	Total	Age 3+	Fixed	Trawl	Discard
70		21600.		44918.		10.6		11.1	195162.	175473.	.009	.020	77.
71		21441.		44489.	10.3	10.5		11.0	194200.	174845.	.011	.021	78.
72		21379.		44043.		10.3		10.8	191554.	172243.	.024	.030	110.
73		21343.		43653.		10.1		10.6	188188.	168914.	.013	.034	124.
74		21300.		43298.		9.9		10.4	184274.	165023.	.037	.027	101.
75		21244.		42852.		9.6		10.1	178360.	159165.	.050	.032	115.
76		21100.		41794.		9.0		9.5	165413.	146353.	.156	.036	129.
77		20978.		41107.		8.5		9.1	154633.	135659.	.045	.039	140.
78		31168.		51906.		8.3		8.9	154739.	130341.	.065	.064	291.
79		11973.		32862.	11.4	8.0		8.7	137460.	118359.	.157	.085	281.
80	34349.	30686.	53418.	49469.	6.8	7.8		8.4	135096.	117320.	.052	.047	187.
81		30530.		52114.	4.8	7.7		8.5	137399.	106415.	.060	.066	330.
82		20790.		43087.		7.9		8.8	131225.	109757.	.087	.121	504.
83	17972.	18420.	40573.	38299.	10.6	7.8		8.6	123266.	107264.	.075	.093	312.
84		15101.		32663.		7.4	9.8	8.1	115424.	100851.	.060	.111	316.
85		11747.		26871.	7.4	6.7		7.2	105614.	94375.	.080	.105	239.
86	20519.	23150.	30856.	37080.		6.0	4.6	6.3	102332.	86027.	.083	.105	324.
87		19879.		35329.	2.8	5.5		6.0	97610.	76840.	.087	.106	364.
88		18209.		34042.		5.6		6.3	94706.	78501.	.071	.085	272.
89		17676.		33202.		5.8		6.4	93178.	77232.	.072	.085	258.
90		17402.		32582.		5.7		6.3	91651.	75972.	.073	.085	253.
91		17222.		32110.		5.7		6.2	90098.	74590.	.074	.086	252.
Q		.99		.87		5387.59		4831.30					
MN		-.011		-.016		-.08		-.06					
SD		.117		.145		.39		.37					

Table 17. Observed and estimated tag returns. Estimated returns are calculated from the time series of F and Z for ages 5+ in the years following the release. For presentation, the expected proportion of returns in each subsequent year is multiplied by the total number of tags actually returned from that release.

Release Year	F	Z		Returns in Year 77	78	79	80	81	82	83	84	85	86	87	Sum
76	.167	.317	E:	50	55	72	19	17	19	10	7	5	3	2	
			O:	30	38	85	16	22	32	21	7	6	3	4	264
77	.068	.218													
78	.104	.254													
79	.202	.352	E:				24	21	24	13	9	6	4	3	
			O:				26	26	20	10	9	10	2	4	107
80	.081	.231	E:					120	134	72	50	37	25	17	
			O:					121	104	137	26	27	32	10	457
81	.102	.252	E:						51	27	19	14	9	6	
			O:						57	27	8	16	16	4	128
82	.168	.318	E:							17	12	9	6	4	
			O:							23	7	6	10	3	49
83	.135	.285	E:								5	4	2	1	
			O:								5	5	2	2	14
84	.138	.288													
85	.152	.302													
86	.153	.303	E:											54	
			O:											54	54
87	.157	.307													

Table 18. Deviations in age composition for the final run. Types are: 1 fixed gear fishery, 2 - trawl fishery, 5 - northern pot survey. LIKE/FISH is the likelihood for that type of data divided by the total number of fish aged.

			--- MEAN AGE ---			
YEAR	TYPE	SEX	OBSERV	EXPECT	DEVIATE	LIKE
83	5	1	4.86	5.30	-.44	-9.46
83	5	2	4.94	5.32	-.38	-49.16
85	5	1	5.02	5.61	-.59	-31.41
85	5	2	4.60	5.66	-1.06	-45.49
86	1	1	7.32	6.93	.39	-2.08
86	1	2	6.67	6.65	.03	-3.48
86	2	1	6.16	5.41	.76	-21.26
86	2	2	5.00	4.99	.01	-9.92
87	1	1	8.47	6.98	1.48	-45.61
87	1	2	7.99	6.66	1.34	-31.68
87	2	1	6.48	5.18	1.31	-81.74
87	2	2	5.13	4.66	.47	-26.01

TYPE	SEX	MEAN DEVIATE	LIKE/ FISH
1	1	.93	-.13
1	2	.68	-.08
2	1	1.03	-.13
2	2	.24	-.04
5	1	-.52	-.06
5	2	-.72	-.13

Table 19. Deviations in size composition in the final run. Types are: 1 fixed gear fishery, 2 - trawl fishery, 4 - trawl survey, 5 - northern pot survey, 6 - southern pot survey.

			— MEAN LENGTH -			
YEAR	TYPE	SEX	OBSERV	EXPECT	DEVIATE	LIKE
71	5	1	55.36	53.52	1.83	-30.51
71	5	2	63.11	59.23	3.88	-44.44
79	5	1	54.24	52.81	1.43	-33.38
79	5	2	60.89	57.82	3.07	-34.89
80	4	1	41.19	40.58	.61	-23.91
80	4	2	42.89	43.84	-.95	-52.78
80	5	1	53.19	52.63	.55	-3.85
80	5	2	57.94	57.61	.33	-7.09
81	5	1	52.78	52.63	.16	-8.30
81	5	2	58.45	57.49	.96	-31.08
83	4	1	42.31	42.02	.29	-12.56
83	4	2	44.22	45.78	-1.55	-29.88
83	5	1	51.42	52.28	-.86	-14.15
83	5	2	56.40	56.77	-.36	-11.07
84	6	1	51.50	51.65	-.15	-2.53
84	6	2	56.12	55.68	.45	-12.14
85	5	1	51.41	52.78	-1.36	-34.35
85	5	2	54.29	57.69	-3.40	-61.85
86	1	1	56.03	56.71	-.68	-19.91
86	1	2	60.07	61.76	-1.69	-14.76
86	2	1	52.37	52.01	.36	-7.45
86	2	2	53.20	54.63	-1.42	-13.14
86	4	1	40.44	40.63	-.20	-10.11
86	4	2	46.31	43.97	2.35	-61.74
86	6	1	51.42	52.05	-.63	-12.00
86	6	2	56.92	56.47	.46	-11.38
87	1	1	56.05	56.75	-.71	-15.63
87	1	2	61.93	61.71	.22	-15.69
87	2	1	50.68	51.45	-.77	-6.43
87	2	2	51.69	53.55	-1.86	-21.25
87	5	1	51.98	52.77	-.79	-16.34
87	5	2	56.58	57.63	-1.05	-13.86

TYPE	SEX	MEAN DEVIATE	LIKE/ FISH
1	1	-.70	-.04
1	2	-.74	-.04
2	1	-.21	-.02
2	2	-1.65	-.04
4	1	.23	-.04
4	2	-.06	-.13
5	1	.14	-.05
5	2	.49	-.08
6	1	-.39	-.02
6	2	.45	-.03

Table 20. Recruitment deviations for the final model. Q is the ratio of the mean estimate to the mean expected. MN is the mean of the log(estimate/expect). SD is the standard deviation of log(estimate/expect).

Virgin spawning biomass = 102686.6 mt of females
Virgin recruitment = 9522.4 thousand per sex
Density-dependence = 0.889

Year-class	Estimate	Expect	Ratio
77	15277.	8929.	.54
78	2075.	8874.	-1.45
79	16854.	8776.	.65
80	12858.	8525.	.41
81	7830.	8488.	-.08
82	8011.	8436.	-.05
83	6214.	8296.	-.29
84	4770.	8221.	-.54
85	12103.	8154.	.39

Q = .892 MN = -0.047 SD = .663

three fold decline from 83 to 87. With higher emphasis on the pot index the model achieves somewhat better tracking (Figure 15), but the SD for the pot index remains above 0.3 as compared to the average coefficient of variation, 0.16, for the 1983, 1985 and 1987 northern pot indexes. The northern and southern pot index are surprisingly similar. They have similar size-specific selectivity patterns (Figures 18-19), similar catchability coefficients, Q, 5388 vs. 4831, and the downward trend from 83-87 seems even more apparent when the two surveys are plotted together (Figure 9). The observed fluctuations in the pot index have shown good coherence along the coast, so changed distribution probably has not caused the fluctuations and the real cause remains an enigma. With the moderately strong 1985 year class entering the size range available to the pot index, the model predicts a leveling off of the pot index values. A southern pot survey is tentatively scheduled for autumn of 1988; the model predicts that the index value will be 6.3 (approximate 95%CI based on SD=0.37 is 3.0 - 13.2).

The pattern of tag returns was well matched by the model (Table 17). The largest deviation occurred for tags released in 1980 and returned in 1983, the returns were nearly twice the expected. Overall there were no obvious patterns to the deviations.

Patterns in the age and size composition data are more difficult to display becuase of the great volume of data (Table 18-19).. The model underestimates mean age and overestimate mean size in the fishery samples, especially in 1987. Mean age is overestimated for the northern pot survey samples and mean size is underestimated in these samples, especially in the early years. There are no age composition data for the trawl survey or the southern pot index and the fit to the size composition data from these surveys seems unbiased. The log likelihood for each type of age or size composition data depends on the number of observations and the number of fish per observation. When the log likelihoods are divided by the total number of fish, we see that the size compositions are fit more precisely than the age compositions and that male size compositions tend to be fit more precisely than female size compositions.

Fit to the spawner-recruitment relationship is given nil weighting in the model, but patterns of deviations still contribute to our understanding of what has happened to the sablefish stock (Table 20). As spawning biomass has decreased, the model predicts that recruitments should have declined from 8929 thousand in 1977 to 8154 thousand in 1985. However, the model estimates that recruitment was better than expected in 1977, 1979, 1980, and 1985. Average recruitments occurred in 1981 and 1982. Poor recruitments occurred in 1978, 1983 and 1984.

The estimated sablefish population at the beginning of 1988 is presented in Table 21. These values and the estimated selectivity functions are used below to forecast the near term changes in the stock and stock equilibrium as a function of different levels of fishing effort.

Table 21. Estimated population at the beginning of 1988 in the final run.

	MALES			FEMALES		
AGE	NUMBERS	BIOMASS	Z	NUMBERS	BIOMASS	Z
1	7908.9	3938.7	.181	7908.9	3938.7	.182
2	6683.0	4789.3	.206	6671.0	5215.3	.219
3	8083.9	7629.8	.237	7938.9	8757.6	.259
4	2463.0	2876.6	.264	2356.1	3404.9	.282
5	2400.0	3314.3	.280	2248.3	4031.8	.288
6	2280.0	3597.3	.287	2119.3	4527.2	.286
7	1629.9	2862.0	.288	1524.5	3758.8	.281
8	1973.1	3777.5	.286	1866.6	5181.2	.275
9	1946.3	3997.6	.283	1877.6	5751.7	.269
10	183.2	398.5	.280	181.5	603.8	.265
11	1037.9	2366.3	.277	1048.6	3738.1	.261
12	479.7	1136.7	.274	489.3	1849.2	.258
13	377.2	922.5	.271	390.9	1551.9	.255
14	299.4	751.8	.269	315.7	1307.2	.253
15	237.7	609.9	.267	253.4	1086.8	.251
16	190.0	496.2	.265	205.3	907.7	.249
17	153.1	406.0	.264	168.5	764.4	.248
18	125.3	336.2	.263	140.7	652.4	.247
19	103.9	281.8	.262	119.1	562.5	.246
20	614.3	1710.2	.259	747.4	3727.2	.243

TOTAL N	77741.
TOTAL BIOMASS	107518.
SPAWNING BIOMASS	33532.
AGE 3+ BIOMASS	89636.

Yield Projections

Results from the synthesis model were used to estimate equilibrium yield and stock size for a range of levels of fishing mortality. Following Getz (1980), we calculated the equilibrium number-at-age vectors at each level of F by defining the equilibrium spawning stock as a function of the number of age-1 females, N_1:

$$SPB = \sum_{a} [N_a * PCTMAT_a * W_{a2}]$$

$$= [N_1 * PCTMAT_1 * W_{1,2}]$$

$$+ N_1 * \sum_{a=2}^{19} \left| PCTMAT_a * W_{a2} * \prod_{J=1}^{a-1} e^{(-M_j - F_j)} \right|$$

$$+ N_1 * PCTMAT_{20} * W_{20,2} *$$

$$\prod_{J=1}^{19} e^{(-M_j - F_j)} / (1 - e^{(-M_{20} - F_{20})})$$

$$= N_1 * SPSUM$$

By substituting N_1*SPSUM for SPB in the stock-recruitment relationship and solving for N_1, the number of recruits was expressed as a function of F:

$$N_1 = VSPB * (VR * SPSUM/VSPB + DD - 1)/ (DD * SPSUM)$$

The numbers at age 1 for males is assumed to be the same as the numbers for females. The number of fish ages 2-20 was calculated from the number at age 1. Equilibrium yield was calculated from the catch equation described earlier except that weight of age-A fish in the catch was obtained from the length-weight relationship using the estimated mean length of age-A, sex-S fish captured by gear type T.

We calculated equilibrium number-at-age vectors and associated yields for a range of trawl and fixed gear F combinations. The resulting matrix of yield values was used to produce response surface plots, with plot contours representing levels of equilibrium yield or the percentage of total yield due to trawl gear (Figures 22-25). The shape and elevation of the response surface for total yield was similar for the seven cases examined, but substantially different for the constant (DD=1.000) and Beverton-Holt (DD=0.889) stock-recruitment cases. As in an earlier study (Francis 1985), highest yields were obtained when fishing was limited to fixed gear vessels (Figures 22, 24). Compared to a fixed gear only fishery, MSY for the Beverton-Holt case was 929 to 1,035 mt lower for the seven cases examined when a 52:48 trawl:fixed gear allocation was maintained. Note that this change in yield may provide an upper bound for the increase in yield that might be obtained by increasing trawl mesh size.

We also calculated equilibrium yield at different total Fs by solving iteratively for the trawl and fixed gear Fs that would result in a 52:48 trawl:fixed

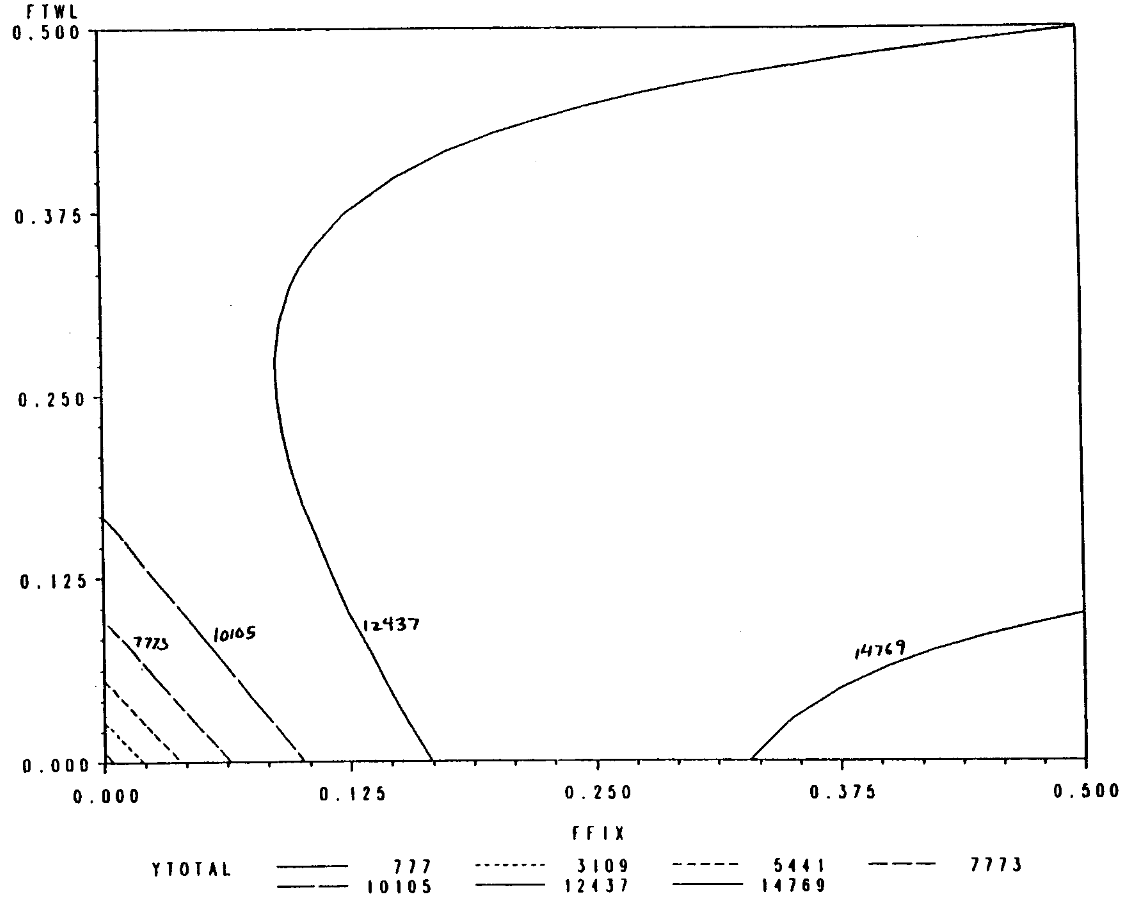


Figure 23. Total yield for various combinations of trawl and fixed gear Fs, using parameter estimates from stock synthesis model run 1, assuming constant recruitment (A=1.000).

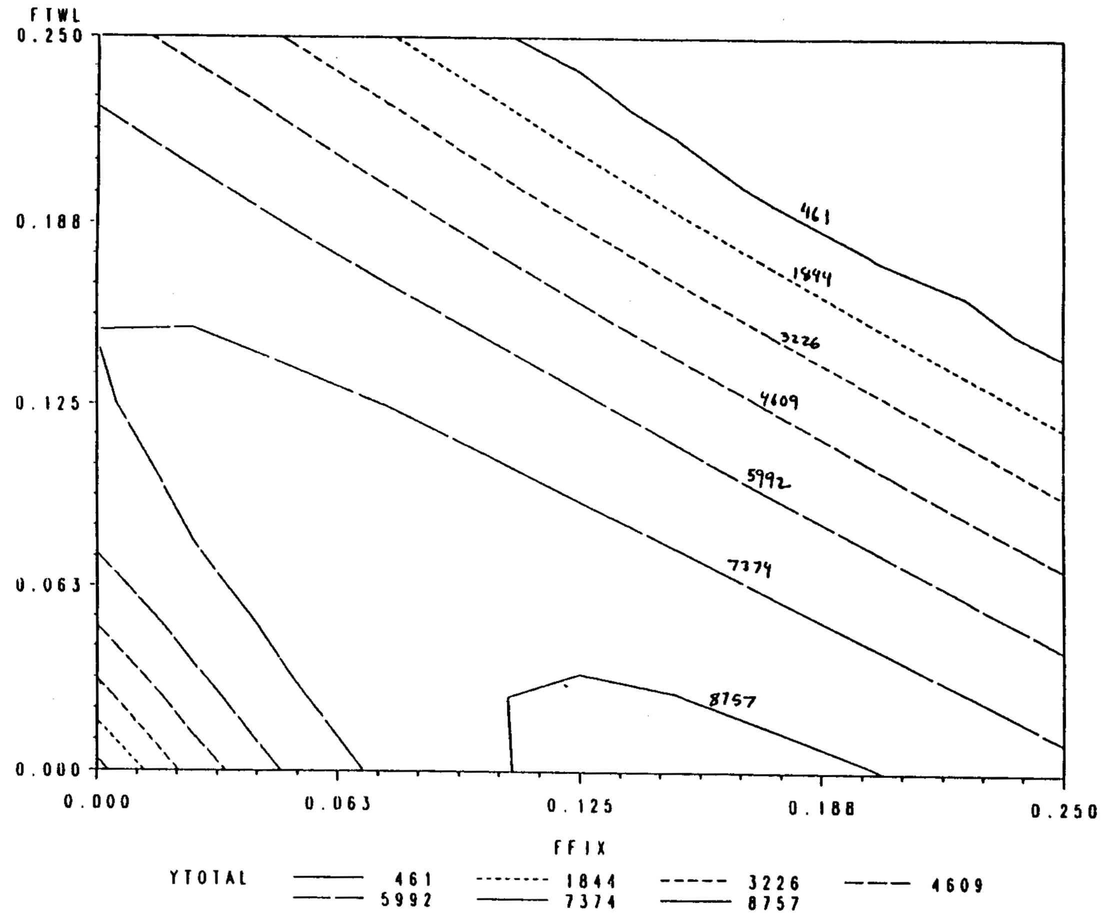


Figure 22. Total yield for various combinations of trawl and fixed gear Fs, using parameter estimates from stock synthesis model run 1.

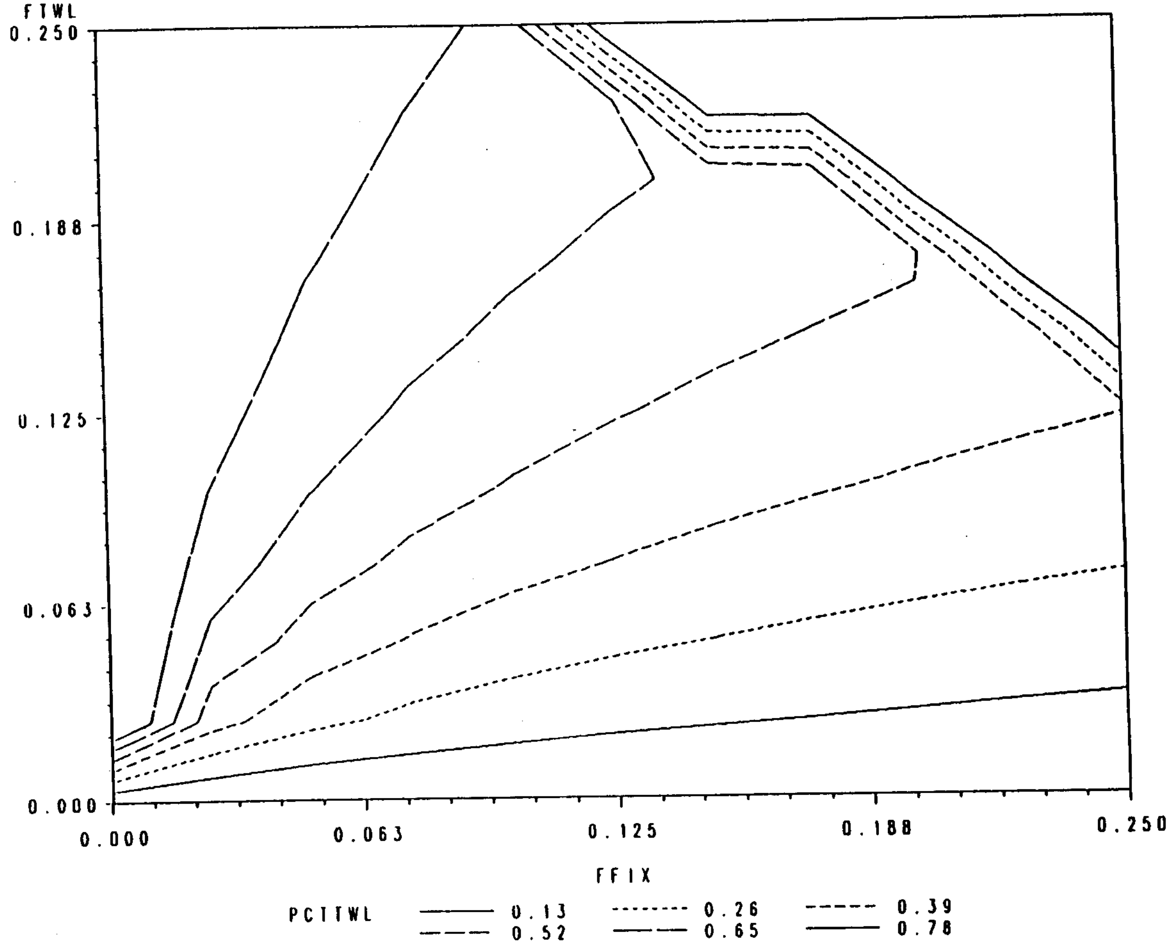


Figure 24. Percentage of total yield due to trawl gear for various combinations of trawl and fixed gear Fs, using parameter estimates from stock synthesis model run 1.

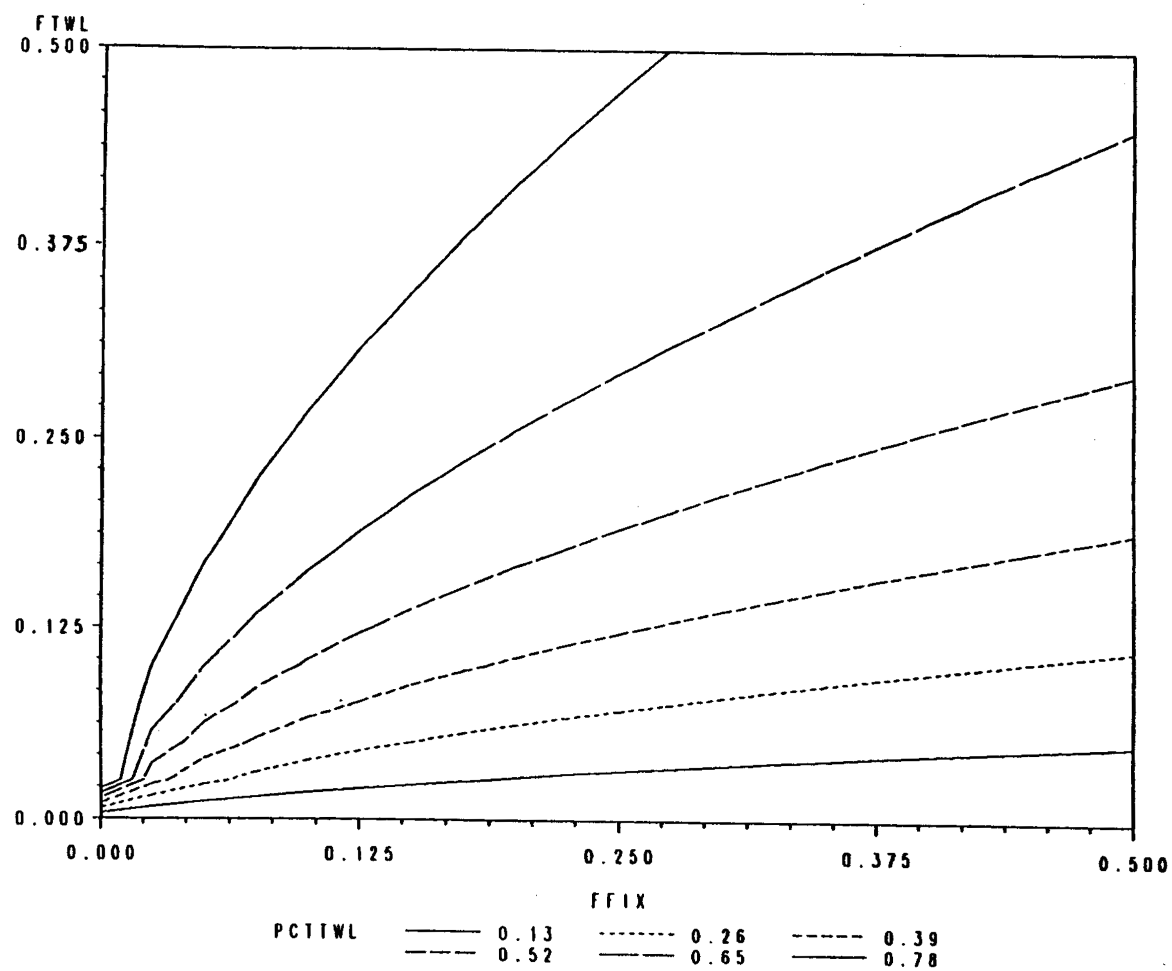


Figure 25. Percentage of total yield due to trawl gear for various combinations of trawl and fixed gear Fs, using parameter estimates from stock synthesis model run 1, assuming constant recruitment (A=1.000).

gear allocation (Figures 26). Yield and stock biomass curves for the seven cases were similar in shape and in magnitude. Yield curves for the two stock-recruitment cases differed considerably, with total yield about 3-4 thousand mt higher under the optimistic constant recruitment assumption. Following Francis (1986), we assumed that F[MSY] and F[0.1] were appropriate Fs for the Beverton-Holt (DD=0.889) and constant recruitment cases (DD=1.000) respectively. For each stock-recruitment case, recommended Fs and yields were similar for the seven cases examined (Tables 22-23). For the density-dependent case, recommended total Fs (F[MSY]) were relatively low (0.11-0.14; less than M in 6 of 7 cases). These conservative results apparently were obtained because of the early age at first recruitment, relative to age at first maturity. When constant recruitment was assumed, recommended total Fs were substantially higher (0.16-0.21 for females). In both cases, recommended Fs were lowest for M=0.11 and highest for the M=0.15 and M=0.17 cases. For the Beverton-Holt case, recommended equilibrium yields ranged from 6,988 to 9,162 mt. For the constant recruitment case, recommended yields ranged from 9,831 to 13,607 mt. Biomass levels at the recommended Fs were similar for all cases examined.

Using the current 52:48 trawl:fixed gear allocation, we solved iteratively for the trawl and fixed gear Fs required to obtain constant catches of 8,000 to 12,000 mt from 1988 through 1992 (Tables 24-25). These Fs can be used to compare the predicted short-term impact of alternative ABC levels. For the Beverton-Holt case, the required Fs change slowly over a 5-year horizon except in cases where the target harvest greatly exceeded MSY (e.g. 12,000 mt harvest for run 3). For the constant recruitment case, required Fs varied only slightly over the 5-year horizon.

We obtained estimates of ABC by assuming a 1988 harvest of 10,000 mt and a constant F in 1989-1990 equal to either F[MSY] (DD=0.889) or F[0.1] (DD=1.000). For a specified total F, we solved iteratively for the trawl and fixed gear Fs that would result in a 52:48 trawl:fixed gear allocation. For runs 1, 2, 6, and 7 the total biomass in 1988 is 8,000 - 16,000 mt greater than the biomass at MSY. For run 5 (natural mortality = .17) the current stock is essentially right on the biomass yielding MSY. For runs 3 and 4 (high pot emphasis or low age composition emphasis) the current biomass is below that producing MSY. Predicted 1989-1990 biomass levels were similar for most cases examined; the lowest estimates were for the cases where the relative importance of the pot survey data was increased (Tables 26-27). For each stock-recruitment case, differences in 1989-1990 yield were due mostly to differences in the starting biomass level. Note that the biomass in 1988 is inversely related to the assumed level of natural mortality and that the F[MSY] is positively related to the assumed level of natural mortality (Table 22). The combination of these two factors produces maximum ABC at an intermediate level of natural mortality, 0.15. There were substantial differences in 1989-1990 yield for the two stock-recruitment cases, due to the differences in F[MSY] and F[0.1].

The stock could be fished down to the B[MSY] level more or less rapidly than the rate indicated by applying F[MSY] to the current stock. Table 28 presents various fishing down scenarios. Here we have set the 1988 total catch at 10,800 mt because of the recently released reserve. If the ABC in 1989 was set equal to 15,400 mt then the B[MSY] level would be reached the following year. However, this would be a risky policy and would result in substantial over-fishing if our assessment has over-estimated sablefish abundance.

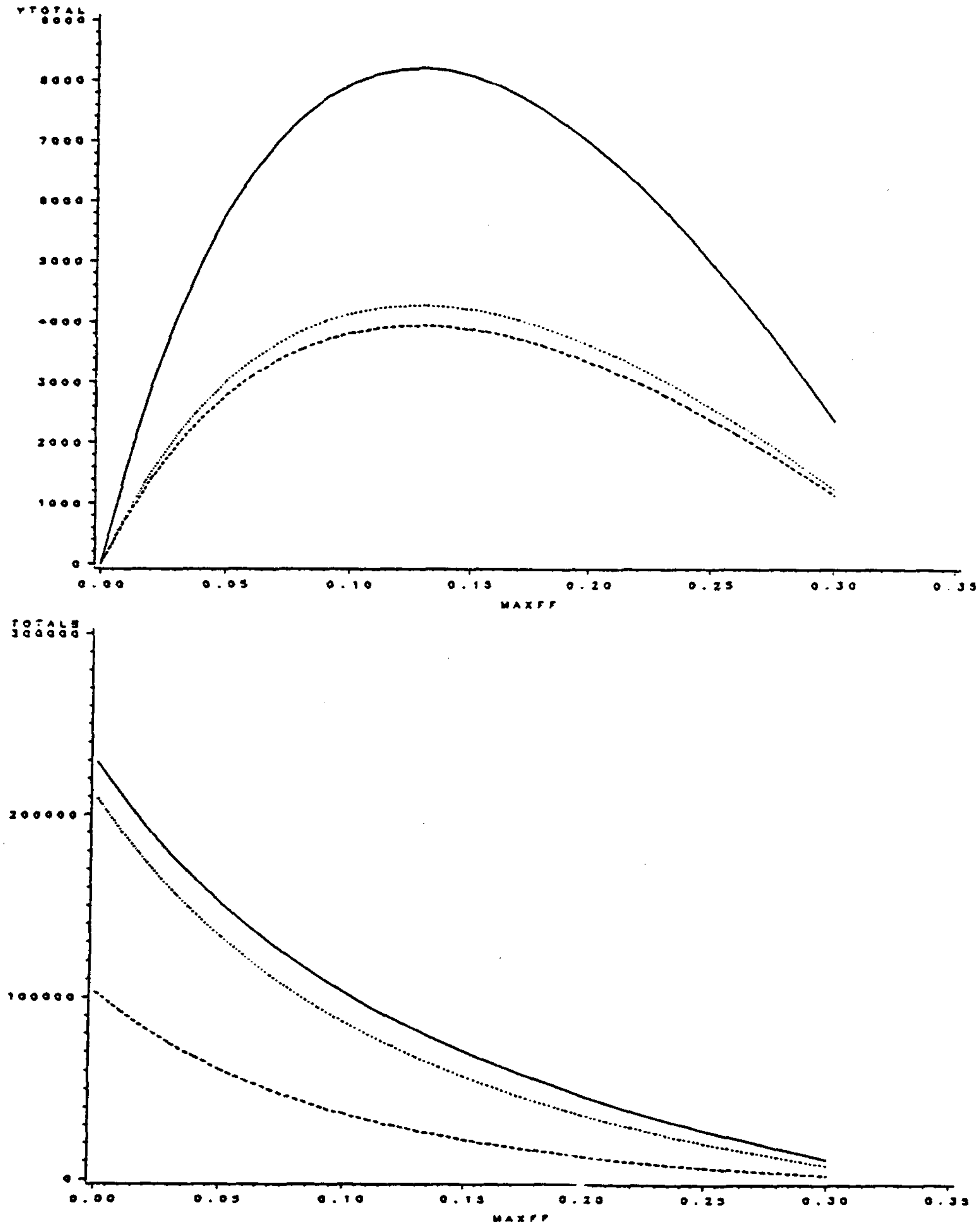


Figure 26. Upper panel: Equilibrium total (solid line), trawl (dotted line), and fixed gear (dashed line) yields as a function of maximum age-specific F for females (Fs for females and males were essentially equivalent). Lower panel: Equilibrium total (solid line), exploitable (ages 3+, dotted line), and female spawning (dashed line) biomass as a function of maximum age-specific F for females. A 52:48 trawl:fixed gear allocation was assumed.

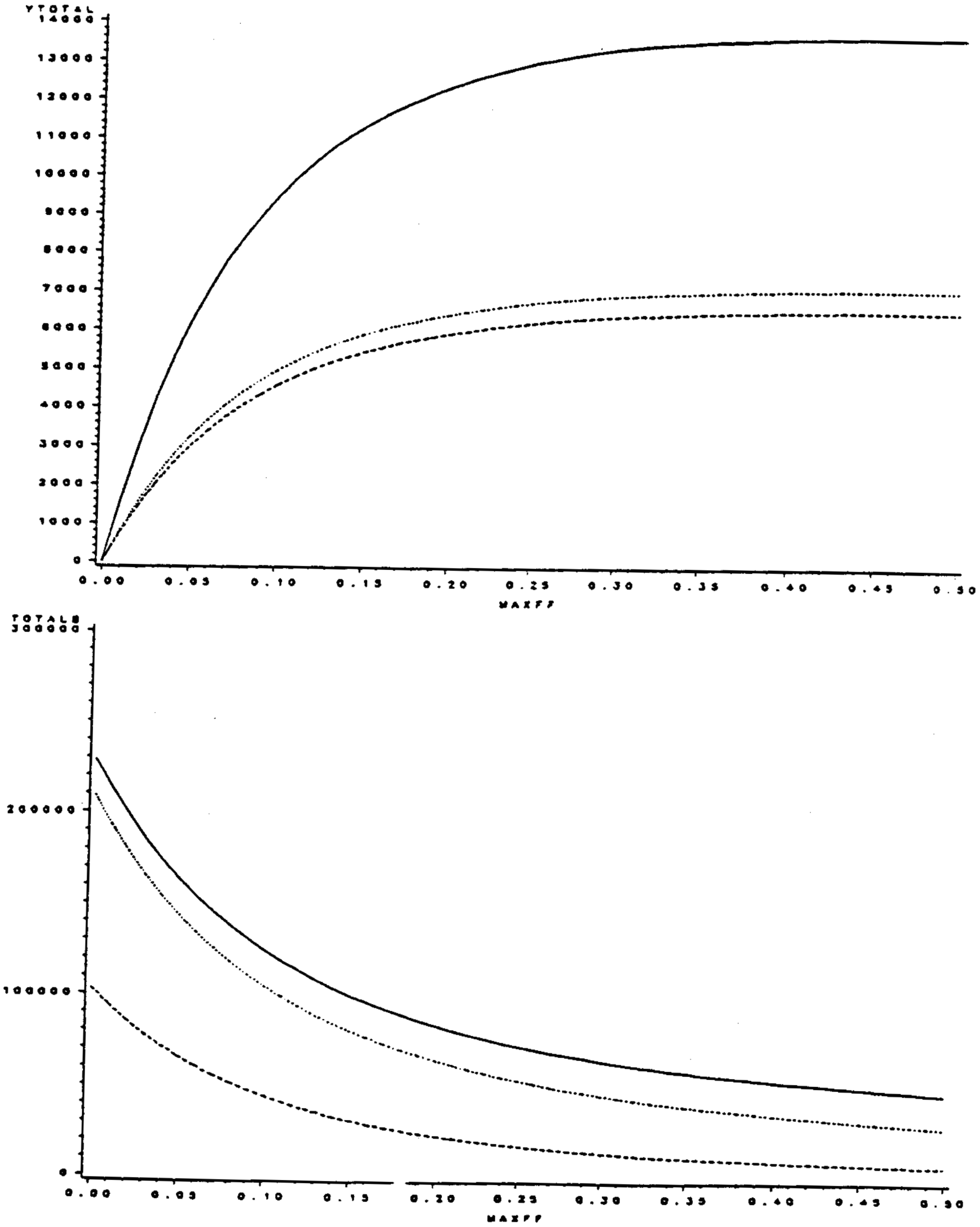


Figure 27. Upper panel: Equilibrium total (solid line), trawl (dotted line), and fixed gear (dashed line) yields as a function of maximum age-specific F for females, assuming constant recruitment (A=1.000). Lower panel: Equilibrium total (solid line), exploitable (ages 3+, dotted line), and female spawning (dashed line) biomass as a function of maximum age-specific F for females, assuming constant recruitment (A=1.000). A 52:48 trawl:fixed gear allocation was assumed.

Table 22. Estimates of MSY, F[MSY], and equilibrium stock biomass levels for seven sets of assessment parameters. The total F[MSY] estimate for each sex is the highest age-specific F, rather than the sum of trawl and fixed gear F multipliers, because the age at full recruitment differs for the two gears.

		F multiplier		Total F					
Run	R1	FIX	TWL	Female	Male	MSY	B[MSY]	S[MSY]	B[MSY,3+]
1 (best, start=8000)	9,522	0.069	0.079	0.130	0.131	8,198	82,676	26,990	67,804
2 (best, start=11000)	10,250	0.068	0.078	0.130	0.131	8,570	87,967	28,853	71,999
3 (10X pot surv abund)	9,716	0.068	0.088	0.140	0.144	7,849	78,330	25,842	63,563
4 (0.1X all age comp)	8,947	0.071	0.081	0.130	0.134	7,454	74,897	24,423	61,112
5 (M=0.17)	11,861	0.077	0.082	0.140	0.141	9,162	87,404	26,143	69,307
6 (M=0.13)	8,426	0.059	0.074	0.120	0.121	7,695	85,848	30,948	72,461
7 (M=0.11)	7,267	0.051	0.070	0.110	0.112	6,988	86,475	34,072	74,918

Table 23. Estimates of Y[0.1], F[0.1], and equilibrium stock biomass levels for seven sets of assessment parameters. The total F[0.1] estimate for each sex is the highest age-specific F, rather than the sum of trawl and fixed gear F multipliers, because the age at full recruitment differs for the two gears.

		F multiplier		Total F					
Run	R1	FIX	TWL	Female	Male	Y[0.1]	B[0.1]	S[0.1]	B[0.1,3+]
1 (best, start=8000)	9,522	0.107	0.109	0.190	0.191	12,170	86,083	23,890	66,871
2 (best, start=11000)	10,250	0.106	0.108	0.190	0.192	12,486	89,811	25,052	69,626
3 (10X pot surv abund)	9,716	0.110	0.125	0.210	0.217	11,706	78,067	21,356	59,170
4 (0.1X all age comp)	8,947	0.112	0.112	0.190	0.196	10,866	76,656	21,202	59,171
5 (M=0.17)	11,861	0.123	0.116	0.210	0.212	13,607	89,970	22,322	66,898
6 (M=0.13)	8,426	0.095	0.105	0.180	0.182	11,199	84,211	25,842	67,378
7 (M=0.11)	7,267	0.079	0.097	0.160	0.162	9,831	83,304	28,744	69,073

Table 24. Total F for female sablefish required to obtain yields of 8,000 to 12,000 mt in 1988-1992, assuming a Beverton-Holt stock recruitment relationship (A=0.889).

Run	Yield (mt)	1988	1989	1990	1991	1992
1 (best, start=8000)	8,000	0.112	0.110	0.109	0.108	0.108
	9,000	0.127	0.126	0.126	0.127	0.128
	10,000	0.142	0.143	0.145	0.147	0.150
	11,000	0.157	0.160	0.164	0.169	0.175
	12,000	0.172	0.178	0.185	0.194	0.203
2 (best, start=11000)	8,000	0.114	0.112	0.110	0.109	0.108
	9,000	0.129	0.128	0.128	0.128	0.128
	10,000	0.144	0.145	0.146	0.148	0.150
	11,000	0.160	0.162	0.166	0.170	0.175
	12,000	0.175	0.181	0.187	0.195	0.203
3 (10X pot surv abund)	8,000	0.198	0.194	0.189	0.186	0.185
	9,000	0.225	0.225	0.223	0.224	0.228
	10,000	0.252	0.257	0.262	0.269	0.280
	11,000	0.280	0.292	0.304	0.322	0.346
	12,000	0.309	0.329	0.352	0.384	0.430
4 (0.1X all age comp)	8,000	0.133	0.129	0.128	0.129	0.131
	9,000	0.150	0.149	0.150	0.153	0.157
	10,000	0.168	0.169	0.173	0.179	0.188
	11,000	0.186	0.190	0.198	0.209	0.223
	12,000	0.205	0.212	0.225	0.242	0.264
5 (M=0.17)	8,000	0.127	0.124	0.121	0.118	0.116
	9,000	0.144	0.143	0.141	0.139	0.138
	10,000	0.161	0.162	0.162	0.162	0.163
	11,000	0.178	0.182	0.184	0.187	0.191
	12,000	0.196	0.203	0.209	0.215	0.223
6 (M=0.13)	8,000	0.108	0.106	0.105	0.106	0.106
	9,000	0.122	0.121	0.122	0.124	0.126
	10,000	0.137	0.137	0.140	0.143	0.148
	11,000	0.151	0.154	0.158	0.165	0.172
	12,000	0.166	0.171	0.178	0.188	0.200
7 (M=0.11)	8,000	0.104	0.102	0.102	0.104	0.106
	9,000	0.118	0.117	0.119	0.122	0.125
	10,000	0.132	0.133	0.136	0.141	0.147
	11,000	0.146	0.148	0.154	0.162	0.171
	12,000	0.160	0.165	0.173	0.185	0.199

Table 25. Total F for female sablefish required to obtain yields of 8,000 to 12,000 mt in 1988-1992, assuming constant recruitment (A=1.000).

Run	Yield (mt)	Year 1988	1989	1990	1991	1992
1 (best, start=8000)	8,000	0.112	0.110	0.108	0.104	0.101
	9,000	0.127	0.126	0.125	0.122	0.119
	10,000	0.142	0.143	0.143	0.141	0.139
	11,000	0.157	0.160	0.162	0.162	0.161
	12,000	0.172	0.178	0.182	0.185	0.186
2 (best, start=11000)	8,000	0.114	0.111	0.108	0.104	0.100
	9,000	0.129	0.127	0.125	0.122	0.118
	10,000	0.144	0.144	0.144	0.141	0.138
	11,000	0.159	0.162	0.163	0.162	0.160
	12,000	0.175	0.180	0.184	0.185	0.185
3 (10X pot surv abund)	8,000	0.197	0.192	0.182	0.169	0.156
	9,000	0.224	0.223	0.215	0.202	0.189
	10,000	0.252	0.255	0.251	0.241	0.228
	11,000	0.280	0.290	0.292	0.286	0.275
	12,000	0.308	0.327	0.337	0.338	0.333
4 (0.1X all age comp)	8,000	0.132	0.129	0.126	0.123	0.119
	9,000	0.150	0.148	0.147	0.145	0.142
	10,000	0.168	0.168	0.169	0.169	0.168
	11,000	0.186	0.189	0.193	0.197	0.198
	12,000	0.204	0.211	0.219	0.227	0.232
5 (M=0.17)	8,000	0.127	0.124	0.119	0.112	0.105
	9,000	0.143	0.142	0.138	0.132	0.125
	10,000	0.160	0.161	0.158	0.153	0.146
	11,000	0.178	0.181	0.180	0.176	0.170
	12,000	0.195	0.202	0.204	0.202	0.197
6 (M=0.13)	8,000	0.108	0.106	0.104	0.102	0.100
	9,000	0.122	0.121	0.120	0.119	0.118
	10,000	0.136	0.137	0.138	0.138	0.138
	11,000	0.151	0.153	0.156	0.158	0.16
	12,000	0.166	0.170	0.176	0.180	0.184
7 (M=0.11)	8,000	0.104	0.102	0.101	0.101	0.100
	9,000	0.118	0.117	0.117	0.118	0.119
	10,000	0.132	0.132	0.134	0.137	0.139
	11,000	0.146	0.148	0.152	0.157	0.161
	12,000	0.160	0.165	0.171	0.179	0.186

Table 26. Projected yield and total biomass assuming a 1988 harvest of 10,000 mt and 1990-1991 Fs equal to F[MSY]. A Beverton-Holt stock-recruitment relationship was assumed (A=0.889).

Run	B[88]	Y[89]	B[89]	Y[90]	B[90]
1 (best, start=8000)	94,694	9,137	93,324	9,127	92,386
2 (best, start=11000)	95,317	9,021	94,230	9,057	93,635
3 (10X pot surv abund)	62,470	5,688	61,811	6,090	63,351
4 (0.1X all age comp)	78,822	7,825	77,971	7,900	77,840
5 (M=0.17)	87,056	8,720	86,502	8,864	86,695
6 (M=0.13)	99,468	8,800	98,065	8,779	97,094
7 (M=0.11)	102,312	8,352	100,944	8,316	100,056

Table 27. Projected yield and total biomass assuming a 1988 harvest of 10,000 mt and 1990-1991 Fs equal to F[0.1]. Constant recruitment was assumed (A=1.000).

Run	B[88]	Y[89]	B[89]	Y[90]	B[90]
1 (best, start=8000)	94,694	13,061	92,912	12,602	90,430
2 (best, start=11000)	95,317	12,897	93,985	12,519	92,018
3 (10X pot surv abund)	62,471	8,353	62,670	8,749	64,581
4 (0.1X all age comp)	78,822	11,187	78,107	10,930	77,144
5 (M=0.17)	87,056	12,756	86,580	12,513	85,850
6 (M=0.13)	99,467	12,904	97,330	12,407	94,244
7 (M=0.11)	102,311	11,916	100,281	11,502	97,406

Table 28. Alternative scenarios for fishing the west coast sablefish stock down to the B[MSY] level. The harvest in 1988 is assumed to be 10,800 mt.

Year	0.13	0.14	0.15	0.17	0.19	0.23
1989	9000	9700	10400	11600	12900	15400
1990	9000	9600	10200	11300	12300	8200
1991	9000	9500	10000	10900	8200	
1992	8900	9400	9800	8200		
1993	8900	9300	9600			
1994	8800	9200	9500			
1995	8700	9000	8200			
1996	8700	9000				
1997	8600	8900				
1998	8600	8200				
1999	8500					
2000	8500					
2001	8500					
2002	8400					
2003	8400					
2004	8400					
2005	8400					
2006	8300					
2007	8300					
2008	8200					

Conclusion

The most likely scenario for sablefish is described by run #1 which strikes a compromise between the decline in the pot index and the relatively high frequency of old fish in the 1987 fishery samples. The mean total biomass during 1988 was 94,700 mt and the age 3+ biomass was 78,600 mt. The biomass levels at the beginning of the year were 107,500 and 89,600 mt, respectively. The total F imposed by a 10,000 mt fishery will be 0.14. We projected future abundance levels using both constant recruitment and Beverton-Holt stock-recruitment functions. Although we do not yet have evidence of declining recruitment at lower spawner biomass levels, we note that the spawning biomass at MSY is only about 25% of the virgin spawning biomass. This large reduction in spawning biomass probably occurs because the fish are available to the trawl fishery several years before they mature. A prudent course of action is to utilize the Beverton-Holt recruitment function to estimate potential yield from the stock. If a 52:48 trawl:fixed gear allocation is maintained, then the MSY for this stock is 8,200 mt at a mean age 3+ biomass of 67,800 mt. An ABC of 9,100 mt is indicated by applying the F[MSY] to the current stock structure. At this level of fishing mortality, and if there are no great deviations in recruitment, the stock would be near the biomass yielding MSY in about 20 years and the ABC would be reduced to 8,200 mt. Our current assessment does not account for trawl discards occurring after the end of the season or additional discarding caused by restrictive trip limits. Subsequent analyses will account for these factors, but we note here that total fishery-induced mortality will be greater than the 9,100 mt ABC, so the stock is being fished down to the B[MSY] level more rapidly than predicted above.

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Appendix Table 1. Age composition data.

Data template is:

year	type	sex	N aged						
age1	2	3	4	5	6	7	8	9	10
11	12	13	14	15-19	20+				
83	5	1	216.						
1.1	14	51	57	28	26	10	6.8	4.8	9.5
2.5	1.9	0	0	2.7	1.1				
83	5	2	326.						
0.4	29	32	115	40	51	24	8.4	7.6	0.8
5.1	5	1.4	2	3.9	0.7				
85	5	1	661.						
0.7	40	101	137	148	107	68	29	15	4.2
7.4	2.4	1.1	1.3	0	0				
85	5	2	553.						
1	75	113	111	85	86	34	20	8.7	6.5
4.3	2.3	3.4	1.4	0.7	1.0				
86	1	1	119.						
0.8	2.4	4.6	7.8	11.7	11.8	11.1	7.8	8.5	6.9
6.2	3.2	3.4	4.0	8.7	1.1				
86	1	2	224.						
0.6	5.5	6.0	8.8	14.5	14.0	12.4	8.4	6.3	5.0
4.2	2.7	2.3	2.9	3.7	2.8				
86	2	1	636.						
2.5	8.4	8.8	12.7	13.1	11.2	9.2	6.0	6.1	5.2
4.0	1.8	2.1	2.4	5.4	1.0				
86	2	2	642.						
7.0	16.6	12.0	11.2	14.3	11.5	7.7	5.1	2.7	2.7
2.0	1.2	1.3	1.4	1.6	1.7				
87	1	1	189.						
0.0	2.5	3.5	3.9	4.0	4.6	9.0	7.6	4.9	10.9
2.9	4.0	3.6	3.1	13.1	22.4				
87	1	2	216.						
0.1	2.5	4.8	5.4	7.7	5.5	8.5	9.7	8.5	13.1
2.8	3.4	2.8	2.0	10.6	12.7				
87	2	1	604.						
1.4	16.2	10.5	7.3	6.6	5.2	7.7	5.7	4.4	7.3
2.4	2.5	2.4	1.5	6.9	12.1				
87	2	2	702.						
2.3	22.0	18.3	11.3	8.7	5.8	5.2	4.2	4.1	5.0
1.3	1.5	1.4	0.6	3.4	4.9				

Appendix Table 2. Size composition data where size is measured in cm fork length.

```
Data template is:
year type sex  Nmeasured
 32-35 36-37 38-39 40-41 42-43 44-45 46-47 48-49 50-51 52-53
 54-55 56-57 58-59 60-63 64-67 68-71 72-75 76-79 80-90  90-

  71    5    1     690.
   0.0   0.0   0.0   0.0   1.3  18.5  39.2  75.1 108.0  85.8
  70.6  86.5  65.8  71.6  46.4  14.7   4.0   1.9   0.9   0.0
  71    5    2    1227.
   0.0   0.0   0.0   0.0   1.3   3.4  23.7  58.6  77.8 120.0
 101.0  91.9  58.3 144.0 155.0 132.0 115.0  80.2  63.6   1.3
  79    5    1    1138.
   0.0   0.0   0.0   0.0   4.9  52.6 159.5 301.8 444.1 584.8
 584.1 409.8 250.8 245.7  48.6   7.3   4.0   0.0   0.0   0.0
  79    5    2    1079.
   0.0   0.0   0.0   2.0   6.1  36.4  76.5 135.2 180.9 235.2
 257.9 243.2 256.2 411.3 327.4 290.7 145.0  88.0  54.0  15.0
  80    4    1     338.
 108.7 243.7 286.1 147.3  51.7  37.4  97.7  85.1  46.1  24.6
   6.3   4.2   0.9   1.3   0.1   0.9   0.6   0.0   0.0   0.0
  80    4    2     328.
  42.6 171.1 261.2 145.6  46.2  27.1  71.3 129.4  76.0  42.6
  13.5   8.3   2.4   4.2   0.2   0.3   0.6   0.9   0.6   0.0
  80    5    1    1050.
   0.0   0.0   1.0   0.0  14.4  85.5 245.9 437.0 503.2 452.8
 376.8 256.1 161.3 197.8  67.5   8.3   2.5   0.0   0.0   0.0
  80    5    2     888.
   0.0   0.0   0.0   7.0   3.6  29.5 129.1 227.0 305.8 317.2
 283.2 169.9 147.7 219.2 170.5 138.7 107.5  76.0  41.0   6.0
  81    5    1     755.
   0.0   0.0   0.0   1.0   9.0  43.3 156.9 312.9 365.9 346.7
 219.0 144.1  72.4  93.3  38.4  11.2   0.0   0.0   0.0   0.0
  81    5    2     655.
   0.0   0.0   0.0   0.0   0.0   6.7  48.1  94.1 176.1 227.3
 219.0 141.9 142.6 144.7 117.6  75.8  75.0  41.0  27.0   0.0
  83    4    1    1584.
 304.1 516.0 423.8 248.9 413.1 354.5 226.6 171.5 108.4  57.1
  54.6  17.5  18.8  13.7  10.2   7.5    .5   0.0   0.0   0.0
  83    4    2    1784.
 195.9 451.2 286.7 218.3 335.6 428.2 325.6 234.3 165.2 135.2
  60.1  45.4  39.6  38.3  12.6   5.6   4.9   3.0   1.3   0.0
  83    5    1     250.
   0.0   0.0   2.0  12.0  35.2  79.8 180.3 283.5 337.0 209.6
 175.6  81.2  54.2  46.4   6.6   0.0   0.0   6.5   0.0   0.0
  83    5    2     350.
   0.0   0.0   2.0   0.0  11.7  53.2 109.7 148.5 158.0 255.4
 226.4 209.8 141.8 192.6 112.4  74.0  44.0   6.5  14.0   0.0
  84    6    1     609.
   0.0   0.0   1.0   0.0  76.0 205.8 536.9 823.2 903.4 700.5
 429.5 292.9 131.8 125.5  32.1   0.0   0.0   0.0   0.0   0.0
  84    6    2     749.
```

```
  0.0   0.0   0.0  16.0  19.0 112.2 185.1 285.8 427.6 456.5
499.5 360.1 355.2 454.5 246.9  97.0  48.0  24.0  16.0   0.0
85    5   1    661.
  0.0   1.0   2.0  18.0  64.0 209.4 408.3 582.2 534.7 381.1
238.4 162.2 121.5 118.7  33.7  17.6   6.0   1.5   0.0   0.0
85    5   2    553.
  0.0   1.0   2.0  12.0  64.0 160.6 237.7 231.8 260.3 265.9
175.6 155.8 124.5 183.3 101.2  75.4  42.0  14.5  15.0   1.0
86    1   1    475.
  0.0   0.0   0.0   1.1   0.2   0.6   4.3   5.6  12.0  18.1
 13.0  11.1  12.7  11.6   6.9   2.3   0.1   0.0   0.4   0.0
86    1   2    832.
  0.0   0.0   0.0   0.3   0.5   1.3   4.0   3.3   7.7  10.8
 10.4   8.7   9.4  13.6  12.2   7.9   5.0   2.0   2.6   0.3
86    2   1   2202.
  0.0   0.0   0.0   2.2   2.9   6.7   8.0  13.9  16.1  14.6
 13.5   9.2   5.2   5.1   1.9   0.8   0.1   0.0   0.0   0.0
86    2   2   2366.
  0.0   0.0   0.0   5.7   4.2   5.8   9.3  11.8  12.9   9.8
  9.6   8.3   5.9   9.5   3.4   2.0   0.8   0.4   0.6   0.2
86    4   1   2442.
355.1 604.7 521.2 289.1 153.5 109.5 107.6  70.1  28.4  22.5
 21.9  15.8  16.0  40.0   7.7   4.6   2.9   0.0   0.0   0.0
86    4   2   2274.
235.8 482.2 499.9 323.0 134.5 114.0  87.0  85.9  70.6  55.1
 29.6  20.2  28.0  77.9  53.9  79.9 102.2  80.2  39.3   9.7
86    6   1    417.
  0.0   0.0  13.0   0.0  72.3 117.7 217.7 317.3 326.3 320.9
254.3 118.4  84.4  30.3  11.5  10.0   0.0   0.0   0.0   0.0
86    6   2    468.
  0.0   0.0   0.0  37.0  20.7  39.2  94.3 172.7 210.7 171.1
193.7 210.6 183.6 299.7 191.5  70.0  32.0  15.0  18.0   0.0
87    1   1   1130.
  0.0   0.0   0.0   0.0   0.7   2.2   3.4   5.3   8.0  13.6
 19.5  16.7  11.8  11.6   4.6   2.6   0.1   0.0   0.0   0.0
87    1   2    987.
  0.0   0.0   0.0   0.3   0.1   1.0   1.9   2.1   2.6   7.3
  9.3  10.9   9.5  17.7  15.5  10.1   7.5   2.0   1.8   0.3
87    2   1   2479.
  0.0   0.0   0.0   5.9   8.1  10.9  10.5  10.6  11.9  12.7
 11.7   7.5   4.4   4.6   0.6   0.2   0.2   0.0   0.0   0.0
87    2   2   2222.
  0.0   0.0   0.0   7.7   6.6   9.7  11.8  10.3  10.5   9.6
 10.0   6.4   6.0   5.5   2.9   1.4   1.0   0.4   0.3   0.1
87    5   1    444.
  0.0   2.0   3.0  13.3  14.4  56.6 133.4 265.7 269.2 235.8
188.8  81.3  39.2  55.2  18.9   8.2   0.0   0.0   0.0   0.0
87    5   2    302.
  0.0   0.0   6.0   1.7  11.6  15.4  39.6  96.3  80.8 105.2
 90.2  92.6  62.8  84.8  67.1  40.8  19.0   7.0   7.0   1.0
```